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APPLICATION OF RED ALGAE (*Palmaria palmata*) IN BRINE-INJECTED PORK LOIN: IMPACTS ON PRODUCT QUALITY PARAMETERS

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Abstract

The trend in the meat industry towards healthy products, coupled with growing concerns about the nutritional and ethical aspects of meat consumption, has led to an increased interest in new approaches to formulate meat products that contain non-meat ingredients. The use of natural marine-derived ingredients as functional additives in meat products is due to their ability to enrich the nutritional value and provide antioxidant properties. The purpose of this study is to evaluate the functional potential of red algae (Palmaria palmata) as a natural additive in smoked meat products. This study focused on the effects of red algae extract in brine injection solutions in the formulation of 3 batches of pork loin (injected with 10% [w/w]): 1 control (with a standard brine) and 2 experimental batches (brine with 1% and 2% extract of Palmaria palmata). Batches were heat-treated and evaluated in terms of physicochemical composition, color parameters, texture profile and sensory perception. The experimental batches showed an improvement in protein content, a reduction in fat and salt content and color changes by increasing lightness (L∗) parameter and reduction of red color intensity (a∗).

Key words: *brine injection, meat product formulation, meat quality, Palmaria palmata.*

INTRODUCTION

Meat is a major source of protein in many people's diets, and people are highly adaptable to meat consumption. In addition, meat is a significant source of micro- and macronutrients in addition to protein, such as essential fatty acids, vitamins, minerals and bioactive compounds, some of which are only available or have higher bioavailability in animal products (Pogurschi et al., 2018; Leroy and Cofnas, 2020; Boișteanu et al., 2023). However, in recent decades, meat production and consumption have come under scrutiny due to major concerns related to the livestock sector, sustainability and ethical aspects of meat production, along with health issues related to meat consumption (Font-i-Furnols, 2023).

In general, additives are used in all branches of the food-producing industry with the clear goals of improving product quality (Zugravu et al., 2017; Flocea et al., 2024). Sodium chloride (NaCl) and phosphates are commonly used additives in the manufacture of meat products that have both preservative and sensory enhancement roles (Ciobanu et al., 2024b). NaCl acts synergistically with phosphates in the extraction and solubilization of myofibrillar proteins, which are responsible for emulsification of water-holding capacity and fat retention (Glorieux et al., 2017). Phosphates can also increase oxidative and microbiological stability as well as improve tenderness and juiciness of meat products (Powell et al., 2019). High levels of NaCl and phosphate negatively affect the nutritional quality of meat products, with an impact on consumer health. Excessive consumption of NaCl, the main source of sodium in meat products, can cause numerous health problems, such as high blood pressure, cardiovascular disease, kidney disease, stroke, gastritis, metabolic syndrome and obesity (Cappuccio et al., 2019; Gonçalves et al., 2016; Taylor et al., 2018).

To counteract this negative impact due to the additives increasingly used in the meat industry, new ingredients from natural sources are being sought with the aim of obtaining healthier protein products (Anchidin et al., 2023; Manoliu et al., 2024). An example in this regard is the integration of functional ingredients, such as vegetable additives (spinach, red lentils) that significantly influence the sensory and physico-chemical profile of meat products (Gucianu et al., 2023; Ciobanu et al., 2025; Boișteanu et al., 2025).

Red algae (*Palmaria palmata*) represent a valuable and functional alternative due to their rich content in proteins, essential amino acids, vitamins and bioactive compounds. They can provide products with antioxidant and shelf-life prolonging properties, thus contributing to improve the nutritional and functional value of meat preparations (Wang et al., 2021).

Therefore, this study aims to evaluate the impact of injecting brine solutions with two variants of red seaweed powder addition (1% and 2%) into pork chops on quality characteristics. The injected products, both the experimental variants and the control sample (injected with a standard brine), are subjected to the smoking heat treatment and evaluated from a physico-chemical and sensory point of view.

MATERIALS AND METHODS

The three formulations of smoked pork loin were obtained in the meat processing workshop of the Iasi University of Life Sciences, as shown in Table 1.

The pork loin was purchased from a local producer in Iasi county, SAGROD, and the seaweed was purchased from ALGAMAR, certified organic red algae (*Palmaria palmata*) in dehydrated form. To prepare the brine, the seaweeds were hydrated in water for 2 hours, then finely ground and added to the brine.

Table 1. Formulations and heat treatment of experimental batches for pork loin injected with different concentrations of red algae

Experimental batches	Injection level	Brine composition	Red algae content in brine	Thermal treatment		
				Air drying (°C/min)	Smoking (°C/min)	Hot air cooking (°C/min)
CC0%	10%	Water + salt	0%	65/30	72/30	86/50
RA1%		Water + salt + red algae	1%			
RA2%		Water + salt + red algae	2%			

CC0% - Control pork loin batch; RA1% – Pork loin with 1% red algae in brine; RA2% – Pork loin with 2% red algae in brine

After the finished products were obtained, they were qualitatively evaluated in the Meat and Meat Products Technology Laboratories and the Sensory Analysis Laboratory.

The proximate chemical composition was determined by a rapid method using the NIR FoodCheck analyzer (Bruins Instruments, OmegAnalyzer).

Determination of colour parameters (L*, a* and b*) was carried out using the Chroma Meter CR-410 (Konica Minolta Inc., Japan), set with D65 light source, 2° observation angle. Based on the obtained values, the following colour parameters were calculated, according to the formulas presented in a previous study (Ciobanu et al., 2024a):

- the colour intensity: $C^*=\sqrt{[(a^*)^2+(b^*)^2]}$;
- hue angle: $H^*=tan^{-1}(\frac{b^*}{a^*})$;
- total colour difference: $\Delta E=\sqrt{[(L^*_s-L^*_{con})^2+(a^*_s-a^*_{con})^2+(b^*_s-b^*_{con})^2]}$.

The determination of the pH value of the products was performed using a direct insertion pH meter (HI98163, Hanna Instruments Romania).

The determination of the textural parameters of shear (force and mechanical work) and compression (hardness, cohesivity, elasticity, gumminess, chewability and adhesiveness) was carried out using a TA1Plus texturometer (Lloyd Instruments, AMETEK, UK), equipped with a 500N force cell. The sample preparation stage for the Warner-Bratzler shear test involved the formation of 18 x 10 mm samples, and 30 mm high sections for the compression test.

The sensory evaluation session involved the organization of a sensory evaluation session in the sensory laboratory under controlled lighting and temperature conditions using a panel of 50 semi-trained evaluators (15 males and 35 females), aged between 20 and 22 years, all of whom were regular pork consumers. In order to familiarize the participants with the product concept, they underwent a training session that included a presentation of the finished product and explanation of the hypothesis.

Given the added algae, affective methods of analysis were used and samples were prepared by uniform portioning, coded with three randomly chosen codes. The questionnaire was implemented in digital format (using google forms platform to centralize the answers) and the scale used was from 1 to 9, where 1 - dislike at all and 9 - like extremely.

The obtained results were statistically evaluated and are expressed as mean values (± standard deviation) and the experimental batches were compared with the control using analysis of variance (ANOVA) followed by Tukey's test at 5% significance level ($p < 0.05$), using IBM SPSS Statistics v.21.

RESULTS AND DISCUSSIONS

The chemical composition of the brine-injected pork loin formulations is presented in Table 2.

In the present study, the inclusion of red algae *(Palmaria palmata)* caused a significant effect ($p < 0.001$) on all analysed chemical parameters when compared to the control sample (CC0%). More precisely, the samples with 1% (RA1%) and 2% (RA2%) red algae dissolved into the brine solution displayed higher humidities, with the highest value observed for RA2% (74.74 ± 0.11%), indicating improved water holding capacity. Likewise, the content of dry matter, fat, and salt were decreased significantly with the increasing incorporation level of red algae, which can be attributed to the higher moisture of the investigated samples treated with the marine algae.

These results are consistent with the results of previous studies on algae addition in meat products, such as the one conducted by Muraguri (2018) who previously found that the addition of seaweed powder (*Eucheuma denticulatum)* into chicken sausage resulted in a better water-holding capacity and lower fat content. Likewise, Hentati et al. (2018) reported that supplementation of burgers with 1% algae (*J. adhaerens* and *C. compressa*) would lead to reduced fat content with an enhancement of technological properties, such as swelling capacity, water and oil holding capacity.

Regarding the protein content, a slight but statistically significant increase was observed for the RA2% sample (21.94 ± 0.05%), which could be due to the protein content from the red algae extract. These results are in agreement with the studies of Idowu (2024) and Cox and Abu-Ghannam (2013) who pointed out that marine algae could have a potential to be used as a source of protein to enrich food matrices. The collagen content, with was reported to the protein content, was comparable in all samples, meanwhile, which indicated that the muscle protein structural integrity was not significantly affected by the addition of algae. Siladji et al. (2024) also reported an increase in protein content in caseless sausages with the addition of three different types of algae (White *C. vulgaris,* sea spaghetti and wakame).

Table 2. Analysis of chemical composition of brine-injected pork loin formulations

Analyzed parameter	Sample			*p-value*
	CC0%	RA1%	RA2%	
Humidity (%)	72.28 ± 0.43 a	73.86 ± 0.36 b	74.74 ± 0.11 c	< 0.001
Dry Matter (%)	27.72 ± 0.43 c	26.14 ± 0.36 b	25.26 ± 0.11 a	< 0.001
Fat (%)	4.40 ± 0.07 c	2.64 ± 0.11 b	1.84 ± 0.17 a	< 0.001
Protein (%)	21.36 ± 0.05 a	21.78 ± 0.04 b	21.94 ± 0.05 c	< 0.001
Colagen*	19.70 ± 0.07 a	20.14 ± 0.09 b	20.30 ± 0.07 c	< 0.001
Salt (%)	1.94 ± 0.11 b	1.54 ± 0.05 a	1.44 ± 0.13 a	< 0.001

CC0% - Control pork loin batch; RA1% – Pork loin with 1% red algae in brine; RA2% – Pork loin with 2% red algae in brine. Values are given as means ± Standard deviation from five repeted determinations. Means with different superscripts in a row orientation indicate significant differences ($p < 0.05$) between samples determined by the Tukey test. *Colagen content is expressed as % from the total protein content.

The colorimetric parameters of brine-injected pork loin formulations are presented in Table 3. The addition of red algae significantly affected ($p < 0.05$) the color parameters L*, a*, b* and C* of the experimental batches, compared to the control (CC0%).

The values for lightness (L*) increased with the percentage of algae added in the brine solution, with the highest L* value found in RA2% (69.31 ± 0.70), indicating a visual brightness of the pork loin samples. This increase in lightness (L*) can be positively correlated with the moisture content and the dilution of myoglobin concentration, that causes the characteristic red color to become paler and the meat to appear brighter.

Regarding the green-red coordonate (a*), a significant decrease in values was detected with algae addition, dropping from 14.23 ± 0.46 in the control sample to 9.54 ± 1.18 in RA1% and 8.15 ± 0.35 in RA2%. This indicates a reduction in the red intensity of the samples, making the surface appear paler and less vivid in red tones.

The b* (yellow-blue coordonate) showed a significant decrease following the addition of red algae into the brine solution. Color saturation (Chroma, C*) also decreased progressively with increasing algae content, reflecting a reduction in overall color intensity. Although the hue angle (h*) increased slightly with the addition of algae – indicating a slight shift toward a more yellowish hue – the difference was not statistically significant (p = 0.066). Total color difference (ΔE) values revealed that both RA1% and RA2% caused perceptible changes in color, with ΔE values of 8.22 ± 0.52 for RA1% and 4.08 ± 2.42 for RA2% compared to the control.

These findings align with those reported by Vilar et al. (2020), who observed that the incorporation of edible algae in frankfurters decreased redness (a*) and yellowness (b*) values in comparison to the control sample. Gullón et al. (2021) state that the color changes occur due to the Maillard reaction between the algae and pork meat, resulting in the formation of dark compounds, and also to the specific colouration of the red algae, that has a darker appearance.

Overall, adding red algae into the brine solution to be injected into pork loins resulted in lighter, less red products with lower color intensity – features that must be cautiously evaluated with respect to consumer expectations, as visual appearance is a decisive factor in the acceptability of meat products. Studies have showed that the effectiveness of traditional functional compounds, such as protein derivatives and starch, in improving the functional properties of meat emulsions (Ianițchi et al., 2023), as well as the influence of technological parameters on tenderness and color (Pătrașcu et al., 2021).

Table 3. Colorimetric parameters of brine-injected pork loin formulations

Analyzed parameter	L*(D65)	a*(D65)	b*(D65)	C*	h*	ΔE	Generated Hex colour
CC0%	65.12 ± 0.47a	14.23 ± 0.46c	14.07 ± 0.34b	20.02 ± 0.36c	44.70 ± 1.28a	-	
RA1%	66.77 ± 3.57ab	9.54 ± 1.18b	8.28 ± 0.27a	12.65 ± 0.97b	41.13 ± 3.36a	8.22 ±0.52	
RA2%	69.31 ± 0.70b	8.15 ± 0.35a	8.05 ± 0.52a	11.47 ± 0.42a	44.63 ± 2.30a	4.08 ±2.42	
p-value	0.027	< 0.001	< 0.001	< 0.001	0.066	-	-

CC0% - Control pork loin batch; RA1% – Pork loin with 1% red algae in brine; RA2% – Pork loin with 2% red algae in brine. L*(D65) – lightness (ranging from 0 = black to 100 = white); a*(D65) – red-green component (positive values = red tones, negative values = green); b*(D65) – yellow-blue component (positive values = yellow tones, negative values = blue); C* – chroma (reepresents the color saturation or intensity, higher values indicate more vivid colors); h* – hue angle (expresses the dominant color tone); ΔE – total color difference. Values are given as means ± Standard deviation from five repeted determinations. Means with different superscripts in a row orientation indicate significant differences (p < 0.05) between samples determined by the Tukey test.

The addition of red algae into brine solutions used for the injection of pork loin significantly influenced the meat's textural characteristics, as determined by the ANOVA statistical test applied on the results presented in Table 4 (Warner-Bratzler shear force measurements and Texture Profile Analysis - TPA). A dose-dependent enhancement in tenderness was observed, with the RA2% treatment (2% red algae) exhibiting the most pronounced effects.

The Warner-Bratzler shear force decreased significantly from 18.61 N/cm^2 in control

(CC0%) to 14.25 N/cm^2 in RA1% and 10.85N/cm^2 in RA2%, respectively ($p = 0.001$). Similarly, the work of shear was also significantly reduced with the increasing red algae concentration ($p = 0.004$). These decreases indicate that red algae components, such as carrageenan, may disrupt muscle fiber integrity and enhance moisture retention, leading to improved tenderness. This result aligns with the observations made by Cofrades et al. (2008), who reported that the addition of hydrocolloids from seaweeds favored the water and fat binding in low-salt meat emulsions, with subsequent alterations in product texture

A significant decrease in hardness was also observed, from 33.14 N in the control to 24.26 N in RA1% and 19.69 N in RA2% ($p < 0.001$). Gumminess and chewiness also decreased with increased doses of red algae ($p = 0.004$ and $p < 0.001$, respectively), reflecting a more tender and palatable texture. Those changes are in accordance with the study by López-López et al. (2009) where the incorporation of seaweed in functional frankfurters decreased hardness and the textural parameters.

While cohesiveness did not show statistically significant differences ($p = 0.124$), a trend towards increased values in the RA2% treatment suggests potential improvements in the structural integrity and resilience of the meat matrix. Adhesiveness significantly decreased from 0.78 in the control to 0.50 in RA2% ($p < 0.001$), indicating a low adhesive surface texture. Such decrease could be related to the water binding capacity of red algae constituents, which can modify the surface properties of meat products. Similar findings were reported by Kim et al. (2014), who observed decreased adhesiveness in cooked sausages formulated with red and green glassworts (*Salicornia herbacea* L.).

Table 4. Warner Bratzler shear forces and textural parameters of brine-injected pork loin formulations

Analyzed parameter	Sample			*p-value*
	CC0%	RA1%	RA2%	
Shear force (N/cm^2)	18.61 ± 1.53 b	14.25 ± 3.38 a	10.85 ± 1.32 a	0.001
Work of shear (mJ)	448.55 ± 6.08 b	345.93 ± 4.34 a	293.23 ± 3.80 a	0.004
Hardness (N)	33.14 ± 2.95 b	24.26 ± 4.37 a	19.69 ± 2.82 a	< 0.001
Cohesiveness (N)	0.21 ± 0.05 a	0.25 ± 0.08 a	0.44 ± 0.28 a	0.124
Elasticity	1.86 ± 0.15 b	1.43 ± 0.34 a	1.09 ± 0.13 a	0.001
Gumminess (N)	4.35 ± 0.85 b	3.35 ± 0.43 a	2.80 ± 0.28 a	0.004
Chewiness (N)	8.01 ± 1.22 b	4.85 ± 1.67 a	3.06 ± 0.59 a	< 0.001
Adhesiveness	0.78 ± 0.08 b	0.57 ± 0.09 a	0.50 ±0.05 a	< 0.001

CC0% - Control pork loin batch; RA1% – Pork loin with 1% red algae in brine; RA2% – Pork loin with 2% red algae in brine. Values are given as means ± Standard deviation from five repeted determinations. Means with different superscripts in a row orientation indicate significant differences ($p < 0.05$) between samples determined by the Tukey test.

The hedonic sensory evaluation of the three variants of injected pork loin - the control batch (CC0%) and the two experimental batches with the addition of 1% (RA1%) and 2% (RA2%) red algae - showed good overall consumer acceptability for all samples, with average scores above 7 on a 9 - point scale (Table 5). This observation suggests that regardless of the addition of red algae, the product was perceived positively and was found to be palatable by the panel of assessors.

The control sample (CC0%) received the highest scores for appearance (7.86 ± 0.42) and section appearance (7.54 ± 0.95), indicating a consumer preference for traditional visual characteristics. The addition of red algae seems to have negatively influenced the section appearance (scores of 6.43 and 6.29), with the results indicating statistically significant differences between the control and the RA1% and RA2% samples. This effect can be attributed to the presence of the algal insert resulting from the injection, perceived as atypical compared to the control.

In terms of colour, the scores were relatively similar, however the mean value for RA2% (6.75 ± 1.15) was significantly lower than for RA1% (6.82 ± 0.95) and control (7.65 ± 0.88), suggesting that the higher algal addition may impart a less familiar or attractive colour hue.

For flavor and taste, the addition of seaweed extract had a beneficial effect on the evaluators' perception. Both RA1% and RA2% samples scored significantly higher than the control, with RA2% reaching 8.22 ± 0.85 (flavor) and 8.43 ± 0.88 (taste), in contrast to the control values of 7.58 and 7.60, respectively. These data suggest that seaweed may provide umami flavor notes or additional flavor complexity that may be well received by consumers.

Texture showed higher scores in the algae extract samples, especially in the RA2% (7.37 ± 1.20) compared to the control (6.89 ± 1.16), suggesting an effective tenderization of the meat possibly influenced by the enzymatic effect of the algae extract or colloidal compounds present in the algae.

Overall acceptability was high for all three batches, but the highest was obtained by RA2% (8.17 ± 0.82), with significant differences from the control. This result reflects the fact that, despite some reservations in terms of visual appearance, consumers perceived positively the overall sensory experience of products with added red algae, especially due to taste and flavor.

According to the results, the addition of red seaweed was hedonically accepted by consumers without significantly exceeding the control sample scores. This trend is also supported by the literature, which points out that high levels of addition may compromise attributes such as flavor and appearance, even though the nutritional benefits remain evident. In addition, maximum sensory acceptability appears to be achieved at low concentrations (≤2.5%) of seaweed extract, which is also consistent with the findings of author Mohammed (2024).

Table 5. Sensory analysis of brine-injected pork loin formulations

Sensory attribute	Samples		
	CC0%	RA1%	RA2%
Appearance	7.86 ± 0.42^{a}	7.61 ± 1.23^{ab}	7.33 ± 1.14^{b}
Section appearance	7.54 ± 0.95^{a}	6.43 ± 1.05^{b}	6.29 ± 0.32^{b}
Color	7.65± 0.88^{b}	6.82 ± 0.95^{a}	6.75 ± 1.15^{ab}
Flavor	7.58 ± 1.28^{b}	8.17 ± 0.74^{a}	8.22 ± 0.85^{a}
Taste	7.60 ± 0.85^{b}	8.37 ± 0.97^{a}	8.43 ± 0.88^{a}
Texture	6.89 ± 1.16^{a}	7.54 ± 1.39^{ab}	7.37 ± 1.20^{b}
Overall acceptability	7.73 ± 0.75^{a}	7.92 ± 0.81^{ab}	8.17 ± 0.82^{b}

CC0% - Control pork loin batch; RA1% – Pork loin with 1% red algae in brine; RA2% – Pork loin with 2% red algae in brine. Values are given as means ± Standard deviation. Means with different superscripts in a row orientation indicate significant differences ($p < 0.05$) between samples determined by the Tukey test.

CONCLUSIONS

This study investigated the impact of incurporating red algae into brine solutions for pork loin injection, aiming to develop a reformulated meat product with improved textural properties and potential functional benefits derived from marine-derived polysaccharides.

The study results showed that the inclusion of red algae in the brine formula improved the nutritional value of pork loin by increasing water and protein content, but decreased fat and salt content of pork loins and promoted the development of healthier meat products. These findings are in accordance with the increasing amount of data that support algae as a source of functional ingredients that is capable not only of providing structure and texture but also of delivering nutritionally enhanced and sustainable foods to the consumer.

From a technological perspective, the incorporation of red algae into the brine solutions significantly influenced the colorimetric properties of pork loin. Lightness (L) increased with the addition of red algae, while the red-green coordinate (a) and yellow-blue coordinate (b*) decreased progressively, indicating a shift toward less saturated red and yellow tones. Consequently, chroma (C*) decreased, and the hue angle (h*) showed a slight but non-significant reduction. These changes suggest a perceptible but modest alteration in visual appearance. However, the total colour difference (ΔE) remained below the threshold generally considered perceptible to consumers, particularly for the RA2% sample (ΔE = 4.08 ± 2.36), implying that the reformulated products retained an acceptable visual quality.

Therefore, in terms of texture modifications, the addition of red algae into pork loin brine solutions significantly enhanced textural properties, particularly at a 2% concentration. Improvements in tenderness, gumminess, chewiness, and overall palatability suggest that red algae can serve as a functional ingredient in meat processing, offering potential benefits for product quality and consumer satisfaction. These findings are corroborated by existing literature on seaweed applications in meat products, highlighting the value of red algae as a natural texturizing agent.

The results confirm the viability of using red algae in the formulation of injected pork loin from the consumer's perspective. While some visual attributes may be slightly affected, the benefits on flavor, taste and texture may offset this, leading to a high overall acceptance of the product. Communication strategies on the functional benefits of seaweed could also improve visual perception among consumers.

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