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Durvillaea antarctica Meal as a Possible Functional Ingredient in Traditional Beef Burgers

John Quiñones [1,2], Rommy Díaz [1,2,*], Lidiana Velázquez [2], Ailín Martínez [3], Gastón Sepúlveda [4], Rodrigo Huaiquipán [2,4], Stefania Short [5], Carla Velásquez [2,4], David Cancino [1,2], Daniela Tapía [2,4], Fernando Abasolo [6] and Néstor Sepúlveda [1,2,*]

1 Faculty of Agricultural Sciences and Environment, University of La Frontera, Temuco 4780000, Chile; john.quinones@ufrontera.cl (J.Q.); david.cancino@ufrontera.cl (D.C.)
2 Center for Meat Technology and Innovation (CTI-Carne), University of La Frontera, Temuco 4780000, Chile; velazquez01@ufromail.cl (L.V.); r.huaiquipan01@ufromail.cl (R.H.); c.velasquez12@ufromail.cl (C.V.); daniela.tapiah28@gmail.com (D.T.)
3 Doctoral Program in Sciences, Major in Applied Cellular and Molecular Biology, University of La Frontera, Temuco 4780000, Chile; vasallo84@gmail.com
4 Doctoral Program in Agri-Food and Environmental Sciences, University of La Frontera, Temuco 4780000, Chile; g.sepulveda10@ufromail.cl
5 Department of Chemical Engineering, Faculty of Engineering and Sciences, University of La Frontera, Temuco 4780000, Chile; stefania.short@ufrontera.cl
6 Faculty of Agricultural and Forestry Sciences, State Technical University of Quevedo, Quevedo 120310, Ecuador; fabasolo@uteq.edu.ec
* Correspondence: rommy.diaz@ufrontera.cl (R.D.); nestor.sepulveda@ufrontera.cl (N.S.)

Abstract: At present, some ingredients called "novel foods", such as seaweed, are being incorporated into meat products. Therefore, this study aimed to evaluate the use of *Durvillaea antarctica* meal as an extender of traditional beef burgers and its effect on quality, fatty-acid profile, and general acceptability. Prototypes including 0.5, 1.0, 1.5, and 3.0% *Durvillaea antarctica* meal were developed and measured for color, pH, water-holding capacity, fatty acids, and cholesterol profile. A trained sensory panel evaluated the organoleptic properties. The results show that as the amount of *Durvillaea antarctica* meal increases, the pH decreases less sharply compared to the control, while the water-holding capacity was similar to, but not better than, the control when including 3.0% of seaweed. On the other hand, the redness significantly decreased, affecting the sensory attributes of the product. The lipid profile was partially altered by the inclusion of the meal; it was observed that the percentage of saturated fats was reduced, and the levels of some omega3 fatty acids increased. Beef burgers made with 0.5% *Durvillaea antarctica* meal showed better acceptability and flavor. The use of seaweed, such as *Durvillaea antarctica*, could be a new alternative for the transformation of traditional meat products into new-generation foods. The evaluation of the functional and microbiological properties of the meat matrix, as well as nutraceutical properties and cost effectiveness, will be addressed in a future study.

Keywords: brown algae; novel foods; meat quality traits; traditional burgers

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1. Introduction

In recent years, there have been several questions about the consumption of meat by health and environmental experts, who claim that its production is unsustainable in the long term [1]. Consequently, the drastic reduction of the production and consumption of meat and its derivatives is advocated in a growing demographic context [2]. This, in turn, has generated a kind of collective awareness regarding the diet–health relationship, and the preference for functional foods has increased in consumers [3–5]. Under these conditions, non-meat protein sources of high biological value become essential, and the incorporation of algae into the diet becomes more relevant. Traditionally, seaweed consumption has

been concentrated in East and Southeast Asian countries, and its demand in the West has increased considerably over the past few years, transforming it into one of the 50 foods of the future, which is why it has been categorized as a "novel food" [6,7]. This designation is because this resource has a rapid growth speed; in a world where terrestrial resources are increasingly limited, seaweed can develop without arable land, freshwater, or fertilizers, providing high value to the diet, environment, economy, and society [8]. It has been observed that the indiscriminate extraction of these bioresources and the possibility of these organisms being trapped or produced in polluting waters depends on the species, origin, extraction, or production policies and contrasts with their high number of nutritional components such as proteins, vitamins, minerals, polyunsaturated lipids, and complex polysaccharides in the form of soluble and insoluble fiber [9–11]. They are one of the few non-meat foods that contain vitamin B12. They are rich in polyphenols, carotenoids, sterols, steroids, and lectins. These macros and micromolecules provide it with various functional properties, such as antioxidant, antimicrobial, antiviral, anticoagulant, and antitumor [10].

From 2015 to the present, Chile has been a major producer globally—and the leading producer in the West—of uncultivated seaweed, which is intended for human food, obtaining hydrocolloids (alginates, agar, and carrageenan), animal feed, biofertilizers, bioenergy, cosmetics, and textiles, among others [12,13]. Among the algae extracted in Chile is *Durvillaea antarctica*.

D. antarctica it is a particular solid-leaf brown macroalgae with a wide distribution in South Pacific areas (Chile, New Zealand, Argentina, and Subantarctic Islands) [14]. In Chile, it is commonly known as "cochayuyo" and is a traditional food that is part of the culinary culture, harvested by the Mapuche ethnic group.

D. antarctica has 11% protein, 65% carbohydrates, 0.8–4.3% lipids, and approximately 25% ash. Because of this, it has recently been studied as a possible additive in the diet of animal species, such as rainbow trout; its polysaccharides seem to be effective against colon cancer; and its consumption generates a positive impact on the human immune system due to the activation of CD19+B lymphocytes and the modulation of the intestinal microbiota due to its β-glucan content [15–18].

Some studies have addressed the use of seaweed in the preparation of beef burgers, which are among the most consumed meat products in the world. Their formulation is easy to modify due to the few ingredients needed for their preparation. Lopez-Lopez et al. [19] reported the preparation of beef burgers with 3.0% wakame seaweed (*Undaria pinnatifida*), allowing the production of a reduced-salt product. Another study replaced between 10% and 40% of meat with cubes of dried sea spaghetti seaweed (*Himanthalia elongata*), showing positive overall acceptability [20]. Recently, it was demonstrated that the inclusion of 1.0% sea spaghetti seaweed can preserve positive sensory characteristics in low-salt hamburgers [21].

Since it is an important nutrient niche, and because of its physical characteristics, its use as an extender ingredient or substitute can have a strong impact on future processed meat production systems, especially in this industry, where the biggest challenge in recent years has been to reduce saturated fat levels and the use of synthetic additives. From a technological point of view, seaweed also has an important value due to its high fiber content, which allows it to behave as a gelling, thickening, and stabilizing agent [22].

However, the use of *Durvillaea antarctica* meal as an additive in beef burger formulation has been little studied. Therefore, this study addressed the effect of incorporating *Durvillaea antarctica* as a new functional ingredient on the beef burger's quality parameters and sensory characteristics.

2. Materials and Methods

2.1. Algal Material

The experiments were carried out at the Center for Technology and Innovation in Meat Quality of the University of La Frontera (CTI-Carne), Temuco, Chile. The algal material *Durvillaea antarctica* was obtained from a commercial establishment on the day

of the experiment during the autumn season. The stem (1 m) of the *D. antarctica* was cut and ground in an ultra-centrifugal mill (Retsch ZM 200, Retsch, Santiago, Chile) to obtain a particle size of 200 µm.

2.2. Preparation of the Beef Burgers

The beef burgers were prepared based on what was described by Velázquez et al. [23]. Table 1 shows the formulation of the beef burgers. All ingredients were commercially sourced. The meat ("*posta rosada*") and handmade bacon (52% protein and 46% fat) were purchased at the local supermarket on the day of the trial. Five treatments of beef burgers were made: (a) Control (0.0% *D. antarctica*); (b) Da0.5%; (c) Da1.0%; (d) Da1.5%; and (e) 3.0% *D. antarctica* meal, based on what is described by Głuchowski et al. [21]. The meat and bacon were processed in a meat grinder. The meat and bacon mixture, along with the ice, was weighed and taken to a mixer. Salt and seasonings were added, and the entire mixture was homogenized for 5 min. The mix was separated into 100 g portions and taken to a beef-burger mold (1.0 cm high and 10 cm diameter) (Figure 1). A total of 15 beef burgers per treatment were produced, vacuum-packed, and stored at 4 °C for 7 days until analysis.

Table 1. Formulation of beef burgers with different levels of *Durvillaea antarctica* meal.

Ingredients	Control	Da0.5% *	Da1%	Da1.5%	Da3.0%
Beef	70.0%				
Salt	1.5%				
Pepper	0.1%				
Garlic	0.1%				
Onion	0.1%				
Paprika	0.1%				
Plus color *	0.5%				
Bancon	10.0%				20.0%
Water (Ice)	18.0%	17.5%	17.0%	16.5%	5.0%
D. antarctica		0.5%	1.0%	1.5%	3.0%

* Da0.5%; Da1.0%; Da1.5%; and 3.0% *Durvillaea antarctica* meal.

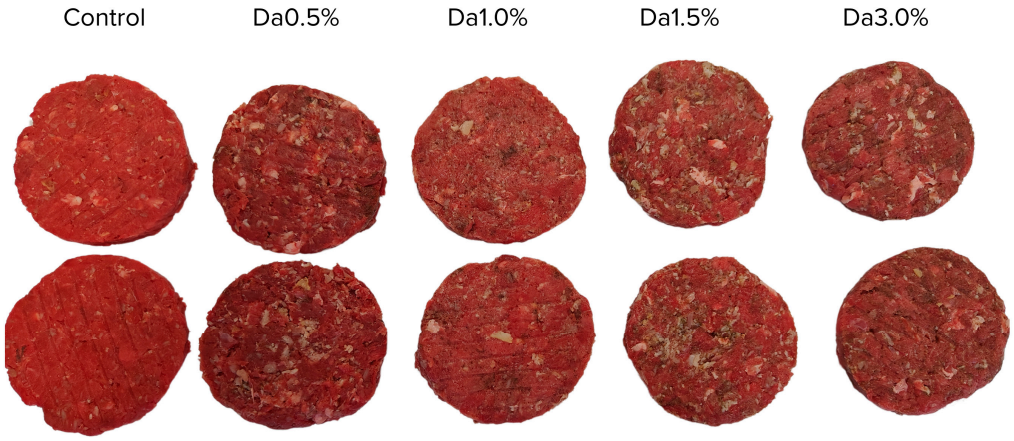

Figure 1. Photograph of beef burgers made with different levels of *Durvillaea antarctica* meal.

2.3. Physicochemical Parameters

The water-holding capacity (WHC) was determined according to the method described by Sañudo [24] and expressed as a percentage. Total lipids were analyzed following the protocol established by Folch et al. [25]. The pH was measured at random points on the burgers (6 times) using a calibrated pH meter (Hanna Instruments Inc., Cluj-Napoca, Romania), and the procedure was repeated after 7 days of storage. The color of the beef burgers was assessed 5 times at random points per burger on day zero, (30 min after processing) with a portable colorimeter (Konica Minolta Sensing, Inc., Tokyo, Japan)

equipped with the CIELab system. A 0° viewing angle geometry and an 8 mm aperture size were used, following the procedure described by Velázquez et al. [23].

2.4. Fatty-Acid Profile

Lipids were extracted from the previously homogenized sample following the methodology described by Folch et al. [25]. Fatty acid methyl esters were obtained by homogenizing the total fat with 1.3 mL of potassium hydroxide 2N in methanol and 800 µL of n–hexane (Merck, Darmstadt, Germany) with a magnetized rod for 30 min. The sample was then left to stand for 5 min. Fatty acid methyl esters were analyzed using a gas chromatograph (Clarus 500, Perkin Elmer, Waltham, MA, USA) coupled with a flame ionization detector (FID) with hydrogen (250 °C). Fatty acid methyl esters separation was performed with an SP^{TM} 2380 fused silica capillary column (60 m × 0.25 mm × 0.2 µm film thickness) (Supelco, Bellefonte, PA, USA) by injecting 1 µL of the sample extract with nitrogen as carrier gas. The temperature gradient was set according to that reported by Quiñones et al. [16]: The initial temperature was 150 °C. After 1 min, the temperature was increased at a rate of 1 °C min^{-1} to 168 °C for 11 min, then increased to 6 °C min^{-1} to 230 °C for another 8 min. Individual fatty acids were identified by using a standard 37-component FAME Mix C4-C24 (Supelco, Bellefonte, PA, USA).

2.5. Organoleptic Analysis

The sensory analyses were carried out at the Meat Technology and Innovation Center of the Universidad de La Frontera. For this, controlled conditions were used, as described by the NCh-ISO 6658 [26] standard. A sensory evaluation of beef burgers with *D. antarctica* meal was carried out in a single session at the beginning of storage (day one) by a trained panel composed of 8 evaluators (4 females and 4 males; 35–54 years old). Evaluators were separated randomly into privacy cubicles and placed in a lighted room. Each evaluator had access to a bottle of non-carbonated, purified water and a package of neutral-flavored crackers; a set of plates, plastic knives, and forks; and napkins. A graphite pencil and an eraser were also provided.

Each burger was cooked at 70 °C using an electrical contact grill (MilanToast, Sulbiate, MB, Italy) using puncture temperature sensors. Each burger was cut into 1.5 cm^3 cubes and wrapped in aluminum foil to maintain the temperature and juices. A code number of three digits was assigned to identify each sample. Each evaluator was randomly given a survey for each product, where the evaluator had to indicate the product code and indicate on a scale of 0–10 the score given to each burger in relation to its tenderness, odor, flavor, and general acceptability.

2.6. Statistical Analysis

The data were sorted and tabulated, followed by normality and homogeneity tests of variance using the Shapiro–Wilk and Levene tests, respectively. A completely randomized design was used: five treatments × fifteen replicates per treatment × two production batches in different times. A two-way analysis of variance test (ANOVA) was performed to analyze pH. Treatment and storage time were considered as fixed effects. Color (a*, b*, c*, L, and h), water-holding capacity (WHC), and fatty-acid profile were evaluated through a one-way ANOVA. When significant differences were detected, Tukey's test was performed. The level of significance was ($p < 0.05$). Results were expressed as the mean ± standard error of the mean. Statistical analysis was performed with the software IBM SPSS Statistics 23 (IBM Corporation, Somerset, NY, USA). The results of the sensory analysis were processed by Principal Component Analysis (PCA) using SensoMineR R 4.0.5 software.

3. Results and Discussion

3.1. Physicochemical Parameters

Beef burgers made by hand with a formulation based on fresh meat (pork or beef), salt, water, and pork bacon, along with other natural seasonings, have a pH that ranges between 5.5 and 5.8 [23,27–30]. In this research, the analysis of variance showed that the inclusion of *Durvillaea antarctica* modified the pH of the burgers from day one (Table 2). Differences were observed between the control, treatments with 0.5 and 1.0% *D. antarctica* meal, and treatments with 1.5 and 3.0% *D. antarctica* meal. Controls and treatments with lower concentrations of *D. antarctica* (0.5 and 1.0%) had a lower pH ($p < 0.05$) than those with higher concentrations (1.5% and 3.0%). In a study reported by Choi et al. [28], they noted that low-fat pork patties made with 3.0% and 5.0% *Laminaria digitata* significantly reduced the pH compared to the control, which is contrary to our results. The authors of other similar studies with Laminaria suggest that this could be related to the components of brown algae, such as fucoidan and alginic acid, which would act as acidifying agents [28,31,32]. The pH of meat and meat products can vary due to microbial contamination, but in this study, during the manufacturing and storage process, all sanitary and handling measures were carefully considered, which prevented the presence of bad odors and undesirable aspects that could be caused by contaminating microorganisms [33]. However, during storage (7 days), a considerable decrease in pH was observed for all treatments. The inter-subject effects test showed a significant interaction between *D. antarctica* levels and storage time on pH ($p < 0.001$). At the end storage, the control treatments had a lower pH (5.29) than the treatments with *D. antarctica* concentrations of 0.5, 1.0, 1.5, and 3.0% (5.35; 5.34; 5.32, and 5.36, respectively). In other words, the pH of the beef burgers decreased slightly less in those treatments with *D. antarctica* meal. These results are consistent with those reported by other authors. For example, Pindi et al. [34] reported a proportional relationship between increasing concentrations of *Kappaphycus alvarezii* meal (2–4%) and pH in chicken burgers. Likewise, Agregán et al. [35] reported similar results in beef burgers formulated with 0.025%, 0.05%, and 0.1% *Fucus vesiculosus* extract. According to the authors, by day seven of storage, the pH had decreased less in the treatments with the three algae levels than in the control treatment. Possibly, the levels of alpha-tocopherol present in *Durvillaea antarctica* could act as modulators of amino acid and lipid oxidation, limiting them [9]. This should be reviewed in upcoming studies.

Table 2. Changes in pH values of beef burgers with different levels of *Durvillaea antarctica* meal during storage.

	Control	Da0.5%	Da1%	Da1.5%	Da3.0%
Day 0	5.56 ± 0.00^{a1}	5.52 ± 0.01^{b1}	5.52 ± 0.01^{b1}	5.59 ± 0.01^{c1}	5.60 ± 0.01^{c1}
Day 7	5.29 ± 0.01^{a2}	5.35 ± 0.01^{bc2}	5.34 ± 0.00^{bc2}	5.32 ± 0.01^{ba2}	5.36 ± 0.00^{c2}

$^{a–c}$. Mean values in the same row (different treatment on same day) with different letters indicate significant difference. $^{1–2}$. Mean values in the same column (same treatment on different days) with different numbers indicate significant difference. ($p < 0.05$; Tukey's test). All parameter values were presented as mean ± standard error.

The effect of including *Durvillaea antarctica* meal on the water-holding capacity (WHC) of beef burgers is presented in Figure 2. The literature indicates that WHC is strongly correlated with pH [36]. This is evident in the pH values observed in this study. The WHC of meat, or an experimental meat product such as beef burgers, is of the utmost importance for evaluating scaling processes, yield, and the profitability of commercialization. The greater the amount of water retained, the greater the product's weight and, consequently, its value. Conversely, a low water-holding capacity can also affect the product's appearance and therefore the consumer's desire to purchase it [37,38]. In this study, we observed that the WHC of the beef burgers varied in relation to the amount of *Durvillaea antarctica* meal incorporated into the meat matrices. Beef burgers made with 3.0% *D. antarctica* meal showed the highest WHC ($p < 0.05$), which was equal to but not better than the control (Figure 2). In this sense, several authors have pointed out that the physicochemical and absorbent properties of algae favor water retention and swelling capacity [39]. Other

authors have observed a similar phenomenon when cooking low-fat pork patties, where the inclusion of between 1.0% and 3.0% of Laminaria japonica meal reduced cooking loss. This most likely occurred because this brown seaweed contains dietary fibers such as alginate and laminarin, which have a high water-holding capacity and binding capacity [28].

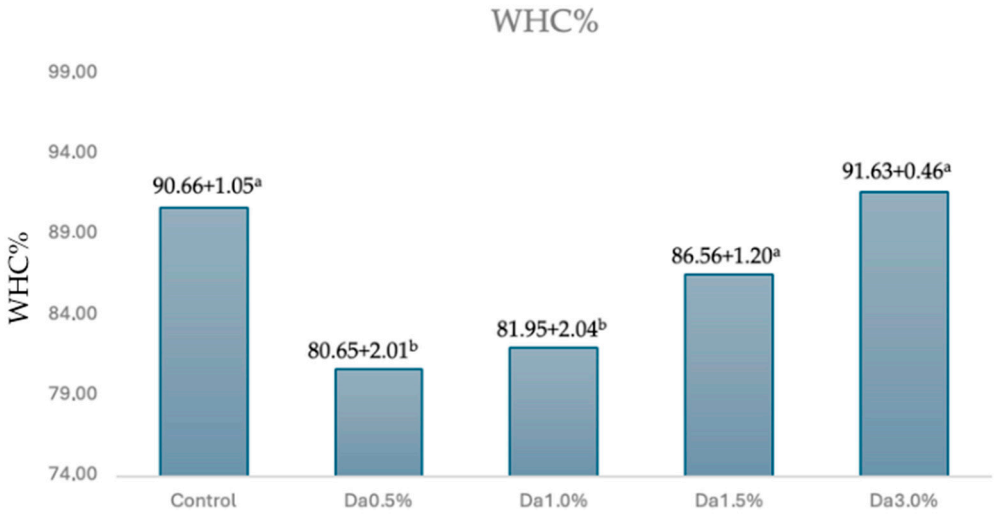

Figure 2. Effect on the water-holding capacity (WHC %) of beef burgers with different levels of *Durvillaea antarctica* meal. Control = beef burgers without *D. antarctica* meal. Da0.5% = beef burgers formulated with 0.5% of *D. antarctica* meal. Da1.0% = beef burgers formulated with 1.0% of *D. antarctica* meal. Da1.5% = beef burgers formulated with 1.5% of *D. antarctica* meal. Da3.0% = beef burgers formulated with 3.0% *D. antarctica* meal. Each column shows the results of the mean of six replicates and the standard error of the mean. Different letters in the same row indicate significant differences ($p < 0.05$; Tukey's test).

On the other hand, the treatments with the lowest concentrations of *D. antarctica* (Da0.5% and Da1.0%) exhibited significantly lower WHC ($p < 0.05$) compared to the control, which suggests a tendency to lose WHC tolerance in the beef burger at these specific concentrations of seaweed. The concentration of seaweed may have altered the levels of minerals such as sodium and potassium (*Durvillaea antarctica* mineral composition: Na: 4.11%; K: 1.59%; Fe: 305.5 μg/g), which could alter the electrical balance of the medium and the isoelectric point of the proteins, significantly reducing water-holding capacity [15,37,40]. A similar phenomenon occurred in the cooking loss of beef burgers and sausages made with 3.0% sea tangle [41]. Cooking loss is an analysis that should be addressed shortly. However, the water-holding capacity of seaweed also depends on ambient temperature and species, and this aspect has only been studied recently [42]. Therefore, the WHC of beef burgers containing *Durvillaea antarctica* could be compared with beef burgers made from other species available in our market under the same processing conditions.

3.2. Color

In well-bled muscle, myoglobin accounts for 80–90% of the total pigments responsible for meat color, and other proteins, such as hemoglobin or cytochrome c, play a relatively minor role. Therefore, the concentration and oxidation state of the myoglobin pigment determine the final color of the flesh (purple-red, cherry-red, brown, green, and cherry-red, respectively) [36]. However, a burger is a composite product, not only consisting of meat but also of fat and seasonings that combine, making it easy to alter these parameters. The redness and brightness of meat and meat products, such as burgers, are always highly valued by consumers and are associated with freshness and safety [43].

The inclusion of *Durvillaea antarctica* meal significantly modified the color of the beef burgers from day zero ($p < 0.05$) (Table 3). The color indicators that were affected were a* (redness) and h* (hue angle). As expected, the control had a redness greater than

a* = 28.4, while the treatment with the highest redness index was Da0.5%, and the inclusion of 3.0% meal negatively modified this index (a* = 16.7). Brown algae such as *D. antarctica* contain pigments such as fucoxanthin (brown-yellow), chlorophyll A (deep green), and chlorophyll C (blue-green), which gives them their characteristic color [44]. In this regard, Uribe et al. [45] reported *D. antarctica* has approximately 698.6 mg/kg DM of chlorophyll A and 108.3 mg/kg DM of chlorophyll C. In this study, the surface color of *D. antarctica* showed a value of redness of a* = 0.25 and a value of yellowness of b* = 1.5. These results indicate that on the coordinate axis of the CIELab system, *D. antarctica* pigments showed a strong tendency towards green for the redness axis (a*) and a tendency towards blue for the yellowness axis (b*), which may have influenced the color parameters of beef burgers.

Table 3. Physicochemical characteristics of beef burgers with different levels of *Durvillaea antarctica* meal.

Color	Control	Da0.5%	Da1.0%	Da1.5%	Da3.0%	*p* Value
a*	28.4 ± 0.82 ^{a}	22.3 ± 0.82 ^{b}	21.6 ± 0.82 ^{b}	21.1 ± 0.824 ^{b}	16.7 ± 0.824 ^{c}	0.001
b*	18.6 ± 0.55 ^{a}	18.0 ± 0.55 ^{a}	18.3 ± 0.55 ^{a}	18.6 ± 0.552 ^{a}	17.8 ± 0.552 ^{a}	0.744
c*	34.0 ± 0.86 ^{a}	28.7 ± 0.86 ^{b}	28.3 ± 0.86 ^{b}	28.2 ± 0.862 ^{b}	24.4 ± 0.862 ^{c}	0.001
L *	43.0 ± 1.24 ^{a}	43.6 ± 1.24 ^{a}	44.4 ± 1.24 ^{a}	42.0 ± 1.245 ^{a}	42.8 ± 1.245 ^{a}	0.718
h *	34.5 ± 1.17 ^{c}	39.0 ± 1.17 ^{bc}	40.9 ± 1.17 ^{b}	41.4 ± 1.17 ^{b}	46.9 ± 1.17 ^{a}	0.001

$^{a–c}$ Mean values in the same row (different treatment in same day) with different letters indicate significant difference. ($p < 0.05$; Tukey's test); * All parameter values were presented as mean ± standard error.

Depending on the dominant chlorophyll, carotenoids, and fucoxanthins present, seaweed can be green, bluish, red, brown, or even golden. Therefore, depending on the species incorporated into the meat mixture, the products can present variations in all CIELab parameters. For example, the inclusion of 1.0% Laminaria japonica in pork burgers significantly reduced the redness; these parameters decreased in relation to the increase in seaweed content, which is consistent with our results. The brightness was also lower compared to the control group [28]. These differences are unique to the ingredients and type of seaweed added to meat products. For example, the inclusion of 2.5% sea spaghetti in pork emulsions altered the yellowness and brightness, but the same concentration of seaweed in a pork sausage formulation did not show these changes [41]. Even so, most reports show a common denominator: a reduction in redness. In this regard, another report on fish burgers shows that the inclusion of different levels of sea lettuce (*Ulva lactuca*) and Catla (*Catla catla*) (0.5%, 1.0%, 1.5%, 2.0%) reduces redness without altering the yellowness and brightness of these prototypes [46]. A study conducted with beef burgers made with a high content of Himanthalia elongata meal (10–40% *w*/*w*) showed that the color parameters were altered similarly to what was observed in this study. This result deserves a more extended review and should be addressed with new experiments since redness is a characteristic related to general acceptability and the consumer's purchase decision [47]. Therefore, its alteration or reduction could be a limitation in the marketing of this product.

On the other hand, it is evident that seaweed could eventually function as a natural colorant and reduce the use of synthetic ingredients in artisanal and industrial meat products.

3.3. Fatty-Acid Profile

Brown seaweed such as as *Durvillaea antarctica* has a low lipid content compared to marine fish [48]. However, the lipid fraction may contain higher levels of polyunsaturated essential fatty acids compared to vegetables [9,49]. In this study, the impact of the inclusion of four levels of *D. antarctica* as a functional ingredient on the fatty-acid profile (%) and cholesterol levels (mg/100 g) of beef burgers was investigated. The fatty-acid profile, nutritional indices, and cholesterol are shown in Table 4. In order, the main groups of FAs found were saturated fatty acids (SFA), 44–52%; monounsaturated fatty acids (MUFA), 33–42%; and polyunsaturated fatty acids (PUFA), 12–15%, approximately. The inclusion of *D. antarctica* significantly modified the content of SFA, MUFA, and PUFA in beef burgers. A

decrease in SFA was observed in the Da1.0% treatment, and the MUFA content increased proportionally by 1.0, 6.0, and 7.0% for the Da1.0%, Da1.5%, and Da3.0% treatments, respectively. This improvement in the MUFA content of the burgers was mainly determined by the increase in oleic acid content (C18:1n9), a major component of biological membranes. Recently, these types of lipids have been associated with the prevention of cardiovascular and metabolic diseases [50]. Oleic acid is the most abundant fatty acid in *D. antarctica*, constituting 25.83% of the total number of fatty acids found in stems [9]. In addition, it has been reported that *D. antarctica* contains other nutritionally important fatty acids, such as C18:2n6 (linoleic acid) and C18:3n3 (linolenic acid) and the eicosanoid precursors C20:4n6 (arachidonic acid) and C20:5n3 (eicosapentaenoic acid, or EPA) [9]. However, in general, the C18:2n6 and C18:3n3 concentrations were not related to the inclusion of *D. antarctica* in any of the beef burger groups, as well as DHA (C22:6n3). Regarding the overall PUFA content, only the Da1.0% treatment was significantly higher than the control (by approximately 0.70%). Although there is no consensus on this, it has long been said that fatty acids can reduce human health because they are involved in mechanisms that favor the development of cardiovascular diseases, which even makes some countries incorporate a distinctive seal on food labels (e.g., traffic lights, black octagons, etc.) which indicates that foods such as meat products have high levels of saturated fats (>4.0%). The inclusion of 1.0, 1.5, and 3.0% *D. antarctica* meal produced a slight but statistically significant decrease ($p < 0.05$) in lauric acid (C12:0), myristic acid (C14:0), palmitic acid (C16:0), and stearic acid (C18:0). On the other hand, the statistical analysis also showed significant differences in the total levels of omega 3 (n3) and the n3/n6 ratio, observing that the levels of n3 differences were manifested with a lower index in the treatments with 1.0 and 1.5% meal compared to the control. Additionally, the cholesterol concentration of the burgers was approximately 109–113 mg/100 g. A significant reduction ($p < 0.05$) in cholesterol was observed for beef burgers with 3.0% D. antarctica meal, which could be related to the fact that unstudied components of *D. antarctica* influence the degradation of the cholesterol molecule or that it is destabilized at the time of the construction of the beef burger matrix. However, further studies need to be carried out to evaluate the lipid dynamics of food matrices, such as those of meat products, against the inclusion of alternative ingredients. This study preliminarily determined that the inclusion of *D. antarctica* could improve the lipid profile of beef burgers through a reduction of the main SFAs, which would allow the development of seal-free meat products soon, while the algae may also contribute to the development of a meat product with more nutraceutical properties by increasing healthier lipids such as n3 and n6 in the burgers.

Table 4. Lipid profile of traditional beef burgers made with different levels of *Durvillaea antarctica* meal.

Fatty Acid (mg/100 g)	Control	Da0.5%	Da1.0%	Da0.5%	Da3.0%	*p* Value
C8:0	31.38 ± 5.85 ^{ab}	33.87 ± 6.32 ^{a}	31.6 ± 5.68 ^{b}	202.79 ± 175.04 ^{b}	47.68 ± 9.42 ^{ab}	0.00380
C11:0	36.95 ± 6 ^{ab}	38.21 ± 6.37 ^{a}	34.2 ± 5.69 ^{c}	235.95 ± 204.25 ^{bc}	52.28 ± 9.45 ^{abc}	0.00120
C12:0	24.86 ± 5.96 ^{ab}	28.29 ± 6.46 ^{a}	22.51 ± 5.69 ^{b}	46.11 ± 28.52 ^{b}	33.45 ± 9.43 ^{ab}	0.00080
C14:0	402.72 ± 10.24 ^{b}	512.2 ± 13.69 ^{a}	471.53 ± 10.66 ^{bc}	6253.44 ± 5813.76 ^{bc}	571.32 ± 18.61 ^{c}	0.00020
C14:1	47.74 ± 7.89 ^{b}	69.52 ± 6.97 ^{a}	50.43 ± 5.74 ^{b}	516.78 ± 468.79 ^{b}	63.76 ± 9.65 ^{b}	0.00220
C15:0	63.97 ± 7.98 ^{a}	67.66 ± 11.27 ^{a}	73.16 ± 5.74 ^{a}	923.65 ± 850.82 ^{a}	88.57 ± 9.65 ^{a}	0.91540
C15:1	37.7 ± 6.91 ^{a}	34.18 ± 7.12 ^{a}	28.36 ± 6.3 ^{abc}	142.76 ± 116.09 ^{c}	43.09 ± 9.65 ^{bc}	0.00340
C16:0	4018.49 ± 76.22 ^{ab}	4640.16 ± 30.28 ^{a}	4627.26 ± 79.6 ^{a}	64,305.34 ± 60,136.18 ^{a}	6222.04 ± 53.04 ^{a}	0.04530
C16:1	564.62 ± 13.64 ^{ab}	686.11 ± 14.61 ^{a}	554.32 ± 62.3 ^{ab}	8454.51 ± 7870.01 ^{ab}	721.99 ± 13.1 ^{b}	0.01740
C17:0	176.34 ± 9.68 ^{a}	229.17 ± 7.71 ^{a}	298.48 ± 49.7 ^{a}	3358.28 ± 3143.71 ^{a}	196.51 ± 9.67 ^{a}	0.05490
C17:1	117.51 ± 14.98 ^{ab}	165.31 ± 6.99 ^{a}	166.01 ± 7.45 ^{ab}	2354.7 ± 2203.47 ^{ab}	157.92 ± 9.82 ^{b}	0.01730
C18:0	2905.34 ± 59.34 ^{bc}	3542.45 ± 52.63 ^{a}	3230.54 ± 116.11 ^{ab}	45,996.71 ± 43,169.86 ^{b}	4166.53 ± 80.8 ^{b}	0.00490
C18:1n9c	4819.24 ± 222.2 ^{a}	5118.49 ± 38.78 ^{b}	6067.48 ± 351.32 ^{bd}	121,070.9 ± 114,189.03 ^{c}	10,526 ± 27.95 ^{d}	0.00120
C18:2n6t	1703.13 ± 64.98 ^{a}	1714.38 ± 111.27 ^{a}	2315.96 ± 143.23 ^{a}	32,469.91 ± 30,571.23 ^{a}	2441.73 ± 162.32 ^{a}	0.15220

Table 4. *Cont.*

Fatty Acid (mg/100 g)	Control	Da0.5%	Da1.0%	Da0.5%	Da3.0%	*p* Value
C18:2n6c	54.55 ± 6.2 ^{a}	63.32 ± 10.45 ^{a}	53.36 ± 5.78 ^{a}	51.49 ± 468.96 ^{a}	58.71 ± 9.98 ^{a}	0.05770
C18:3n6	144.74 ± 6.96 ^{a}	154.15 ± 6.45 ^{a}	164.07 ± 7.37 ^{a}	95.48 ± 1792.41 ^{b}	77.08 ± 9.45 ^{c}	<0.0001
C20:0	79.18 ± 12.47 ^{a}	111.99 ± 12.1 ^{a}	129.98 ± 6.22 ^{a}	1497.25 ± 1378.89 ^{a}	193.75 ± 10.31 ^{a}	0.15140
C18:3n3	94.89 ± 6.79 ^{a}	76.03 ± 11.66 ^{ab}	58.87 ± 6.24 ^{a}	527.45 ± 467.91 ^{b}	162.52 ± 11.35 ^{c}	0.00100
C21:0	82.8 ± 6.76 ^{a}	82.54 ± 8.03 ^{a}	104.33 ± 8.15 ^{a}	1138.17 ± 1056.96 ^{a}	120.26 ± 11.36 ^{a}	0.50240
C20:2	28.33 ± 6.04 ^{b}	45.65 ± 7.04 ^{a}	29.98 ± 6.66 ^{b}	381.33 ± 352.19 ^{b}	38.5 ± 9.45 ^{b}	0.00450
C20:3n3	51.86 ± 6.11 ^{ab}	73.55 ± 13.44 ^{a}	29.33 ± 6.76 ^{b}	93.08 ± 56.61 ^{b}	44.01 ± 10.49 ^{b}	0.00390
C22:0	113.12 ± 6.62 ^{a}	64.87 ± 14.26 ^{bc}	108.55 ± 6.86 ^{ab}	1285.75 ± 1204.73 ^{ab}	52.28 ± 10.13 ^{c}	0.00020
C20:3n6	25.48 ± 6.02 ^{a}	28.6 ± 6.39 ^{bc}	22.19 ± 5.71 ^{b}	48.31 ± 28.34 ^{b}	107.86 ± 13.58 ^{a}	<0.0001
C23:0	33.95 ± 5.89 ^{ab}	35.42 ± 6.77 ^{a}	25.76 ± 5.9 ^{c}	141.82 ± 116.17 ^{c}	38.5 ± 9.49 ^{abc}	0.00090
C22:2	36.43 ± 6.92 ^{a}	39.45 ± 6.46 ^{a}	23.81 ± 5.78 ^{b}	230.61 ± 204.73 ^{b}	35.28 ± 9.45 ^{b}	<.0001
C20:5n3	39.78 ± 6.15 ^{ab}	46.58 ± 6.43 ^{a}	33.88 ± 5.69 ^{c}	294.73 ± 263.36 ^{c}	52.28 ± 9.44 ^{bc}	<0.0001
C24:0	39.98 ± 7.02 ^{a}	41.93 ± 6.52 ^{a}	37.77 ± 5.77 ^{a}	87.43 ± 56.8 ^{a}	49.98 ± 9.41 ^{a}	0.09670
C24:1n9	65.89 ± 6.42 ^{a}	57.12 ± 7.78 ^{ab}	47.19 ± 5.82 ^{c}	394.2 ± 351.01 ^{c}	70.19 ± 9.86 ^{bc}	0.00010
C22:6n3	30.56 ± 6.05 ^{a}	27.67 ± 6.4 ^{a}	24.78 ± 5.67 ^{ab}	78.01 ± 57.61 ^{b}	35.74 ± 9.44 ^{ab}	0.00030
SFA	8008.13 ± 175.67 ^{a}	9428.7 ± 118.03 ^{a}	9195.66 ± 215.11 ^{bc}	125,472.69 ± 117,334.39 ^{b}	11,833.14 ± 188.8 ^{b}	0.00060
MUFA	5652.7 ± 210.02 ^{c}	6130.7 ± 47.14 ^{c}	6913.79 ± 316.3 ^{bc}	132,933.85 ± 125,198.08 ^{ab}	11,582.95 ± 57.13 ^{a}	0.00160
PUFA	1969.69 ± 78.38 ^{a}	2269.33 ± 115.17 ^{a}	2756.22 ± 159.21 ^{a}	36,550.82 ± 34,261.67 ^{a}	3053.71 ± 180.92 ^{a}	0.20730
n3	217.08 ± 24.47 ^{ab}	223.81 ± 29.43 ^{a}	146.86 ± 23.21 ^{c}	993.27 ± 844.83 ^{bc}	294.55 ± 38.65 ^{ab}	<0.0001
n6/n3 ratio	10.26 ± 69.47 ^{ab}	11.39 ± 2.28 ^{a}	24.1 ± 4.38 ^{b}	161.02 ± 134.55 ^{ab}	11.29 ± 1.84 ^{a}	0.00220
Trans F.A.	1703.13 ± 69.47 ^{a}	1714.38 ± 111.27 ^{a}	2315.96 ± 143.23 ^{a}	32,469.91 ± 30,571.23 ^{a}	2441.73 ± 162.32 ^{a}	0.15550
Cholesterol (mg/100 g)	112.49 ± 0.13 ^{bc}	113.00 ± 0.13 ^{ab}	113.26 ± 0.13 ^{c}	112.16 ± 0.127 ^{d}	109.26 ± 0.127 ^{d}	<0.0001

Different letters in the same row indicate significant differences ($p < 0.05$; Tukey's test). All parameter values were presented as mean ± standard error.

3.4. Sensory Parameters

Considering the inclusion of seaweeds in the formulation of meat products such as sausages and burgers is quite a challenge, especially when cultural, geographical, and sensory aspects generate rejection or emotions in the consumer that could negatively predispose their purchase decision [51]. A study reported the emotions generated by the combination of seaweed and certain foods, including hamburgers and sausages, where participants (n = 108) did not associate or consider buying seaweed with any of these products [5]. Therefore, in this study, we only considered evaluating *Durvillaea antarctica* beef burgers preliminarily with a trained panel that could provide us with more objective data regarding the sensory attributes and general acceptability of these products.

Each expert was able to significantly differentiate the sensory attributes they assessed. The principal component analysis (PCA) showed a significant correlation between general acceptability and taste concerning dimension 1, which largely explains the variability of the data (77.47%) (Figure 3B). The odor was significantly affected in all treatments containing D. antarctica. Regarding the overall flavor and acceptability, it was better in the control treatments and those with 0.5% of the meal, with a clear decrease in the score of these sensory indices as the concentration of *D. antarctica* meal increased (Figure 3A). These results are consistent with those recently reported by Głuchowski et al. [21], who investigated the sensory response and general acceptability of a trained panel (n = 8) that tasted beef burgers with 0.5%, 1.0%, 2.5%, and 5.0% Himanthalia elongata meal, observing that the burgers with higher seaweed content were negatively evaluated. Another previous report by Cox and Abu-ghannam [20] also noted this effect in beef burgers enriched with Himanthalia elongata, which should be related to the overall acceptability. Additionally, the general acceptability of frankfurters made with the edible seaweeds Porphyra umbilicalis or Palmaria palmata was low, mainly due to the intense marine flavor [51].

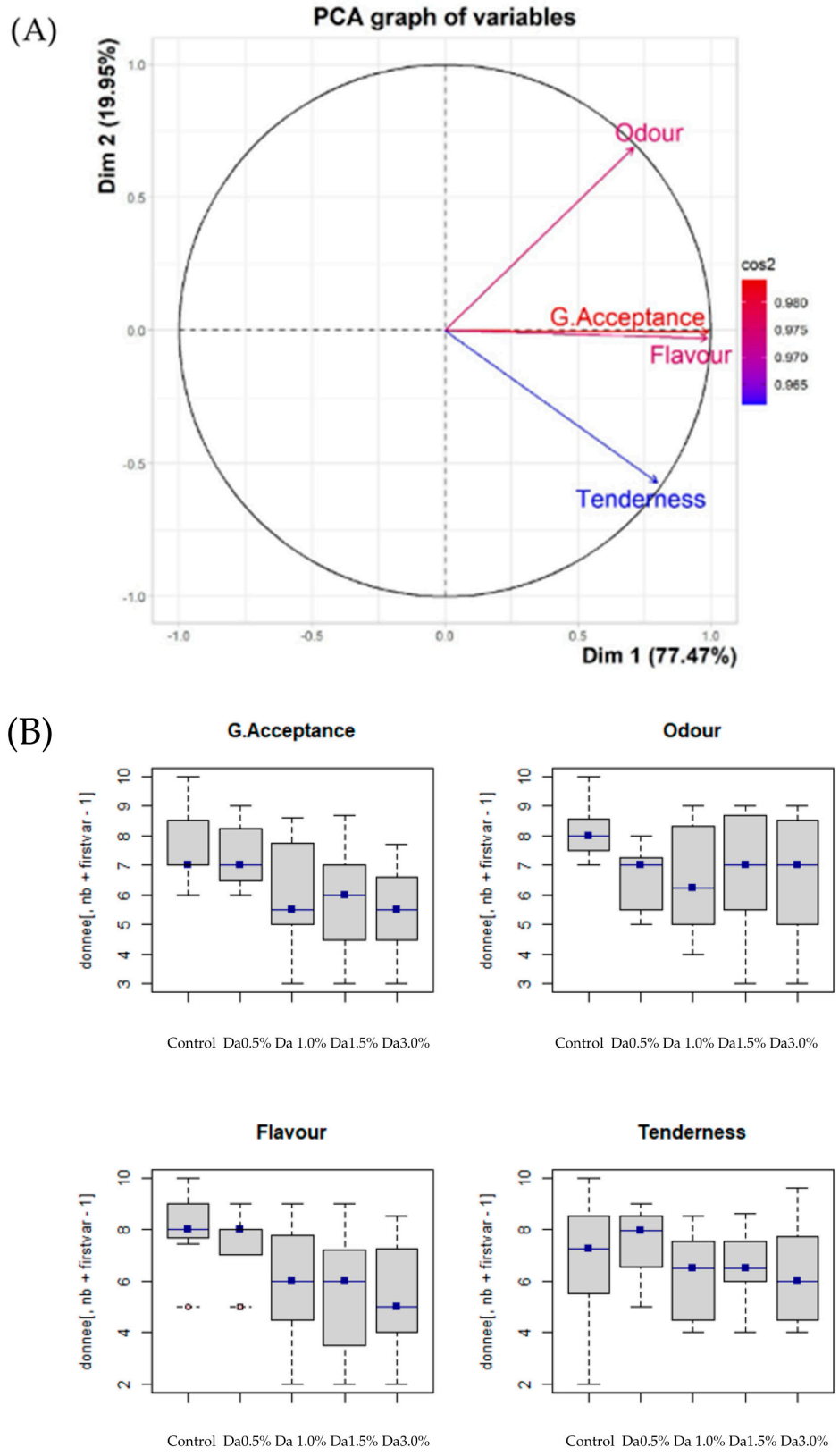

Figure 3. *Cont*.

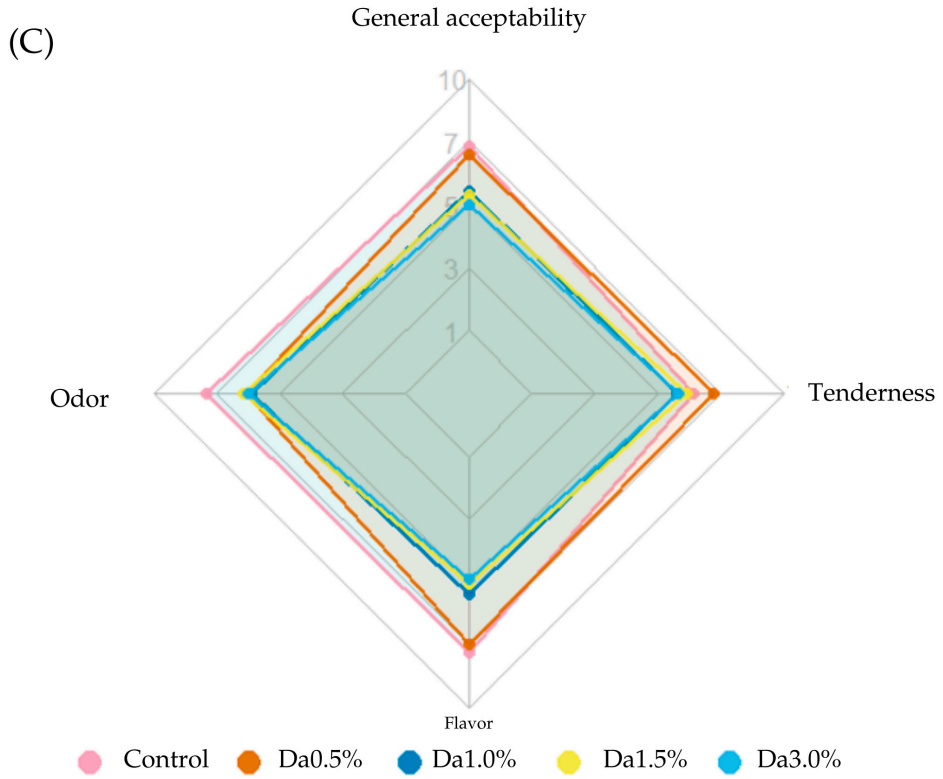

Figure 3. (**A**) Principal component analysis (PCA) of the variables that explain the variance in the general acceptability of beef burgers with different levels of *Durvillaea antarctica*. (**B**) Descriptive statistics of the scores given to sensory variables of beef burgers with different levels of *Durvillaea antarctica*. (**C**) Organoleptic evaluation of beef burgers with different levels of *Durvillaea antarctica*.

The sensory characteristics reported in this study may be related to the mineral-salt content of brown seaweed, which causes an excessively salty taste and a characteristic marine smell that, in Western culture, is not associated with meat products such as beef burgers, and *Durvillaea antarctica* is typically known for its high iodine content [52]. Additionally, a study conducted by Kryzhova et al. [53] recommends not using the macroalga Laminaria in the preparation of meat products due to its high iodine and selenium content. Tenderness, on the other hand, was like the control with the inclusion of 0.5% *D. antarctica* meal (Figure 3C). As the concentration of *D. antarctica* increased, this characteristic was negatively perceived. This could be explained by the amount of water (ice) in that formulation (17.5%), which was like the control (18.0%). However, this formula had a very low water-retention capacity, so the amount of water may have been masked by the gelling, stabilizing, and thickening properties that *D. antarctica* and other seaweed possess due to their high insoluble fiber content (45%). This fiber may have been able to form a three-dimensional network that retains fat inside, resulting in variations in tenderness and providing different sensations when chewing [22,45,54]. In this study, beef burgers made with 0.5% *D. antarctica* meal preliminarily showed better overall acceptability and taste, with the control being identified as having a better odor and better tenderness compared to the other treatments (Figure 3C). It is important to note that none of the indices evaluated obtained a score lower than five. The preliminary results of this study indicated that the concentration of *D. antarctica* and the adequacy of this ingredient should be reviewed in greater detail in future studies, as increasing concentrations of this ingredient resulted in an increase in marine odor, hardness, and chewiness due to the high fiber and iodine content of the seaweed.

4. Conclusions

This study evaluated the potential use of *Durvillaea antarctica* meal in the preparation of beef burgers and its effect on the physicochemical and sensory characteristics of this product. There are inconclusive results regarding the use of seaweed in the production of meat products. Evidence shows that they are a source of high-nutritional-value elements, such as healthier lipids, but there are also studies indicating that some species may present antinutritional elements, such as metals, that need to be carefully reviewed. Additionally, there is an issue related to emotional aspects. Although not addressed in this study, the literature indicates that consumers exhibit some reluctance to mix terrestrial elements with marine-origin ingredients due to cultural aspects or negative sensory characteristics, such as marine odor and loss of redness. These latter aspects were also observed in our study. The *D. antarctica* meal possibly improves water-retention capacity and limits the sharp drop in pH during the storage process of burgers, which could free these products from synthetic preservatives or nutritional warning labels on an artisanal or industrial scale. However, to confirm this thesis, further studies are necessary, including microbiological analyses and consumer-panel evaluations.

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