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The Physical, Sensory, and Microbial Qualities of Broth Gels Enclosing Food Cubes and Their Changes during Cold Storage

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Abstract: Due to their unusual textural properties and semblance, gel foods have been welcomed by consumers. In this study, we designed a novel gel food, that is, broth jellies that enclosed particular food dices (shrimp, chicken, and potatoes). Briefly, various ratios of gelling molecules (gelatin and κ-carrageenan) were added to chicken broth, the food dices were placed in the center of the gels, and their characteristics and stabilities were verified during cold storage (4 °C) for 14 days. As a result, the mix of κ-carrageenan and gelatin led to the formation of firm cross-junctions with an elevated hardness compared to gelatin singular gel. In contrast, the gelatin sole gel showed different sensory attributes, such as a high chewiness and meltiness. The thick gel barriers of the products fairly increased the stability of the inner food ingredients. By blocking the loss of moisture, the texture and sensory traits were well preserved; moreover, the gelling molecules greatly impeded microbial decay by decreasing the water activity due to their strong water-binding capacity. In conclusion, the mix ratio of gelatin and κ-carrageenan affected the gel characteristics by shifting the gel matrices, and the gel barriers improved the food quality and inner food preservability.

Keywords: chicken stock; gel food; jelly; gelatin; κ-carrageenan; sensory evaluation

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1. Introduction

Gel-based foods and food gels have received attention because of their unique textural properties and mouthfeels; therefore, they are attractive items to consumers and the food industry. Diverse fruit jellies, konjac, tapioca gels, and surimi (gelled foods made from fish flesh) are examples of popular gel-based foods, and their inventions have fulfilled the demands of consumers [1–3]. Gels show a viscoelastic property, which is the combined rheological characteristics of solid (elastic) and liquid (viscous), and it results in the distinct texture of gel foods [4]. To develop gel structures in matrices, special materials are needed, which are called gelling agents or gelling molecules. The gel structure is developed by three-dimensional networks of gelling molecules, such as polysaccharides and proteins, and from their cross-linking or aggregation, cheese and jelly are typical and easily found gelled foods [5]. Gelling agents are widely used as coating agents, thickeners, and emulsifiers in various industries such as foods, pharmaceuticals, and cosmetics.

Hydrocolloids are gel-forming molecules enabled to retain plenty of moisture in their structure due to their abundant hydroxyl groups [6]. Gelatin is a prominent gelling agent that can be obtained from animal sources. It is derived from collagen, the most abundant protein in animal bodies, after the destruction of partial chemical structures [7]. Gelatin is produced by the breakage of the cross-linkages of the parent protein (collagen), the degradation of the polypeptide bonds in the collagen structure, and a series of denaturations that result in the transformation of collagen into gelatin [8]. The application of gelatin in the food industry is mostly found in jelly production, and the use of gelatin has been long-standing worldwide [9]. A single gelatin molecule has a flexible random coil structure,

but gelatin molecules interpenetrate one another and form coil–helix structures resembling the stereoscopic conformation of collagen molecules at temperatures below melting point, resulting in gel formation [10,11]. Likewise, each hydrocolloid shows its own particular molecular binding structure in matrices, which develops multifarious types of end products with distinct rheological properties. Therefore, a specialized gel can be produced by the copulation of different gelling molecules, and they can exercise synergy due to their unique polymorphic linkages. For instance, the addition of certain hydrocolloids to gelatin gel evokes ionotropic gelation via cross-links between the hydrocolloid and gelatin molecules; therefore, it organizes specific networks in the gel structures compared to single-molecule-based gels [6]. K-carrageenan, a hydrocolloid extracted from certain types of red seaweeds, is a gelling molecule that is frequently used to invest a viscous texture into foods [12]. During the sol-gel transition, the random-coiled κ-carrageenan molecules form junctions with each other and shift to double-helical conformation [13]. κ-carrageenan is known as an effective helper in reorganizing gelatin cross-linkages by building polyelectrolyte complexes in company with gelatin molecules [14]. Notably, carrageenan–gelatin cooperated gels have shown an increased strength, rigidity, and thermal stability in comparison to sole gelatin gels [15].

Assessments of food shelf life generally include a preservation period for the evaluation of the food qualities and decay times, which are mainly affected by microorganisms [16]. Gelling agents have been occasionally used for shelf-life extension and physicochemical property improvements. Encapsulation or coating technologies are newer applications of gelling agents used in various industries, including food and pharmaceuticals [17,18]. The encapsulation process is applied to small particle matrices and elongates shelf life, enhances physical stability, and assigns certain functional properties, such as bioavailability and absorption rate in the body [19]. Likewise, specific gel-coating techniques have enhanced the quality preservation and delayed the decay rates in their respective products [20]. Hence, we anticipate that the shelf life of foods can be elongated by enveloping them with gels.

The objective of the present study was to prepare a new type of gel food that could be introduced to the food industry and to understand its overall characteristics. In our study, the shape, composition, and flavor of the gel food were designed to represent molecular gastronomy dishes. Firstly, three food ingredients (shrimp, chicken, and potato) were prepared in 1 cm dice form. Each food cube was placed in the center of a 3 cm dice form gel, and the outer gel was made with chicken broth for adding harmonized flavors. Because previous studies have mostly applied gelling agents to desserts, the use of chicken bouillon as a gel base is a distinctive attempt and we expect unique gel properties due to the constituents in chicken broth. To test the suitable gelling molecules, different proportions of gelatin and κ-carrageenan were tested. We hypothesized that the type of inner food and identity and ratio of the gelling agents would result in distinct food qualities and shelf lives. We analyzed the moisture, water activity, color, texture, and sensory and microbial safety properties of the samples during cold storage (4 °C) for up to 14 days. Through these evaluations, we aimed to identify the appropriate conditions for making novel gel foods and better understanding the influences of inner foods and gelling agents on the formation and disruption of gel food structures.

2. Materials and Methods

2.1. Preparation of Jelly Samples

Commercial chicken stock (Herb-Ox Chicken Bouillon Cubes; Hormel Foods, Austin, MN, USA) was purchased to make a chicken broth gel base. Following the recommended directions of the providers, 4 g of chicken stock was mixed with 1 L of tap water, boiled for 3 min, and cooled to 70 °C in a water bath (Jeio Tech Co., Dajeon, Republic of Korea). Considering the evaporation of the water during boiling, the volume of the chicken broth was re-adjusted by adding boiled tap water, and different ratios of hydrocolloid powders (gelatin 1.0% and κ-carrageenan 1.0%, G1C1; gelatin 1.5% and κ-carrageenan 0.5%, G1.5C0.5; gelatin 2.0% only, G2C0; *w*/*w*%) (bovine gelatin powder, 242 bloom grade; Sinvii

International, Pocheon, Republic of Korea) (κ-carrageenan; ES Food, Gunpo, Republic of Korea) were added. The temperature of the liquid was maintained at 70 °C until the hydrocolloid materials were completely dissolved, and the liquid was then cooled to 40 °C. The ratios of the gelatin and κ-carrageenan were set by a preliminary experiment and some previous studies [15,21].

For the jelly inner foods, three different ingredients were prepared (frozen peeled pacific white shrimp obtained from Vietnam; chicken breast from Korea; and potatoes harvested in Korea). The shrimps were thawed in water at 20 °C and blanched in boiling water for 3 min. The chicken breast was cut into 3 cm dices and blanched for 10 min in boiling water with 0.5% salt. The potatoes were cut into 2 cm dices, soaked in water at 20 °C for 10 min, and blanched for 7 min in boiling water with 0.3% salt. The blanching time was set to the internal temperatures of all three ingredients, reaching to over 75 °C to minimize microbial hazards [22]. The three blanched ingredients were cooled to 20 °C, removed from the water using a paper towel, and cut into 1 × 1 × 1 cm cubes.

Airtight containers (LOCK & LOCK, Asan, Republic of Korea) were prepared for molds (each cell size was 3 × 3 × 3 cm dice shapes). The prepared chicken broth gel bases (40 °C) were poured into each cell up to 1 cm in height and solidified at 4 °C. The food cubes were laid on 1 cm high gels, and each cell was filled with chicken broth gel bases again to form 1 cm thick gels on all sides (width, length, and height). The jelly samples were solidified at 4 °C in an incubator (IL3-25; Jeio Tech Co., Daejeon, Republic of Korea) and covered tightly with plastic wraps. The gels were stored at 4 °C in an incubator for up to 14 days to verify quality changes in the samples during cold storage.

2.2. Moisture and Water Activity

The moisture content of the samples was analyzed following the methods of AOAC [23]. In brief, the chopped broth jelly or inner food cubes were dried at 105 °C for 12 h in a dry oven (FO-600M; Jeio Tech Co., Daejeon, Republic of Korea). The dried sample weights were measured repeatedly, until they reached a constant weight (N = 3). The water activity of the samples was determined using a thermoconstanter (TH-200; Novasina, Lanchen, Switzerland), following manuals from the manufacturer (N = 3).

2.3. Color Values

The color values were measured using a colorimeter (CM-3500d; Minolta, Tokyo, Japan), with six replicates per sample group. The condition of the light source was D65-10°, and the Hunter L*a*b* value was used to represent the samples' color traits.

2.4. Texture Analysis

The texture characteristics of the broth jelly and food dices were analyzed using a texture analyzer (COMPAC-100II, Sun Scientific Co., Tokyo, Japan) (N = 9). The samples were prepared in 1 × 1 × 1 cm form, and the hardness of the samples was analyzed using a compression test. The compression test mode was conducted for detection, and the No. 1 compression probe (diameter 25 mm) was used. The pre-test speed of the probe was 10 mm/s and the test speed was 1 mm/s. The probe was compressed until it condensed the samples up to 60% of their height. The post-test speed of the probe was set to 10 mm/s and the trigger force was 5 g.

2.5. Sensory Evaluation

A total of 15 panelists were voluntarily recruited from Woosong University, and the panelists had previously undergone sensory evaluation tests. After a pre-test to check their sensitivities for tasting foods, 12 members were selected (all the panelists were aged in 20–29). Sensory training was carried out eight times for two months, following the protocols of Lawless and Heymann [24]. During the training periods, the panelists developed a total of nine lexicons for evaluating the outer gel and inner foods, consulting reference lexicons [25]. Two terms for appearance (transparent and yellowness), one term for taste

(salty), one term for flavor (fishy), one term for aftertaste (aftertaste), and four terms for texture (hardness, moisture, chewiness, and meltiness) were used for verifying the sensory characteristics of the outer gel parts. For the inner foods, one term for appearance (whiteness), one term for odor (odor of inner food), one term for taste (salty), two terms for flavor (fishy and flavor of inner food), one term for aftertaste (aftertaste), and three terms for texture (hardness, moisture, and chewiness) were used. To quantify the sensory traits, a quantitative descriptive analysis (QDA) method was introduced, and a 15 cm line scale was used [26]. The sensory evaluation proceeded obeying the Institutional Review Board (IRB) document (1041549-191011-SB-79) approved by the Woosong University IRB Committee.

2.6. Total Aerobic Bacteria and Detection of Escherichia coli (E. coli)

To determine the microbial safety of the samples, the total aerobic plate count (APC) and the prevalence of *E. coli* were determined. Each sample (5 g) was mashed with a sterile saline solution (1:10, *w*/*v*) using a sample preparation bag and serially diluted ten times. The microbial counts were examined using 3M Petrifilms (3M, St. Paul, MN, USA) following the manufacturer's instructions.

2.7. Statistical Analysis

All the data of the present study are represented as mean ± standard deviation (SD). To determine the significant statistical differences within the sample groups, the one-way analysis of variance (ANOVA) method was used, and Duncan's multiple-range test was conducted for a post hoc test. The SPSS version 25.0 (IBM Inc., Armonk, NY, USA) statistical program was used for the statistical analysis.

3. Results and Discussion

3.1. Moisture and Water Activity of Gel Foods

The moisture content of gels relates to the gel structure deformation and highly affects the textural perceptions of consumers; therefore, sometimes, additives are added into gel bases to increase their water-holding capacity [27]. The moisture loss or gain in foods is an important factor that alters the food qualities and organoleptic characteristics; therefore, water retention is an essential component for maintaining food quality [28]. In our study, gelatin singular gels (G2C0) presented a significantly lower moisture content than the G1C1 gels at day 0 ($p < 0.05$); however, their gap was less than 1% (Table 1). In addition, the gelling molecule ratios did not induce significant differences in the moisture contents of the gels from day 3. The moisture contents of the inner food cubes were not much affected by the gelling molecule ratios either; however, we detected striking elevation in the moisture contents of the inner foods at day 3. This may have been caused by water migration from the gel parts to the inner foods due to the luxuriant moisture contents of the gels. In addition, the increased moisture contents of the inner foods were retained until day 14. In previous studies, edible coatings with gums or chitosan have behaved as barriers against the atmosphere and protected the loss of moisture from foods [29,30]. Likewise, the moisture content of the inner food was preserved efficiently by the thick gels in the present study.

Meanwhile, the water activities of the gels differed in terms of supplementation with κ-carrageenan (Table 2). While the gelatin singular gels showed higher water activity at day 0, the addition of κ-carrageenan decreased the water activity of the gels. Because there was no significant distinction in the water contents between the gelatin singular gels and the gelatin–carrageenan mixed gels, the low water activity of the κ-carrageenan mixed gel implies an enforced water-binding power. Lewicki et al. [31] also revealed that the water-binding ability of κ-carrageenan is relatively higher than that of gelatin and starch, and this ability of κ-carrageenan is firmly manifested even in low concentrations. Meanwhile, interestingly, the inner food kind was an important factor considering changes in this water activity depending on the storage period. The different gelling molecules ratios caused different variance ratios in the water activity during storage. A gelatin singular gel (G2C0)

did not show a significant difference in water activity between day 0 and 14, regardless of its inner food type, but the some of κ-carrageenan-added groups showed significant changes in water activity during storage and these changes were affected by the inner food types. Many solutes, including cations, proteins, and sugars, carry interactions with κ-carrageenan and mediate a gel's strength and stability [32]. In the present study, the water activity of the G1.5C0.5 group was lowered at day 14 when the shrimp and chicken were used as the inner foods. Carrageenan contains sulphate groups in its structure and its electrostatic attraction with proteins intensifies the gel's strength [33]; therefore, the proteins of the shrimp and chicken may have permeated to the outer gels and increased the water-binding activity. On the contrary, G1C1 showed dramatic influences on the water binding-activity when potatoes were used as the inner food. Potatoes contain high carbohydrate contents, and some kinds carbohydrates could elevate the gel's strength and the water-binding activity of the κ-carrageenan [34]. The results of the water activity demonstrate the interplay between the gel and inner food during storage, and how the major components of the inner food were related to it. However, further study is still required to elucidate their correlation.

Table 1. Moisture contents of broth jelly and inner food cubes.

(Unit: %)

Moisture Content of Outer Broth Gel					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S [1]	G1C1 [2]	97.38 ± 0.06 ^{bX} [3]	97.06 ± 0.04 ^{cZ}	96.99 ± 0.08 ^{dZ}	97.17 ± 0.02 ^{dY}
	G1.5C0.5	97.43 ± 0.05 ^{abX}	97.18 ± 0.07 ^{bcY}	97.12 ± 0.20 ^{cdY}	97.24 ± 0.06 ^{cdXY}
	G2C0	96.40 ± 0.20 ^{eY}	97.18 ± 0.12 ^{bcX}	97.16 ± 0.14 ^{bcdX}	97.27 ± 0.12 ^{bcdX}
C	G1C1	97.42 ± 0.02 ^{ab,NS}	97.32 ± 0.09 ^{ab}	97.37 ± 0.05 ^{ab}	97.39 ± 0.02 ^{ab}
	G1.5C0.5	97.60 ± 0.15 ^{aX}	97.29 ± 0.02 ^{abY}	97.32 ± 0.04 ^{abcY}	97.32 ± 0.04 ^{abcY}
	G2C0	96.92 ± 0.13 ^{dY}	97.30 ± 0.09 ^{abX}	97.39 ± 0.08 ^{aX}	97.42 ± 0.06 ^{aX}
P	G1C1	97.48 ± 0.05 ^{abX}	97.23 ± 0.06 ^{abcY}	97.24 ± 0.13 ^{abcY}	97.36 ± 0.05 ^{abcXY}
	G1.5C0.5	97.13 ± 0.12 ^{c}	97.44 ± 0.28 ^{a}	97.24 ± 0.12 ^{abc}	96.96 ± 0.09 ^{a}
	G2C0	96.96 ± 0.09 ^{cdY}	97.34 ± 0.02 ^{abX}	97.34 ± 0.05 ^{abX}	97.43 ± 0.04 ^{aX}
Moisture Content of Inner Food Cubes					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S	G1C1	83.84 ± 0.41 ^{aY}	86.37 ± 1.38 ^{abX}	86.33 ± 0.59 ^{aX}	86.93 ± 0.98 ^{aX}
	G1.5C0.5	83.71 ± 0.33 ^{aY}	86.92 ± 0.20 ^{aX}	88.24 ± 0.59 ^{aX}	87.96 ± 1.21 ^{aX}
	G2C0	83.39 ± 0.72 ^{aY}	86.84 ± 1.62 ^{aX}	87.66 ± 0.70 ^{aX}	87.86 ± 0.44 ^{aX}
C	G1C1	66.63 ± 1.34 ^{dY}	74.49 ± 0.33 ^{eX}	74.23 ± 0.74 ^{dX}	75.25 ± 2.22 ^{dX}
	G1.5C0.5	67.25 ± 0.33 ^{dY}	74.57 ± 0.87 ^{eX}	75.79 ± 1.07 ^{dX}	75.44 ± 1.27 ^{dX}
	G2C0	68.36 ± 0.50 ^{dY}	78.13 ± 0.44 ^{deX}	78.25 ± 2.32 ^{cX}	77.15 ± 1.31 ^{dX}
P	G1C1	80.23 ± 2.76 ^{b,NS}	83.04 ± 1.97 ^{bc}	83.25 ± 2.46 ^{b}	83.35 ± 1.73 ^{b}
	G1.5C0.5	76.40 ± 0.62 ^{cZ}	81.35 ± 1.66 ^{cdY}	83.95 ± 0.54 ^{bX}	80.37 ± 0.21 ^{cY}
	G2C0	79.31 ± 2.44 ^{b,NS}	82.21 ± 5.00 ^{c}	83.14 ± 0.95 ^{b}	80.41 ± 1.36 ^{c}

All data are represented as mean ± standard deviation (SD). [1] S, shrimp; C, chicken; P, potato [2] G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; and G2C0, gelatin 2% (*w*/*w*%) [3] Different superscripts within column (a–e) or within row (X–Z) indicate significant differences at $p < 0.05$. NS, not significant within row.

Table 2. Water activity of broth gels and inner ingredients.

(Unit: a_w)

Water Activity of Outer Broth Gel					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S [1]	G1C1 [2]	0.865 ± 0.057 cNS (3)	0.891 ± 0.005 ^{a}	0.887 ± 0.024 ^{a}	0.883 ± 0.024 ^{a}
	G1.5C0.5	0.924 ± 0.018 ^{abX}	0.930 ± 0.009 ^{aX}	0.890 ± 0.018 ^{aY}	0.808 ± 0.010 ^{bZ}
	G2C0	0.936 ± 0.017 ^{a}	0.919 ± 0.016 ^{a}	0.871 ± 0.066 ^{a}	0.915 ± 0.011 ^{a}
C	G1C1	0.874 ± 0.045 ^{bcX}	0.761 ± 0.008 ^{bY}	0.815 ± 0.086 ^{abXY}	0.899 ± 0.017 ^{aX}
	G1.5C0.5	0.915 ± 0.013 ^{abX}	0.902 ± 0.001 ^{aX}	0.889 ± 0.042 ^{aX}	0.778 ± 0.024 ^{bY}
	G2C0	0.933 ± 0.010 ^{a}	0.904 ± 0.014 ^{a}	0.910 ± 0.018 ^{a}	0.917 ± 0.026 ^{a}
P	G1C1	0.917 ± 0.006 ^{abX}	0.688 ± 0.083 ^{cY}	0.764 ± 0.082 ^{bY}	0.772 ± 0.021 ^{bY}
	G1.5C0.5	0.904 ± 0.018 abc,NS	0.927 ± 0.015 ^{a}	0.908 ± 0.015 ^{a}	0.912 ± 0.023 ^{a}
	G2C0	0.932 ± 0.014 ^{aX}	0.907 ± 0.022 ^{aXY}	0.898 ± 0.006 ^{aY}	0.918 ± 0.018 ^{aXY}
Water Activity of Inner Food Cubes					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S	G1C1	0.922 ± 0.010 ^{cX}	0.899 ± 0.011 ^{aY}	0.914 ± 0.002 ^{aX}	0.894 ± 0.005 ^{abY}
	G1.5C0.5	0.931 ± 0.006 ^{bcX}	0.914 ± 0.001 ^{aXY}	0.907 ± 0.017 ^{aY}	0.801 ± 0.006 ^{dZ}
	G2C0	0.937 ± 0.008 ^{abX}	0.910 ± 0.009 ^{aY}	0.919 ± 0.015 ^{aXY}	0.924 ± 0.012 ^{aXY}
C	G1C1	0.901 ± 0.003 ^{dX}	0.744 ± 0.038 ^{cY}	0.912 ± 0.007 ^{aX}	0.878 ± 0.019 ^{bcX}
	G1.5C0.5	0.925 ± 0.004 ^{cX}	0.901 ± 0.008 ^{aXY}	0.924 ± 0.009 ^{aX}	0.852 ± 0.054 ^{cY}
	G2C0	0.944 ± 0.006 ^{aX}	0.921 ± 0.006 ^{aY}	0.921 ± 0.003 ^{aY}	0.931 ± 0.012 ^{aXY}
P	G1C1	0.905 ± 0.004 ^{d,NS}	0.807 ± 0.094 ^{b}	0.815 ± 0.061 ^{b}	0.795 ± 0.020 ^{d}
	G1.5C0.5	0.924 ± 0.001 ^{c,NS}	0.907 ± 0.009 ^{a}	0.919 ± 0.004 ^{a}	0.926 ± 0.024 ^{a}
	G2C0	0.932 ± 0.011 abc,NS	0.923 ± 0.009 ^{a}	0.918 ± 0.007 ^{a}	0.925 ± 0.003 ^{a}

All data are represented as mean ± standard deviation (SD). [1] S, shrimp; C, chicken; P, potato [2] G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; and G2C0, gelatin 2% (*w*/*w*%) [3] Different superscripts within column (a–d) or within row (X–Z) indicate significant differences at $p < 0.05$. NS, not significant within row.

3.2. Color Values of Gel Foods

The color values of the jelly samples were determined using Hunter's Lab scale, and their L* (lightness) values are presented in Table 3. The lightness values of the outer gels ranged from 4.43 to 8.89 at day 0 and were significantly low in comparison to those of Sinthusamran et al. [35] (ranging from 43.12 to 71.39), who tested different gelatin and κ-carrageenan ratios for gel production. The L* value difference in the previous study seemed to be caused by the different gel bases used in the present study, the chicken stock. Chicken stock contains versatile compounds from chicken, such as proteins, carbohydrates, lipids, minerals, and organic acids. Moreover, commercial chicken stock includes additional ingredients, such as herbs and salt. Likewise, the gap in the color traits between the pure water and chicken broth base gels was also found to have redness (a*) and yellowness (b*) values (Tables S1 and S2). As for the outer gels, the addition of κ-carrageenan resulted in an increase in the L* and b*, but a decrease in the a* compared to the G2C0 gel type. Gelatin has specific inherent color traits, namely a yellowish color [36], while carrageenan does not;

therefore, this could be one of the reasons why the gels varied. However, we focused on other possible causes of this color difference, such as a shift of the gel microstructure upon the addition of κ-carrageenan to the gelatin gels.

Table 3. Lightness values of broth gels and inner food dices.

Lightness (L*) of Outer Broth Gel					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S [1]	G1C1 [2]	82.40 ± 0.53 ^{b,NS} [3]	82.10 ± 0.27 ^{c}	82.94 ± 0.09 ^{ab}	82.13 ± 0.79 ^{d}
	G1.5C0.5	81.16 ± 0.22 ^{aY}	80.23 ± 0.48 ^{aY}	83.54 ± 1.38 ^{bZ}	74.64 ± 1.11 ^{abX}
	G2C0	85.60 ± 0.43 ^{dY}	87.18 ± 0.31 ^{eZ}	87.69 ± 0.59 ^{cZ}	78.09 ± 0.38 ^{cX}
C	G1C1	81.57 ± 0.84 ^{abYZ}	80.40 ± 0.34 ^{aX}	81.85 ± 0.37 ^{aZ}	80.76 ± 0.47 ^{dXY}
	G1.5C0.5	81.14 ± 0.47 ^{aY}	80.54 ± 0.45 ^{abY}	82.68 ± 0.53 ^{abZ}	73.91 ± 0.91 ^{aX}
	G2C0	84.48 ± 0.36 ^{cY}	86.67 ± 0.58 ^{deZ}	87.67 ± 0.59 ^{cZ}	75.30 ± 1.65 ^{abX}
P	G1C1	81.57 ± 0.84 ^{abYZ}	80.40 ± 0.34 ^{aXY}	82.16 ± 0.79 ^{aZ}	80.23 ± 0.44 ^{dX}
	G1.5C0.5	81.36 ± 0.73 ^{abY}	81.21 ± 0.36 ^{bY}	81.83 ± 0.35 ^{aY}	74.49 ± 0.22 ^{aX}
	G2C0	85.47 ± 0.67 ^{cdY}	86.34 ± 0.58 ^{dYZ}	87.89 ± 0.55 ^{cZ}	76.46 ± 2.05 ^{bcX}
Lightness (L*) of Inner Food Cubes					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S	G1C1	48.52 ± 2.12 ^{c,NS}	47.01 ± 0.77 ^{d}	44.72 ± 4.75 ^{c}	48.24 ± 3.13 ^{c}
	G1.5C0.5	49.09 ± 1.48 ^{cX}	45.09 ± 0.37 ^{dXY}	42.84 ± 3.71 ^{cY}	45.60 ± 2.79 ^{cXY}
	G2C0	45.71 ± 3.47 ^{cNS}	48.44 ± 2.62 ^{d}	46.03 ± 1.61 ^{c}	48.43 ± 1.48 ^{c}
C	G1C1	70.85 ± 1.36 ^{aX}	69.92 ± 2.95 ^{aX}	61.73 ± 2.02 ^{abY}	67.59 ± 1.56 ^{aX}
	G1.5C0.5	68.49 ± 3.86 ^{a,NS}	68.58 ± 1.54 ^{a}	66.14 ± 4.58 ^{ab}	67.14 ± 2.56 ^{a}
	G2C0	68.23 ± 3.06 ^{aX}	63.17 ± 3.28 ^{bY}	67.39 ± 1.60 ^{aXY}	68.14 ± 0.77 ^{aX}
P	G1C1	61.12 ± 1.95 ^{bY}	63.02 ± 0.96 ^{bXY}	62.68 ± 0.32 ^{abXY}	63.59 ± 1.01 ^{bX}
	G1.5C0.5	61.65 ± 1.55 ^{bX}	58.68 ± 1.51 ^{cY}	61.99 ± 0.55 ^{abX}	63.18 ± 0.89 ^{bX}
	G2C0	61.27 ± 1.15 ^{b,NS}	60.69 ± 1.38 ^{bc}	60.43 ± 3.90 ^{b}	61.43 ± 2.07 ^{b}

All data are represented as mean ± standard deviation (SD). [1] S, shrimp; C, chicken; P, potato [2] G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; and G2C0, gelatin 2% (*w*/*w*%) [3] Different superscripts within column (a–e) or within row (X–Z) indicate significant differences at $p < 0.05$. NS, not significant within row.

Microstructures, such as the arrangement of polymers or the pore size and depth on food surfaces, can alter the color traits of foods with identical components [37]. When gels form, their cross-linking traits and network density are strongly associated with the color and transparency of products [38]. Therefore, the color values were affected by the specific interactions between the κ-carrageenan and gelatin molecules in the gel matrices. In addition, the proper mixing ratio of κ-carrageenan strengthened the color stability during storage. On day 14, the G1.5C0.5 and G2C0 ratio gels showed dramatic changes in all their color values (L*, a*, and b*) compared to day 7, while the color of the G1C1 type gel changed less than the others. This may have been because the G1C1 gel had more specific cross-structures between gelatin and κ-carrageenan than G1.5C0.5 and G2C0, and these structures were much more stable and long-lasting.

A change in the color values of food products during storage is a natural phenomenon that involves several factors and impinges upon consumer acceptability. Therefore, the

objective of hindering food products' color changes has been addressed, and water retention maintenance is crucial. The addition of ingredients that have a high water-holding capacity to food products or a coating to protect water vaporization have effectively lowered color shifts during storage [39]. Likewise, the lightness values of the inner foods in this study did not significantly differ between days 0 and 14, except for those of P-G1C1.

Pigments are chemical compounds that manifest inherent hues, and their chemical shifts alter the color values of food products [40]. In the present study, sharp changes in redness values for the inner foods were found at day 3, compared to day 0, regardless of the food ingredients ($p < 0.05$); however, we did not observe significant differences in the redness values between days 3 and 14 for all groups. Early changes in food redness are mainly related to browning reactions, which result in an increased a* value. Phenol or polyphenol oxidases are the principal culprits that initiate browning reactions in foods during storage, and their activations are commonly discovered both in protein and vegetation foods [41,42]. Therefore, it was anticipated that the elevation of redness at day three represented this process. However, without early changes in redness values, the inner food color traits were substantially invariant. Many pigments can be easily dimmed and vary in color when exposed to oxygen and light [42]; therefore, the obstruction of such encounters can mitigate unintended changes. The gel-coating process is also known to preserve the color characteristics of foods by limiting the direct exposure of products to air and a loss of humidity [43], and its merit was also revealed in our results.

3.3. Mechanical Texture Evaluation of Gel Foods

The textural property of gel food is key to consumers' perceptions of the food's quality and acceptability [44]. Therefore, the textural properties of the samples were analyzed using a texture analyzer, and the results are presented in Table 4. The hardness in the texture profile analysis of the foods reflects the required force that is required for the sample to reach a certain deformation ratio, and fairly affects the sensory characteristics and consumer acceptability [45]. When κ-carrageenan and gelatin were used in the same amounts (for 1% each), the gel hardness significantly increased compared to the hardness of the gelatin singular gels, regardless of the inner food type ($p < 0.05$). An increase in gel strength with a κ-carrageenan addition to gelatin gel has also been reported in other studies, and this phenomenon is grounds for a distinctive cross-linking structure between κ-carrageenan and gelatin molecules in gel matrices [46,47]. κ-carrageenan has abundant negatively charged regions, but contrariwise, gelatin molecules have positively charged regions in their structures; therefore, their conjunction elevates gel hardness and elasticity through the development of polyelectrolyte junctions [15]. Likewise, the presence of positive monovalent ions, such as potassium ions, helps to form tight gel matrices in κ-carrageenan gel [48]; therefore, the plentiful minerals in the chicken broth used in this study may have heightened the hardness of the G1C1 condition gels. The hardness of the G1.5C0.5 and G2C0 gel samples generally presented the highest values at day 7, although the hardness dropped at day 14. Because the moisture content and water activity of the outer gels did not show similar patterns to the hardness, it was expected that the changes in hardness were affected by the transition of the molecular connections between the gelling molecules, rather than water loss. The connection strength of the gelling molecules was increased at day seven, but it was gradually loosened by a partial collapse of the gel matrices afterward.

Meanwhile, the hardness of the inner food dices at day 0 were different according to the food ingredients (shrimp, 610–636 g; chicken, 910–934 g; and potato, 157–234 g). For shrimps and potatoes, the outer gel types did not cause alterations to the hardness values on the same day. In addition, the hardness of the potatoes did not change during cold storage for 14 days, in the case of the G1C1 and G1.5C0.5 gels being adopted. On the other hand, the chicken showed striking increases in hardness at day 3 compared to day 0 ($p < 0.05$), and the hardness did not change until day 14. The hardness of

the shrimp also significantly increased during storage ($p < 0.05$), but this increase, like that of chicken, was only found during a particular period. In the case of protein foods, such as chicken and shrimp, their skeletal muscles chiefly contribute to their textural characteristics. These skeletal muscles are composed of bundles of muscle fiber that contain myofibrils and sarcomeres [49]. The length and arrangement of the sarcomere structures affect the muscle function, characteristics, and texture of these protein foods. A study by Feng et al. [50] reported that changes in myofibrils cause the shrinkage of the food surfaces during cold storage, which raises the hardness of products. Likewise, it is expected that rearrangements and changes in the lengths of the sarcomeres and myofibrils also occurred in this study, at a certain time for each food ingredient.

Table 4. Mechanical texture evaluation of broth gels and inner food cubes.

(Unit: g)

Hardness of Outer Broth Gel					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S [1]	G1C1 [2]	1093 ± 157 ^{aWX} [3]	938 ± 82 ^{bXY}	1225 ± 269 ^{aW}	849 ± 108 ^{cY}
	G1.5C0.5	557 ± 85 ^{bW}	331 ± 49 ^{eX}	579 ± 89 ^{cW}	320 ± 45 ^{deX}
	G2C0	524 ± 91 ^{bX}	325 ± 75 ^{eY}	801 ± 96 ^{bW}	279 ± 40 ^{deY}
C	G1C1	1239 ± 219 ^{aWX}	1058 ± 15 5^{aX}	1168 ± 164 ^{aWX}	1350 ± 197 ^{aW}
	G1.5C0.5	589 ± 72 ^{bX}	695 ± 139 ^{cX}	851 ± 110 ^{bW}	389 ± 75 ^{deY}
	G2C0	591 ± 29 ^{bX}	426 ± 57 ^{deY}	827 ± 124 ^{bW}	287 ± 74 ^{deZ}
P	G1C1	1607 ± 155 ^{a,NS}	1000 ± 135 ^{ab}	1252 ± 147 ^{a}	1070 ± 290 ^{b}
	G1.5C0.5	629 ± 62 ^{bX}	488 ± 96 ^{dY}	791 ± 96 ^{bW}	413 ± 47 ^{dY}
	G2C0	534 ± 64 ^{bX}	323 ± 85 ^{eY}	794 ± 137 ^{bW}	258 ± 44 ^{eY}
Hardness of Inner Food Cubes					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S	G1C1	636 ± 68 ^{bX}	663 ± 85 ^{cX}	623 ± 58 ^{cX}	770 ± 109 ^{cW}
	G1.5C0.5	610 ± 42 ^{bX}	601 ± 119 ^{cX}	653 ± 148 ^{cX}	850 ± 91 ^{cW}
	G2C0	629 ± 54 ^{bX}	764 ± 50 ^{cW}	779 ± 76 ^{cW}	750 ± 69 ^{cW}
C	G1C1	910 ± 92 ^{aX}	2022 ± 325 ^{aW}	1786 ± 295 ^{aW}	1888 ± 207 ^{aW}
	G1.5C0.5	934 ± 97 ^{aX}	1590 ± 336 ^{bW}	1716 ± 213 ^{aW}	1644 ± 270 ^{bW}
	G2C0	924 ± 183 ^{aX}	1518 ± 281 ^{bW}	1004 ± 243 ^{bX}	1661 ± 277 ^{bW}
P	G1C1	234 ± 12 ^{c,NS}	222 ± 33 ^{d}	240 ± 49 ^{d}	213 ± 37 ^{d}
	G1.5C0.5	199 ± 35 ^{c,NS}	157 ± 34 ^{d}	170 ± 37 ^{d}	176 ± 45 ^{d}
	G2C0	157 ± 15 ^{cX}	187 ± 21 ^{dWX}	178 ± 42 ^{dWX}	222 ± 45 ^{dW}

All data are represented as mean ± standard deviation (SD). [1] S, shrimp; C, chicken; P, potato [2] G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; and G2C0, gelatin 2% (*w*/*w*%) [3] Different superscripts within column (a–e) or within row (W–Z) indicate significant differences at $p < 0.05$. NS, not significant within row.

Water loss is another major factor that affects the increasing hardness of foods. Water evaporation leads to pore breakage and structure shrinkage and results in dense food matrices [51]. However, the enclosing of food with gels blocked the intrinsic water loss from the inner foods in the present study, and water retention helped the inner foods to

maintain their firmness. The unvaried hardness values in foods are also evidence that they do not undergo reactions with enzymes and microbes. The actions of enzymes and microbes in protein foods are closely related to the decomposition of protein structures and food quality. The denaturation of proteins enhances the disintegration of the myofibril structure and strongly disrupts the elasticity and firmness of protein foods [52]. None of the inner foods showed a significant decrease in their hardness values, which indicates that the actions of enzymes and microbes were suppressed. This may have been associated with the low water activity in the products that was due to the strong water-holding capacity of the gelling molecules.

3.4. Sensory Properties of Gel Foods

QDA is a typical method for identifying the broad sensory modalities of products, covering appearance, odor, texture, flavor, taste, and aftertaste properties, and helping to verify consumer sensations in detail [26]. Although the original shape of the prepared product in this study was food dices thickly surrounded by chicken broth gel, for precise assessments, the QDA was conducted after the outer gel and inner food part were divided. The QDA results are presented in a spider web chart (Figures 1 and 2) and Tables S3–S5. In the gel parts, the addition of κ-carrageenan caused changes in the appearance parameters (transparent and yellowness). The low yellowness value of the κ-carrageenan mixed gels may have been due to the color of the gelling molecules, because gelatin has a yellowish color itself, and it is assumed that the transparency difference was related to the gel matrices. The mix of κ-carrageenan elevated the connection strength in the gel matrices, as found in the mechanical texture analysis, and also in the hardness value of the sensory evaluation. The increase in the gel strength indicated the formation of dense junctions between the gelling molecules and debased the transparent rate of light through the gel [53]. In addition, the other two textural modalities (chewiness and meltiness) significantly differed between the G1C1 and G2C0 gel types for all groups at day 0 ($p < 0.05$), and the addition of κ-carrageenan caused these values to decrease. In the study of Hayakawa et al. [54], gelatin gels showed a low hardness but high cohesiveness and adhesiveness traits, and it was also found that gelatin gels melt quicker than κ-carrageenan gel. In the case of a whey protein/κ-carrageenan mixed gel, the addition of κ-carrageenan enhanced the gel firmness and fracturability, but reduced the meltiness and chewiness [55]. Likewise, the presence of κ-carrageenan significantly affected the gel texture and appearance in the present study. However, there were no meaningful changes in these parameters during cold storage for up to seven days, similar to the mechanical color and texture analysis results. Although there were some distinctions in certain sensory characteristics for the outer gel parts that were due to the ratio of the gelling agents, we could not find any obvious trends across all the sensory traits for the inner foods, despite the different outer gels that were tested. Furthermore, most of the sensory traits did not significantly change during storage for any of the inner food sample groups. These results imply an enhanced durability of the sensory qualities of the inner foods induced by the gel enclosure process. The preservation of food quality during storage is important for commercial food products; therefore, diverse methods have been developed to hinder their deterioration. Hydrocolloids have been used to enhance food stability due to their excellent water-binding capacity, which enables product shelf-life elongation [39]. Likewise, adopting gel barriers for food dices successfully retained the sensory traits of the inner foods in the present study.

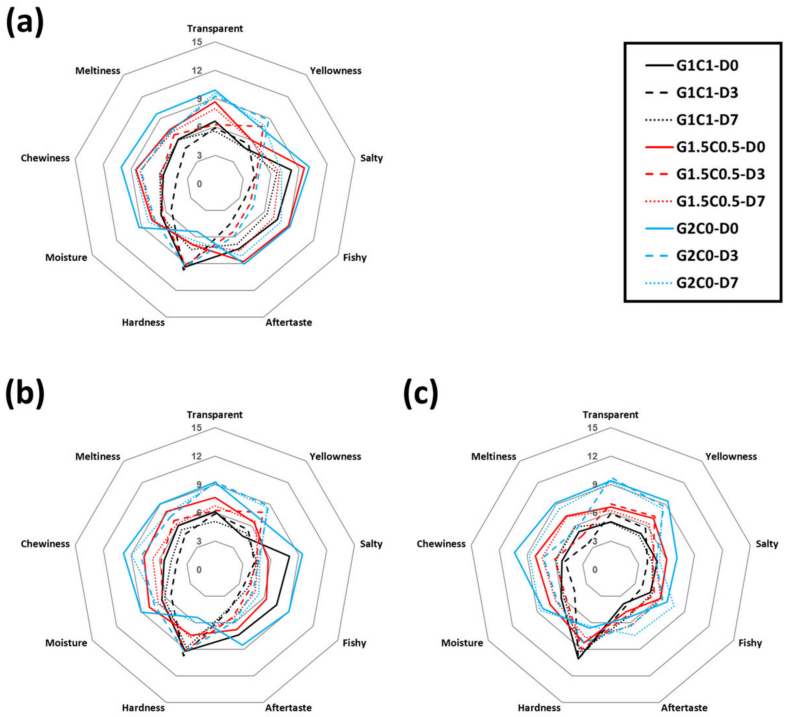

Figure 1. Quantitative description analysis traits of broth jelly cubes ((**a**), shrimp; (**b**), chicken; and (**c**), potato). The means of each sensory trait is presented using a spider web diagram. The sensory evaluation was conducted after outer jelly parts and inner food parts were separated. G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; G2C0, gelatin 2% (*w*/*w*%); and D, storage day.

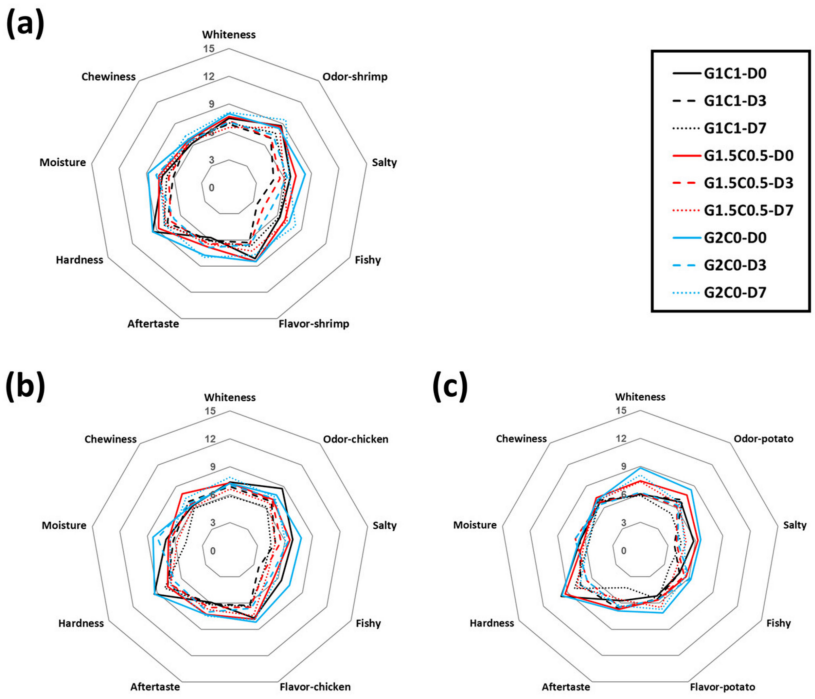

Figure 2. Quantitative description analysis traits of inner ingredients (shrimp, (**a**); chicken, (**b**); and potato, (**c**)). The means of each sensory trait are presented using a spider web diagram. The sensory evaluation was conducted after outer jelly parts and inner food parts were separated. G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; G2C0, gelatin 2% (*w*/*w*%); and D, storage day.

3.5. Microbial Safety of Gel Foods

Microbial safety is a critical point for hygiene and determines the shelf life of food products. In this study, the gel base (chicken broth) and two inner foods (chicken and shrimp) represented protein-rich ingredients that are vulnerable to the flourishing of microbes. Therefore, we confirmed the microbial safety by detecting APCs and *E. coli* in the food products during cold storage (Table 5). While 10^7 CFU/g is regarded as a critical criterion for decay [56], all the analyzed outer gels and inner food samples showed lower APCs (below 10^2 CFU/g) than this criterion, and *E. coli* was not detected in any of the samples. According to previous studies, boiled chickens generally contain 2–4 $\log_{10}$(CFU)/g APCs and these increase to 6–8 in cold storage at 4 °C for 2 weeks [57,58]. Shrimp show a similar tendency to chickens [59], and they require the management of microbial hazards. Without the addition of anti-microbial agents or a specific storage environment, the thick gel coating of our study evidently hindered the growth of microbes in the foods, regardless of the gel composition.

Table 5. Aerial plate counts of broth jelly and inner food cubes.

(Unit: $\log_{10}$ CFU/g)

Aerial Plate Counts of Outer Broth Gel					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S [1]	G1C1 [2]	0.97 ± 0.68 $^{ab\ (3)}$	0.90 ± 0.85 ^{ab}	0.93 ± 0.81 ^{abc}	0.63 ± 0.58 ^{b}
	G1.5C0.5	1.64 ± 0.35 ^{aX}	0.33 ± 0.58 ^{bY}	0.33 ± 0.58 ^{cY}	ND
	G2C0	0.68 ± 0.48 ^{ab,NS}	1.15 ± 0.64 ^{ab}	ND	0.94 ± 0.62 ^{ab}
C	G1C1	1.65 ± 0.30 ^{aX}	1.07 ± 0.97 ^{abXY}	0.74 ± 0.52 ^{bcY}	1.51 ± 0.75 ^{abXY}
	G1.5C0.5	0.83 ± 0.75 ^{abXY}	1.72 ± 0.42 ^{aX}	0.66 ± 0.42 ^{bcY}	1.82 ± 0.51 ^{aX}
	G2C0	1.00 ± 0.89 ^{ab,NS}	0.68 ± 0.48 ^{ab}	0.63 ± 0.52 ^{bc}	0.33 ± 0.58 ^{b}
P	G1C1	0.45 ± 0.31 ^{b,NS}	0.61 ± 0.28 ^{ab}	0.77 ± 0.43 ^{bc}	0.36 ± 0.24 ^{b}
	G1.5C0.5	1.50 ± 0.17 ^{a,NS}	1.26 ± 0.68 ^{ab}	1.54 ± 0.28 ^{a}	1.32 ± 0.55 ^{ab}
	G2C0	1.30 ± 0.30 ^{a,NS}	1.05 ± 0.11 ^{ab}	1.50 ± 1.38 ^{abc}	0.93 ± 0.81 ^{ab}
Aerial Plate Counts of Inner Food Cubes					
Inner food	Gelling agent	Storage time (days)			
		0	3	7	14
S	G1C1	1.62 ± 1.41 ^{ns,NS}	0.77 ± 0.68 ^{ns}	0.83 ± 0.76 ^{ns}	0.33 ± 0.58 ^{ns}
	G1.5C0.5	ND	0.87 ± 0.75 ^{XY}	1.20 ± 0.35 ^{X}	0.59 ± 0.48 ^{Y}
	G2C0	0.77 ± 0.34 ^{NS}	1.66 ± 1.46	0.48 ± 0.30	0.67 ± 0.24
C	G1C1	ND	1.14 ± 1.21	0.92 ± 0.69	ND
	G1.5C0.5	1.62 ± 1.21 ^{NS}	0.92 ± 0.87	1.93 ± 1.70	0.87 ± 0.57
	G2C0	1.72 ± 1.55 ^{NS}	1.38 ± 1.20	ND	ND
P	G1C1	1.03 ± 1.04 ^{NS}	0.87 ± 0.81	1.16 ± 1.01	1.10 ± 0.17
	G1.5C0.5	1.37 ± 0.56 ^{NS}	1.05 ± 0.57	1.15 ± 0.54	ND
	G2C0	1.64 ± 1.47 ^{NS}	1.28 ± 1.11	1.76 ± 0.43	1.55 ± 1.43

All data are represented as mean ± standard deviation (SD). [1] S, shrimp; C, chicken; P, potato [2] G1C1, gelatin 1% and carrageenan 1% mixture; G1.5C0.5, gelatin 1.5% and carrageenan 0.5% mixture; and G2C0, gelatin 2.0% [3] Different superscripts within column (a–c) or within row (X–Y) indicate significant differences at $p < 0.05$. NS, not significant within row. ns, not significant within column.

The edible-film-coating technique assigns several additional merits to food products, including an improved storability. A reduction in water loss and blocking out oxygen are the primary targets of this approach, and various gelling molecules have been applied [60,61]. A coating layer alters the sensorial properties of foods, and the thickness of the layer is an inevitable factor. Although a thin coating method extends the shelf life of food products [62], it showed limitations for controlling water activity and could not evade the menace of microbes effectively. A basic thin coating method usually decreases APCs by 10–30%, but it was not sufficient to evade microbial hazards [62,63]. Therefore, anti-microbial gelling molecules, such as chitosan and anti-microbial agents, have been utilized for the microbial control of products [61,64,65]. The thick gel coating is a dated technology, but its efficiency in decreasing the migration of oxygen and moisture is noteworthy, and it can also significantly decrease water activity [66]. In the present study, we used a 1 cm gel barrier in all directions (width, length, and height) for the gel food, and it effectively maintained the low water activity under 0.95, which represents a very harsh condition for microbe propagation [67]. Hence, the decreased water activity may have postponed the decay time of the gel foods without the blending of anti-microbial agents.

4. Conclusions

The purpose of this study was to verify the characteristics and stability of newly developed gel foods. When the outer gel was prepared, a mixture of κ-carrageenan and gelatin increased the strength of the gels by building specific cross-linkage structures, and the disruption of the gel structure was delayed by the addition of the κ-carrageenan. In the sensory evaluation, while the gel hardness was significantly elevated upon the addition of κ-carrageenan, the gelatin sole gel showed a higher chewiness and meltiness. The enclosure of the food dices with a 1 cm thick gel strikingly alleviated moisture loss, even though the gel provided plentiful moisture to the inner foods. Because water loss is a key inducer of food quality changes, the surrounding gel helped the inner foods to maintain their food qualities. Moreover, the gel barriers drastically alleviated the threat of microorganisms by lowering the water activity. Hence, the thick gel surrounding technique can provide unique textural properties and significantly enhance the stability of inner foods.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pr11082327/s1, Table S1: Redness of broth gels and food cubes, Table S2: Yellowness of broth gels and inner food cubes, Table S3. QDA results of broth gels and inner food cubes (shrimp), Table S4: QDA results of broth gels and inner food cubes (chicken), Table S5: QDA results of broth gels and inner food cubes (potatoes).

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Data Availability Statement: The all datasets used in the study are available from the authors on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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