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Effects of Salt Reduction and the Inclusion of Seaweed (*Kappaphycus alvarezii*) on the Physicochemical Properties of Chicken Patties

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Abstract: This study investigates the effect of salt reduction through the inclusion of seaweed (*Kappaphycus alvarezii*) on the physicochemical and sensory qualities of chicken patties. A control sample (1.5% salt and without seaweed) and four chicken patty formulations were used with two levels of salt (1% and 1.5%) and two levels of seaweed (2% and 4%). Adding seaweed improves water holding capacity and minimized cooking loss in reduced-salt patties. In addition, adding seaweed decreases the shrinkage of the diameter and thickness of chicken patties ($p > 0.05$). However, adding seaweed made the patties darker, as shown by lower L* values ($p > 0.05$). Additionally, the incorporation of seaweed significantly increased ($p < 0.05$) the hardness, chewiness, cohesiveness, and elasticity of patties. Reduced-salt chicken patties with the addition of 2–4% of seaweed showed lower extracted water than 1.5% salt chicken patties with seaweed ($p < 0.05$), indicating a higher water holding capacity. The sensory evaluation showed that the chicken patty with 1.5% salt and 4% seaweed had the highest overall acceptability. However, the overall acceptability of the chicken patties with 1% salt and 4% seaweed was significantly higher ($p < 0.05$) than the control. In conclusion, the addition of *Kappaphycus alvarezii* to reduced salt patties improved textural properties with acceptable taste profiles.

Keywords: seaweed; reduced salt; meat emulsion; physicochemical properties; sensory; meat products; patty

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1. Introduction

Specific population groups widely consume comminuted meat products such as sausages and patties, positively impacting the food sector's economy [1]. However, some processed meat products have high salt content. Due to its low cost and various technological properties, salt is a multipurpose ingredient in processing meat [2]. Table salt (NaCl) is mostly used in meat formulations to improve shelf life, sensory properties, and convenience [3]. However, other additives of sodium salts, such as phosphates, glutamates, lactases, and nitrites, could add to the sodium burden [4].

About 75% of the daily sodium globally comes from processed food items, with 20–30% from meat products [5]. Excessive sodium intake can lead to hypertension, increasing the risk of cardiovascular illnesses, a significant public health issue [6]. The World Health Organization (WHO) have set an adult intake of NaCl limit to less than 5 g/day to overcome health-related issues [7]. The food sector has been encouraged to develop low-salt meat products due to health recommendations and customers' awareness of their health.

Meat products normally contain 7 to 39 g/kg of sodium chloride since most meat formulations require at least 2% salt content for the ionic strength necessary for solubilising and extracting the salt-soluble proteins [8]. Therefore, a decrease in salt content can deteriorate the flavour intensity because NaCl provides features necessary in meat products [8].

The low-salt formulation also tends to have higher cooking loss owing to lower water holding capacity and poor solubilisation of myofibrillar proteins [9].

Various strategies have been considered to minimise salt content and create meat products that meet nutritional recommendations. In processing Chinese bacon, NaCl was partially replaced with potassium chloride to promote the growth of *Lactobacillus* and impacted proteolysis and lipid oxidation [10]. During salami processing, replacing the NaCl with a mixture of KCl, $CaCl_2$, and $MgCl_2$ decreases the sodium content by 40%, with minor effects on sensory qualities. Still, there was a significant increase in lipid oxidation. Other alternatives include incorporating naturally salty-tasting ingredients such as seaweed [2].

Seaweeds contain nutrients and biological compounds, such as proteins, polysaccharides, omega-3 fatty acids, and vitamins [11]. The fatty acid contents of red seaweed were primarily made up of palmitic acid (31.62–41.71%), oleic acid (9.21–10.33%), and arachidonic acid (29.40–38.33%) [12]. *K. alvarezii* also exhibited high amount of soluble (16.73 g/100 g), insoluble (42.24 g/100 g), and total dietary fibre (58.97 g/100 g) [13]. In addition, seaweed contains minerals, including Ca (262.98 mg/100 g), Fe (11.34 mg/100 g), and Zn (0.29 mg/100 g) [14]. Due to their high mineral content, seaweeds can serve as salt substitutes in meat products, reducing sodium intake while increasing the consumption of other minerals unavailable in NaCl-salted processed meat [15]. Seaweeds have a low Na/K ratio, ideal for avoiding hypertension and cardiovascular disorders [2].

The red seaweed *Kappaphycus alvarezii* belongs to the phylum *Rhodophyta* and serves as a source of kappa carrageenan, a phyllocoloid used as a stabilising and thickening agent in food [16]. The phenolic compounds found in abundance in *K. alvarezii* have antioxidant, anti-allergenic, anti-inflammatory, and cardioprotective properties [17]. The antioxidant potency composite index of *K. alvarezii* was 87.93%, owing to the presence of hydroxybenzoic acid, hydroxycinnamic acid, and flavonoid [18,19].

As the research shows [20], adding 4% of *K. alvarezii* to chicken sausage increased the overall phenolic content, reduced lipid oxidation, and showed acceptable sensory results. Additionally, the incorporation of red seaweeds (*Poryphyra umbilicalis* and *Palmaria palmata*) in frankfurters showed decreased ash and estimated shelf-life similar to the control [21]. However, little is known about the effects of *K. alvarezii* addition to reduced-salt patty. Thus, the objective of this study was to develop a chicken patty that could satisfy the need for meat products with lower salt content while promoting consumer acceptance of functional food through different inclusion levels of *K. alvarezii*. The reformulated patties were assessed based on their rheological, physicochemical, and sensory parameters.

2. Materials and Methods

2.1. Preparation of Seaweed Powder

K. alvarezii seaweed purchased from a local market in Kota Kinabalu was rinsed with tap water to remove the dirt, sand, adhesives and epiphytes and dried for 48 h at 45 °C in a drying cabinet (TD-150F, Thermoline Scientific, Wetherill Park, NSW, Australia) [22]. The dried sample was ground into powder using a grinder (WSG30E, Waring, Zhengzhou, China) for 5 min and filtered using a refiner machine (R50, TEM, Modena, Italy). The samples were kept at 4 °C in an airtight container for further analyses [23].

2.2. Preparation of Chicken Patty

Boneless chicken breasts were purchased from Desa Hatchery Sdn. Bhd. and ground using a 4 mm hole plate meat grinder (4812, Hobart, Offenburg, Germany). Four batches of patties were prepared with different salt levels ranging from 1% to 1.5% and *K. alvarezii* (dry matter basis) levels ranging from 2% to 4%, as shown in Table 1. One batch of the patty was prepared at a normal salt (dry matter basis) level without adding seaweed as a control. The patty preparation was modified based on the formulations described by [24]. The ground chicken breast was mixed with other ingredients, such as seaweed powder, potato starch, ice water, and spices, by a mixer (KM331, Kenwood Chef Classic, Petaling

Jaya, Malaysia) for 3 min. Next, 70 g portions of batter were moulded in a hamburger maker with a diameter of 100 and a 10 mm height.

Table 1. Chicken patty formulation with seaweed.

Ingredients	Formulation (%)				
	Control	F1	F2	F3	F4
Chicken breast	65.0	65.0	65.0	65.0	65.0
Seaweed	0	2	2	4	4
Ice water	25.0	23.5	23.0	21.5	21.0
Potato starch	6.0	6.0	6.0	6.0	6.0
Salt	1.5	1.0	1.5	1.0	1.5
Sugar	1.0	1.0	1.0	1.0	1.0
Black pepper	0.5	0.5	0.5	0.5	0.5
White pepper	0.5	0.5	0.5	0.5	0.5
Garlic	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100

Control (without seaweed), F1 (2% seaweed and 1.0% salt), F2 (2% seaweed and 1.5% salt), F3 (4% seaweed and 1.0% salt), F4 (4% seaweed and 1.5% salt).

2.3. Texture Profile Analysis

The texture profile of the patty was analysed using a texture analyser machine (TA. XT Plus, Stable Micro Systems, Surrey, UK) [23]. The test condition was set at a speed of 1.5 mm/s and a height of 2.0 cm. The patty sample was sliced into a 2.0 cm cylindrical shape and compressed to 40% of the original thickness using a 3.5 cm cylindrical probe. The texture profile results were obtained, and the hardness, cohesiveness, chewiness, and elasticity were analysed.

2.4. Colour Analysis

The surfaces of the patty samples were evaluated using a HunterLab Colorimeter (Colorflex-EZ, HunterLab, Reston, VA, USA) [25]. The CIELAB colour system (L* = 0, black; L* = 100, white; +a* = redness; −a* = greenness; +b* = yellowness; −b* = blueness) was measured. The colorimeter was calibrated using a white tile as reference (L* = 93.97; a* = −0.08, and b* = 1.21).

2.5. pH Determination

A total of 10 g of sample was mixed with 90 mL of distilled water for 30 s. The pH of the chicken patty was measured using a pH meter (340, Mettler-Toledo, Greifensee, Switzerland) using the method described in [26].

2.6. Water Activity

The water activity analysis for the chicken patty was carried out using a water activity indicator (HYGROLAB C1, Rotronic, South Burlington, VT, USA) at 25 °C. About 2 g of chicken patty batter was placed into a 3 mm sized cell [27]. Water activity samples were analysed twice, and the average results were recorded.

2.7. Water Holding Capacity

The water holding capacity of the chicken patty was determined by the modified method [28]. A total of 10 g of chicken patty sample was placed in a beaker and heated in a water bath at 90 °C for 1 h. The cooled sample was centrifuged (X3R, Thermo Scientific, USA) at 4 °C and 4000 rpm for 15 min. The water holding capacity is the weight loss after centrifugation and calculated using Equation (1):

$$\text{Water holding capacity } (\%) = \frac{1 - \text{B} - \text{A}}{\text{M}} \times 100 \quad (1)$$

where A is the weight of the chicken patty before heating, B is the weight after centrifugation, and M is the total water content in the sample.

2.8. Cooking Loss

Patty samples were cooked in a steamer for 30 min at 80 °C and then cooled for 30 min [20]. The weight of patty samples before and after cooking was recorded. Cooking loss is the difference in the weight of uncooked and cooked samples as shown in Equation (2):

$$\text{Cooking loss } (\%) = \frac{\text{A} - \text{B}}{\text{A}} \times 100 \tag{2}$$

where A is the weight of the chicken patty before cooking, and B is the weight of the chicken patty after cooking.

2.9. Shrinkage in Diameter and Thickness

The shrinkage in diameter and thickness of raw and cooked chicken patty was measured using a vernier callipers (530-122, Mitutoyo, Japan) [25]. The results were calculated by using Equations (3) and (4):

$$\text{Diameter shrinkage } (\%) = \frac{\text{Diameter of raw patty} - \text{Diameter of cooked patty}}{\text{Diameter of raw patty}} \times 100 \tag{3}$$

$$\text{Thickness shrinkage } (\%) = \frac{\text{Thickness of raw patty} - \text{Thickness of cooked patty}}{\text{Thickness of raw patty}} \times 100 \tag{4}$$

2.10. Rheological Properties

Dynamic rheological properties of the patty sample were examined using an AR500 rheometer (AR500 TA Co., Ltd., New Castle, DE, USA) equipped with a 50 mm parallel plate [24]. A strain sweep test was performed at 20 °C to measure the storage modulus (G'), loss modulus (G''), and loss factor (tan δ). Angular frequency, shear strain, and amplitude were set at 6.283 rad/s, 0.5%, and 0.1–100 Hz, respectively.

2.11. Sensory Evaluation

The sensory evaluation of the chicken patty was conducted using a 7-point hedonic scale (1 = extremely dislike, 7 = extremely like). About 30 untrained panellists aged 20–26 years (15 males and 15 females) of the Faculty of Food Science and Nutrition, Universiti Malaysia Sabah were selected to evaluate the patty samples' colour, aroma, taste, elasticity, and overall acceptance. The patty was grilled until the internal temperature reached 80 °C. The sample was then uniformly cut into rectangular pieces (5.0 cm × 5.0 cm × 2.0 cm) and served to each panellist at the Sensory Evaluation Laboratory along with a random three-digit code. Water at room temperature was provided for mouth rinsing before trying a new sample [20]. Panellists were instructed and reminded to rinse their mouth prior to testing a new sample formulation.

2.12. Statistical Analysis

The statistical analysis was performed using a one-way Analysis of Variance (ANOVA) to evaluate the effects of salt reduction and seaweed addition on the patty's physicochemical and sensory properties. Data were analysed using the SPSS statistical processor software version 26.0 (IBM Corp., Armonk, NY, USA). Tukey HSD test was used to evaluate the significant difference between the means for the various attributes ($p < 0.05$). All analyses were performed in triplicate.

3. Results and Discussion

3.1. Texture Profile Analysis

Texture profile analysis was conducted on patty samples with and without the addition of *K. alvarezii*, as shown in Table 2. Adding seaweed into the chicken patty significantly increased the hardness ($p < 0.05$). Hardness is the maximum force during the first compression of the food sample on the texture analyser [29,30]. The greatest hardness value (2.86 N, Table 2) was obtained in F4 containing 4% *Kappaphyccus alvarezii* and a similar salt content to the control formulation. The protein from the seaweed created a more rigid protein network, creating a harder and coarse texture patty. The low-salt meat was faced with a lack of protein aggregation to form a strong protein network. However, the increased hardness indicated that *Kappaphycus alvarezii* can overcome texture issues in low salt patties.

Table 2. Textural properties of chicken patties with and without the addition of seaweed at different salt levels.

Formulation	Hardness (N)	Chewiness (N)	Cohesiveness	Elasticity (mJ)
Control (C)	1.32 ± 0.06^{d}	1.06 ± 0.02^{b}	0.76 ± 0.02^{c}	0.93 ± 0.01^{b}
F1 (2KA, 1.0S)	1.81 ± 0.18^{c}	1.41 ± 0.02^{b}	0.78 ± 0.01^{bc}	0.95 ± 0.03^{ab}
F2 (2KA, 1.5S)	2.44 ± 0.07^{b}	1.98 ± 0.18^{a}	0.79 ± 0.02^{bc}	0.96 ± 0.02^{ab}
F3 (4KA, 1.0S)	2.62 ± 0.08^{ab}	2.01 ± 0.18^{a}	0.82 ± 0.03^{ab}	0.98 ± 0.03^{ab}
F4 (4KA, 1.5S)	2.86 ± 0.18^{a}	2.20 ± 0.30^{a}	0.86 ± 0.01^{a}	1.01 ± 0.03^{a}

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for different formulation of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

In addition, F4 (2.20 N) showed a significantly higher ($p < 0.05$) chewiness value than the control sample (1.06 N). The effort to chew the food product is positively associated with the food's hardness value, increasing the chewiness value [31]. A similar finding was also reported by [32], in which the sausage with a higher salt content tended to be harder to chew. The cohesiveness and elasticity values also rose as more seaweed was added to the patty (Table 2). However, there was no significant difference ($p > 0.05$) in the cohesiveness of F1 (0.78) and F2 (0.79) from the control (0.76). The result demonstrates the ability of *Kappaphycus alvarezii* as a meat extender at reduced-salt content.

3.2. Cooking Loss, Water Holding Capacity, and pH of Patty

Cooking loss in meat products is closely related to the water holding capacity of meat [23]. A high percentage of water holding capacity indicates a high percentage of cooking yield. Whereas meat with low water holding capacity results in more water and cooking losses. In this study, adding seaweed powder significantly ($p < 0.05$) reduced the cooking loss (Table 3). F4 had the lowest (10.02%) cooking loss, while the control patty showed the highest (16.85%) cooking loss. Seaweed is a rich source of dietary fibre [33], affecting meat properties, including water and fat binding ability. As the dietary fibre was hydrated, the water molecules were retained and occupied in the pore space of fibre, which eventually minimised the cooking loss [34]. The results were in agreement with [23], which reported that adding seaweed (*Kappaphycus alvarezii*) powder in mechanically deboned chicken meat (MDCM) sausages reduced the percentage of cooking loss compared to those without seaweed ($p < 0.05$).

The water holding capacity (WHC) is expressed as the percentage of extracted water, as presented in Table 3. The results showed that the F2, F3, and F4 samples retained more water than the control patty ($p < 0.05$). At similar seaweed content, treatments containing higher levels of salt (F2 and F4) showed lower percentages of extracted water, which were 10.03% and 8.25%, respectively. A low salt concentration affected the heat-induced gelation in meat products due to low myofibrillar protein dissolution. On the contrary, a high amount of salt minimized the extracted water by increasing the solubility and strength of myofibrillar proteins network [3]. However, F1 (11.26%) and F3 (8.50%) showed lower extracted water than the control (12.60%, $p < 0.05$), despite having lower salt content, indicating that *K. alvarezii* could retain water in meat products.

Table 3. Cooking loss, percentage of extracted water, and pH reading for a different formulation of the chicken patty.

Formulation	Cooking Loss (%)	Extracted Water (%)	pH
Control (C)	16.85 ± 0.01 ^{a}	12.60 ± 0.66 ^{a}	5.47 ± 0.10 ^{c}
F1 (2KA, 1.0S)	15.19 ± 0.03 ^{b}	11.26 ± 1.01 ^{ab}	5.64 ± 0.20 ^{bc}
F2 (2KA, 1.5S)	12.37 ± 0.02 ^{c}	10.03 ± 0.31 ^{bc}	5.92 ± 0.02 ^{ab}
F3 (4KA, 1.0S)	10.38 ± 0.04 ^{d}	8.50 ± 0.50 ^{cd}	6.05 ± 0.02 ^{a}
F4 (4KA, 1.5S)	10.02 ± 0.02 ^{e}	8.25 ± 0.23 ^{d}	6.06 ± 0.08 ^{a}

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for different formulations of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

pH is an important factor associated with the meat's water-holding capacity. Except for F1, the addition of *Kappaphycus alvarezii* significantly increased ($p < 0.05$) the pH of the patty, with F4 showing the highest pH value of 6.06. The pH of meat products affects their texture, as low pH indicates a decreased water holding capacity [35]. The pH value shown in Table 3 agreed with the texture profile analysis (Table 2), as the addition of seaweed increased the hardness, chewiness, cohesiveness, and elasticity of the patties.

3.3. Colour Evaluation

Colour is an important parameter that determines the meat wholesomeness and consumer acceptance of a product [31]. The colour distinguishes the water content, meat pigments, and fat of processed meat products. The colour analysis results were expressed as L*(0) = black, L*(100) = white, +a* = redness, −a* = greenness, +b* = yellowness, and −b* = blueness [30]. It was observed that the brightness (L*) and yellowness (b*) of a patty did not show any significant difference among the F1, F2, F3, and F4 samples. Based on the report by [34,36], the L* value is influenced by the moisture content and pH value of meat products. In the present study, it could be concluded that higher pH values (Table 3) resulted in lower brightness (Table 4) of patty samples.

Table 4. Colour of different formulation of chicken patty.

Formulation	L*	a*	b*
Control (C)	54.37 ± 0.98 ^{a}	3.69 ± 0.19 ^{c}	19.17 ± 0.91 ^{a}
F1 (2KA, 1.0S)	52.20 ± 1.93 ^{ab}	3.74 ± 0.19 ^{c}	15.52 ± 0.34 ^{b}
F2 (2KA, 1.5S)	50.45 ± 6.40 ^{ab}	4.15 ± 0.55 ^{bc}	18.45 ± 0.41 ^{ab}
F3 (4KA, 1.0S)	47.99 ± 1.37 ^{ab}	4.51 ± 0.13 ^{ab}	17.91 ± 1.18 ^{b}
F4 (4KA, 1.5S)	44.80 ± 0.68 ^{b}	5.06 ± 0.10 ^{a}	17.44 ± 1.73 ^{b}

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for a different formulation of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

The a* value of F1 and F2 were similar ($p > 0.05$) with the control, while F3 and F4 showed higher redness ($p < 0.05$). *K. alvarezii* falls under the Rodophyte division, which contains high phycoerythrin and phycocyanin [16]. The colours of these compounds are stronger than other pigments such as chlorophyll and beta-carotene [16]. In terms of yellowness (b*), [37] associated the reduced b* value with the higher WHC of meat products caused by the addition of seaweed in the formulations.

3.4. Water Activity

Water activity (a_w) is a physicochemical parameter that can control the food quality by determining the growth capacity of microorganisms and measuring the ratio between water pressure in the material and air pressure outside the material [38,39]. Table 5 shows that water activity decreased with the addition of seaweed, but only F4 showed a significant difference ($p < 0.05$) with the control sample. The presence of seaweed acts as a humectant, reducing the a_w. This finding agrees with [40], stating that dietary fibre from a nonmeat ingredient can act as a humectant in meat products.

Table 5. The water activity of different chicken patty formulations.

Formulation	Water Activity
Control (C)	0.947 ± 0.00^{a}
F1 (2KA, 1.0S)	0.940 ± 0.01^{ab}
F2 (2KA, 1.5S)	0.936 ± 0.00^{ab}
F3 (4KA, 1.0S)	0.933 ± 0.01^{ab}
F4 (4KA, 1.5S)	0.920 ± 0.00^{b}

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for different formulations of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

Additionally, higher salt content reduced ($p > 0.05$) the a_w, as proved by F2 (0.936) and F4 (0.920). Salt plays an important role in maintaining the quality of meat products by reducing the water activity in meat products. Previous research reported that a reduction in salt from 1.5% to 1.0% might alter the shelf life of meat products [41]. Most pathogens require a minimum a_w of 0.95, while the growth of *Clostridium botulinum E* required a minimum a_w of 0.97. However, some bacteria can produce toxins in even in low a_w conditions, such as *Listeria monocytogenes* (a_w = 0.92) and *Staphylococcus aureus* (a_w = 0.86) [42].

3.5. Shrinkage of Diameter and Thickness of Chicken Patty

The diameter and thickness shrinkages of chicken patties are closely associated with fat levels. The decreasing of fat levels caused a significant decrease in the diameter and thickness of the chicken patty ($p < 0.05$). Table 6 listed the diameter and shrinkage thickness of different chicken patty formulation types.

Table 6. Shrinkage of diameter and thickness of chicken patties with different formulations.

Formulation	Shrinkage of Diameter (%)	Shrinkage of Thickness (%)
Control (C)	31.33 ± 3.21^{a}	53.00 ± 3.61^{a}
F1 (2KA, 1.0S)	18.00 ± 3.46^{ab}	36.67 ± 11.55^{a}
F2 (2KA, 1.5S)	14.67 ± 1.53^{c}	26.67 ± 15.28^{ab}
F3 (4KA, 1.0S)	13.33 ± 1.53^{c}	20.67 ± 9.29^{ab}
F4 (4KA, 1.5S)	6.33 ± 3.51^{d}	15.33 ± 6.11^{b}

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for different formulations of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

A significant decrease in diameter and thickness shrinkage was shown in the patties with added seaweed. F4 had the lowest diameter and thickness shrinkage of 6.33 mm and 15.33 mm, followed by F3, F2, F1, and the control sample. Seaweed containing cation concentrations such as potassium and calcium ions could retain the gel structure of carrageenan in situ and link with the meat protein matrix to absorb the water and had fat-holding properties [43]. In addition, the salt content of F4 was 1.5%, which can bind water and form a more stable gel. In contrast, a salt reduction in 1.0% in F1 showed a significant difference in diameter and thickness shrinkage ($p < 0.05$) but adding seaweed as a substitute could reduce the shrinkage of the diameter and thickness of chicken patties [44]. The formation of carrageenan gel structure by potassium and calcium ions in *Kappaphycus alvarezii* can increase the linkages with the meat–protein matrix to absorb and improve the water and fat-holding properties, which resulted in a reduction in the shrinkages of the patties [43].

3.6. Dynamic Rheological Properties of Chicken Patty

The high storage modulus (G′) compared to the loss modulus (G″) indicate the solid-like texture of the profile. High G′ indicated a harder emulsion texture. Based on Figure 1, F4 had the highest G′, validating the findings in Table 2. The sample with shorter linear G′ when shear stress is applied indicated a weak protein–protein myofibrillar interaction, which indicated a brittleness. F4 had a shorter linear G′, while the control sample had a more constant G′ linear. A high seaweed concentration improved the chicken patty's hardness but slightly altered the matrix's protein interaction.

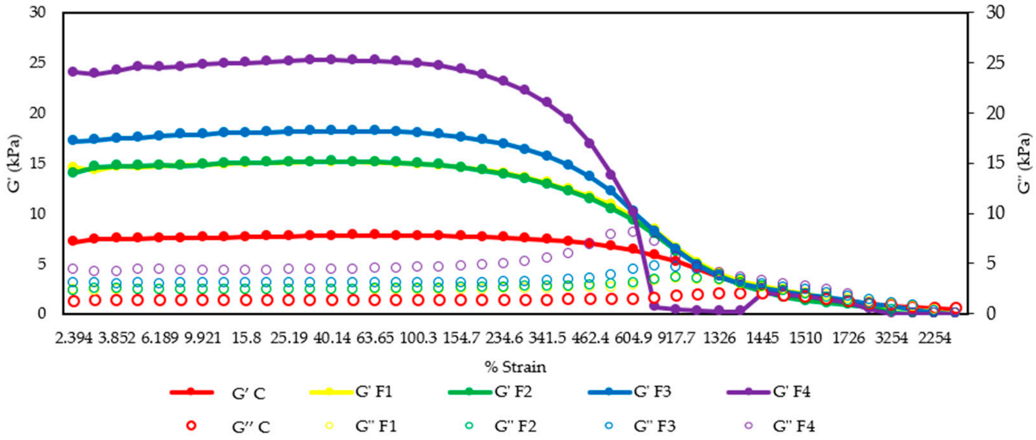

Figure 1. Strain sweep test for the effect of salt reduction and addition of seaweed (*K. alvarezii*) on the chicken patty.

Table 7 shows the maximum range of the Linear Viscoelastic Region (LVR) value and loss tangent (tan δ). The G′ and G″ values were directly proportional. The higher the G′ value, the higher the G″ chicken patty's value. The increased shear rate was required to break a harder G′, as supported in Figure 1. Although F4 had the highest G′ value of 17.24 kPa, the deformation was found under a low strain percentage of 527.6%. F4 was brittle and unable to restrain the applied stress. A stable protein network exhibits a high tangent value [21]. F4 had the lowest tangent value, while F3 had the highest tangent value, as shown in Table 7. A higher tangent indicates higher elasticity properties than viscosity, forming a more orderly gel network structure to increase the water-holding capacity of the low-salt chicken patty. Thus, F3 exhibited a strong protein network, while a weak protein network was shown in F4 [45].

Table 7. Strain sweep analysis for different formulations of chicken patty samples.

Formulation	Strain Oscillation Test	
	G′ (kPa)	G″ (kPa)
Control (C)	4.76 ± 0.40 [a]	1.48 ± 0.05 [a]
F1 (2KA, 1.0S)	7.23 ± 0.98 [a]	2.09 ± 0.42 [a]
F2 (2KA, 1.5S)	7.27 ± 1.51 [a]	2.30 ± 0.51 [a]
F3 (4KA, 1.0S)	12.87 ± 1.21 [b]	4.84 ± 4.41 [a]
F4 (4KA, 1.5S)	17.24 ± 0.49 [c]	4.50 ± 3.37 [a]

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for different formulation of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

3.7. Sensory Evaluation of Low-Salt Chicken Patty with Seaweed

A 7-scale Hedonic test determined consumer acceptance of the sensory attributes of the *Kappaphycus alvarezii* seaweed-mixed low-salt chicken patty. The sensory attributes tested consisted of colour, aroma, hardness, elasticity, juiciness, and overall acceptance, as shown in Table 8.

Table 8. Sensory attributes for different formulations of chicken patty.

Formulation	Sensory Attributes					
	Colour	Aroma	Hardness	Elasticity	Juiciness	Overall Acceptance
Control (C)	4.70 ± 1.58 ^{a}	5.60 ± 1.40 ^{a}	3.97 ± 1.27 ^{a}	4.03 ± 1.54 ^{a}	5.37 ± 1.43 ^{a}	4.33 ± 1.37 ^{a}
F1 (2KA, 1.0S)	4.97 ± 1.10 ^{ab}	5.03 ± 1.35 ^{a}	4.50 ± 1.11 ^{ab}	4.43 ± 1.17 ^{a}	5.13 ± 1.41 ^{ab}	4.40 ± 1.28 ^{a}
F2 (2KA, 1.5S)	5.10 ± 1.03 ^{abc}	5.00 ± 1.31 ^{a}	5.20 ± 1.24 ^{b}	4.60 ± 1.59 ^{ab}	4.60 ± 1.04 ^{ab}	4.70 ± 0.88 ^{ab}
F3 (4KA, 1.0S)	5.60 ± 1.07 ^{bc}	4.83 ± 1.18 ^{a}	5.30 ± 1.06 ^{bc}	5.50 ± 1.20 ^{bc}	4.40 ± 1.19 ^{b}	5.27 ± 0.94 ^{b}
F4 (4KA, 1.5S)	5.87 ± 0.97 ^{c}	4.73 ± 1.66 ^{a}	6.03 ± 1.13 ^{c}	5.67 ± 1.24 ^{c}	4.33 ± 1.42 ^{b}	6.10 ± 1.02 ^{c}

Mean ± standard deviation (SD) with different lowercase superscripts showed significant differences for different formulation of samples ($p < 0.05$). Control = 0% *Kappaphycus alvarezii*, 1.5% salt; F1 = 2% *Kappaphycus alvarezii*, 1.0% salt; F2 = 2% *Kappaphycus alvarezii*, 1.5% salt; F3 = 4% *Kappaphycus alvarezii*, 1.0% salt; F4 = 4% *Kappaphycus alvarezii*, 1.5% salt.

F4 received the highest score in colour likeness compared to other formulations ($p < 0.05$). Although the seaweed-treated patty was darker than the control sample, the panellist favoured the seaweed-treated patty. The control sample received the lowest colour acceptance with a brownish-white colour. This finding is supported by the colour analysis of the redness value a*, as shown in Table 4. A high redness a* value of the patty was commonly perceived as positive and is observed in most commercial patties.

There is no significant difference ($p > 0.05$) in aroma attributes. F4 received the highest acceptance score for its hardness and elasticity attributes with values of 6.03, signicantly higher than the control patty ($p < 0.05$). The high hardness and elasticity acceptance score in the seaweed-treated patty agreed with the texture profile improvement described in Table 4.

Juiciness, or the amount of water in meat products, is an important element for taste enhancement and meat tenderness, making it easy to chew. The decreased trend in juiciness with higher seaweed concentrations is shown in Table 8 F4 received the lowest score value among the five formulations ($p < 0.05$). However, there was no significant difference in juiciness score ($p > 0.05$) for the control sample, F1, and F2. Although the WHC improved as more seaweed was added to the patty, the seaweed patty perceived a drier mouth feel, reducing the juiciness acceptance in a patty with a high concentration of seaweed [46].

F4 received the highest score for overall acceptance and was closely followed by F3. Despite a low score for juiciness, F4 received a high score for acceptance in most other sensory attributes such as colour, hardness, and elasticity. Furthermore, salt is commonly used to enhance the organoleptic properties of meat products. Therefore, reducing salt contents deteriorated sensorial properties, although the addition of seaweed did compensate for some attributes such as hardness and elasticity.

4. Conclusions

This study investigates the effect of adding *Kappaphycus alvarezii* seaweed on the low-salt chicken patty in terms of its physicochemical properties. Adding *K. alvarezii* lowered the percentage of cooking loss, shrinkage of diameter and thickness while improving the water holding capacity. *K. alvarezii* could also improve the texture attributes such as the hardness, elasticity, chewiness, and cohesiveness of the patty. In addition, seaweed addition influenced the colour of sample by increasing the brightness (L*) and redness (+a*), while decreasing the yellowish value (+b*). The water activity remained unchanged despite the increased addition of seaweed. Additionally, *K. alvarezii* improved the dynamic rheological properties, owing to the presence of the kappa carrageenan and salt-binding properties between the meat protein matrices. The sensory evaluation results showed that salt reduction to 1.0% with the addition of 4% *K. alvarezii* into the chicken patty sample (F3) was still acceptable and preferred, despite the highest overall acceptance of F4. Future studies will concentrate on increasing the health advantages of the patty through the combination of salt and fat reduction, using *K. alvarezii* at the acceptable inclusion levels identified in the present study.

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