Journal of Engineering Science *Vol. XXXIII, no. 1 (2026), pp. 165 - 182*
Fascicle *Food Engineering* *ISSN 2587-3474*
Topic *Food Technologies and Food Processes* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2026.33(1).11
UDC 664.9:635.94:543

EVALUATION OF THE IMPACT OF SEA BUCKTHORN POMACE ADDITION ON THE PHYSICOCHEMICAL AND QUALITY PROPERTIES OF MEAT SNACK PRODUCTS

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Received: 02. 14. 2026
Accepted: 03. 25. 2026

Abstract. The utilization of fruit-processing by-products is a practical approach to develop sustainable, value-added meat snacks. Sea buckthorn pomace, rich in colored and acidic compounds, is expected to influence dehydration behavior, appearance and storage stability of deshydrated meat products. The study was designed to investigate how different inclusion levels of sea buckthorn pomace powder (SBPP) - 0.75%, 1.25%, and 2.5% (*w/w*) - influence the quality and safety attributes of fermented and dehydrated meat snack products. The samples underwent fermentation at 25 ± 1 °C for a period of 12 hours, followed by dehydration at 50 ± 5 °C for 6 hours. Subsequent analyses comprised the assessment of key physicochemical parameters (moisture content, pH, and water activity), instrumental color measurement using the CIELab system, sensory profiling, determination of lipid oxidation through peroxide value, and evaluation of microbiological indicators. Increasing SBPP level decreased moisture (15.79% to 7.93%), water activity (0.455 c.u. to 0.358 c.u.) and pH (6.16 to 5.65), indicating enhanced shelf-stability. Color shifted toward a darker red-orange profile (L* 47.85 to 20.64; a* up to 27.09). Peroxide value remained low and unchanged (1.60 to 1.70 mEq O_2/kg). Coliforms, moulds/yeasts and *Salmonella* were not detected. SBPP is therefore a clean-label ingredient enabling differentiated ripening-dehydrated meat snacks while supporting circular valorization of processing residues.

Keywords: *antioxidant activity; bioactive compounds; carotenoids; food sustainability; sensory Quality.*

Rezumat. Valorificarea produselor secundare rezultate din procesarea fructelor reprezintă o abordare practică pentru dezvoltarea unor gustări din carne sustenabile, cu valoare adăugată. Tescovina de cătină, bogată în compuși bioactivi și acizi organici, influențează asupra procesului la deshidratare, aspectul și stabilitatea la depozitare a produselor din carne deshidratată. Prezentul studiu a avut ca scop studierea impactului pulberii de tescovină de cătină (PTC) (0.75; 1.25 și 2.5%, m/m) asupra calității și siguranței gustărilor din carne deshidratate. Probele au fost maturate la 25 ± 1 °C timp de 12 ore și ulterior deshidratate la 50 ± 5 °C timp de 6 ore, fiind apoi supuse analizelor fizico-chimice (umiditate, pH, activitatea apei), determinării culorii prin sistemul CIELab, caracteristicilor senzoriale, indicelui de peroxid și indicatorilor microbiologici. Creșterea concentrației de PTC a determinat diminuarea conținutului de umiditate (de la 15.79% până la 7.93%), a activității apei (de la 0.455 u.c. până la 0.358 u.c.) și a pH-ului (de la 6.16 la 5.65), indicând o îmbunătățire a stabilității la depozitare. Culoarea s-a modificat către un profil roșu-portocaliu mai închis (L* de la 47.85 la 20.64; a* până la 27.09). Indicele de peroxid a rămas scăzut și nemodificat semnificativ (1.60–1.70 mEq O_2/kg). Coliformii, mucegaiurile/drojdiile și Salmonella nu au fost detectate.
Prin urmare, SBPP poate fi considerat un ingredient de tip *clean label*, care permite obținerea unor produse din carne maturate și deshidratate variate, susținând în același timp valorificarea circulară a reziduurilor provenite din procesare.

Cuvinte-cheie: *activitate antioxidantă; compuși bioactivi; carotenoizi; sustenabilitate alimentară; acceptabilitate senzorială.*

1. Introduction

In recent decades, the food industry has experienced a marked shift toward the development of functional products that combine nutritional value with beneficial effects on consumer health. These products rely on the use of natural ingredients rich in bioactive compounds, capable of providing antioxidants, dietary fiber, and phytonutrients with protective roles [1, 2]. At the same time, the growing emphasis on sustainability and food waste reduction has driven increased research efforts focused on the valorization of by-products generated from fruit and vegetable processing [3].

Sea buckthorn (*Hippophae rhamnoides* L.) is one of the most valuable fruit species from both nutritional and functional perspectives, due to its high content of vitamins (particularly C and E), carotenoids (β-carotene, zeaxanthin, lutein), polyphenols, and unsaturated fatty acids [4-6]. These compounds contribute to the high antioxidant activity as well as to the anti-inflammatory and antimicrobial properties of the product [7]. Fruit processing for the manufacture of juice, oil, or purée results in the generation of substantial quantities of sea buckthorn pomace, a solid residue abundant in bioactive constituents and dietary fiber, yet still insufficiently exploited at the industrial scale [8].

The reutilization of this pomace in the form of sea buckthorn pomace powder (SBPP) provides a sustainable solution, contributing to the circular economy and the development of food products with enhanced functional value [9]. Moreover, the natural pigment compounds, particularly carotenoids, impart an intense yellow-reddish coloration, which can positively influence the visual appearance and sensory acceptability of the products [10].

In recent years, the incorporation of plant-derived by-products into meat formulations has attracted growing attention as an effective approach to enhance their nutritional and technological value. Previous studies have demonstrated that the use of antioxidant- and

fiber-rich plant powders, including those obtained from sour cherries, cranberries, currants, and sea buckthorn, may limit lipid oxidation, improve mineral composition, and contribute to greater product stability [11–13]. At the same time, these additions can alter color indices and sensory profiles due to their phenolic and carotenoid composition [14].

2. Materials and Methods

2.1. Raw Material

The sea buckthorn pomace, obtained by direct pressing of the juice from *Hippophae rhamnoides* L. fruits, variety Clara and Mara, harvested in 2024, was provided by the local producer BUKKER S.R.L. (Orhei, Republic of Moldova) and subsequently used in the research. Refrigerated, boneless, and skinless chicken meat was supplied by the company AXEDUM S.R.L. (Republic of Moldova). Commercially available salt, sugar, black and white pepper powders, as well as garlic powder, were used as seasoning and auxiliary materials. The starter culture *SafePro EasyCure LC*, produced by CHR HANSEN, was obtained from INGREDA S.R.L. (Chișinău, Republic of Moldova).

2.2. Chemicals

Commercially available reagents were used throughout the investigation. Chemapol (Prague, Czech Republic) provided sodium hydroxide, methanol, ethyl acetate, petroleum ether, and ethanol. From Sigma-Aldrich (Schnelldorf, Germany), the following reagents were employed: n-hexane (>95%), hydrogen peroxide (30% and 35%), hydrochloric acid (38%), potassium bicarbonate (97%), nitric acid (ACS reagent, 70%), perchloric acid (ACS reagent, 70%), deionized water, ninhydrin, sulfuric acid (96-98%), 2,6-dichloroindophenol, sodium thiosulfate, and sodium bicarbonate. Trolox (purity ≥97%) and Folin-Ciocalteu phenol reagent (2.1 N) were obtained from Chem-Lab NV (Zedelgem, Belgium). ABTS and DPPH radicals were purchased from Alpha Aesar (Haverhill, MA, USA). The microbiological media, namely buffered peptone water, potato dextrose agar with chloramphenicol, and plate count agar, were supplied by Altmann Analytik GmbH & Co. KG – Analytics-Shop (Munich, Germany).

2.3. Production of SBPP

Drying of sea buckthorn pomace was performed by forced convection in a laboratory drying oven (SLW 115 SMART, Pol-Eco Aparatura, Wodzisław Śląski, Poland) at 53 ± 2 °C with an air velocity of 1.5 ± 0.1 m/s until a residual moisture content of ⩽9% was achieved. Thereafter, the seeds were separated, and the seed-free pomace fraction was finely milled with a PULVERISETTE 11 grinder (Fritsch GmbH, Idar-Oberstein, Germany), yielding powder with a particle size of 70 ± 10 μm. The final material was sieved through a CLM-200 stainless steel laboratory sieve, vacuum packed, and stored in the absence of light under dry conditions at 20 ± 2 °C.

2.4. SBPP Characterization

2.4.1. Physicochemical Analysis

The physicochemical characteristics of SBPP, including moisture content (MC), ash content (AC), titratable acidity (TA), and pH, were assessed using the corresponding ISO standard methods [15-17]. Protein (PC) and fat (FC) contents were quantified according to AOAC procedures (2012). The aw values were recorded with a LabSwift-aw analyzer (Novasina AG, Lachen, Switzerland).

2.4.2. Analysis of *L*-ascorbic acid content

The *L-ascorbic* acid content (AAC) in SBPP was determined using a potentiometric titration procedure based on ISO 6557-2 [18], with minor adjustments. The dried pomace sample was first ground to ensure homogeneity. An accurately weighed amount was then treated with 2% hydrochloric acid to protect ascorbic acid from oxidation, and the obtained extract was subsequently filtered. Potentiometric titration was performed with standard 2,6-dichlorophenolindophenol solution under constant agitation. A platinum electrode served as the indicator electrode, while a silver/silver chloride electrode was used as the reference. The endpoint was identified from the sudden shift in redox potential measured by the potentiometer. Each determination was carried out at least in triplicate. The AAC values were calculated according to the consumed titrant volume, its concentration, the mass of the analyzed sample, and the corresponding conversion factors, and were expressed as mg/100 g dry matter (mg/100 g DM).

2.4.3. Analysis of Antioxidant Activity

The antioxidant activity of SBPP was evaluated in hydroalcoholic extracts prepared by ultrasound-assisted extraction (UAE) [19-21]. For extraction, 0.5 g of sample was combined with 25 mL of 73% ethanol and kept under static conditions for 24 h at 20 ± 2 °C in the absence of light. The mixture was then subjected to ultrasonic treatment in an ultrasonic bath (ISOLAB 621.06.006, Eschau, Germany) at 30 ± 1 °C for 25 min and 37 kHz. After extraction, the samples were centrifuged (MPW-380R, Warsaw, Poland) at 8,000 rpm for 10 min at room temperature, filtered, and stored at 4 ± 1 °C until analysis. These extraction conditions were selected based on previously published studies [22-26]. The Trolox-equivalent antioxidant activity was first assessed using the DPPH radical scavenging assay, following the procedure reported by Paulpriya et al. [20]. The results were expressed as mg TE/100 g DM using a Trolox calibration curve constructed in the concentration range of 0-500 μmol/L (R^2 = 0.9992).

ABTS radical cation scavenging activity was also determined in terms of Trolox-equivalent antioxidant capacity using the method of Arnao et al. [27], slightly modified for the present study. The working ABTS•+ solution was prepared from 7 mM ABTS and 2.45 mM potassium persulfate and allowed to stand in darkness for 16 h. Prior to measurement, the solution was diluted with ethanol until an absorbance of 0.70 ± 0.02 at 734 nm was reached. For the assay, 100 μL of extract or Trolox standard was added to 2.4 mL of ABTS reagent. After incubation for 6 min at 30 °C, absorbance was recorded. Antioxidant activity was reported as mg TE/100 g DM based on the corresponding calibration curve (0-500 μmol/L, R^2 = 0.9992).

Total polyphenol content (TPC) was determined by the Folin–Ciocalteu assay according to the methods reported by Paulpriya et al. and Waterman et al. [26, 28], with minor adjustments for the present study. For the analysis, 20 μL of the extract was allowed to react with Folin–Ciocalteu reagent in the presence of 10% Na_2CO_3. After incubation at 40 ± 1 °C for 30 min, the absorbance response was used to calculate the polyphenol content. The final values were reported as mg GAE/100 g DM based on a gallic acid calibration curve prepared within the concentration interval of 0-500 mg/L (R^2 = 0.9980).

The determination of total carotenoid content (TCC) was carried out following a method based on the protocol proposed by Ghendov-Mosanu et al. [29]. According to the

absorption spectrum obtained, quantification was performed at 450 nm, which represented the absorbance maximum.

2.5. Meat Snacks Preparation

To investigate the impact of SBPP on product quality, meat snack samples were produced with SBPP added at concentrations of 0.75, 1.25, and 2.5%. These formulations were designated as S1, S2, and S3, respectively. SBPP was incorporated directly into the minced meat mixture. A control formulation lacking SBPP (CS) was also prepared to enable comparative evaluation.

Chicken breast, chicken thigh, salt, sugar, black and white pepper powders, garlic powder, and the starter culture *SafePro EasyCure LC* (CHR HANSEN) were used in the production of meat snacks. The composition of the formulated samples is given in Table 1.

Table 1

Composition of experimental meat snack samples per 100 kg of unsalted raw material

Ingredients	CS	S1	S2	S3
Chicken breast, kg	70	69.475	69.125	68.25
Chicken thigh, kg	30	29.775	29.625	29.25
SBPP, kg		0.750	1.250	2.500
Salt, g	1800	1800	1800	1800
Sugar, g	800	800	800	800
Black pepper powder, g	100	100	100	100
White pepper powder, g	100	100	100	100
Garlic powder, g	200	200	200	200
Fermentation starter culture *SafePro EasyCure LC, g*	25	25	25	25

CS - control sample; S1- sample with 0.75% of SBPP; S2 - sample with 1.25% of SBPP; S3 - sample with 2.5% of SBPP, SBPP - sea buckthorn pomace powder.

After grinding, homogenization and stuffing into casings, the meat mixture was subjected to a controlled fermentation (maturation) stage. Fermentation was carried out in a laboratory drying oven at 25 ± 1 ^{0}C, with a relative humidity of 85–90% and with airflow set at 1.5 m/s over a 12 h period. During this period, the pH of the product decreased from 5.8–6.0 to 5.2–5.4, indicating adequate acidification.

Following fermentation, pre-drying and compaction were performed under the same temperature and airflow conditions to stabilize the product structure. Subsequently, the samples were subjected to shock freezing at -35 ^{0}C for 6 h to ensure uniform slicing.

Dehydration was conducted in an AIM AGHD-15ELC heat pump dehydrator (Nantou, Zhongshan, Guangdong) at 50 ± 5 ^{0}C for 6 h. The finished meat snacks were packaged and stored for subsequent physicochemical, microbiological and sensory analyses.

2.6. Meat Snacks Quality Analysis

2.6.1. Sensory Analysis

The sensory properties of the developed meat snack samples were assessed by five trained panelists according to ISO 6658:2017. A five-level scoring system was applied for each evaluated attribute: score 5 reflected the absence of deviations from the predefined sensory profile, score 4 indicated slight changes, score 3 represented clearly perceptible

deviations, score 2 denoted marked deviations, and score 1 corresponded to very marked deviations. The final acceptability of each sample was calculated from the panel evaluation results as the arithmetic mean of the mean scores recorded for all sensory descriptors [30].

2.6.2. Color Analysis

Color characteristics of the meat snack samples were instrumentally assessed using a Chroma Meter CR-400 (Konica Minolta, Japan) [31]. Sample color was described in the CIELab system by recording lightness (L*), the red–green coordinate (a*), and the yellow–blue coordinate (b*). The overall color difference (ΔE) between the enriched samples and the control was calculated according to Equation (1):

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}, \quad (1)$$

where:

$\Delta L^* = L^*_{ES} - L^*_{CS}, \Delta a^* = a^*_{ES} - a^*_{CS}, \Delta b^* = b^*_{ES} - b^*_{CS},$

$L^*_{ES}, a^*_{ES}, b^*_{ES}$ – the CIELab color coordinates of the experimental samples containing SBPP,

$L^*_{CS}, a^*_{CS}, b^*_{CS}$ – the corresponding coordinates of the control sample.

The browning index (BI), used as an indicator of brown color development, was determined using Equation (2):

$$BI = 588.235\left(\frac{a^*+1.75*L^*}{5.645*L^*+a^*-3.012*b^*} - 0.31\right), \quad (2)$$

Color saturation was characterized by chroma (C*), which reflects color intensity and was calculated as follows:

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2}, \quad (3)$$

The hue angle (h, °), describing the dominant chromatic tone on a 0–360° scale, where 0° corresponds to bluish-red, 90° to yellow, 180° to green, and 270° to blue, was calculated according to Equation (4):

$$h^* = atan2(b^*, a^*), \quad (4)$$

2.6.3. Psysicochemical Analysis

The physicochemical characteristics of the meat snack samples were assessed by standard analytical procedures. MC was determined gravimetrically [32] in an SLW 115 SMART laboratory oven (Pol-Eco Aparatura, Wodzisław Śląski, Poland) at 103 ± 2 °C until no further mass change was observed. AC was measured according to ISO 936:1998 [33]. FC was determined by Soxhlet extraction [34] of the dehydrated material with organic solvents. PC was analyzed by the Kjeldahl method [35], based on nitrogen conversion, ammonia distillation, titration, and subsequent recalculation into protein content. pH measurement was performed at 20 °C using a digital pH meter (Mettler Toledo, Columbus, OH, USA). All measurements were performed in triplicate [36].

2.6.4. Analysis of Peroxide Value

Primary oxidation of the lipid fraction during storage was monitored through peroxide value (PV) determination [37]. For the analysis, the fat extracted from the sample was introduced into a reaction system containing distilled water, starch solution, chloroform, acetic acid, and potassium iodide, after which the liberated iodine was titrated with 0.01 mol/dm³ sodium thiosulfate. The PV, expressed as mEq O2/kg, was calculated using Equation (5):

$$PV = \frac{(V-V_1)K*0{,}00127}{m} * 100, \quad (5)$$

where:

V – the volume of sodium thiosulfate solution consumed in the main titration, cm^3;

V_1 – the corresponding volume used for the blank sample, cm^3;

K – the correction factor for the actual concentration of the sodium thiosulfate solution;

0.00127 – corresponds to the amount of substance equivalent to 1 cm^3 of 0.01 mol/dm^3 $Na_2S_2O_3$;

m – the mass of the extracted fat subjected to analysis, g.

2.6.5. Water Activity Determination

The aw values of the samples were recorded with a LabSwift-aw analyzer (Novasina AG, Lachen, Switzerland) using a rapid measurement approach [38]. This technique is intended for the assessment of free water present in the product matrix.

2.6.7. Microbiological Analysis

Microbiological quality evaluation of meat snacks included the enumeration of mesophilic aerobic and facultative anaerobic microorganisms (QMAFAnM), as well as yeasts and moulds, using ISO-based standard methods [39-42]. To prepare the initial suspension, 10 g of sample was aseptically mixed with 90 mL of sterile 0.1% buffered peptone water and homogenized for 2 min, yielding a 10^{-1} dilution [43]. Further decimal dilutions up to 10^{-3} were then prepared. All analyses were performed in triplicate, and 1 mL portions of the appropriate dilutions were plated onto the required culture media by either the pour plate or spread plate method, depending on the target group of microorganisms.

Enumeration of yeasts and moulds was performed on potato dextrose agar containing 2% chloramphenicol after incubation at 25 °C for 7 days. QMAFAnM was determined on plate count agar (casein-peptone glucose yeast extract agar) following incubation at 37 °C for 48 h [43]. After colony development, representative isolates were examined microscopically. Colonies with characteristic morphology were purified and subjected to routine assessment of cultural and morphological traits for tentative yeast identification, while bacterial cultures were additionally evaluated by Gram staining. Microbial counts were reported as CFU/g and expressed in $\log_{10}$ CFU/g. The calculations considered the colony number, plated dilution, and inoculated volume. The practical limit of detection under these conditions was close to 10 CFU/g, equivalent to approximately 1.0 $\log_{10}$ CFU/g [39-42]. Compliance of the obtained microbiological values was judged according to the applicable sanitary and regulatory criteria [43].

3. Results and discussion

3.1. Physicochemical Characterization of SBPP

The physicochemical profile of SBPP used as a functional ingredient in the meat snack formulations is summarized in Table 2. The MC of fruit pomace is largely affected by the drying conditions, including both the processing regime and the initial water content of the raw material. Under the drying conditions applied in the present study, the MC of SBPP reached 7.05%.

Similar MC values have been documented in the literature. In one study, researchers [24] reported an MC of 7.84% for apple pomace, whereas another investigation involving pomace powders in marshmallow-like confectionery systems recorded a value of 8.0% [44]. The proximity of these results to those obtained in the present work supports the consistency of our data and highlights the potential of dried SBPP for use in food formulations.

Table 2

Physicochemical characteristics of SBPP

Indicators	Value
MC, %	7.05 ± 0.28
AC, %	3.15 ± 0.16
TA, % expressed in malic acid	2.81 ± 0.01
pH	3.49 ± 0.01
PC, %	19.92 ± 0.15
FC, g/100 g DM	30.07 ± 0.15
a_w, c.u.	0.228 ± 0.003

MC – moisture content; AC – ash content; TA – titratable acidity; FC – fat content; PC – protein content; a_w – water activity. Results are presented as mean ± standard deviation.

The analyzed SBPP showed a TA of 2.81%, expressed as malic acid equivalent, and a pH of 3.49. The TA and pH values of sea buckthorn matrices vary significantly depending on the cultivar, ripening stage, and processing conditions. For example, a study on fresh sea buckthorn fruits reported an average pH ranging from 2.7 to 2.9 and TA between 2.0% and 3.7%, expressed as malic acid [45]. Another study on sea buckthorn pomace reported a pH of 3.53 and a TA of 4.48% for the pomace [46].

These values indicate a pronounced acidic character of the plant matrix, typical of fruits with a high content of organic acids, such as sea buckthorn (*Hippophae rhamnoides* L.). These properties can influence both the microbiological stability of the products in which it is incorporated and the final sensory profile.

The SBPP showed a high PC (19.92%) and FC (30.07%). In another study [47], a PC of 21.09 g/100 g DM was reported for sea buckthorn pomace, a value considered relatively high compared to other fruit pomaces, according to the data presented by [47]. This highlights the potential to explore techniques through which plant protein from sea buckthorn pomace could partially replace animal-derived protein.

The AC of the analyzed pomace (3.15%) falls within the range reported in the literature, where values can vary significantly depending on the cultivar, structural characteristics, processing conditions, and the origin of the raw material. Studies have shown that AC in pomace can range from 3.7% to 9.2% [48-50], while lower values of 2.02% or 2.09% have been reported in other studies, depending on the grape variety and processing method [49].

Water activity (a_w) is a key factor for sea buckthorn (*Hippophaë rhamnoides* L.) powder, affecting microbial stability, shelf life, and bioactive compound preservation. The powder shows very low a_w values (0.228 c.u.), well below 0.6 c.u. and comparable to or lower than other fruit powders, effectively inhibiting microbial growth and maintaining phenolic content and antioxidant activity during storage [51].

3.2. Bioactive Compounds and Antioxidant Capacity of SBPP

Table 3 summarizes the levels of major bioactive compounds and antioxidant-related parameters determined in SBPP, highlighting its potential technological and functional relevance.

SBPP contains measurable amounts of antioxidant-related bioactive compounds, including L-ascorbic acid (22.98 mg/100 g DM), carotenoids (96.4 mg/100 g DM), and total polyphenols (10.94 mg GAE/100 g DM). Its antioxidant activity, evaluated by the DPPH and

ABTS assays, reached 3.36 and 3.57 mg TE/100 g DM, respectively, indicating a moderate radical-scavenging capacity.

Table 3

Bioactive compounds and antioxidant-related parameters of SBPP

Indicators	Value
AAC, mg/100g DM	22.98 ± 0.03
TCC, mg/100g DM	96.41 ± 0.88
TPC, mg GAE/100 g DM	10.94 ± 0.16
Antioxidant activity:	
• DPPH, mg TE/100 g DM	3.36 ± 0.07
• ABTS, mg TE/100 g DM	3.57 ± 0.07

AAC – *L*-ascorbic acid content, TCC – total carotenoid content; TPC – total polyphenol content; ABTS – 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonates); DPPH – 2,2-diphenyl-1-picrylhydrazyl-hydrate; GAE – gallic acid equivalent; TE – Trolox equivalent; DM – dry matter. Results are presented as mean ± standard deviation.

Taken together, these results support the functional value of SBPP and are in line with published data on sea buckthorn powders and extracts, in which carotenoids, phenolic compounds, and related antioxidants are considered important contributors to oxidative protection [19, 52-57].

3.3. Sensory Analysis of Meat Snacks

The analyzed product, presented in the form of rings, exhibited a uniform and well-defined external appearance, free of surface defects or composition flow marks, indicating appropriate processing conditions. The color varied from light pink to deep orange, attributed to the incorporation of SBPP, with a homogeneous distribution of particles throughout the matrix and without visible voids or grayish areas. The aroma was characteristic of sea buckthorn–based products, displaying a pleasant, natural, and slightly spicy scent, with no foreign or off-notes detected. The taste was delicate and typical of sea buckthorn, pleasant and mildly spicy, without the presence of any undesirable flavors (Figure 2).

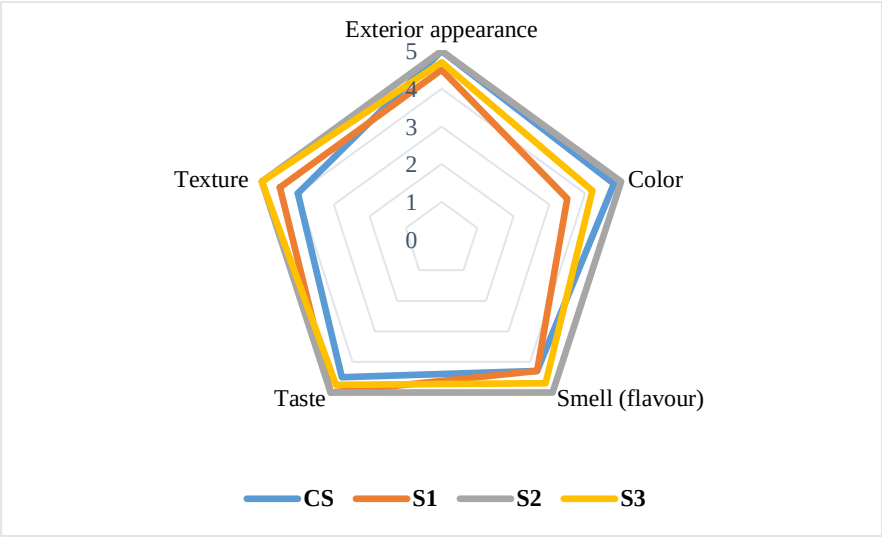

Figure 2. Sensory characteristics for the evaluation of meat snack samples: CS - control sample; S1- sample with 0.75% of SBPP; S2 - sample with 1.25 % of SBPP; S3 - sample with 2.5% of SBPP.

Compared to conventional meat snacks, the rings formulated with SBPP demonstrated a distinct sensory profile, characteristic of a functional and innovative product emphasizing natural ingredients such as sea buckthorn. While typical meat snacks exhibit a darker reddish-brown coloration, mainly resulting from the meat matrix and the maturation process, the analyzed samples presented lighter and more varied hues (pink to orange), attributed to the presence of plant-derived pigments. The aroma of the SBPP-enriched product was fresh, fruity, and more subtle than that of conventional counterparts. The taste of the analyzed rings was pleasant, delicate, and well-balanced. The texture was compact, smooth, and homogeneous, indicating a uniform structure suitable for development as an alternative or functional food product.

3.4. Color Analysis

The color parameters (CIELab) of meat snacks and SBPP was presented in Table 4.

Table 4

Color parameters (CIELab) of meat snacks and SBPP

CIELab Color Parameter	SBPP	Meat snack sample			
		CS	S1	S2	S3
L*	69.71 ± 0.71	47.85 ± 0.19	42.82 ± 0.15	48.10 ± 0.19	20.64 ± 0.12
a*	17.46 ± 0.54	19.65 ± 0.26	20.94 ± 0.9	22.02 ± 0.27	27.09 ± 0.49
b*	65.69 ± 0.41	32.42 ± 0.37	39.08 ± 0.46	38.61± 0.35	24.67 ± 0.13
ΔE	-	-	8.42 ± 0.40	5.41 ±0.41	31.21 ± 0.07
BI	202.56 ± 3.22	134.21 ± 1.91	206.73 ± 2.26	170.07 ± 2.19	354.21 ± 3.14
C*	62.97 ± 0.01	37.91 ± 0.05	44.34 ± 0.03	44.45 ±0.05	36.64 ± 0.04
h,°	75.12 ± 0.01	58.78 ± 0.01	61.82 ± 0.01	60.30 ± 0.01	42.32 ± 0.01
					

SBPP - sea buckthorn pomace powder; CS - control sample; S1- sample with 0.75% of SBPP; S2 - sample with 1.25 % of SBPP; S3 - sample with 2.5% of SBPP, L* - luminosity; a* - red/green component; b*- yellow/blue component; ΔE - total color difference; BI - browning index; C* - chroma; h°- hue angle. Results are presented as mean ± standard deviation.

SBPP is characterized by a bright color with intense yellow-reddish tones, as indicated by high a* values (17.46), reflecting a rich content of carotenoids such as β-carotene and zeaxanthin. These pigments are responsible for both the pronounced visual appearance and the antioxidant potential of the product [58-60]. Colorimetric analysis using CIELab parameters confirms that increasing SBPP concentration in meat snacks leads to a significant decrease in L*, from 47.85 in the control to 20.64 at 2.5% SBPP, indicating a darker, more intense coloration. This is consistent with findings that carotenoids absorb light in the blue region, contributing to red-orange hues [58-60].

The a* increases with SBPP concentration, confirming a shift toward red tones, while b* decreases, indicating reduced yellow intensity and a transition to darker red-orange shades. Such chromatic shifts are typical for carotenoid accumulation, especially β-carotene and zeaxanthin, as documented in sea buckthorn pomace and pulp [69-71]. The ΔE rises

substantially at higher SBPP levels, reflecting major visual changes, while the BI and C* also vary, with BI increasing due to pigment oxidation or Maillard reactions [61, 62].

These results align with studies showing that sea buckthorn by-products are rich in carotenoids, and their incorporation into foods significantly alters color parameters, enhances antioxidant activity, and increases visual appeal [58-60, 63, 64]

3.5 Psysicochemical Analysis of Meat Snacks

Table 5 summarizes the physicochemical characteristics of the meat snack samples supplemented with SBPP.

Table 5

Physicochemical characteristics of meat snacks

Indicators	Meat snack samples			
	CS	S1	S2	S3
MC, %	15.79 ± 0.39	8.94 ± 0.51	8.55 ± 0.77	7.93 ± 0.49
AC, %	8.36 ± 0.29	8.96 ± 0.17	9.0 ± 0.43	9.09 ± 0.11
FC, %	12.96 ± 0.76	14.13 ± 0.15	14.85 ± 0.60	15.52 ± 0.38
PC, %	59.16 ± 0.01	58.31 ± 0.04	60.95 ± 0.02	61.75 ± 0.02
pH	6.16 ± 0.03	5.88 ± 0.01	5.81 ± 0.06	5.65 ± 0.01
a_w	0.455 ± 0.002	0.370 ± 0.001	0.362 ± 0.001	0.358 ± 0.002
PV, mEq O2/kg	1.65 ± 0.01	1.60 ± 0.01	1.65 ± 0.02	1.70 ± 0.02

MC - moisture content; AC - ash content; FC - fat content; PC - protein content; a_w - water activity; PV - peroxid value. Results are presented as mean ± standard deviation.

A clear decreasing trend in MC was observed with the gradual increase of SBPP concentration, from 15.79% in the CS to 7.93% in the S3 formulation. This reduction in moisture is attributed to the high fiber content of sea buckthorn pomace, which enhances water binding and retention during processing, facilitating moisture loss during drying [47]. Similar moisture-decreasing effects have been reported in meat systems fortified with fruit pomace or dietary fibers, as these ingredients increase water-holding capacity and promote dehydration [65, 66].

Consistent with the decrease in MC, water activity (a_w) also dropped from 0.455 in CS to 0.358 in the S3 sample. Lower aw values indicate improved microbiological stability and shelf-life, as water activity below 0.6 generally inhibits most microbial growth [66]. Therefore, SBPP addition not only alters texture and color but also contributes to product safety and preservation.

The AC showed a slight but consistent increase with higher SBPP inclusion, from 8.36% in CS to 9.09% in the S3 sample, reflecting the high mineral composition of SBPP, which is rich in potassium, calcium, magnesium, and iron [65].

The FC also increased gradually (12.96% →15.52%), likely due to the contribution of residual lipids present in the pomace, including valuable unsaturated fatty acids such as oleic, linoleic, and palmitoleic acids [65].

The PC remained relatively stable across samples, ranging between 58.3% and 61.8%. The slight increase in the S3 sample may be explained by the concentration effect due to reduced moisture, as well as potential protein contribution from the pomace matrix [65].

The pH values decreased significantly from 6.16 in CS to 5.65 in the S3 sample, suggesting a mild acidifying effect associated with organic acids naturally present in sea

buckthorn (citric, malic, and quinic acids) [67, 68]. This acidification may improve the sensory profile and microbiological safety of the product.

The PV, an indicator of primary lipid oxidation, remained relatively stable across all samples (1.60–1.70 mEq O2/kg), indicating that SBPP addition did not accelerate oxidative degradation. The high concentration of natural antioxidants such as tocopherols and carotenoids in SBPP may help maintain lipid stability during processing and storage [5, 68-70, 85-87].

3.6. Microbiological Analysis of Meat Snacks

Microbiological quality indicators of meat snacks enriched with SBPP are presented in the Table 6.

Table 6

Microbiological quality indicators of meat snacks

Microbiological indicators	Meat snack samples			
	CS	**S1**	**S2**	**S3**
Minced mixture for meat snacks				
QMAFAnM, $\log_{10}$ CFU/g	5.20 ± 0.08	5.10 ± 0.06	5.05 ± 0.07	4.95 ± 0.05
Yeasts and moulds, $\log_{10}$ CFU/g	<1.0	<1.0	<1.0	<1.0
Coliform bacteria in 0,0001 g	Were not found	Were not found	Were not found	Were not found
Pathogenic microorganisms, including *Salmonella*	Were not found	Were not found	Were not found	Were not found
Meat snacks				
QMAFAnM, $\log_{10}$ CFU/g	3.80 ± 0.10	3.20 ± 0.09	3.00 ± 0.08	2.70 ± 0.07
Yeasts and moulds, $\log_{10}$ CFU/g	<1.0	<1.0	<1.0	<1.0
Coliform bacteria in 0,0001 g	Were not found	Were not found	Were not found	Were not found
Pathogenic microorganisms, including *Salmonella*	Were not found	Were not found	Were not found	Were not found

Note. QMAFAnM – quantity of mesophilic aerobic and facultative anaerobic microorganisms; CFU – colony-forming unit. Results are presented as mean ± standard deviation.

The minced mixtures demonstrated moderate background levels of QMAFAnM (≈5.0 $\log_{10}$ CFU/g), which is consistent with the expected microbiological load of chilled poultry raw material and processing under hygienic conditions. Importantly, the obtained total counts remained well below the regulatory maximum for minced meat (⩽5×10^6 CFU/g) established by the Uniform sanitary and epidemiological and hygienic requirements approved by Decision of the Customs Union Commission No. 299 (28 May 2010) [43]. This confirms the adequate microbiological quality of the initial raw material and indicates that the preparation procedures did not introduce significant contamination during chopping, mixing, and stuffing.

At the same time, it must be emphasized that the formulation included a starter culture (*SafePro EasyCure LC*) added at 25 g per batch. Therefore, the QMAFAnM values in minced mixtures may partially reflect the presence of beneficial microorganisms (e.g., lactic acid bacteria) originating from the starter preparation rather than representing spoilage flora.

After processing, the final dried snack samples showed a pronounced reduction of QMAFAnM (from ~5.0 $\log_{10}$ CFU/g in minced mixture to ~2.7–3.8 $\log_{10}$ CFU/g in the final product). This decrease can be explained by the hurdle effect produced by drying, reduced

available water, and formulation factors. The finished products exhibited very low water activity, ranging from 0.455 c.u. in the control to 0.358 c.u. in the S3 sample. Such aw levels strongly limit microbial growth and metabolic activity, making the product inherently resistant to microbial proliferation.

Increasing the level of sea buckthorn pomace powder (SBPP) was associated with lower QMAFAnM values in the final product. The literature further supports the biological plausibility of an additional "plant-derived" antimicrobial contribution: sea buckthorn (*Hippophae rhamnoides* L.) contains phenolics and other bioactive compounds with documented antimicrobial potential [71].

Evidence from applied meat research likewise indicates that sea buckthorn preparations can support microbial/quality stability depending on the matrix and dosage: for example, enrichment of cooked-smoked sausages with sea buckthorn ingredients (in combination with other extracts) has been associated with improved quality parameters and reported microbiological shelf-life benefits [72].

Yeasts and moulds were not detected (<1.0 $\log_{10}$ CFU/g) in either minced mixtures or final products. This result is technologically consistent with the extremely low aw reached after dehydration and indicates good control of airborne contamination and hygienic handling during processing. In dried meat snacks, yeasts and moulds are typically the primary concern during storage due to their greater tolerance to reduced moisture. Therefore, their absence supports the conclusion that the applied process and hygienic practices effectively prevented fungal contamination.

In line with sanitary requirements [43], the absence of coliform bacteria (including *E. coli*) and major pathogens such as *Salmonella spp., Listeria monocytogenes, Staphylococcus aureus*, and sulfite-reducing clostridia is the most critical indicator of microbiological safety for the investigated product category. The overall microbial profile of the final snacks, combined with the low aw and slightly reduced pH, demonstrates that the developed formulation provides a microbiologically stable product when produced under appropriate sanitary conditions.

5. Conclusions

The inclusion of SBPP in meat snack formulations exerted a clear and practically significant influence on the quality of the final products. These findings confirm the potential of this fruit-processing by-product for effective valorization in meat technology, not only as a source of bioactive constituents, but also as a technologically functional ingredient able to modulate critical parameters associated with product stability and consumer perception of dried snack products.

The pomace evaluated in this work contained considerable amounts of carotenoids, polyphenols, and ascorbic acid, which were associated with significant antioxidant capacity and a well-defined pigment composition. These properties provide a strong functional rationale for its incorporation into meat systems. These properties are highly relevant for modern product development, where oxidative stability, natural ingredient composition, and clean-label approaches are increasingly prioritized. In this context, SBPP can be considered a promising multifunctional ingredient that simultaneously supports both quality and product differentiation.

A consistent effect of SBPP addition was the progressive reduction in moisture content and water activity with increasing inclusion levels. This finding has strong technological

significance because water activity is one of the most critical factors governing the microbiological robustness and overall stability of dried meat snacks. The observed trend indicates that SBPP may contribute to the formation of less favorable conditions for microbial development and, consequently, may enhance product safety and stability under proper processing and packaging conditions. In addition, enrichment with SBPP resulted in increased ash and fat contents, reflecting the mineral- and lipid-containing fractions of the pomace and highlighting its potential contribution to the nutritional profile of the product. The slight decrease in pH further confirmed the natural acidic character of sea buckthorn, which may provide an additional preservation-supporting effect and contribute to a more balanced sensory profile.

Colorimetric evaluation confirmed that SBPP inclusion strongly influenced the visual properties of the snacks. The increase in red–orange tonalities, driven by carotenoid pigments, produced a distinctive and attractive appearance that can be considered an important advantage for snack-type products, where visual perception strongly affects consumer acceptance. This effect is particularly valuable because it is achieved using a natural, plant-derived ingredient and therefore supports product positioning toward more natural and functional concepts. Sensory evaluation complemented the instrumental results by indicating that the SBPP-enriched snacks retained a pleasant color, fresh aroma, and balanced taste characteristics, which suggests that functional enrichment can be achieved without negatively affecting key sensory expectations.

Overall, the findings demonstrate that sea buckthorn pomace powder is a valuable ingredient for the development of meat-based snack products with improved technological characteristics and enhanced functional positioning. The study is scientifically and practically significant because it combines product quality optimization with sustainable resource utilization, offering an innovative pathway for integrating fruit processing residues into high-value meat formulations. The results provide a strong foundation for further optimization of formulation ratios and for comprehensive assessment of long-term quality changes during storage, including oxidative processes, microbiological stability, and broader consumer acceptance. In this way, the present work contributes to the development of innovative, sustainable, and competitive meat snack products aligned with current demands for functionality, stability, and responsible use of food industry by-products.

Acknowledgments*: This work was supported by a grant of the Ministry of Education and Research, CCDI-UEFISCDI, project number PN-IV-PCB-ROMD-2024-0135, within PNCDI IV and NARD, 25.80013.5107.29ROMD.*

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

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Citation: Dianu, I., Macari, A., Dabija, A., Netreba, N., Sandu, I., Oroian, M., Buculei, A., Gâtlan, A.-M., Cușmenco, T. (2026). Evaluation of the impact of sea buckthorn pomace addition on the physicochemical and quality properties of meat snack products. *Journal of Engineering Science*. 2026, 33 (1), pp. 165-182. https://doi.org/10.52326/jes.utm.2026.33(1).11.

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