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FORMULATION OF A FUNCTIONAL MEAT PRODUCT WITH A COMPACT STRUCTURE BY INCORPORATING *Cetraria islandica*, A UNDEREXPLOITED INGREDIENT, AND EVALUATION OF ITS POTENTIAL IN THE MEAT INDUSTRY

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Abstract

Nowadays, consumer demands for more natural products have forced the food industry to increasingly exclude synthetic compounds from its products and to explore natural sources of bioactive ingredients such as natural antioxidants. All parts of plants, such as fruits, nuts, seeds, leaves, roots and barks, contain antioxidant compounds, making them potentially valuable ingredients for the food industry in the production of products with functional properties. In order to improve the functional properties of meat products, we have developed a meat product assortment with a compact structure, incorporating lichen (Cetraria islandica), an antioxidant ingredient that is unconventional for this type of products, thus exploring new ways of innovation in the meat industry. In order to compare the effect of the addition of Cetraria islandica, we manufactured three batches (1%, 3%, 5%) and a control batch. The resulting products were analyzed internally and externally for physicochemical quality and antioxidant capacity, with highly significant differences ($p<0.001$) observed between the internals and externals, and sensory evaluations were performed on the whole product.

Key words*: antioxidants, functional food, meat products, sensory analysis, quality analysis.*

INTRODUCTION

Since ancient times, meat has been a staple of the human diet, as it is a nutrient-rich food high in protein, vital amino acids, vitamins (especially B vitamins) and minerals such as iron and zinc (Bis-Souza et al., 2019; Manoliu et al., 2024; Boișteanu et al., 2023; Ianițchi et al., 2024) that fulfill various functions in the human body (Manoliu et al., 2023) and that can be more easily assimilated from meat than from other foods (Ciobanu et al., 2024). These include maintenance of normal physiological processes (Anchidin et al., 2024a), increased immunity and avoidance of certain diseases such as malnutrition (Ciobanu et al., 2023). However, consumers perceive meat consumption as linked to various health hazards due to high fat, salt and additives content.

One of the most important industries in the world is the meat sector (Boișteanu et al., 2025). The demand for meat and meat products has increased in different regions of the world over the last 20 years (Anchidin et al., 2024b), tripling globally in the last 50 years (Ciobanu et al., 2025). Currently, one of the main forces behind new trends and breakthroughs in the creation of new healthy products, including those derived from meat, is the growing market demand for healthier and more functional foods (Ruiz-Capillas & Herrero, 2021). This trend also relates to meat products, as consumer predilection for animal products is likely to persist. (Kumar et al., 2013). By reducing consumption of foods that are commonly consumed, functional foods aim to reduce the prevalence of chronic diseases. Large food corporations, including the meat industry, are becoming very interested in formulating foods based on the potential benefits their non-nutritional constituents may have for the consumer (Fernández-Ginés et al., 2005).

Functional foods are a remarkable and interesting category of foods with health-promoting qualities, such as anti-carcinogenic, antioxidant and cholesterol-lowering qualities, which make them attractive to consumers (Anchidin et al., 2023).

The need to provide enhanced food products with components that promote health and prevent nutrition-related diseases is well recognized in the industry (Mironeasa & Ungureanu-Iuga, 2024), as consumers are becoming increasingly demanding about the type of food they buy and consume (Pogurschi et al., 2018; Ciobotaru et al., 2024a). In response to increasing consumer demands, the food industry is reformulating food products to enhance the physiological performance of natural nutrients or by incorporating a bioactive component (Anchidin et al., 2023; Ciobotaru et al., 2024b). One way to procure improved/ functional foods in modern food processing involves the use of different food enhancers, such as plant agents (Zugravu et al., 2017). Studies on potential applications of different products and by-products from plants, lichens and algae in the food sector, as well as studies to better understand these concerns, have been conducted in increasing numbers. The aim of these studies is to capitalize on non-traditional sources of bioactive chemicals to sustainably improve the nutritional content of staple foods or meat quality (Mironeasa & Ungureanu-Iuga, 2024).

In nature, lichen is a unique type of plant (Calcott et al., 2018). It is a mutualistic entity consisting of a fungus (mycobiont) and an alga (photobiont) allied with a robust and specific composition (cyanobacteria or other microbial species) (Thakur et al., 2023). Some metabolites and minerals found in lichens are a valuable source of nutritious food for invertebrates and vertebrates (humans and some reptiles), mites, termites, snails, caterpillars, etc. *Cetraria Islandica*, sometimes known as Icelandic moss, has been consumed as food in a number of nations including Scandinavian nations, Sweden, Norway and Iceland and Bosnia and North Africa mainly (Sharma & Mohammad, 2020).

Because of the bioactive substances they contain, lichens are extremely important for nutrition. Long used as a food, lichen is a multifunctional, nutrient-rich food that can be consumed almost every day. These invaluable natural resources are now being exploited for a variety of other applications (Thakur et al., 2023).

Lichens are notable for their production of unique primary and secondary metabolites, including amino acids, polysaccharides (lichenin, isolichenin), vitamins and pigments. Lichen polysaccharides, mainly composed of galactomannans, α-glucan and β-glucan, exhibit diverse biological properties. According to recent research, the metabolites generated by lichens have substantial biological potential and active properties such as antifungal, antibacterial, anticarcinogenic, antiviral, antioxidant and anti-inflammatory properties (Bao & Bau, 2013; Huang et al., 2018; Olafsdottir & Ingólfsdottir, 2001; Ullah et al., 2019). Among the biologically active components that *Cetraria islandica* contains, phenolic compounds, diterpenoids, depsides, and various benzenoid and non-benzenoid derivatives have been identified (Yusuf, 2020).

Because they contain more than 500 potentially bioactive substances that have been discovered to date, lichens (phylum *Lichenophyta*, to which *Cetraria islandica* belongs), the least-utilized subdivision of fungi, are composite plants used in folk medicine to treat a variety of ailments, from digestive to respiratory. The chemical substances they contain, which include lichenic acids such as usnic acid, lobar acid, lecanoric acid or salazine acid, are cytotoxic, antioxidant and antibacterial agents (Patriche et al., 2019).

There are two types of antioxidants: natural and synthetic (Flocea et al., 2024). When developing new meat products, it is important to keep in mind that chemically and biologically synthesized products can block food poisoning. The food industry utilizes a variety of natural and synthetic materials that are gatekeepers against oxidative and microbiological spoilage to stop these events (Krotova et al., 2023). However, a significant element influencing the acceptability of food and food innovation products is their perceived naturalness (Siegrist & Sütterlin, 2017). Thus, the use of natural antioxidant ingredients represents a promising alternative for the meat industry.

According to research conducted by Gülçin et al. (2002), in comparison with various standards including α-tocopherol, BHA, BHT and quercetin, *C. islandica* exhibits strong antioxidant activity, reducing power, DPPH

radical and superoxide anion scavenging capacities. The study findings indicate that *C. islandica* may find successful applications in the pharmaceutical or food/food supplement industry.

Due to the information collected so far from the literature on *Cetraria Islandica* and as a way to innovate in the meat industry by using sources with extremely restricted utilization we decided to develop three batches of pastrami-type products with added lichen. This, in our opinion, is an area with potential but limited research. In order to explore the benefits of *Cetraria islandica*, we aimed to analyze the effects of its addition in different concentrations on the quality and bioactivity of meat products.

MATERIALS AND METHODS

In the framework of this research, four batches of pastrami (made out of pork leg) were manufactured, three of them with 1, 3 and 5% added *Cetraria islandica* lichen in their composition, and the fourth batch was the control batch (without added *Cetraria islandica*) in order to perform a comparative qualitative analysis between them. All the described batches were manufactured at the "Ion Ionescu de la Brad" Iasi University of Life Sciences (IULS). The raw material, consisting of boneless pork leg, was purchased from SC SAGROD SRL (Botoșani, Romania), the lichens *Cetraria islandica* were purchased from SC STEFMAR PRODUCȚIE SRL (Râmnicu Vâlcea, Romania) and the seasoning ingredients used were purchased from a company specialized in their commercialization in Iasi County, SC Rocas FDS SRL (Iasi, Romania).

The experimental batches, in addition to the meat used and the addition of *Cetraria islandica*, also contained the following spices: salt, ground black pepper, garlic powder and sweet paprika. The lichen (*Cetraria islandica*) powder was solubilized in a 10% brine solution and subsequently introduced into the meat pieces by vacuum tumbling, allowing the penetration of the solution into the muscle tissue.

The spices were integrated in a batter through which the meat pieces were passed, followed by hanging them on the rack trolley and putting them through the heat treatment, the stages of which are shown in Table 1. After completion of this, the samples were cooled, vacuum-packaged and stored at refrigeration temperatures (0-4ºC) until physico-chemical and phytochemical analyses were carried out.

The physico-chemical analyses consisted in the analysis of the pH of the samples, colorimetric parameters, textural profile, protein content, fat content, moisture content, dry matter, ash, collagen and salt content. The phytochemical content of the samples and their antioxidant capacity were also analyzed.

The pH values of the samples were carried out with pH meter HI98163 with electrode FC23232323 (SC Hanna Instruments SRL).

The color analyses of the samples, which involved the analysis of color parameters in three-dimensional CIELAB space, were performed using the Konica Minolta CR-410 colorimeter (Konica Minolta, Inc.).

Table 1. Heat treatment applied to the experimental batches

Experimental batches	Heat treatment							
	Drying I		Smoking		Boiling		Drying II	
	T (ºC)	Time (min)	T (ºC)	Time (min)	T (ºC)	Time (min)	T (ºC)	Time (min)
P0L P1L P3L P5L	60	30	65	40	75	-	80	20

P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens.

The colorimetric parameters Hue (h°), Chroma (C*), and visually perceived color difference between samples (ΔE) were also calculated using formulas (1), (2), and (3) based on the data collected from these parameters. Hue (hº) and Chroma (C*) were computed following the approach described by Salueña et al. (2019), while ΔE was calculated according to the

method proposed by Wei et al. (2012). The textural profile of the samples (TPA) was carried out with the TA1+1K Plus textuometer (Ametek, Inc.), equipped with a cylindrical compression probe, which performed a double compression. The following parameters were measured during this analysis: hardness, cohesiveness, elasticity, adhesiveness, gumminess, chewiness.

$$H° = \arctan \frac{b^*}{a^*} \quad (1)$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (2)$$

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (3)$$

The chemical, colorimetric and phytochemical analyses performed on the analyzed samples were carried out both at ~0.3 cm from the surface of the products and inside the products, as differences in the absorption of the brine solution with lichens inside the samples were noticed. This is due to the increased viscosity of the solution caused by the addition of lichens which made it difficult for the solution to penetrate deep into the meat pieces.

Proximate composition analysis of moisture, protein, collagen, fat, ash and salt content were carried out using the Food Check Meat Analyzer (Bruins Instruments GmbH, KPM Analytics), a near-infrared spectroscopy (NIR) based system, recognized for its flexibility and accuracy in quantitative analysis of meat composition.

To evaluate the antioxidant capacity of the analyzed samples, the first step was the extraction of bioactive compounds. For this purpose, 1 g of sample was taken from *Cetraria islandica* powder and meat samples and mixed with 10 ml of 70% ethanol as an extractive solvent. The preparation of the extract for the determination of flavonoids and polyphenols followed the first method described by Trifunschi et al. (2017), only using ethanol instead of methanol. The determination of antioxidant capacity by DPPH method was performed according to the method described by Pires et al. (2017), and the ABTS method according to the method of Dumitrașcu et al. (2022).

The Specord Plus 210 UV-vis spectrophotometer Specord Plus 210 UV-vis (Analytik Jena, Germany) was used to measure the absorbance of the materials. Heating in an ultrasonic water bath and, in some cases, centrifugation was followed by sampling to ensure reproducibility. Flavonoids were expressed in mg/g DW, polyphenols in mg GAE/g DW, DPPH assay results in µMol Trolox/g DW and percent (inhibition), and ABTS assay results in µMol Trolox/g DW and percent (inhibition). The solutions used for the analyses of phytochemical content and antioxidant capacity were purchased from Sigma Aldrich Steinheim (Darmstadt, Germany) for antioxidant assays.

In addition to the objective analysis presented above, the sensory evaluation of the samples was carried out as a subjective method to assess the quality of the experimental batches realized in this study. The analysis was performed by a panel of 12 semi-trained tasters (9 women and 3 men). The decision to include this stage was motivated by the importance of consumer acceptability as an imperative factor in the success of functional food products. Sensory evaluation involves the analysis of consumer reactions based on perceptions generated by the human senses (visual, olfactory, gustatory, tactile and auditory), having a major influence on the perception of overall product quality (Ciobanu et al., 2023). The analysis was performed 72 hours after the preparation of the experimental batches under blind test conditions, the samples were coded with randomized three-digit numerical combinations. In this study, we used the external PrefMap analysis, an advanced sensory method based on multivariate data, which allows the correlation between quantitative scores of sensory attributes and preferences expressed by consumers (Boișteanu et al., 2025).

All parameters were analyzed in ten replicates per sample, with the exception of the bioactive compound determinations, which were carried out in five replicates.

RESULTS AND DISCUSSIONS

Table 2 presents the results of the chemical composition of the analyzed samples (mean ± SD) which are composed of: fat, dry matter, humidity, protein, collagen, salt and pH (this represents the only physical parameter in this table). The analyses were performed by taking samples from ~0.3 cm from the surface of the meat pieces and from their central area in order to highlight possible compositional differences, as presented in the Table 2. For the control batch P0L, differentiated analyses were not performed for the subsurface and interior, because this sample does not contain lichens that would limit the distribution of the brine solution in the center of the sample and create qualitative differences.

Statistical differences identified as significant ($p < 0.05$) between batches and between the analyzed regions are highlighted by lowercase letters (for the subsurface area) and uppercase letters (for the interior area).

The addition of lichens influenced the fat content of the samples in both analyzed regions, but especially in the samples taken from the subsurface where more pronounced differences are observed between the P0L sample (control sample) and the samples with 1, 3 and 5% addition of lichens. As for the samples taken from the inside, no significant differences ($p > 0.05$) are observed between the P0L sample and the sample with 1% addition of lichens (P1L). Very significant differences ($p < 0.05$) are observed with the addition of 5% *Cetraria islandica* in terms of the decrease in the fat content inside the samples compared to the P0L batch. It can be seen that with the increase in the concentration of *Cetraria islandica*, a decrease in the fat content occurs in both analyzed regions. Even though the values obtained in the samples taken from the central area of the samples do not present such obvious differences as those taken from the subsurface area, an influence caused by the addition is still observed within the samples.

The statistical interaction between interior and surface for fat shows very significant differences ($p < 0.001$) for all 3 batches with the addition of *Cetraria islandica*, from which we can deduce that it is not completely absorbed to the center of the samples, but it is still absorbed as shown by the results recorded in Table 2.

The moisture content of the samples and their dry matter content were also influenced by the addition of *Cetraria islandica*. The samples taken from the subsurface region for both parameters did not show significant differences ($p > 0.05$) between the analyzed samples, which shows that this addition helps to better retain the moisture of the samples, especially in the external area, where most often there are higher moisture losses compared to the internal area. Also, an initial decrease in the moisture content of the samples and an increase in the dry matter in the sample with 1% addition (P1L) compared to the control sample (P0L), from 70.81 ± 0.26% to 70.70 ± 0.00% and, respectively, 29.19 ± 0.26% to 29.30 ± 0.00%. In the sample with 3% addition (P3L), equal values are observed for the two mentioned parameters, and as for the P5L sample, a slight increase in humidity (71.16 ± 0.26%) and a decrease in dry matter (28.85 ± 0.26%) is observed in the samples in the subsurface area, which indicates that the addition of *Cetraria islandica* helps to retain water in the samples, especially in the area where the meat is more prone to moisture loss and to reduce losses following heat treatment, even if the differences in the subsurface area for the dry matter and humidity parameters do not differ significantly between the samples ($p > 0.05$). As for the analyses of the samples from the central area of the meat pieces, they present significant differences ($p < 0.05$) between the P0L control sample and the other samples studied. At present, we have not identified any articles indicating an influence of the addition of *Cetraria islandica* on the moisture or moisture retention capacity of meat samples, but our results indicate such an influence. However, the study by Antropova et al. (2021) shows that lichens contain a high amount of hydrophilic polysaccharides that can contribute to increased water retention in meat products. The statistical differences between the samples analyzed at the subsurface and those from the interior are highly significant for all samples with studied additions ($p < 0.001$), as can be seen in Table 2.

The mean values of protein and collagen parameters show initial increases in the P1L

sample compared to the P0L sample for samples taken from the subsurface region, followed by a successive decrease in the P3L and P5L samples. The samples taken from the center of the meat pieces show a decrease in the values for protein and collagen in the P1L samples (20.50 ± 0.07% and, respectively, 18.56 ± 0.15%) and P3L (19.84 ± 0.12% and, respectively, 18.15 ± 0.15%) compared to the control sample, with significant differences observed between them ($p < 0.05$). However, in the P5L sample, a decrease is no longer observed, but a maintenance of the values of these parameters identical to those present in the P3L sample. These results indicate a common trend, both in the superficial and central layers, of decreasing protein and collagen losses with increasing *Cetraria islandica* concentration, especially at the 5% concentration. However, the statistical differences between the internal and superficial areas were highly significant for protein and collagen parameters ($p < 0.001$) in most of the analyzed batches. A notable exception was batch P5L, where the mean collagen content values did not show significant differences between the two sampling regions ($p > 0.05$), suggesting a uniform distribution of collagen in the product at the maximum lichen concentration used.

The salt content of the samples shows an initial increase in the value for the subsurface region from 1.71 ± 0.03% in the control sample to 1.81 ± 0.11% in the sample with 1% lichen addition (P1L), the differences between them being significant ($p < 0.05$). In the samples with 3% (P3L) and 5% (P5L) addition within the same analyzed region, a constant decrease in salt content is observed with the increase in lichen content below the value of the control sample and inherently below the value of the P1L sample, obtaining values of 1.66 ± 0.05% (P3L) and 1.58 ± 0.07 (P5L), which show significant differences ($p < 0.05$) compared to the P1L and P0L samples. These values are correlated with the increase in moisture content in the samples with 3 and 5% lichen, which indicates a dilution of the salt content and also the ability of the lichen to reduce the salt content of the meat samples, results that are in accordance with those presented by Thakur et al., 2023 which demonstrate the ability of lichens to reduce salt in food, thus having beneficial effects on health by reducing the risk of hypertension. The salt content shows an even more pronounced decrease in the samples from the central region of the samples, with extremely significant differences ($p < 0.001$) in the case of the P1L sample and very significant ($p < 0.01$) in the case of the P5L sample. These differences mainly indicate a limitation of the penetration of the salt solution inside the samples caused by the viscosity of the solutions with the addition of lichen. However, the P3L sample does not show significant differences ($p > 0.05$) between the interior and subsurface regions.

The pH values were also highly significantly different between the two regions ($p < 0.001$), with lower values in the superficial layer. The pH values of the sample with the addition of 1% lichen (P1L) showed a slight increase in both the subsurface region (5.92 ± 0.017%) and the interior region (6.08 ± 0.02%) compared to that of the control sample P0L (5.90 ± 0.05%), with significant differences observed between it and the interior P1L sample ($p < 0.05$), but insignificant in the subsurface region of the same sample ($p > 0.05$). The P5L sample achieved the greatest reduction in pH value in the subsurface region, being 5.81 ± 0.03%, the differences between it and the other samples taken from the same region (subsurface) being significant ($p < 0.05$). The P3L sample for the same region recorded an intermediate value between P5L and P1L, of 5.89 ± 0.02%, which does not show significant differences compared to the P0L and P1L samples ($p > 0.05$), but only compared to the P5L sample ($p < 0.05$). The more pronounced decrease in pH caused by the increase in the *Cetraria islandica* content is most likely due to its 3-5% content of organic acids (usnic, protolichesterinic, protocetraric, and others) which have a biological and biochemical role, as shown by the research of Podterob (2008).

Regarding the pH of the samples from the central region, it recorded higher values than in the subsurface region, which indicates a weaker acidic character. The sample from the central region with the highest amount of lichen, P5L, presented the lowest pH value, of 5.93 ± 0.05% compared to the other samples taken from the same region, the differences between it and the

control sample (P0L) being not significant ($p > 0.05$). Regarding the statistical correlations with the P3L and P5L samples, the P1L and P0L samples present significant differences ($p < 0.05$). Also, the statistical differences between the 2 studied regions (subsurface*center) for all the analyzed samples present extremely significant differences ($p < 0.001$) between them (Table 2). Table 3 presents the values of the colorimetric parameters L*, a*, b*, hue (h°), chroma (C*) and the total color difference (ΔE) between the brown batch and the batches with the addition of 1%, 3% and 5% *Cetraria islandica*, determined both at ~0.3 cm from the surface of the samples (subsurface) and inside them. Small and large letters indicate statistically significant differences ($p < 0.05$) within each row, for the superficial area and the internal area, respectively.

Table 2. Chemical composition of the studied batches (mean ± SD; n = 10)

Studied chemical parameters		Batches			
		P0L	P1L	P3L	P5L
Fat	Subsurface	$6.78 \pm 0.37^{c,B}$	5.84 ± 0.15^{b}	5.75 ± 0.22^{b}	5.31 ± 0.28^{a}
	Center		6.51 ± 0.10^{B}	6.41 ± 0.47^{AB}	6.11 ± 0.25^{A}
Dry Matter	Subsurface	$29.19 \pm 0.26^{a,C}$	29.30 ± 0.00^{a}	29.19 ± 0.75^{a}	28.85 ± 0.26^{a}
	Center		28.56 ± 0.20^{B}	28.14 ± 0.45^{A}	27.99 ± 0.29^{A}
Humidity	Subsurface	$70.81 \pm 0.26^{a,A}$	70.70 ± 0.00^{a}	70.81 ± 0.75^{a}	71.16 ± 0.26^{a}
	Center		71.44 ± 0.20^{B}	71.86 ± 0.45^{C}	72.01 ± 0.29^{C}
Protein	Subsurface	$20,69 \pm 0.13^{a,C}$	21.26 ± 0.14^{b}	20.80 ± 0.40^{a}	20.76 ± 0.28^{a}
	Center		20.50 ± 0.07^{B}	19.84 ± 0.12^{A}	19.84 ± 0.12^{A}
Collagen	Subsurface	$18,89 \pm 0.11^{c,C}$	19.11 ± 0.14^{d}	18.52 ± 0.15^{b}	18.25 ± 0.22^{a}
	Center		18.56 ± 0.15^{B}	18.15 ± 0.15^{A}	18.15 ± 0.14^{A}
Salt	Subsurface	$1.71 \pm 0.03^{b,C}$	1.81 ± 0.11^{c}	1.66 ± 0.05^{ab}	1.58 ± 0.07^{a}
	Center		1.52 ± 0.10^{AB}	1.60 ± 0.00^{B}	1.45 ± 0.11^{A}
pH	Subsurface	$5.90 \pm 0.05^{b,A}$	5.92 ± 0.017^{b}	5.89 ± 0.02^{b}	5.81 ± 0.03^{a}
	Center		6.08 ± 0.02^{C}	5.98 ± 0.04^{B}	5.93 ± 0.05^{A}
Statistical significance (p-value) between Subsurface*Center	Fat	-	***	***	***
	Dry Matter	-	***	***	***
	Humidity	-	***	***	***
	Protein	-	***	***	***
	Collagen	-	***	***	ns
	Salt	-	***	ns	**
	pH	-	***	***	***

P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens.
Values within the same row followed by different lowercase letters (a, b, c, d) differ significantly ($p < 0.05$) for subsurface samples; Values followed by different uppercase letters (A, B, C, D, E) differ significantly ($p < 0.05$) for interior samples.
Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

The L* values in the subsurface area registered an initial decrease in the batch with 1% addition of *Cetraria islandica* (63.69 ± 0.67%) compared to the control batch (64.97 ± 0.89%), the differences between them are significant ($p < 0.05$). In batches P3L and P5L in the subsurface area, the mean values of L* increased progressively with the addition of lichen, indicating an intensification of the product's brightness, up to the maximum value of 73.73 ± 0.50%, observed in batch P5L. The differences between all batches analyzed for the colorimetric parameter L* analyzed in their subsurface region were significant ($p < 0.05$). The same trend was also observed in the interior region of the samples for this parameter (L*), except that within it and the P1L sample increased compared to the control sample. As with the samples from the subsurface region, the analyses performed in this region also showed significant differences between all the samples studied ($p < 0.05$). Also, the statistical differences between the analyzed regions showed highly significant differences for all the analyzed lots ($p < 0.001$).

The results for the colorimetric parameter L* can be correlated with the results for the average humidity of the analyzed samples (Table 2). The increase in the average humidity value is directly proportional to the increase in

the brightness values of the samples. Also, the P1L (subsurface area) sample is the only one that recorded an average humidity value lower than the control sample (Table 2), the same situation being identified in the case of the L* parameter (Table 3).

The colorimetric parameter a*, which indicates the intensity of the red-green colors (red for positive values and green for negative values) of the samples, decreased successively with the increase in the concentration of *Cetraria islandica*, both on the surface and inside, the decrease being more pronounced in the case of the samples analyzed from the Subsurface region. Lot P5L recorded the lowest average value (3.19 ± 0.43 within the subsurface region), which indicates a slight change in the specific color of the meat towards the color of the lichen. The more pronounced decreases of the a* parameter in the area closer to the outside of the samples show a limited penetration of the brine solution with lichens inside the meat samples due to its viscosity.

Regarding the statistical differences between the mean values of the samples from the subsurface region and the interior region, significant differences were recorded in the case of the P1L group ($p < 0.05$), insignificant in the case of the P3L group ($p > 0.05$) and extremely significant in the case of the P5L group ($p < 0.001$).

The colorimetric parameter b* increased significantly with the addition of lichen, from the minimum recorded in the P0L control sample (9.01 ± 0.37) to the maximum in the P5L batch (11.92 ± 0.42, subsurface region). This result suggests that *Cetraria islandica* induces a slight intensification of the yellow shade in the final color of the products. The interior area of the samples, where the lichen brine solution does not have a very good penetration, presents higher values of the b* parameter, which may indicate that it is not necessarily the addition of *Cetraria islandica* that leads to the increase of this parameter, but the increase in the humidity of the samples (Table 2) which, most likely, causes the decrease of hemin pigments. For this parameter, the statistical differences between the subsurface and the interior are very significant for the P1L and P3L samples ($p < 0.01$) and extremely significant in the case of the P5L sample ($p < 0.001$).

The hue angle (hº) followed a clear downward trend. This change is especially evident in the P5L group, which presents the lowest values (subsurface - 12.75º, interior - 26.67º). The high values of hue correspond to a visually less "yellow" and more "reddish" tone, which is not consistent with the decrease in the colorimetric parameter a* and may be caused by the presence of negative values in the data set for the a* parameter that caused the direct relationship between the hue angle values, calculated based on the calculation relationship, to no longer be easily correlated, as shown by McLellan et al. (1995). The lower values and in the case of some negative samples of the a* parameter and the positive values of the b* parameter suggest a shift of the chromatic vector in quadrant II of the a*-b* plane, specific to the Hunter Lab space (McLellan et al., 1995), which corresponds to a yellow-green dominance. The statistical differences between the P0L control sample and the samples with the addition of lichens were significant ($p < 0.05$). The statistical interaction between the two analyzed regions of the same sample presented extremely significant statistical differences only within the P5L group ($p < 0.001$), in the case of the other groups no significant differences were identified ($p > 0.05$).

The perceived color intensity, chroma (C*) showed reductions in its value in the lichen-added and subsurface groups, with the lowest level identified in the P5L group (12.34 ± 0.43). The statistical differences between the values in the subsurface group do not show statistical differences ($p > 0.05$) for the lichen-added groups. The statistical differences are found only between these groups and the control group, which are significant ($p < 0.05$). These results show that the addition of lichens influences the perceived color saturation of the samples. In contrast, the samples in the interior region with lichen addition show a very slight decrease in color saturation (C*) for the P1L and P3L samples, which does not represent a significant difference ($p > 0.05$). However, there are significant differences between the P5L sample and the P1L and P3L samples ($p <$

0.05), but insignificant compared to the P0L control sample ($p > 0.05$).

The visually perceived color difference (ΔE) was significantly different for all samples analyzed within the same region ($p < 0.05$) (Table 3), especially within sample P5L, where ΔE reached mean values of 11.85 ± 0.97 (subsurface) and 8.41 ± 1.08 (interior). These values indicate visual changes clearly perceptible to the naked eye, confirming that the addition of lichen strongly influences the visual appearance of the products that are the subject of this research. The differences between regions in the case of the same sample were highly significant in the case of sample P5L ($p < 0.001$), significant for sample P3L ($p < 0.05$) and insignificant in the case of sample P1L ($p > 0.05$). These results indicate a clear influence of *Cetraria islandica* on the appearance of the samples, especially at concentrations higher than 3%, and also, somewhat limited absorption of the brine solution with lichens to the center of the samples can be observed.

Table 3. Colour parameters of the studied batches (L, a*, b*, h°, C*, ΔE values; mean ± SD; n = 10)

Studied colour parameters		Batches			
		P0L	P1L	P3L	P5L
L*	Subsurface	$64.97 \pm 0.89^{b,A}$	63.69 ± 0.67^{a}	70.73 ± 0.59^{c}	73.73 ± 0.50^{d}
	Interior		67.33 ± 0.46^{B}	68.78 ± 0.53^{C}	71.19 ± 0.46^{D}
a*	Subsurface	$10.56 \pm 0.69^{c,C}$	6.87 ± 2.33^{b}	5.85 ± 0.20^{b}	3.19 ± 0.43^{a}
	Interior		8.38 ± 0.37^{B}	6.80 ± 0.43^{A}	6.40 ± 0.22^{A}
b*	Subsurface	$9.01 \pm 0.37^{a,A}$	10.06 ± 0.65^{b}	11.04 ± 0.25^{c}	11.92 ± 0.42^{d}
	Interior		10.70 ± 0.29^{B}	11.76 ± 0.26^{C}	12.75 ± 0.28^{D}
Hue (h°)	Subsurface	$49.49 \pm 2.37^{c,D}$	33.31 ± 11.15^{b}	27.91 ± 1.16^{b}	15.39 ± 2.18^{a}
	Interior		38.05 ± 1.77^{C}	30.04 ± 2.13^{B}	26.67 ± 0.89^{A}
Chroma (C*)	Subsurface	$13.89 \pm 0.53^{b,AB}$	12.34 ± 1.26^{a}	12.50 ± 0.20^{a}	12.34 ± 0.43^{a}
	Interior		13.60 ± 0.22^{A}	13.59 ± 0.05^{A}	14.27 ± 0.28^{B}
ΔE	Subsurface	-	4.40 ± 2.30^{a}	7.77 ± 0.88^{b}	11.85 ± 0.97^{c}
	Interior		3.72 ± 1.08^{A}	6.10 ± 1.04^{B}	8.41 ± 1.08^{C}
Statistical significance (p-value) between Subsurface*Inner	L*	-	***	***	***
	a*	-	*	ns	***
	b*	-	**	**	***
	Hue (H°)	-	ns	ns	***
	Chroma (C*)	-	***	***	***
	ΔE	-	ns	*	***

P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens.

Values within the same row followed by different lowercase letters (a, b, c, d) differ significantly ($p < 0.05$) for subsurface samples; Values followed by different uppercase letters (A, B, C, D, E) differ significantly ($p < 0.05$) for interior samples.

Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

The texture profile analysis (TPA) of the samples, presented in Table 4, highlights their mechanical properties and reveals the influence of *Cetraria islandica* compared to the control sample (without the addition of the lichen).

The textural parameters of pork legs were in most cases significantly affected by the addition of *Cetraria islandica* ($p < 0.05$), according to the results obtained (Table 4).

The Hardness parameter showed significant differences between all the analyzed samples ($p < 0.05$), its values registering more pronounced decreases concomitantly with the increase in the concentration of lichens added to the analyzed samples. The highest value for this parameter was identified in the case of the control sample P0L (21.56 ± 2.20 N), and the lowest in the P5L batch (8.87 ± 0.54 N). These results can be correlated with the higher moisture content of the samples with a higher concentration of lichens which determines a decrease in this parameter. Thus, we can deduce the obvious influence of lichens on the hardness of the samples. The influence of lichens is initially more evident between the P0L-P1L and P1L-P3L samples, showing decreases in the average value of over 5N, and between the P3L-P5L batches the decrease in the hardness of the samples is below 2N. This phenomenon can be attributed to a possible saturation of the meat matrix's capacity to integrate additional available water, suggesting

the existence of an efficiency threshold beyond which the additional addition of lichen no longer produces significant changes in hardness. The statistical differences between each of the samples with *Cetraria islandica* and the control sample are highly significant ($p < 0.001$).

Adhesiveness is the only textural parameter that recorded increases in average values with the increase in the amount of lichen added, which indicates a slight change in the surface interaction of the samples, but without a very perceptible impact from a subjective point of view, as we will see in the sensory analysis, but only in the case of subjective analysis. The control sample P0L and the sample with 1% lichen addition P1L did not identify significant differences ($p > 0.05$), and between P0L and samples P3L and P5L very significant differences ($p < 0.01$) and extremely significant differences ($p < 0.001$) were identified. As for the differences between samples with the addition of *Cetraria islandica*, they are statistically significant only between P1L and P5L ($p < 0.05$).

The elasticity, although it did not register drastic variations, nevertheless showed very significant differences between the control sample and the P3L and P5L samples ($p < 0.001$), showing a decreasing trend with the increase in the addition of lichen, the values decreasing from 0.43 ± 0.03 mJ in the control sample (POL) to 0.32 ± 0.05 mJ in the batch with 5% addition of *Cetraria islandica*. This decrease in elasticity caused by the vegetable addition affecting the protein networks (decrease in protein and collagen content, as can be seen in Table 2) of the samples determines a weaker return of the sample to its initial shape after deformation.

As for cohesiveness, it presents statistical significance only between the control sample and the samples with 3 and 5% addition of *Cetraria islandica*, as in the case of elasticity, the differences being very significant for the P3L sample ($p < 0.01$) and extremely significant for the P5L sample ($p < 0.001$). From these results we can deduce that the structural stability of the product is slightly affected at additions above 3% *Cetraria islandica* which slightly affects the protein content causing slight structural changes.

The gumminess and chewiness of the samples, on the other hand, are extremely significantly affected ($p < 0.001$) by the samples with the addition of *Cetraria islandica* (P1L, P3L and P5L) compared to the control sample (P0L). These, as was also identified for all other textural parameters except adhesiveness, recorded successive reductions in the average values concomitant with the increase in the *Cetraria islandica* content. The lowest values of these two parameters were identified within the batch with 5% addition of *Cetraria islandica*, being 4.72 ± 0.68 N for gumminess and 1.53 ± 0.42 J for chewiness. No significant differences were identified between the P5L and P3L samples in the case of chewiness ($p > 0.05$), but significant differences were identified between these two samples and the P1L sample ($p < 0.05$). In contrast, for the textural parameter gumminess, significant differences were identified between all 3 samples with the addition of *Cetraria islandica* ($p < 0.05$).

Following the analysis of the textural profile of the investigated products (Table 4), it was found that the addition of *Cetraria islandica* causes a significant reduction in most textural parameters, especially hardness and chewiness. These changes suggest an improvement in tenderness, leading to meat products with a softer consistency and easier chewing compared to the control sample (P0L). The effect is observed through reduced values of hardness and chewiness, which decrease with increasing concentration of added lichen. These results correlate positively with consumer research suggesting that tenderness is a very important element of edible quality and that variations in tenderness and chewiness affect the decision to consume and purchase meat (Maltin et al., 2003).

To our knowledge, no other research on the effect of *Cetraria Islandica* on the texture of meat products has been conducted so far.

Table 4. Instrumental texture profile analysis (TPA) of the samples (mean ± SD; n = 10)

Texture profile analysis parameters		Batches			
		P0L	P1L	P3L	P5L
Hardness (N)		21.56 ± 2.20^{d}	16.04 ± 1.02^{c}	10.60 ± 0.88^{b}	8.87 ± 0.54^{a}
Adhesiveness (mJ)		0.02 ± 0.03^{a}	0.03 ± 0.02^{ab}	0.05 ± 0.01^{bc}	0.07 ± 0.02^{c}
Elaticity		0.43 ± 0.03^{c}	0.40 ± 0.03^{bc}	0.35 ± 0.06^{ab}	0.32 ± 0.05^{a}
Cohesiveness		0.65 ± 0.05^{c}	0.62 ± 0.05^{bc}	0.57 ± 0.05^{ab}	0.53 ± 0.07^{a}
Gumminess (N)		14.09 ± 1.54^{d}	10.00 ± 1.10^{c}	6.06 ± 0.93^{b}	4.72 ± 0.68^{a}
Chewiness (J)		6.07 ± 0.87^{c}	3.96 ± 0.55^{b}	2.12 ± 0.58^{a}	1.53 ± 0.42^{a}
Statistical significance (p-value) between the control batch (P0L) and the other batches	Hardness (N)	-	***	***	***
	Adhesiveness (mJ)	-	ns	**	***
	Elaticity	-	ns	***	***
	Cohesiveness	-	ns	**	***
	Gumminess (N)	-	***	***	***
	Chewiness (J)	-	***	***	***

P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens.
Values within the same row followed by different lowercase letters (a, b, c, d) differ significantly ($p < 0.05$) for subsurface samples; Values followed by different uppercase letters (A, B, C, D, E) differ significantly ($p < 0.05$) for interior samples.
Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Existing studies focus mainly on the antioxidant and antimicrobial effects of this plant, omitting its other possible benefits.

The phytochemical composition and antioxidant capacity of pastrami samples with added *Cetraria islandica*, both thermally treated and untreated, are presented in Table 5 for both analyzed regions of the meat pieces (subsurface and center). The phytochemical and antioxidant characterization of *Cetraria islandica* is also presented in order to be able to follow the effect compared to the meat samples. It was found that the addition of lichens does not modify the flavonoid content of the studied samples in any of the analyzed regions, the differences observed being insignificant ($p > 0.05$). The content of phenolic compounds in the interior of the samples presents the same results regarding statistical differences as the content of phenolic compounds. However, in the subsurface region, statistical differences were observed between the control samples and the samples with the addition of lichens, the differences being significant ($p < 0.05$), but between the batches that presented the addition of 1, 3 and 5% *Cetraria islandica*, slight increases in the average values were recorded concomitantly with the increase in the addition of lichens in the samples, especially in the heat-treated samples, but the differences were statistically insignificant ($p > 0.05$). Also, the Tukey test did not register significant differences between the treated and non-heat-treated samples in terms of the content of flavonoids and polyphenols ($p > 0.05$).

In contrast, the antioxidant capacity of the products evaluated by the DPPH and ABTS methods presented very differentiated results between the average results of the samples depending on the concentration of *Cetraria islandica* added and depending on the heat treatment, as can be seen in Table 5. In the case of the DPPH analysis, a successive increase in antioxidant activity was observed concomitant with the increase in the concentration of lichens added both in terms of the amount of µMol Trolox/g DW and, inherently, the inhibition of DPPH oxidation. In the subsurface region, the DPPH value (µMol Trolox/g DW) increased from 0.60 ± 0.43 µMol Trolox/g DW in the non-thermally treated samples to 7.50 ± 0.31 µMol Trolox/g DW in the samples with 5% *Cetraria islandica* addition and in the thermally treated samples from 0.70 ± 0.06 µMol Trolox/g DW to 7.72 ± 0.32 µMol Trolox/g DW. The inhibition of DPPH oxidation (%) showed increases from the P0L control sample value of 1.52 ± 0.70% to 13.65 ± 0.55% in the non-thermally treated samples and from 1.98 ± 0.12% to 16.14 ± 0.65% in the thermally treated samples. In the inner region, the increase in antioxidant activity determined by the DPPH method was observed, but the values were not as high. The values of the control samples in the centeral region were identical to those of the subsurface region, but in this case the average values increased only to

4.73 ± 0.25 µMol Trolox/g DW in the non-thermally treated samples and to 5.82 ± 0.33 µMol Trolox/g DW in the thermally treated samples. Also, the DPPH inhibition was lower in the central region of the samples, with a maximum of 8.52 ± 0.43% in the non-thermally treated samples and 11.94 ± 0.65% in the thermally treated samples.

Table 5. Antioxidant capacity and phytochemical compound content in compact-structured meat products with added *Cetraria islandica* (mean ± SD)

Studied antioxidant characteristics			Batches							
		Cetraria islandica	P0L		P1L		P3L		P5L	
			NT	TT	NT	TT	NT	TT	NT	TT
Total flavonoids (mg CE/g DW)	Subsurface	0.14 ± 0.01^{b}	0.001 ± 0.00^{a}	0.001 ± 0.00^{a}	0.004 ± 0.00^{a}	0.005 ± 0.00^{a}	0.005 ± 0.00^{a}	0.006 ± 0.00^{a}	0.005 ± 0.00^{a}	0.007 ± 0.00^{a}
Total polyphenols (mg AG/g DW)		0.07 ± 0.00^{c}	0.001 ± 0.00^{a}	0.002 ± 0.00^{a}	0.005 ± 0.00^{ab}	0.008 ± 0.00^{ab}	0.006 ± 0.00^{ab}	0.009 ± 0.00^{b}	0.006 ± 0.00^{ab}	0.010 ± 0.00^{b}
DPPH (µMol Trolox/g DW)		4.19 ± 0.01^{c}	0.60 ± 0.43^{a}	0.70 ± 0.06^{a}	1.84 ± 0.07^{b}	4.49 ± 0.71^{c}	4.09 ± 0.59^{c}	5.71 ± 0.15^{d}	7.50 ± 0.31^{e}	7.72 ± 0.32^{e}
DPPH (% Inhibition)		29.89 ± 0.07^{g}	1.52 ± 0.70^{a}	1.98 ± 0.12^{a}	3.62 ± 0.12^{b}	9.76 ± 1.46^{d}	7.58 ± 1.01^{c}	12.21 ± 0.31^{e}	13.65 ± 0.55^{e}	16.14 ± 0.65^{f}
ABTS (mMol Trolox/g DW)		258.56 ± 4.05^{c}	65.09 ± 2.69^{a}	199.08 ± 3.18^{b}	489.22 ± 4.65^{d}	905.20 ± 5.75^{g}	578.36 ± 7.14^{e}	1354.73 ± 6.25^{h}	659.54 ± 3.15^{f}	1605.41 ± 4.39^{i}
ABTS (% Inhibition)		38.41 ± 0.51^{f}	8.38 ± 0.10^{a}	12.94 ± 0.12^{b}	20.40 ± 0.14^{c}	39.25 ± 0.21^{g}	23.64 ± 0.22^{d}	55.79 ± 0.23^{h}	26.46 ± 0.10^{e}	64.38 ± 0.16^{i}
Total flavonoids (mg CE/g DW)	Center	0.14 ± 0.01^{b}	0.001 ± 0.00^{a}	0.001 ± 0.00^{a}	0.001 ± 0.00^{a}	0.004 ± 0.00^{a}	0.004 ± 0.00^{a}	0.005 ± 0.00^{a}	0.004 ± 0.00^{a}	0.005 ± 0.00^{a}
Total polyphenols (mg AG/g DW)		0.07 ± 0.00^{b}	0.001 ± 0.00^{a}	0.002 ± 0.00^{a}	0.003 ± 0.00^{a}	0.003 ± 0.00^{a}	0.004 ± 0.00^{a}	0.005 ± 0.00^{a}	0.004 ± 0.00^{a}	0.006 ± 0.00^{a}
DPPH (µMol Trolox/g DW)		4.19 ± 0.01^{d}	0.60 ± 0.43^{a}	0.70 ± 0.06^{ab}	1.40 ± 0.24^{b}	3.36 ± 0.33^{c}	3.29 ± 0.61^{c}	4.28 ± 0.48^{d}	4.73 ± 0.25^{d}	5.82 ± 0.33^{e}
DPPH (% Inhibition)		29.89 ± 0.07^{g}	1.52 ± 0.70^{a}	1.98 ± 0.12^{ab}	2.87 ± 0.39^{b}	7.27 ± 0.65^{cd}	6.03 ± 1.01^{c}	8.98 ± 0.95^{e}	8.52 ± 0.43^{de}	11.94 ± 0.65^{f}
ABTS (mMol Trolox/g DW)		258.56 ± 4.05^{d}	65.09 ± 2.69^{a}	199.08 ± 3.18^{c}	167.21 ± 8.56^{b}	715.20 ± 5.77^{g}	309.58 ± 2.02^{e}	885.65 ± 5.15^{h}	381.44 ± 4.13^{f}	956.29 ± 3.32^{i}
ABTS (% Inhibition)		38.41 ± 0.51^{h}	8.38 ± 0.10^{a}	12.94 ± 0.12^{c}	10.57 ± 0.26^{b}	31.52 ± 0.21^{f}	14.92 ± 0.06^{d}	37.22 ± 0.18^{g}	17.23 ± 0.13^{e}	39.56 ± 0.12^{i}
Statistical significance (p-value) between Thermal treatment within the same region (subsurfaceor interior)	Total flavonoids	Subsurface	-	-	ns		ns		ns	
		Center			ns		ns		ns	
	Total polyphenols	Subsurface			ns		ns		ns	
		Center			ns		ns		ns	
	DPPH	Subsurface			***		***		ns	
		Center			***		**		**	
	DPPH (%Inhibition)	Subsurface			***		***		***	
		Center			***		***		***	
	ABTS	Subsurface			***		***		***	
		Center			***		***		***	
	ABTS (%Inhibition)	Subsurface			***		***		***	
		Center			***		***		***	

Nt – not-thermally treated; TT – thermally treated

P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens.

Values within the same row followed by different lowercase letters (a, b, c, d) differ significantly ($p < 0.05$) for subsurface samples; Values followed by different uppercase letters (A, B, C, D, E) differ significantly ($p < 0.05$) for interior samples.

Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Statistically, the differences in DPPH antioxidant capacity in terms of the amount of µMol Trolox/g DW depending on the presence or absence of heat treatment were highly significant ($p < 0.001$) for samples with 1% addition of *Cetraria islandica* in both regions and in the region with 3% addition in the subsurface region, and in the interior region for the same concentration very significant differences were observed ($p < 0.01$), as in the case of the same region at the concentration of 5% addition of lichens. In contrast, at this concentration, but in the subsurface region, insignificant differences were observed between the treated and untreated samples ($p > 0.05$).

Results with the same trends as DPPH were also observed in the case of ABTS analysis, except that the latter recorded higher average values of antioxidant capacity, demonstrating its greater compatibility with the food matrix used (meat), also having a wider applicability than the DPPH method which allows the identification of a more developed spectrum of

compounds with antioxidant action. The antioxidant activity values evaluated by the ABTS method in the subsurface region, recorded within the experimental batches maximum values in the batches with 5% addition of lichens of 1605.41 ± 4.39 mMol Trolox/g DW and inhibition of 64.38 ± 0.16% in the heat-treated batch, which even exceeds the antioxidant capacity of *Cetraria islandica* which shows an inhibition of only 38.41 ± 0.51%. Also, the batches with 1 and 3% addition of heat-treated *Cetraria islandica* show a higher oxidation inhibition capacity than *Cetraria islandica* of 39.25 ± 0.21% and, respectively, 55.79 ± 0.23% and an activity of 905.20 ± 5.75 mMol Trolox/g DW and, respectively, 1354.73 ± 6.25 mMol Trolox/ g DW.

The non-thermally treated samples, on the other hand, present an ABTS antioxidant activity lower on average by approximately 520 mMol Trolox/g DW and an inhibition lower by approximately 28% compared to the thermally treated samples, being obtained for the samples with 1, 3 and 5% addition of *Cetraria islandica* the average antioxidant activity value of 489.22 ± 4.65 mMol Trolox/g DW, 578.36 ± 7.14 mMol Trolox/g DW and, respectively, 659.54 ± 3.15 mMol Trolox/g DW, with an inhibitory capacity of 20.40 ± 0.14%, 23.64 ± 0.22% and, respectively, 26.46 ± 0.10%, values which, in contrast to the thermally treated batches, do not exceed the inhibitory capacity of *Cetraria islandica* but only that of the control batches. (untreated and heat-treated), which obtained antioxidant activity values of 65.09 ± 2.69 mMol Trolox/g DW in the non-heat-treated batch and 199.08 ± 3.18 mMol Trolox/g DW in the heat-treated batch, corresponding to inhibitions of 8.38 ± 0.10% and, respectively, 12.94 ± 0.12%.

All batches analyzed in the case of ABTS analysis (antioxidant activity and oxidation inhibition) showed significant differences between them ($p < 0.05$) both in the subsurface region and in the central region. In the center of the meat pieces, the ABTS analysis values, as also happened in the case of DPPH analysis, were much lower than those in the subsurface region, also demonstrating the limited absorption of the *Cetraria islandica* brine solution due to its viscosity which is higher than a regular brine. The maximum values in this case were also obtained in the batch with 5% addition of *Cetraria islandica*, but which, in this case, were much lower, registering an antioxidant activity of 956.29 ± 3.32 mMol Trolox/g DW in the heat-treated batch and 381.44 ± 4.13 mMol Trolox/g DW in the non-heat-treated batch and an oxidation inhibition capacity of 39.56 ± 0.12% and 17.23 ± 0.13%, respectively.

The batches with 1 and 3% addition of *Cetraria islandica* recorded slightly lower values compared to the batch containing this addition in a percentage of 5%, the minimum (in a batch with *Cetraria islandica*) was observed in batch P1L, which presented an antioxidant activity of 715.20 ± 5.77 mMol Trolox/g DW in the heat-treated batch and of 167.21 ± 8.56 mMol Trolox/g DW in the non-heat-treated batch and an oxidation inhibition capacity of 31.52 ± 0.21% and, respectively, 10.57 ± 0.26%. The results obtained show that the addition of *Cetraria Islandica* also presents an antioxidant effect inside the meat pieces, but not as strong as in the subsurface region.

However, the results of the P5L batch (central region) show an oxidation inhibition capacity that is superior to *Cetraria islandica* and the P3L batch (interior) has a very similar inhibition value. Regarding the statistical differences between the heat-treated and untreated samples within the same region, highly significant statistical differences ($p < 0.001$) are observed between all the batches studied.

The results obtained show that the bioactive compounds in lichens are thermally stable, not being susceptible to thermal degradation under the specific treatments for the production of meat products with a compact structure (which do not fall into the category of raw-dried products). Thermal treatment even helps to release and activate compounds with antioxidant functions from the vegetable addition, probably by breaking the bonds between them and the structural components. Our results are consistent with those reported by Gülçin et al. (2002), highlighting that *Cetraria islandica* has antioxidant activity and potential for use in the food industry. In the present study, it was demonstrated that this lichen can be successfully applied in the meat

industry, due to its resistance to the temperatures specific to the thermal treatments used in meat processing.

Similar results were reported by Krotova et al. (2023), who added a 1% vegetable extract of milk thistle and Icelandic moss to the composition of minced meat semi-finished products, referred to as "Special cutlets". As in our study, they observed an improvement in the antioxidant value of the products without negatively affecting their sensory properties. For batch P1L, with the addition of 1% *Cetraria islandica*, we also obtained similar results in the sensory analysis, the studied characteristics not being negatively affected by the vegetable addition, as we can see in Table 6 and Figure 1. However, the batches with the addition of 3 and 5% lichen suffered sensory changes that led to their low acceptability among consumers.

Table 6. Sensory characteristics of the experimental pastrami batches with *Cetraria islandica* addition (Mean ± SD; n = 12)

Sensory attributes	Samples				*p*-value
	P0L	P1L	P3L	P5L	
Colour uniformity	8.08 ± 0.90	7.83 ± 0.84	7.33 ± 0.99	6.75 ± 1.29	0.013 (*)
General aspect	8.58 ± 0.52	7.83 ± 0.94	6.92 ± 0.67	6.83 ± 0.94	0.000 (***)
Specific smell of meat	8.67 ± 0.65	8.42 ± 0.79	8.17 ± 0.84	7.67 ± 0.89	0.025 (*)
Smoky odor	7.50 ± 0.80	7.42 ± 1.17	7.25 ± 1.14	7.33 ± 1.07	0.945 (ns)
Plant odors	1.08 ± 0.29	1.33 ± 0.65	1.67 ± 0.65	2.33 ± 0.78	0.000 (***)
Foreign odors for meat products	1.17 ± 0.39	1.42 ± 0.67	1.67 ± 0.78	2.00 ± 1.04	0.060 (ns)
Meat odour intensity	5.75 ± 0.75	5.33 ± 0.89	4.75 ± 0.75	4.25 ± 1.06	0.001 (***)
Unpleasant odor	1.00 ± 0.00	1.00 ± 0.00	1.17 ± 0.39	1.25 ± 0.45	0.113 (ns)
Global odour perception	8.25 ± 0.62	8.00 ± 0.95	7.75 ± 0.97	7.17 ± 1.03	0.035 (*)
Specific meat product taste	8.92 ± 0.29	8.50 ± 0.80	7.92 ± 0.80	6.67 ± 0.49	0.000 (***)
Salty taste	5.50 ± 0.67	5.08 ± 0.67	4.75 ± 0.62	4.17 ± 0.72	0.000 (***)
Smoky taste	5.00 ± 0.74	4.58 ± 0.52	4.25 ± 0.62	3.67 ± 0.78	0.000 (***)
Bitter taste	1.08 ± 0.29	1.17 ± 0.39	1.58 ± 0.52	2.08 ± 0.52	0.000 (***)
Taste persistence	6.58 ± 0.79	6.75 ± 0.75	6.83 ± 0.72	6.50 ± 0.80	0.703 (ns)
Taste balance	7.75 ± 0.87	6.92 ± 0.79	5.75 ± 0.87	5.00 ± 0.74	0.000 (***)
Tender	5.75 ± 0.62	5.83 ± 0.72	6.08 ± 0.67	6.25 ± 0.62	0.239 (ns)
Juiciness	5.67 ± 0.78	5.75 ± 0.62	6.00 ± 0.60	6.08 ± 0.67	0.381 (ns)
Grany texture	1.42 ± 0.67	1.75 ± 1.06	2.25 ± 1.14	2.42 ± 1.00	0.062 (ns)
Firmness	5.25 ± 0.87	4.92 ± 1.00	4.58 ± 0.79	4.50 ± 0.80	0.148 (ns)
Overall product acceptability	8.33 ± 0.65	7.75 ± 0.62	7.33 ± 0.99	6.50 ± 0.80	0.000 (***)

P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens.
Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 6 presents the sensory characteristics evaluated by tasters during the sensory analysis of pastrami batches with the addition of *Cetraria islandica*. The products were affected by this addition especially in terms of sensory characteristics related to the appearance, smell and taste of the samples.

The appearance of the samples, characterized by the characteristics of colour uniformity and general aspect, showed significant differences ($p < 0.05$) and, respectively, highly significant ($p < 0.001$) between the analyzed samples, registering lower average scores in batches P3L and P5L compared to batches P0L (without addition of lichens) and P1L (the batch with the lowest concentration of lichens). These results are most likely caused by the color changes that are quite evident in the batches with 3 and 5% addition of lichens, as highlighted by the instrumental color analyses in Table 3 and the non-uniform dispersion of lichen in the product mass.

From the olfactory side of the sensory analysis, the appearance of plant odour was observed, which caused very significant differences between the samples ($p < 0.001$), which also caused a decrease in meat odour intensity and specific meat product taste, with extremely significant differences between the samples analyzed ($p < 0.001$). However, these changes in odour were not considered unpleasant, since the Unpleasant odour attribute did not present statistical differences between the samples studied ($p > 0.05$).

The taste was most strongly affected by the addition of lichens, leading to a decrease in the specific taste of meat, salt and smoke and to an increase in bitter taste, with extremely significant differences between samples ($p < 0.001$). The taste balance of the products was also greatly affected by the vegetable addition, higher concentrations of the addition leading to a significant decrease in it. Most likely, the bitter taste induced by the addition of lichens contributed to a decrease in perceived balance and overall hedonic response, reflected in our study by the parameter "Overall product acceptability". This attribute showed an extremely significant reduction in scores ($p < 0.001$), particularly in the samples with higher lichen concentrations (P3L and P5L, 3% and 5%, respectively).

The parameters referring to the texture of the samples were not significantly affected by the addition of lichens, presenting insignificant differences between batches ($p > 0.05$). However, a positive trend of improving the tenderness and juiciness of the products by increasing the addition of *Cetraria islandica* is observed, which confirms the results obtained by us in the objective analysis of the texture (Table 4).

Figure 1 shows the PrefMap (preference map) that graphically shows where the four pastrami samples analyzed in this study (P0L, P1L, P3L and P5L) are located. As we can see, the samples P0L and P1L are located approximately in the same color area of the graph, which denotes a similar preference for them.

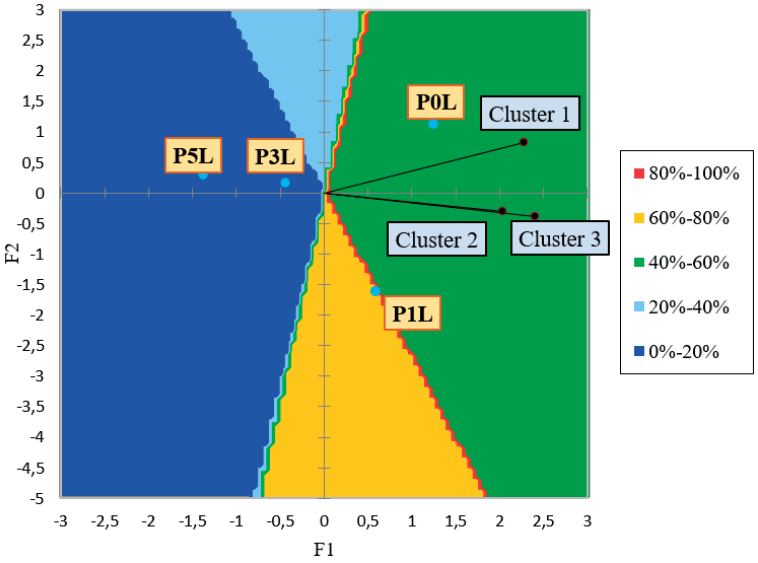

Figure 1. PrefMap for sensory profile and assessor preferances for the experimental batches
P0L - control pork leg (no added lichens); P1L - pork leg with 1% added lichens; P3L - pork leg with 3% added lichens; P5L - pork leg with 5% added lichens; Clusters indicate groups of consumers with similar preferences towards the analyzed samples

Also, the three clusters of tasters are located only in this part of the graph, being close to each other, which shows that the preferences of all participants in the sensory analysis were aligned with each other, which indicates a common preference. As we can observe in Figure 1, the samples with the highest addition of *Cetraria islandica*, P3L and P5L are located on the left of the graph, in the dark blue area, which denotes a low preference for these products, below 20%, which correlates with the hedonic score. Overall product acceptability present in table 6 and shows that, among tasters, products with 3 and 5% addition of lichens have a low acceptability. The sample with 1% addition of lichens, on the other hand, enjoys good acceptability among consumers, being located between the red and yellow areas, which indicates an acceptability of approximately 80% among tasters.

The green area of the graph, as we can see, is not identical to the one in the legend, which indicates that it is an overlap of two colors in the graph (most likely red and green), meaning that it belongs to an intermediate preference, but not in a certain score of a color in the legend. This shows that the tasters' preferences for the samples located in this area were not identical, but not in contradiction either, there being no polarization of the product scores, since they were, however, coherent.

CONCLUSIONS

The physicochemical results show that the addition of lichens leads to a better water retention capacity in the samples and an increase in their tenderness. A reduction in fat and salt content was also observed, which corresponds to current consumer requirements.

The evaluation of the antioxidant capacity of experimental meat samples enriched with *Cetraria islandica* suggests that this lichen can be successfully used in compact meat products to enhance their phytochemical profile. Notably, the antioxidant activity of these products is further increased by the application of heat treatment, which is essential for producing market-ready formulations. Our results use this lichen as a functional ingredient in innovative meat products, because it possesses a nutritional value created compared to a conventional one, high antioxidant properties and good potential for prolonging the oxidative stability of meat products such as pastrami.

Unfortunately, homogeneous penetration to the center of the pieces is not possible due to the high viscosity of the solution containing *Cetraria islandica*, which limits diffusion into the meat mass. This unequal distribution affects the product's functional and qualitative homogeneity by determining notable differences in the physicochemical and phytochemical parameters between the core and peripheral regions. The uniform penetration of the lichen solution into the meat mass may be enhanced by the use of micronized powders or sophisticated injection technologies, which would help produce products with consistent functional qualities.

In contrast, consumers do not particularly prefer products with higher additions of lichens, 3 and 5%, due to the modified characteristics that distance them from the control batch and, inherently, from the classic meat products found on the market, this fact slightly affecting the sensory acceptability of the products.

Our results highlight the need to identify an optimal balance between the functionality and acceptability of new products, in order to develop products that meet both the nutritional and sensory requirements of consumers.

All the results obtained in our study show that *Cetraria islandica* could be successfully utilized in the food industry in terms of improving the physical and biochemical quality of meat products with compact structure. Higher inclusion levels, however, have a detrimental effect on the products sensory quality, as demonstrated by our research. Nonetheless, moderate levels are well accepted by consumers and contribute to an overall improvement in both the sensory quality and antioxidant potential of the final products.

REFERENCES

Anchidin, B.G., Gucianu, I., Lipșa, F.D., Ciobanu, M.M., Flocea, E.I., & Boișteanu, P.C. (2024b). From waste to valuable food: development and qualitative differential characterization of bone broths from juvenile and adult cattle. *Scientific Papers. Series D. Animal Science*, *67*(1), 355-365.

Anchidin, B.G., Lipșa, F.D., Manoliu, D.R., Ciobanu, M.M., Ciobotaru, M.C., Gucianu, I., & Boișteanu, P.C. (2024a). Enhancing antioxidant capacity in functional meat products through infusion with sea buckthorn oil to combat inherent antioxidant deficiency. *Scientific Papers. Series D. Animal Science*, *67*(1), 366-380.

Anchidin, B.G., Manoliu, D.R., Ciobotaru, M.C., Ciobanu, M.M., Gucianu, I., Sandu, G.A., & Boișteanu, P.C. (2023). Development of a functional meat product with sea buckthorn oil and analysis of its sensory and physicochemical quality. *Scientific Papers. Series D. Animal Science, 66*(1), 370-376.

Antropova, G.A., Zheznyakovskaya, L.F., Egorova, E.S., Okonenko, T.I., & Proshina, L.G. (2021). Possibilities of using biologically active substances of Iceland moss. In *IOP Conference Series: Earth and Environmental Science, 852*(1), 012008.

Bao, H.Y., & Bau, T. (2013). Advance in studies on chemical constituents and pharmacological activity of lichens in *Usnea* genus. *Zhongguo Zhong yao za zhi= Zhongguo Zhongyao Zazhi= China. Journal of Chinese Materia Medica*, *38*(4), 539-545.

Bis-Souza, C.V., Barba, F.J., Lorenzo, J.M., Penna, A.B., & Barretto, A.C.S. (2019). New strategies for the development of innovative fermented meat products: a review regarding the incorporation of probiotics and dietary fibers. *Food Reviews International*, *35*(5), 467-484.

Boișteanu, P.C., Anchidin, B.G., & Ciobanu, M.M. (2025). Exploring Sensory Attributes in Spinach-and Offals-Filled Chicken Roulades: An Empirical Analysis. *Foods*, *14*(2), 303.

Boișteanu, P.C., Manoliu, D.R., & Ciobanu, M.M. (2023). The effect of red lentil flour on the quality characteristics of beef burgers obtained from two different anatomical regions. *Scientific Papers. Series D. Animal Science*, *66*(1), 385-390.

Calcott, M.J., Ackerley, D.F., Knight, A., Keyzers, R.A., & Owen, J.G. (2018). Secondary metabolism in the lichen symbiosis. *Chemical Society Reviews*, *47*(5), 1730-1760.

Ciobanu, M.M., Flocea, E.I., & Boișteanu, P.C. (2024). The Impact of Artificial and Natural Additives in Meat Products on Neurocognitive Food Perception: A Narrative Review. *Foods*, *13*(23), 3908.

Ciobanu, M.M., Manoliu, D.R., Ciobotaru, M.C., Flocea, E.I., & Boișteanu, P.C. (2025). Dietary Fibres in Processed Meat: A Review on Nutritional Enhancement, Technological Effects, Sensory Implications and Consumer Perception. *Foods*, *14*(9), 1459.

Ciobanu, M.M., Manoliu, D.R., Ciobotaru, M.C., Flocea, E.I., Anchidin, B.G., Postolache, A.N., & Boișteanu, P.C. (2023). Sensorial characterization of mutton products in membrane made in the meat processing. *Scientific Papers. Series D. Animal Science*, *66*(2), 453-458.

Ciobotaru, M.C., Manoliu, D.R., Matei, M., Calcan, R.A., Boișteanu, P.C., & Ciobanu, M.M. (2024b). Qualitative differences caused by the addition of liquid smoke in meat products with different structures compared to traditional smoking. *Scientific Papers. Series D. Animal Science*, *67*(1), 404-413.

Ciobotaru, M.C., Manoliu, D.R., Matei, M., Gheorghe, B.A., Boișteanu, P.C., & Ciobanu, M.M. (2024a). The impact of bone broth addition on the sensory acceptability of assorted meat products with heterogeneous structure. *Scientific Papers. Series D. Animal Science*, *67*(1), 414-419.

Dumitrașcu, L., Lanciu, A., & Aprodu, I. (2022). A preliminary study on using ultrasounds for the valorization of spent brewer's yeast. *The Annals of the University Dunarea de Jos of Galati. Fascicle VI-Food Technology*, *46*(2), 141-153.

Fernández-Ginés, J.M., Fernández-López, J., Sayas-Barberá, E., & Pérez-Alvarez, J.A. (2005). Meat products as functional foods: A review. *Journal of food science*, *70*(2), R37-R43.

Flocea, E.I., Ciobanu, M.M., Anchidin, B.G., Ciobotaru, M.C., Manoliu, D.R., Gucianu, I., & Boișteanu, P.C. (2024). Evaluation Of The Impact Of Artificial Additive On Physicochemical Quality Parameters In A Functional Meat Product With Heterogeneous Structure. *Scientific Papers. Series D. Animal Science*, *67*(1).

Gülçin, İ., Oktay, M., Küfrevioğlu, Ö.İ., & Aslan, A. (2002). Determination of antioxidant activity of lichen Cetraria islandica (L) Ach. *Journal of ethnopharmacology*, *79*(3), 325-329.

Huang, X., Ma, J., Wei, L., Song, J., Li, C., Yang, H., & Bi, H. (2018). An antioxidant α-glucan from Cladina rangiferina (L.) Nyl. and its protective effect on alveolar epithelial cells from Pb^{2+}-induced oxidative damage. *International journal of biological macromolecules*, *112*, 101-109.

Ianiţchi, D., Poşan, P., Maloş, I.G., Nistor, L., Maftei, M.L., Nicolae, C.G., & Hodoşan, C. (2024). Effects Of Meat Consumption On Consumers'health. Scientific Papers. *Series D. Animal Science*, *67*(1), 465-480.

Krotova, O., Mashtykov, S., Konieva, O., Gordeeva, N., & Pavlenko, T. (2023). The use of natural polysaccharides in the production of functional meat products. In *E3S Web of Conferences*, *Vol. 413*, p. 01013. EDP Sciences.

Kumar, S.U.N.I.L., Bhat, Z.F., Kumar, P.A.V.A.N., & Mandal, P.K. (2013). Functional meat and meat products. *Animal products technology*. New Delhi, India: Studium Press, 404-455.

Maltin, C., Balcerzak, D., Tilley, R., & Delday, M. (2003). Determinants of meat quality: tenderness. *Proceedings of the Nutrition Society*, *62*(2), 337-347.

Manoliu, D.R., Ciobanu, M.M., Ciobotaru, M.C., Anchidin, B.G., & Boișteanu, P.C. (2024). The Impact Of Fruit Fiber On Meat Products: A Mini Review. *Scientific Papers. Series D. Animal Science*, *67*(1), 481-489.

Manoliu, D.R., Ciobanu, M.M., Ciobotaru, M.C., Postolache, A.N., Anchidin, B.G., & Boișteanu, P.C. (2023). Physico-chemical and sensory evaluation of three types of pork mortadella manufactured in the IULS meat processing microsection. *Scientific Papers. Series D. Animal Science*, *66*(2), 527-531.

McLellan, M.R., Lind, L.R., & Kime, R.W. (1995). Hue angle determinations and statistical analysis for multiquadrant Hunter L, a, b data. *Journal of food quality*, *18*(3), 235-240.

Mironeasa, S., & Ungureanu-Iuga, M. (2024). Plants, Lichens, Fungi and Algae Ingredients for Nutrition and Health. *Applied Sciences*, *14*(7), 2800.

Olafsdottir, E.S., & Ingólfsdottir, K. (2001). Polysaccharides from lichens: structural characteristics and biological activity. *Planta medica*, *67*(03), 199-208.

Patriche, S., Ghinea, I.O., Adam, G., Gurau, G., Furdui, B., Dinica, R.M., & Lupoae, M. (2019). Characterization of bioactive compounds from Romanian Cetraria islandica (L). *Revista de Chimie*, *70*, 2186-2191.

Pires, M.A., Munekata, P.E., Villanueva, N.D., Tonin, F.G., Baldin, J.C., Rocha, Y.J., & Trindade, M.A. (2017). The antioxidant capacity of rosemary and green tea extracts to replace the carcinogenic antioxidant (BHA) in chicken burgers. *Journal of Food Quality*, *2017*(1), 2409527.

Podterob, A.P. (2008). Chemical composition of lichens and their medical applications. *Pharmaceutical Chemistry Journal*, *42*(10), 582-588.

Pogurschi, E.N., Munteanu, M., Nicolae, C.G., Marin, M.P., & Zugravu, C.A. (2018). Rural-urban differences in meat consumption in Romania. *Scientific Papers Series D, Animal Science*, *61*(2), 111-115.

Ruiz-Capillas, C., & Herrero, A.M. (2021). Novel strategies for the development of healthier meat and meat products and determination of their quality characteristics. *Foods*, *10*(11), 2578.

Salueña, B.H., Gamasa, C.S., Rubial, J.M.D., & Odriozola, C.A. (2019). CIELAB color paths during meat shelf life. *Meat science*, *157*, 107889.

Sharma, M., & Mohammad, A. (2020). Lichens and lichenology: Historical and economic prospects. *Lichen-Derived Products: Extraction and Applications*. Massachusetts, USA: Scrivener Publishing LLC, 101-118.

Siegrist, M., & Sütterlin, B. (2017). Importance of perceived naturalness for acceptance of food additives and cultured meat. *Appetite*, *113*, 320-326.

Thakur, M., Kasi, I.K., Islary, P., & Bhatti, S.K. (2023). Nutritional and health-promoting effects of lichens used in food applications. *Current Nutrition Reports*, *12*(4), 555-566.

Trifunschi, S., Munteanu, M. F., Pogurschi, E., & Gligor, R. (2017). Characterisation of Polyphenolic Compounds in Viscum album L. and Allium sativum L. extracts. *Revista de Chimie*, *68*, 1677-1680.

Ullah, S., Khalil, A.A., Shaukat, F., & Song, Y. (2019). Sources, extraction and biomedical properties of polysaccharides. *Foods*, *8*(8), 304.

Wei, S.T., Ou, L.C., Luo, M.R., & Hutchings, J.B. (2012). Optimisation of food expectations using product colour and appearance. *Food Quality and Preference*, *23*(1), 49-62.

Yusuf, M. (2020). A review on trends and opportunity in edible lichens. *Lichen-Derived Products: Extraction and Applications*. Massachusetts, USA: Scrivener Publishing LLC, 189-201.

Zugravu, C.A., Pogurschi, E.N., Pătrașcu, D., Iacob, P.D., & Nicolae, C.G. (2017). Attitudes towards food additives: A pilot study. *Annals of the "Dunarea de Jos" University of Galati. Fascicle VI-Food Technology*, *41*(1), 50-61.