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Effect of Dry Salting and Brining on the Consumer Acceptance of *Saccharina latissima* (Sugar Kelp)

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Abstract: Brining and dry salting are traditional preservation techniques used to extend the shelf life of foods including seaweeds. In this study, brining (40% NaCl solution weight/volume) and dry salting (30% weight/weight) processes were applied to fresh kelp to achieve a target water activity of less than 0.77, and the effect of salting treatment on consumer acceptance was assessed. The processed samples were stored at 4 °C for 2 weeks until the sensory analysis. Processed kelp samples were used as the primary ingredient in a salad with shredded carrots and sesame dressing. Three salad samples (salad with fresh kelp (control), brined, or dry salted sugar kelp) were presented to the panelists to assess the liking of sensory attributes including salt intensity, color, aroma, flavor, texture, and overall liking. Significant differences in the liking of flavor and texture were observed, with consumers rating both treatments made with salted seaweed higher than a salad made from fresh seaweed. Panelists identified the availability and lack of information regarding nutritional benefits as barriers to their seaweed consumption. These results indicate that in addition to extending shelf life, the preservation of kelp by salting may increase consumer acceptability.

Keywords: seaweed; macroalgae; sensory testing; preservation



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1. Introduction

Sugar kelp is a brown alga that is consumed for its nutritional benefits, such as vitamins, minerals, dietary fiber, etc. It is harvested as a seasonal crop in Asian countries, such as China and Japan; Europe; and the coastal fronts of North America [1–3]. *Laminaria* and *Saccharina* species constitute approximately 35% of the global macroalgae cultivation and are used primarily for human consumption [4]. Sugar kelp is a highly significant species for cultivation in the North Atlantic and Pacific regions. It is considered the fastest-growing species of cultivated kelp, with estimated annual production capacities ranging from 75 to 200 tons of wet weight per hectare at sea [4–6]. Recent studies have shown an increase in public awareness and a perception shift towards the environmental impacts of agribusiness industries [7,8]. The increased awareness of the public can impact the food industry and can increase the demand of sustainable food production practices, thus becoming more aware of the importance of sustainable agriculture methods [7,8]. Seaweed farming is considered sustainable as it does not require fresh water, fertilizers, or land, making it an alternative to land-based agriculture. Studies have indicated that seaweed farming can help mitigate climate changes by sequestering CO₂ marine habitats [9–11]. Seaweed can be used as an alternative source of energy production in the form of biofuel to minimize the heavy reliance on fossil fuels. Additionally, seaweed can be incorporated into ruminant livestock's feed to reduce methane emissions [9,12].

Despite the long history of seaweed consumption and culture in Asian countries, macroalgae are still considered to be novel foods in the United States [13]. The nutritional benefits of seaweed have led to an increase in demand in western countries including the USA [14,15]. Seaweeds are rich in dietary fibers, complex carbohydrates, bioactive

compounds, and minerals. The nutritional composition of seaweed varies from species to species. Sugar kelp, being brown macroalgae, are abundant in specific nutrients and phytochemicals, such as dietary fibers, phlorotannins, fucoxanthin, and minerals [16]. Edible brown seaweeds are marketed in various forms, including nutraceutical supplements, due to their reported antioxidant, anticancer, antitumor, antiviral, anti-inflammatory, antibacterial, etc., abilities [13,16]. Kelp aquaculture represents the fastest growing segment of the aquaculture sector in the US [13], where the majority of farms are located in the northern latitudes off the coasts of Alaska and New England. These areas are typically remote, making localized processing infrastructure a significant bottleneck in the growth of the industry [17]. Sugar kelp is highly perishable, with a high moisture content (~75–90% wet weight basis) that makes it susceptible to microbial degradation, enzymatic deterioration, and lipid oxidation [18,19]. Therefore, the post-harvest processing of sugar kelp is needed to increase its shelf life and improve its quality. Drying is the most common process for seaweed preservation worldwide but presents a number of challenges related to quality (i.e., breakage, color loss, etc.). While freezing may result in a higher quality product, the access to processing equipment, as well as temperature-controlled storage and transportation, can be substantial barriers to the utilization of this method [17]. Salting (encompassing both dry salting and brining) can also be used as a post-harvest processing method to extend sugar kelp's shelf-life and to diversify fresh seaweed products. Salting and brining may be cost-effective and easy to use for kelp post-harvest processing as compared to other methods, such as freezing and oven drying, due to a reduced need for capital equipment and energy use [20]. However, the impact of added sodium on consumer acceptance should be assessed in accordance with US public health efforts to control diet-related comorbidities such as hypertension [21].

Several authors [22–25] have reported that salting treatments can increase the shelf life of various seaweeds, but *Saccharina latissima* is not among the species evaluated. When *Alaria esculenta* was dry salted (0–200 NaCl, g/kg), refrigerated shelf life reached 90 days [24]. In consumer sensory evaluation of a salad made from salted *A. esculenta*, the overall liking was similar, regardless of the salt level used for preservation [24]. While our work suggests that both salting and brining are capable of extending sugar kelp's shelf life while preserving quality [26], it is unclear whether the sensory qualities imparted by either process will result in a preferable product. Therefore, the aim of this study is to evaluate the effects of dry salting {30% weight/weight (w/w)} and brining {(40 weight/volume (w/v))} on the consumer acceptance of sugar kelp.

2. Materials and Methods

2.1. Sample Preparation

Fresh sugar kelp sourced from Springtide Seaweed (Gouldsboro, ME, USA) and Ocean's Balance (Biddeford, ME, USA) was washed by hand with tap water to remove biofouling. Washed sugar kelp (Figure 1a) was divided into two groups—one group was subjected to brining treatment, and the second was subjected to dry salting.

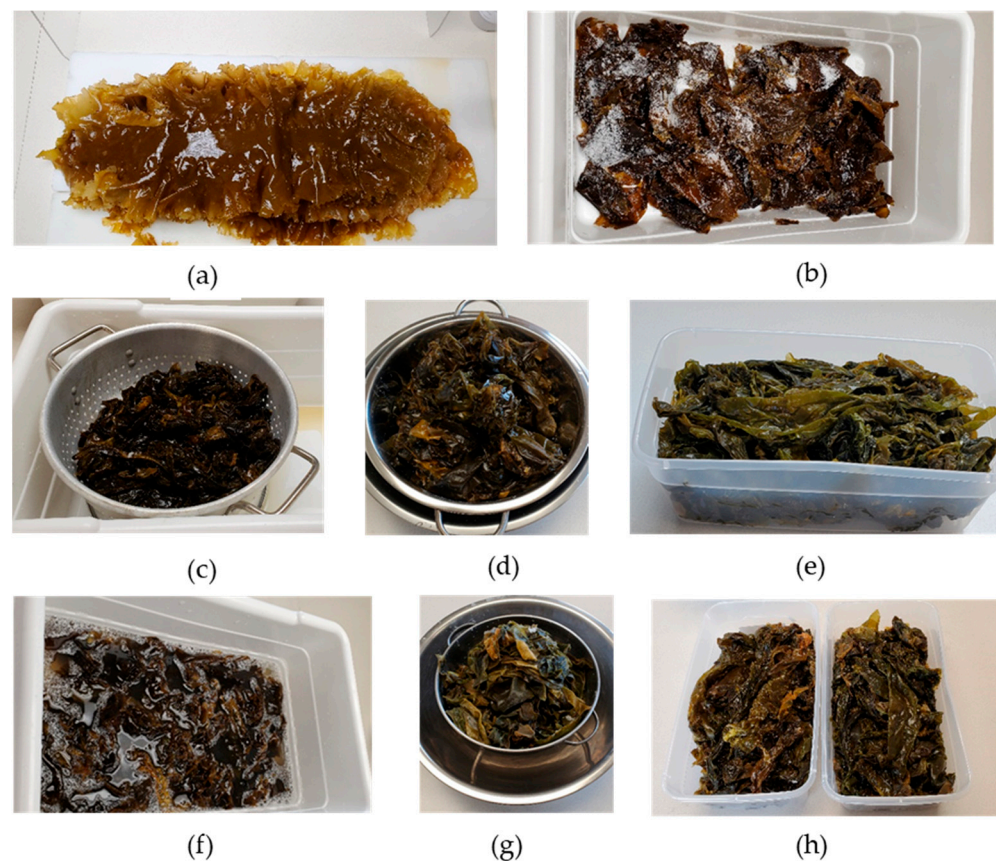


Figure 1. Sugar kelp processing: (a) fresh kelp, (b) dry-salting of fresh kelp, (c) dry-salted kelp in a colander to allow draining, (d) dry-salted kelp after draining, (e) dry-salted kelp stored in a food-grade plastic container for further analysis, (f) brining of sugar kelp, (g) draining brined kelp in a colander, and (h) final brined sugar kelp samples kept in a food-grade plastic container for further analysis.

2.2. Treatment

For the dry salting treatment, kosher salt (NaCl; Morton Salt, Chicago, IL, USA) was mixed with fresh sugar kelp on a 30% weight basis (w/w) (Figure 1a). The dry salted sugar kelp samples were placed into a colander at ambient temperature to allow for draining, as shown in Figure 1b. Excess exuded water was allowed to drain from the dry salted sugar kelp for 24–48 h to achieve the target water activity of 0.77 (measured using an Aqualab 3TE water activity meter). After confirmation of the target water activity, dry salted kelp was transferred into food-grade plastic deli containers with lids, as shown in Figure 1e. The dry salted sugar kelp samples were stored at 4 °C for 2 weeks until the sensory analysis.

Similarly, the second group of sugar kelp was subjected to a brining treatment, in which the sugar kelp samples were immersed in a salt solution (40% w/v NaCl in distilled water), with a sugar kelp to salt solution ratio of 1:4 (Figure 1f), and were continuously agitated for 30 min. The water activity of the final processed sample was confirmed using the Aqualab water activity meter to make sure the water activity of the final processed samples was below 0.77. At this point, the salt solution was drained from the brined sugar kelp samples using a colander (Figure 1g). The brined sugar kelp samples were then transferred into food-grade plastic deli containers with lids (Figure 1h) and were stored at 4 °C for 2 weeks before sensory analysis.

2.3. Salad Preparation

Dry salted and brined sugar kelp samples were rinsed in a colander for 3 min under cold tap water, and were kept at room temperature for 5 min in the colander to remove

excess salt and water before salad preparation. Three salad samples, including one control salad sample with fresh raw sugar kelp, one salad sample with brined sugar kelp, and one sample with dry salted sugar kelp, were prepared to present to the panelists for the assessment of the liking of sensory attributes.

Sugar kelp was mixed with fresh carrots (matchstick; Hannaford Bros. Co., Scarborough, ME, USA), toasted sesame seeds (JFC International, Los Angeles, CA, USA), grated ginger (Spice World, Orlando, FL, USA), soy sauce (Hannaford Bros. Co., Scarborough, ME, USA), and white distilled vinegar (Hannaford Bros. Co., Scarborough, ME, USA), as summarized in Table 1 (also displayed in Figure 2a).

Table 1. Seaweed salad recipe formula.

Salad Ingredients	Amount g/kg (w.w.b ¹)
Sugar kelp ² (Rinsed, drained)	750
Carrots (shredded)	130
Toasted sesame seeds	30
Ginger (grated)	30
Soy sauce	30
Distilled white vinegar	30

¹ w.w.b: wet weight basis. ² Fresh, dry salted, or brined.

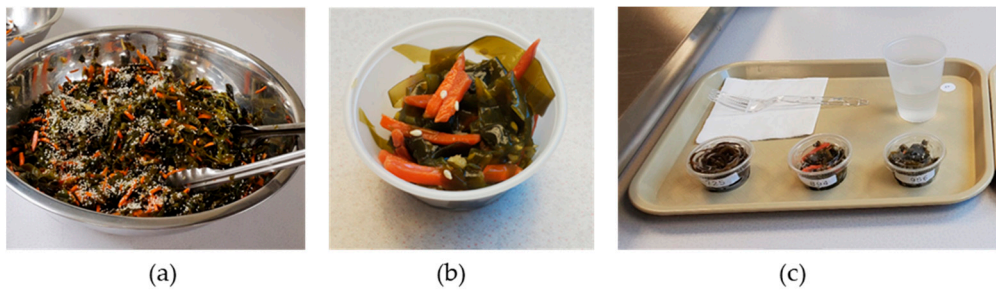


Figure 2. Sugar kelp salad preparation: (a) mixed salad ingredients, (b) sugar kelp salad in a food-grade sample cup for evaluation, and (c) samples arranged in a tray for sensory evaluation.

2.4. Sensory Evaluation

The study was conducted at the Sensory Evaluation Center at the University of Maine. The University of Maine Institutional Review Board for the protection of human subjects judged this research as being exempt from further review. All research participants were provided informed consent. The test randomizations, experimental designs, data collection, and analyses were executed using SIMS 2000 v2.4.38 (Sensory Computer Systems, Berkeley Heights, NJ, USA) software. This software was used to create a questionnaire and randomized sample order presentations to reduce experimental errors due to sampling order. Windows tablet computers were used for data collection.

Sensory evaluation was conducted to determine the effects of dry salting and brining on the consumer acceptance of salad made from sugar kelp. A total of 41 sensory panelists (at least 18 years old) in the greater Orono, ME area interested in seaweed and not allergic to seaweed or the other salad ingredients were recruited via email and flyer notices to assess the acceptability of sugar kelp salad. The testing lasted 20–25 min.

Panelists were seated in individual booths with a combination of fluorescent and incandescent lighting. During testing, the rooms were well-lit to control environmental variables and biases. Prior to the presentation of the salad samples, panelists were asked a series of questions including demographics (age, gender, and race), seaweed consumption habits and preferences (frequency, form, etc.), and questions about sodium consumption. Panelists were simultaneously presented with three 20 g samples of control fresh kelp salad, dry salted kelp salad, and brined kelp salad in food-grade plastic sample cups (Figure 2b). All samples were kept at a similar temperature in the refrigerator until serving.

The three products were labeled with random 3-digit codes, and sample orders were randomized according to the SIMS software to reduce the effects of flavor carry-over and order bias. A tray containing the salad samples was served along with spring water for palate cleansing, a napkin, and a fork, as shown in Figure 2c.

Each participant was instructed to evaluate the samples from left to right in the order shown on the tablet screen, to take a sip of spring water (Nature's Promise, Hannaford Bros. Co., Scarborough, ME) before testing each sample, and to rate their liking of specific sensory attributes of the samples. A 9-point hedonic scale (from 1 = "Dislike Extremely" to 9 = "Like Extremely", with 5 = "Neither Like nor Dislike") was used to assess the acceptability of appearance, color, flavor, aroma, texture, saltiness, and the overall liking of the samples [27]. Hedonic data were analyzed using a one-way ANOVA and Tukey's HSD post hoc test, with a p -value of ≤ 0.05 considered significant.

Panelists were also asked about levels of saltiness, tenderness, and firmness. These questions were posed using five-point just-about-right (JAR) scales (from 1 = "Not X" to 5 = "Much too X" with 3 = "Just about right", where X represents each trait. JAR ratings were compressed into a three-point scale for graphical representation and were subjected to penalty analysis to assess impact on overall liking using XLSTAT 2024 (Lumivero, Denver, CO, USA).

2.5. Sodium Analysis

The salt content of dry salted and brined kelp before and after rinsing was analyzed according to the AOAC method (938.08) [28]. One gram of sample was dried at 100 °C for 6 h in a convection oven and the dried sample was ashed in a muffle furnace at 550 °C for 6 h. The ashed samples were dissolved in concentrated acid ($\text{HNO}_3\text{:HCl}$; 1:1 v/v), and were then brought to volume (100 mL) with distilled water. The samples were then analyzed using inductively coupled plasma optical emission spectroscopy (Thermo Elemental IRIS Intrepid DUO ICP-OES, Waltham, MA, USA) to determine their sodium, calcium, magnesium, and potassium content. All the samples were analyzed in duplicate and reported on a wet weight basis (w.w.b).

3. Results and Discussion

3.1. Demographics

Demographic and consumption trend questions were asked before the salads were evaluated. More females (56.1%) took part in the evaluation (Table 2). The majority (63.4%) of the sensory participants for the kelp salad evaluation were 35 years old or younger. About 17% of the participants were Asian, and 61% were Caucasian.

Panelists indicated that they most often consumed seaweed as an ingredient of other food such as sushi (53.7%), with about 17% consuming it as salad, 9.8% as soup, 4.9% as roasted or slightly toasted seaweed snacks, and the remainder in other forms. Unfortunately, a large portion of the panelists indicated that they consume seaweed every 2–3 months or less frequently. When asked what factors might increase seaweed consumption (check all that apply), 53.7% of respondents indicated availability as a limiting factor (Table 3), while 46.3% sought more information regarding nutritional value, among other reasons, signifying the importance of diversifying seaweed products to the U.S market.

When asked about appropriate pricing for a four ounce, ready-to-eat seaweed salad bowl, the majority of respondents were willing to pay USD 3.00–4.00 (Table 4).

Current estimates suggest that approximately half of US adults suffer from hypertension and approximately five percent suffer from coronary artery disease [29,30]. These populations are strongly encouraged to limit dietary sodium intake, and public health outreach in the United States commonly focuses on the health risks associated with excess dietary sodium [21]. In order to determine whether a salt-based preservation method would be unappealing to consumers, panelists were asked a short series of questions about sodium (Table 5), including "Do you think a diet high in sodium could lead to health complications?", "How important to you is decreasing sodium consumption in your diet?",

and “Do you regularly monitor or control sodium intake in your diet?” The majority of panelists (65.9%) indicated that a higher sodium intake could lead to health complications, but, interestingly, a similar percentage (68.3%) reported that they do not regularly monitor or control sodium in their diets. About a third of the panelists had no opinion or were neutral on decreasing sodium intake in meals, while 33.7% said it was moderately-to-very important. These percentages are likely to have been affected by the preponderance of younger adults on the panel in this study, as diet-related diseases (including hypertension) are more prevalent in older age groups [30]. Raw kelp contains 233 mg of sodium per 100 g [31]. In this study, salting and brining were used as food processing methods that can increase the sodium content of salted kelp products. Though the processed (dry salted and brined) kelp was rinsed before preparing the salad, the sodium content of the resulting product is increased when compared to fresh kelp. In our study, the sodium content of the raw kelp, dry salted, and brined kelp (before rinsing) was 2.53 ± 0.2 , 94.84 ± 1.3 , and 123.63 ± 2.96 g/kg (w.w.b), respectively. After rinsing, the sodium content of rinsed dry salted and brined kelp were 12.90 ± 0.94 and 16.45 ± 0.65 g/kg (w.w.b). Additional work with consumers is needed to assess whether these sodium content levels are prohibitive for some consumers. However, most of the panelists (80.5%) deemed seaweed as a healthy food, with about 17% being uncertain about its health status, suggesting that messaging around nutritional quality could be improved.

Table 2. Demographics of participants for kelp salad sensory evaluation (n = 41).

Characteristics		Number (%)
Gender	M	16 (39.0)
	F	23 (56.1)
	Nonbinary	2 (4.9)
Age (years)	18–25 years	15 (36.6)
	26–35	11 (26.8)
	36–45	8 (19.5)
	46–55	3 (7.1)
	56–65	4 (9.8)
	65+	0 (0)
Race	American Indian/Alaska Native	0 (0)
	Asian	7 (17.1)
	Black/African American	8 (19.5)
	White (Caucasians)	25 (61.0)
	Native Hawaiian/Other Pacific Islander	0 (0)
	Prefer not to say	0 (0)
	Did not answer	1 (2.4)

Table 3. What would make you consume seaweed more often? (n = 41).

Factors	No. of Responses (%) ¹
Knowing the nutritional value	19 (46.3)
Lower price	11 (26.8)
More availability	22 (53.7)
Longer shelf-life	2 (4.9)
Sustainably grown	6 (14.6)
Minimally processed	6 (14.6)
Sold fresh	4 (9.8)
Sold in ready-to-eat dishes	6 (14.6)
Grown in Maine	6 (14.6)
Others	2 (4.9)

¹ More than one answer could be selected.

Table 4. How much would you pay for a ready-to-eat four-ounce (4 oz) seaweed salad bowl? (n = 41).

Descriptors	No. of Responses (%)
Would not purchase	2 (4.9)
USD 2.00	6 (14.6)
USD 3.00	15 (36.6)
USD 4.00	14 (34.1)
USD 5.00 or more	4 (9.8)

Table 5. Panelist opinions regarding dietary sodium intake.

Question	Responses	Number (%)
Do you think a diet high in sodium could lead to health complications	Yes	27 (65.9)
	No	5 (12.2)
	No opinion	9 (22.0)
Do you regularly monitor or control sodium intake in your diet?	Yes	12 (29.3)
	No	28 (68.3)
How important to you is decreasing sodium consumption in your diet?	Not at all important	4 (9.8)
	Low importance	6 (14.6)
	Slightly important	3 (7.3)
	Neutral or no opinion	12 (29.3)
	Moderately important	7 (17.1)
	Very important	6 (14.6)
	Extremely important	3 (7.3)

3.2. Sensory Attributes

When asked about the relative importance of sensory characteristics, flavor (75.6%) was overwhelmingly reported to be the most important, followed by aroma (12.2%) and then texture (9.8%) (Table 6). It is interesting that no panelist chose the attribute “color”, as that was a common answer in a previous kelp salad consumer acceptance test [24]. This could be due to the increasing availability of seaweed on the market, resulting in greater consumer familiarity with and acceptance of the color of seaweed.

Table 6. Which sensory characteristic of seaweed is most important to you? Please choose only one answer. (n = 41).

Characteristic	Responses (%)
Flavor	31 (75.6)
Texture	4 (9.8)
Color	0 (0)
Aroma	5 (12.2)
Other	1 (2.4)

The mean acceptability scores for seven sensory attributes (appearance, color, aroma, texture, saltiness, flavor, and overall liking) of the kelp salads all fell in the range of 5.0 to 6.8 on the 9-point hedonic scale, which was between “neither like nor dislike” and “like moderately” (Table 7). Generally, the treated samples used to prepare kelp salad were liked more than the raw sample for color, texture, flavor, and overall liking.

Generally, a mean overall liking score of ≥ 7 on a 9-point hedonic scale is associated with a highly acceptable sensory quality [32]. The overall liking scores for sensory evaluation for the salad treatments (control, 5.0; dry salted, 6.0; and brined, 6.3) suggest that salt treatment had a positive impact on the consumer acceptance of kelp salads. Penalty analysis suggests that this lower acceptability may be related to the percentage of consumers feeling that control salad samples were “Too tender” (Figure 3). This finding is consistent with the significantly higher scores observed for the liking of the texture of the salted salad samples. Notably, the flavor of the salads made with salted seaweeds was liked significantly more

than the flavor of the salad made from unsalted kelp. While no differences in the liking of saltiness were observed from hedonic testing, results from the JAR question about saltiness suggest that panelists did perceive a difference in saltiness across samples, with a large percentage of panelists indicating that the salad made from brined seaweed was “Too salty” (Figure 3). This factor was not, however, predicted to be responsible for a decrease in the overall liking of either salted sample.

Table 7. Liking of sensory attributes of salted seaweed salads.

Attributes	Control	Dry salted	Brined
Appearance	5.9 ± 0.2 ^a	6.5 ± 0.2 ^a	6.8 ± 0.2 ^a
Color	6.0 ± 0.2 ^b	6.8 ± 0.2 ^a	6.7 ± 0.2 ^{ab}
Aroma	5.2 ± 0.3 ^a	5.9 ± 0.3 ^a	6.0 ± 0.3 ^a
Texture	5.3 ± 0.3 ^b	6.7 ± 0.3 ^a	6.8 ± 0.3 ^a
Saltiness	5.3 ± 0.3 ^a	6.0 ± 0.3 ^a	5.4 ± 0.3 ^a
Flavor	5.1 ± 0.3 ^b	6.1 ± 0.3 ^a	6.2 ± 0.3 ^a
Overall liking	5.0 ± 0.3 ^b	6.2 ± 0.3 ^a	6.3 ± 0.3 ^a

Each value is the mean ± standard deviation (n = 41). Superscripts: Different letters within rows indicate significant differences among treatments (Tukey’s HSD, *p* ≤ 0.05). 1 = Dislike Extremely and 9 = Like Extremely.

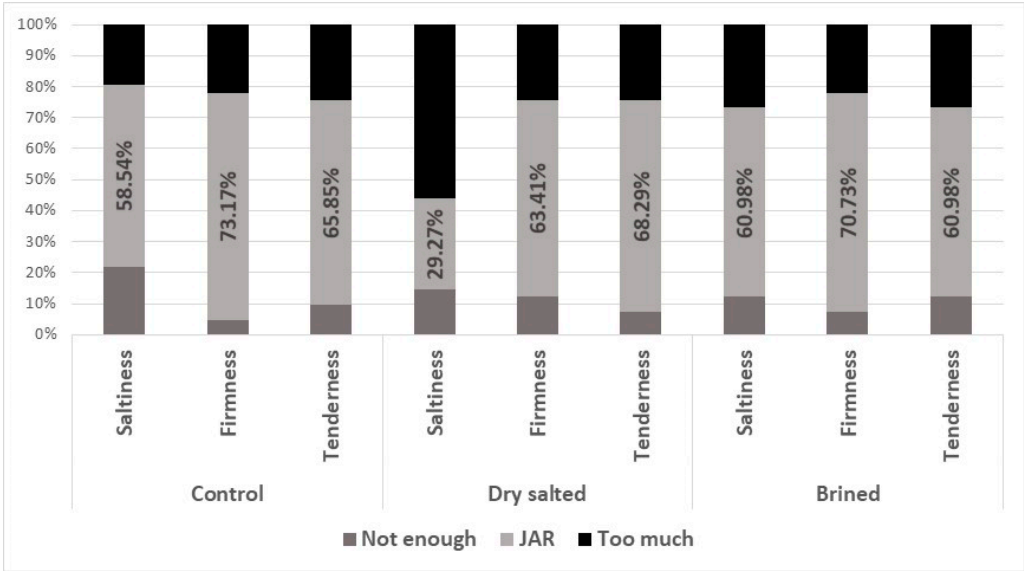


Figure 3. Just-about-right ratings for sensory characteristics of seaweed salad (n = 41).

Panelists were given the chance to provide comments, and control treatments elicited comments including: “The lack of salt makes it seem bland”, “it does have a satisfying crunch with the bite”, “smoothness of the seaweed wasn’t my favorite”, and “It tasted fresh, but no other aroma or flavor”. These comments suggest that additional investigation regarding the liking of kelp flavor (in the absence of other ingredients) may be warranted. No significant differences in the liking of any sensory attribute were observed between the salted treatments, but the low frequency of seaweed consumption reported by panelists may indicate a limited capability to discriminate subtle differences in this food product. The most substantial limiting factor of this study is the lack of power due to the small panel size. Analysis by a larger group of consumers would allow for a more nuanced interpretation of the liking results, providing a greater insight into the importance of specific sensory characteristics. Similarly, data regarding dietary sodium intake and the importance of this factor in product consumption are likely skewed in this study by the number of panelists aged 18–35, and this should be explored in more detail with older consumers. However, the trends in our data clearly indicate a greater degree of liking for multiple sensory attributes in salads made from salt-treated kelp. These results reinforce the promise of salt treatments

as a preservation method for kelp since they not only extend shelf life, but also positively impact consumer liking.

4. Conclusions

Seaweed-based products are becoming increasingly available in the West. Preservation methods such as salting and brining can tackle the challenge of the seasonal availability of seaweed. Brining and dry salting can improve the quality and shelf life of sugar kelp. The cost-effectiveness and ease of operation make salt-based preservation an attractive alternative post-harvest processing method. Further refinement of processing should involve evaluation by a larger and more diverse group of consumers.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Institutional Review Board (or Ethics Committee) of The University of Maine, U.S.A. (“Application # 2022-05-07”, approved on 1 June 2022 for sugar kelp salad).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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

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