The object of this study was cooked sausages developed specifically for elderly nutrition, addressing the problem of achieving high protein density together with improved technological and oxidative stability. The study evaluated the combined effects of collagen hydrolysate 10 and cranberry powder 2% on composition, functionality, color, oxidative stability, and in-vitro digestibility. Enrichment significantly increased protein content 13.68 vs. 10.91%, moisture 77.2 vs. 72.7%, and reduced fat 6.7 vs. 9.1%. Alkali-soluble proteins rose 10.07 vs. 8.49%, texture strengthened 88.2 vs. 60.4 kPa, and water-holding capacity improved by 19%. The fatty acid profile shifted toward slightly higher SFA C16:0, C18:0 and lower MUFA C18:1, with a minor rise in ALA n-3, while trans isomers remained < 0.1%. After 10 days of storage, peroxide values were lower 8.1 vs. 9.8 meq/kg, indicating delayed lipid oxidation. Color stability reached 94%, with improved redness retention in enriched samples. In-vitro digestibility increased, with peptide release + 21.2% (pepsin) and + 10.3% (trypsin). These effects can be explained by the synergistic role of collagen peptides in enhancing protein functionality and the antioxidant properties of cranberry polyphenols in suppressing lipid peroxidation. The distinctive feature of this approach is the dual action of natural additives, providing a cleaner-label product with improved nutritional density and stability. Practical relevance lies in applying collagen hydrolysate and cranberry in functional meat technologies aimed at elderly-oriented diets, offering a feasible strategy for the meat industry to support healthy ageing and reduce risks related to poor protein intake and oxidative stress

Keywords: collagen hydrolysate, cranberry, functional sausage, elderly, oxidative stability, protein digestibility

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EVALUATION OF SAUSAGE PRODUCTS WITH COLLAGEN HYDROLYSATE AND CRANBERRY FOR ELDERLY

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1 Introduction

The problem of rational nutrition for the elderly population remains highly relevant, as aging is associated with physiological changes, reduced protein synthesis, impaired nutrient absorption, and an increased risk of chronic degenerative diseases [1]. In this context, functional foods play a crucial role in preventing age-related disorders and supporting musculoskeletal health, skin elasticity, and immune defense [2]. Meat products are a valuable source of high-quality animal protein, iron, and essential amino acids and are traditionally part of the diet of older adults. However, conventional sausages often contain excessive amounts of saturated fats, cholesterol, and sodium, which may aggravate cardiovascular and metabolic diseases prevalent among elderly people [3]. Therefore, modifying meat products with bioactive compounds to enhance their nutritional and biological value while reducing health risks is an important research direction [4]. Collagen hydrolysate is one of the most promising functional ingredients for elderly nutrition. Studies have demonstrated that collagen peptides are highly digestible and exert positive effects on connective tissue, joints, and skin, thereby contributing to healthy aging. A systematic review and meta-analysis confirmed significant improvements in skin hydration, elasticity, and wrinkle reduction after oral collagen supplementation in adults and older individuals. Similarly, a randomized controlled trial showed that hydrolyzed collagen improved skin health parameters in adult females without side effects [5]. Cranberry represents another important bioactive additive due to its richness in polyphenols, anthocyanins, proanthocyanidins, and vitamin C. These compounds exhibit strong antioxidant, anti-inflammatory, and antimicrobial activities, making cranberry highly relevant for functional foods aimed at elderly consumers [6]. Furthermore, in vitro studies confirmed that cranberry extracts reduce oxidative stress and support vascular and urinary tract health, which are key concerns in aging populations [7]. Incorporating cranberry into meat products has been shown to improve oxidative stability and extend shelf life without compromising sensory properties [4]. More-

over, fruit-derived antioxidants provide a natural alternative to synthetic preservatives, which is consistent with the global clean-label trend in functional meat processing [8]. Considering the growing demand for functional products designed for elderly consumers, the development of sausages enriched with collagen hydrolysate and cranberry appears highly promising. Such products may not only diversify the range of functional meat assortments but also contribute to improving health outcomes by addressing nutritional deficiencies, enhancing antioxidant defense, and supporting musculoskeletal and cardiovascular health in the aging population [9].

Therefore, research on developing sausages enriched with collagen hydrolysate and cranberry for elderly consumers is highly relevant, as it addresses protein density, techno-functional performance, oxidative stability, and clean-label reformulation needs.

2. Literature review and problem statement

The paper [10] shows that diet quality is tightly linked to healthy aging, with high-quality protein intake and evidence-based dietary patterns supporting functional outcomes in older adults. But unresolved questions remain about how to implement such principles in convenient everyday foods for seniors, especially processed meats. The reasons may include technological complexity and consumer acceptance. An option to overcome this is targeted reformulation of familiar products such as sausages.

The paper [11] provides a systematic review of functional foods and highlights that age-specific formulations modulate inflammation and anabolic signaling. However, it does not address how these strategies translate into complex meat matrices. The reason is the focus on general nutrition rather than specific food systems. An option is to conduct product-level trials in meat products.

The paper [12] reports that hydrolyzed collagen peptides improve skin elasticity and hydration in clinical trials. Yet unresolved questions remain about peptide stability in cooked sausages compared to supplements. The reasons may be peptide denaturation during heating and interactions with heme compounds. An option is to apply low-molecular-weight fractions or protective carriers.

The study [13] confirms collagen's benefits for musculoskeletal support and connective tissue health. But it does not clarify whether such effects persist when collagen is embedded in protein-rich meat systems. This may be due to insufficient interdisciplinary research. An option is factorial trials combining meat technology with bioavailability analysis.

The paper [14] characterizes cranberry polyphenols (proanthocyanidins, anthocyanins, phenolic acids) and their antioxidant activity. However, open questions remain regarding bitterness, astringency, and stability in thermally processed sausages. The reasons are polyphenol-protein interactions and dose limitations. Encapsulation or controlled-release systems may mitigate these issues.

The research [15] demonstrates cranberry's positive effects on vascular and urinary tract health in aging populations. But its incorporation into meat systems has been limited. Likely reasons are variability of extracts and potential sensory drawbacks. An option is standardized extracts with validated dosing in meat matrices.

The paper [16] shows that plant-derived antioxidants inhibit lipid oxidation and extend shelf life in sausages. Yet gaps remain in long-term stability and large-scale cost-effectiveness. Reasons include variability in botanical sources and multifunctional roles of nitrite. Multi-hurdle approaches (partial salt replacement, starter cultures, packaging synergies) may provide solutions.

The study [17] reports that cranberry addition can improve oxidative stability in meat products without compromising sensory quality. But unresolved questions remain about optimal dosing for elderly-oriented sausages. The reasons are matrix-dependent effects and dose-flavor interactions. Response-surface optimization may be an appropriate tool.

The review [18] analyzes salt reduction strategies in processed meats. It is shown that gradual sodium reduction and alternative structuring agents are feasible. But unresolved challenges persist in maintaining texture and microbial safety for elderly consumers. The reasons are sodium's multifunctional roles in protein extraction and preservation. Stepwise reduction combined with functional ingredients is a promising way forward.

All this allows to argue that it is appropriate to conduct a study devoted to the development of functional sausages enriched with collagen hydrolysate and cranberry, as this approach addresses nutritional density, oxidative stability, sodium reduction, and consumer acceptance in elderly-oriented meat products.

3. The aim and objectives of the study

The aim of the study is to evaluate poultry-beef sausages for the elderly using collagen hydrolysate 10% and cranberry powder 2% to enhance nutritional value, functional properties, oxidative stability, and digestibility, which will allow the meat industry to create functional products with improved quality and suitability for elderly nutrition.

To achieve this aim, the following objectives were accomplished:

– to determine the chemical composition (moisture, protein, fat, carbohydrates);

– to determine the fatty-acid profile;

– to determine lipid and protein oxidation;

– to determine instrumental color parameters of sausages (L, a, b* values and color stability;

– to determine in-vitro digestibility

4. Materials and methods

4. 1. The object and hypothesis of the study

Object of the study is cooked poultry-beef sausages developed for elderly nutrition:

1) a control sample without additives;

2) an experimental sample enriched with 10% collagen hydrolysate and 2% cranberry powder (percentages relative to the minced mass).

All other ingredients and technological parameters were identical between the two samples.

The main hypothesis of the study is that the combined incorporation of collagen hydrolysate 10% and cranberry powder 2% will increase protein density, improve techno-functional properties, such as water-holding capacity and texture strength, enhance oxidative and color stability during refrigerated storage, and promote in-vitro protein digestibility, resulting in a formulation more suitable for elderly nutrition.

Assumptions made in the study are:

– raw materials poultry, beef, and auxiliary ingredients were of comparable quality across all batches;

– analytical instruments GC-FID for fatty acids, Konica Minolta CM-2300d spectrophotometer for color, Grau-Hamm press for moisture binding, titration for peroxide value, and UV spectrophotometry for peptide quantification were properly calibrated and ensured valid between-group comparisons;

– storage at 4°C and the peroxide value were sufficient indicators of short-term lipid oxidation in cooked sausages;

– the sequential pepsin-trypsin hydrolysis method adequately reflected relative differences in digestibility between samples;

– cranberry polyphenols acted primarily as antioxidants at the applied dose without introducing confounding antimicrobial or sensory effects.

Simplifications adopted in the study are:

– a fixed formulation 10% collagen hydrolysate, 2% cranberry powder was tested without dose optimization;

– the study focused on short-term refrigerated storage 10 days using the peroxide value as the main oxidative stability indicator; protein carbonyls were measured only at baseline;

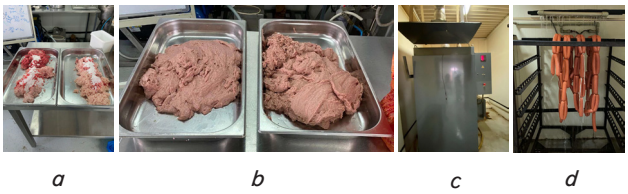
– sensory evaluation and microbiological analysis were not included;

– fatty-acid composition was reported as relative area percentages GC-FID rather than absolute concentrations;

– levels of salt, egg, starch, and technological regimes were kept constant to isolate the effects of collagen hydrolysate and cranberry addition.

4. 2. Materials

Materials of the study are two boiled sausage samples. The first sample is a control poultry-beef sausage without collagen hydrolysate and cranberry. The second sample is a test poultry-beef sausage with the addition of collagen hydrolysate (10% of the minced mass; 10 kg per 100 kg) and cranberry powder (2% of the minced mass; 2 kg per 100 kg). In both samples, hen egg and starch (3% each) were included according to the basic recipe; kitchen salt and a standard spice blend were added at identical levels. Boiled sausages with the addition of collagen hydrolysate and cranberry were produced according to the standard technology of boiled sausages. The cranberry powder used in this study was purchased from the retail chain Multivitamin (Almaty, Republic of Kazakhstan), where it was produced and packaged. The powder was incorporated directly during the cutter stage of sausage mince preparation together with collagen hydrolysate and spices, ensuring uniform distribution throughout the meat matrix. Collagen hydrolysate and cranberry powder were introduced during the minced-meat cutting step. The technological process is shown in Fig. 1.



a *b* *c* *d*

Fig. 1. The process of preparing boiled sausages enriched with collagen hydrolysate and cranberry powder: *a* – primary ground meat with the addition of spices, collagen hydrolysate and cranberry powder; *b* – secondarily shredded(cutting) sausage minced meat; *c* – heat treatment in a universal thermal chamber; *d* – finished products

The formulations of the experimental and control sausages are presented in Table 1.

Table 1

Sausage recipes

Component	Sausage without collagen hydrolysate and cranberry	Sausage with collagen hydrolysate and cranberry
Poultry meat	64	52
Beef	30	30
Collagen hydrolysate	–	10
Cranberry powder	–	2
Hen egg	3	3
Starch	3	3
Total	100	100

The heat treatment was carried out to an internal temperature of 72°C at the geometric center of each loaf. The samples were developed at the pilot production facility of Almaty Technological University.

4. 3. Analysis of methyl esters of fatty acids

Fatty acids were methylated and analyzed on an Agilent 7890 GC (Agilent Technologies, Santa Clara, CA, USA) with FID and an HP-Innowax capillary column (60 m × 0.32 mm × 0.5 μm). Nitrogen was the carrier gas. The oven program was 100 → 260°C at 10°C/min; injector split 1:100; injection volume 1 μL; detector 250–300°C. Peaks were identified using a FAME standard mix (Supelco 47885U) and quantified by internal normalization for C6-C24 fatty acids. Results are reported as area % (mean ± SD, $n = 3$).

4. 4. Determination of the ultimate shear stress

The limiting shear stress of the samples was determined on the Geppler consistometer according to the formula, Pa

$$\theta_0 = K\alpha^*(M / h^2), \quad (1)$$

where θ_0 – the limiting shear stress, Pa;

$K\alpha$ – the constant of the cone, depending on the angle α at its vertex;

M – the mass of the load acting on the cone, kg;

h – the immersion depth of the cone, m.

4. 5. Determination of the moisture binding capacity of sausages

MBC was determined by the Grau-Hamm press method adapted for cooked sausage batters. A 0.30 ± 0.01 g slice of homogenized sample was weighed onto a polyethylene disk (Ø15–20 cm), transferred to a decontaminated filter paper (Ø 9–11 cm) placed on a glass/PMMA plate, covered with a second plate, and pressed with a 1 kg load for 10 min at room temperature (22 ± 2°C). After removing the load, the outline of the compressed sample and the wet spot were traced after air-drying. Areas were measured with a planimeter. Using the calibration 1 cm^2 = 8.4 mg water, the mass of expressed water (m_exp) was calculated from the wet-spot area minus the sample area.

4. 6. Measurement of the peroxide number

This method relies on the reaction involving the initial products of fat oxidation, primarily peroxides and hydroperoxides, in the presence of potassium iodide under acidic con-

ditions. Subsequently, titration is carried out using a sodium thiosulfate solution, enabling the quantitative determination of the liberated iodine.

4. 7. Determination of carbonyl content

Carbonyls reacted with 2,4-dinitrophenylhydrazine, and the products were detected by measuring absorption at 370 nm. Protein concentrations were calculated by measuring absorption at 280 nm using bovine whey protein as the standard. The carbonyl content was calculated using an extinction coefficient equal to 22, 000 0 $M^{-1}cm^{-1}$.

4. 8. Determination of color characteristics

Color was measured with a Konica Minolta CM-2300d spectrophotometer (calibrated on supplied white/black tiles) in the CIELab system: L^* (lightness), a^* (redness), b^* (yellowness). For light-stability, slices were exposed for 1 h to an artificial light source (incandescent/fluorescent lamp, ≥40 W) at a fixed distance; color was recorded before (subscript 1) and after (subscript 2) exposure. The composite color stability index Y (%) was calculated as

$$Y = \left(1 - \left(\frac{L_1 - L_2}{3 * L_1} + \frac{a_1 - a_2}{3 * a_1} + \frac{b_1 - b_2}{3 * b_1}\right)\right) * 100\%, \quad (2)$$

where L_1 and L_2 – the values of the light index before and after exposure to light;

a_1 and a_2 – the values of the redness index before and after exposure to light;

b_1 and b_2 – the values of the yellowness index before and after exposure to light.

In the assessment of color stability to light, the sample was positioned beneath an artificial light source, specifically an incandescent fluorescent lamp with a minimum power rating of 40 watts. Color attribute changes were measured instrumentally after 1 hour from the commencement of the experiment.

4. 9. Digestibility of sausage proteins by digestive enzymes

Digestibility was assessed by sequential pepsin-trypsin hydrolysis (Pokrovsky-Yertanov protocol, adapted). Finely minced sausage (0.50 g) was mixed with 25 mL of freshly prepared pepsin solution (1 mg/mL in 0.02 N HCl, pH ≈ 1.2) and incubated at 37°C for 3 h with gentle shaking. The slurry was neutralized with 0.65 mL of 2 N NaOH, then 25 mL of 0.02 N $NaHCO_3$ (pH ≈ 8.2) and trypsin were added to reach 0.5 mg/mL, followed by 37°C for 3 h. Digests were frozen at −40°C, thawed, and centrifuged (14,000 rpm, 20 min). The supernatant was used to quantify soluble peptides (C, μg/mL) by UV absorbance at 280 nm against a BSA calibration curve. Results are reported as mean ± SD, $n = 3$ per stage per formulation.

5. Results of the study of the functional parameters of sausages

5. 1. Results of the study of chemical composition, protein fractions and texture properties

Table 2 presents the chemical composition, protein fractions, and an instrumental texture index for boiled sausages formulated without vs with collagen hydrolysate 10% and cranberry powder 2%. The reformulation targets an elderly-oriented profile-higher protein density with lower fat-given consistent evidence that older adults benefit from greater high-quality protein intakes to mitigate sarcopenia and preserve function.

Table 2

Physicochemical parameters of boiled sausage samples with and without the addition of collagen hydrolysate and cranberry

Name of the indicators to be determined	Unit of measurement	Test results	
		Sausage without collagen hydrolysate and cranberry	Sausage with collagen hydrolysate and cranberry
Mass fraction of moisture	%	72.7 ± 7.3	77.2 ± 7.7
Mass fraction of fat	%	9.1 ± 1.2	6.7 ± 1.0
Mass fraction of protein	%	10.91 ± 2.09	13.68 ± 1.90
Carbohydrates	%	1.0	4.4
Water-soluble proteins	%	1.31	1.34
Salt-soluble proteins	%	0.58	0.57
Alkali-soluble proteins	%	8.49	10.07
Cutoff voltage	kPa	60.4 ± 0.42	88.2 ± 0.45

Compared with the control, the sausage enriched with collagen hydrolysate 10% and cranberry powder 2% showed higher moisture 77.2 ± 7.7% vs. 72.7 ± 7.3; +4.5 pp, lower fat 6.7 ± 1.0% vs. 9.1 ± 1.2; –2.4 pp, and higher protein 13.68 ± 1.90% vs. 10.91 ± 2.09; +2.77 pp. Carbohydrates increased from 1.0% to 4.4%. Fractions of water-soluble 1.31 → 1.34% and salt-soluble proteins 0.58 → 0.57% were essentially unchanged, while alkali-soluble proteins rose from 8.49% to 10.07%. The instrumental texture index (cutoff voltage) increased from 60.4 ± 0.42 to 88.2 ± 0.45 kPa.

5. 2. Results of the study of fatty-acid composition and moisture binding capacity

Table 3 presents the fatty-acid (FA) composition of the control sausage versus the formulation enriched with collagen hydrolysate (10%) and cranberry powder (2%). The comparison is intended to show whether the non-lipid additives and the associated recipe shift alter the relative proportions of short-/medium-chain FA, saturated FA (SFA), monounsaturated FA (MUFA), and polyunsaturated FA (PUFA, n-3/n-6).

Relative to the control, the enriched sausage shows:

1) higher SFA, driven mainly by palmitic (C16:0) and stearic (C18:0);

2) lower MUFA, primarily due to a reduction in oleic (C18:1), with palmitoleic (C16:1) also slightly lower;

3) similar n-6 PUFA, with linoleic (C18:2 n-6) only modestly higher;

4) a small rise in ALA (C18:3 n-3), while long-chain n-3 PUFA (EPA/DHA) remain < 0.1%;

5) very low trans-isomers (elaidic and linoelaidic < 0.1% in the enriched sample).

Short/medium-chain FA (C4:0-C12:0) remain below detection (< 0.1%) in both products. Overall, the HC+cranberry recipe shifts the profile toward slightly greater SFA and lower MUFA, with minimal changes in total PUFA aside from a minor increase in ALA.

Table 3

Fatty acid composition of sausages

Name of the Indicator	Unit of measurement	Sausage without collagen hydrolysate and cranberry	Sausage with collagen hydrolysate and cranberry
Butyric acid (C4:0)	%	< 0.1	< 0.1
Caproic (Hexanoic) acid (C6:0)	%	< 0.1	< 0.1
Caprylic (Octanoic) acid (C8:0)	%	< 0.1	< 0.1
Capric (Decanoic) acid (C10:0)	%	< 0.1	< 0.1
Undecanoic acid (C11:0)	%	< 0.1	< 0.1
Lauric acid (C12:0)	%	< 0.1	< 0.1
Tridecanoic acid (C13:0)	%	< 0.1	< 0.1
Myristic acid (C14:0)	%	< 0.1	< 0.1
Pentadecanoic acid (C15:0)	%	0.2 ± 0.4	< 0.1
Palmitic acid (C16:0)	%	20.2 ± 2.1	26.5 ± 2,1
Margaric (Heptadecanoic) acid (C17:0)	%	0.3 ± 0.4	0.3 ± 0.4
Stearic acid (C18:0)	%	6.0 ± 2.1	14.1 ± 2,1
Arachidic acid (C20:0)	%	0.3 ± 0.4	0.4 ± 0.4
Heneicosanoic acid (C21:0)	%	< 0.1	< 0.1
Behenic acid (C22:0)	%	0.4 ± 0.4	0.3 ± 0.4
Tricosanoic acid (C23:0)	%	0.6 ± 0.4	0.4 ± 0.4
Lignoceric acid (C24:0)	%	< 0.1	< 0.1
Myristoleic acid (C14:1)	%	< 0.1	< 0.1
cis-10-Pentadecenoic acid (C15:1)	%	< 0.1	< 0.1
Palmitoleic acid (C16:1)	%	3.4 ± 0.4	2.9 ± 0.4
Heptadecenoic acid (C17:1)	%	< 0.1	< 0.1
Oleic acid (C18:1)	%	45.1 ± 2.1	30.6 ± 2,1
Elaidic acid (trans-C18:1)	%	0.3 ± 0.4	< 0.1
Gondoic acid (C20:1)	%	0.5 ± 0.4	0.6 ± 0.4
Erucic acid (C22:1)	%	< 0.1	< 0.1
Nervonic acid (C24:1)	%	< 0.1	< 0.1
α-Linolenic acid, ALA (C18:3 n-3)	%	0.8 ± 0.4	1.2 ± 0.4
Eicosapentaenoic acid, EPA (C20:5 n-3; timnodonic)	%	< 0.1	< 0.1
Eicosatrienoic acid (C20:3 n-3)	%	< 0.1	< 0.1
Docosahexaenoic acid, DHA (C22:6 n-3)	%	< 0.1	< 0.1
Linoleic acid (C18:2 n-6)	%	21.2 ± 2.1	22.4 ± 2,1
Linoelaidic acid (trans-C18:2 n-6)	%	0.2 ± 0.4	< 0.1
Dihomo-γ-linolenic acid, DGLA (C20:3 n-6)	%	< 0.1	< 0.1
Arachidonic acid (C20:4 n-6)	%	0.5 ± 0.4	0.4 ± 0.4
Eicosadienoic acid (C20:2 n-6)	%	< 0.1	< 0.1
Docosadienoic acid (C22:2 n-6)	%	< 0.1	< 0.1

Moisture-binding capacity (MBC) is a key functional and technological indicator of cooked sausages, directly influencing yield, juiciness, and sliceability. In sausages produced from local raw materials, the formulation enriched with collagen hydrolysate 10% and cranberry powder 2% exhibited a higher MBC than the formulation without these additives (Table 4).

Table 4

Moisture binding capacity of sausages

Title	Sausage without collagen hydrolysate and cranberry	Sausage with collagen hydrolysate and cranberry
Moisture binding capacity	65.24 ± 0.21	77.65 ± 0.23

The sausage with collagen hydrolysate and cranberry achieved 77.65 ± 0.23% MBC versus 65.24 ± 0.21% in the sausage without the additives $\Delta = +12.41$ percentage points, $\approx +19\%$. This improvement indicates enhanced water retention during thermal processing and storage, which is expected to reduce cooking loss and purge and to support better sensory juiciness and sliceability.

5. 3. Results of lipid and protein oxidation

Table 5 presents lipid and protein oxidation markers for the control sausage and for the formulation enriched with collagen hydrolysate 10% and cranberry powder 2% during chilled storage.

Peroxide values (*PV*) were comparable at day 0 and day 6 between formulations, but by day 10 the enriched sample showed a lower *PV* 8.1 ± 0.4 meq/kg than the control 9.8 ± 0.5 meq/kg, i. e., ~17% lower. The increase over time was also slower in the enriched product $\Delta PV = +3.6$ meq/kg, ~+80% from baseline versus the control $\Delta PV = +5.7$ meq/kg, ~+139%, indicating improved lipid oxidative stability attributable to the cranberry polyphenols and, potentially, antioxidant activity of

collagen peptides. Baseline carbonyls were slightly higher in the enriched sample 102.61 vs 98.80 nmol/mg protein, ~+3.9%. This small difference may reflect analytical variability or early polyphenol-protein interactions influencing the carbonyl assay signal. A time-course of protein carbonyls would clarify whether the HC+cranberry system slows carbonyl accumulation during storage. Overall, the data suggest that HC+cranberry attenuates lipid oxidation over 10 days.

Table 5

Dynamics of fat oxidation and protein oxidation (background) in boiled products during storage

Name of the indicators to be determined	Unit of measurement	Sausage without collagen hydrolysate and cranberry	Sausage with collagen hydrolysate and cranberry
Peroxide number (0 day)	meq/kg	4.1 ± 0.4	4.5 ± 0.5
Peroxide number (6 days)	meq/kg	4.5 ± 0.5	5.0 ± 0.5
Peroxide number (10 days)	meq/kg	9.8 ± 0.5	8.1 ± 0.4
Carbonyl compounds	nmol/mg of protein	98.80	102.61

5. 4. Results of color stability

Table 6 summarizes instrumental color (CIELab) of the control sausage and the formulation enriched with collagen hydrolysate 10% and cranberry powder 2% measured before and after standardized light exposure, with a composite color stability (%) index to indicate overall photostability.

Table 6

Color characteristics of sausages

Samples	Color characteristics before exposure to light			Color characteristics after exposure to light			Color stability, %
	L-lightness	*a*-redness	*b*-yellowness	*L*-lightness	*a*-redness	*b*-yellowness	
Sausage without collagen hydrolysate and cranberry	61.14 ± 0.50	17.82 ± 0.15	13.70 ± 0.24	60.04 ± 0.42	16.46 ± 0.45	14.80 ± 0.61	94.20 ± 1.50
Sausage with collagen hydrolysate and cranberry	63.91 ± 0.97	13.82 ± 0.24	12.27 ± 0.17	62.62 ± 0.61	13.75 ± 0.76	13.98 ± 0.39	93.58 ± 1.76

At baseline, the enriched sausage was lighter (L^* 63.91 vs 61.14) but showed lower redness (a^* 13.82 vs 17.82), consistent with partial replacement of meat and the hue effects of berry phenolics. After light exposure, both products faded slightly in L^* (–1.10 in control; –1.29 in enriched), but redness was better preserved in the enriched sample ($\Delta a^* \approx -0.07$; –0.5%) than in the control ($\Delta a^* \approx -1.36$; –7.6%). Conversely, yellowness increased in both, with a larger shift for the enriched formulation (Δb^* +1.71 vs +1.10), indicating a modest move toward yellow hues under illumination-likely linked to phenolic-protein/pigment interactions. The composite color stability was comparable (≈ 94% in both groups), suggesting that adding collagen hydrolysate + cranberry does not compromise overall photostability, while it helps retain redness but may introduce a slight yellow shift.

5. 5. Results of in-vitro digestibility

To assess whether enrichment improves proteolysis relevant to elderly nutrition, in-vitro digestibility was measured as the concentration of soluble peptides (C, μg/mL) released after Stage 1 (pepsin; gastric) and Stage 2 (trypsin; intestinal) hydrolysis for sausages with and without collagen hydrolysate 10% and cranberry powder 2%. The results are presented in Table 7.

The enriched sausage yielded higher peptide release at both steps: + 21.2% under pepsin 756.8 ± 29.5 vs 624.6 ± 35.4 μg/ml and + 10.3% under trypsin 409.7 ± 10.9 vs 371.3 ± 11.4 μg/ml. The slightly lower SDs also suggest more uniform hydrolysis. These results indicate that adding collagen hydrolysate and cranberry enhances overall in-vitro digestibility, supporting the intended design for older consumers.

Table 7

Results of the evaluation of the digestibility of sausages

Title	*C*, mcg/ml	
	Sausage without collagen hydrolysate and cranberry	Sausage with collagen hydrolysate and cranberry
Stage 1 hydrolysis (pepsin)	624.635.4±	756.8 ± 29.5
Stage 2 hydrolysis (trypsin)	371.311.4±	409.7 ± 10.9

6. Discussion of chemical composition and functional parameters of sausages

Reformulating the sausage with 10% collagen hydrolysate (CH) and 2% cranberry powder yielded a profile aligned with elderly nutrition goals-higher protein, lower fat, and greater moisture (Table 2). These changes enhance yield and juiciness while improving protein density per serving. The rise in alkali-soluble proteins in the enriched sample indicates a more collagen-rich, heat-stable matrix, supporting stronger gel formation (Table 2). The increase in cutoff voltage also reflects reinforcement of the myofibrillar network (Table 2), consistent with CH's role in stabilizing protein gels. Cranberry phenolics, through protein–phenol interactions, likely contributed to improved water-holding capacity (Table 4) and slower lipid oxidation (Table 5). The enriched sausage showed a modestly higher SFA C16:0, C18:0 and lower MUFA C18:1 content (Table 3), which is explained by partial fat displacement with protein- and water-rich additives. At the same time, peroxide values increased more slowly over storage (Table 5), confirming the antioxidant role of cranberry polyphenols, while digestibility was improved due to the solubility of CH peptides (Table 7). Comparable techno-functional effects have been observed in other protein systems. For instance, studies with pork gelatin demonstrated reduced cooking losses at different fat levels [19], while cuttlefish-skin gelatin improved emulsion stability and sliceability in turkey sausages [20]. These findings support our results

by showing that collagen-derived additives can strengthen the protein matrix, enhance water retention, and contribute to better processing stability in comminuted meat products. Protein-phenolic interactions observed here are consistent with reviews on protein-polyphenol complexes, which can remodel gelation and texture depending on dose [21]. From a nutritional standpoint, our + 2.77 pp protein increase is practically meaningful, in line with PROT-AGE and ESPEN guidelines recommending ≥ 1.0 g/kg·day for older adults [22]. The slower peroxide-value rise is consistent with studies showing that fruit phenolics extend shelf life [23], and cranberry-specific work in fermented sausages demonstrated reduced oxidation and microbial modulation [24]. Reviews further confirm that plant antioxidants maintain meat quality while extending storage stability [25]. Collagen peptides themselves contribute antioxidant and chelating activity, as reported previously [26]. Color changes observed (Table 6) align with known effects of anthocyanins, which reduce redness but can improve redness stability under light [27]. The + 12.41 pp increase in MBC matches reports that gelatin/CH improves water retention [19], while fruit-derived fibers add further immobilization. Enhanced in-vitro digestibility reflects the high solubility of CH peptides and the enzyme-accessibility effects of moderate phenolic levels, similar to findings in protein hydrolysate studies [28]. Finally, the trend towards sodium-reduction strategies in functional meat design supports the practical relevance of our approach [29].

The present results are limited to cooked poultry-beef sausages and may not fully translate to other meat matrices. The antioxidant effect of cranberry was observed up to 10 days of chilled storage; longer-term stability was not assessed. Digestibility was studied only under in-vitro conditions, which do not fully reproduce in-vivo digestion dynamics. The applicability of the findings is therefore bounded by product type, storage time, and the laboratory-scale nature of the trials. One disadvantage is that protein carbonyls were measured only at baseline; the dynamics of protein oxidation over storage were not determined. Sensory evaluation was not included, which limits conclusions on consumer acceptance, particularly regarding color shifts or potential astringency from cranberry phenolics.

The study was conducted on cooked poultry – beef sausages with a fixed formulation (10% collagen hydrolysate and 2% cranberry powder), so extrapolation to other product types requires further validation. Storage stability was evaluated up to 10 days at 4°C, and longer-term performance remains to be studied. Further research may focus on optimizing the levels of collagen hydrolysate and cranberry, as well as extending storage trials with a wider range of oxidative and microbiological indicators. Including sensory and consumer studies, especially with elderly participants, would help to better evaluate product acceptance. Mechanistic analyses such as LC-MS/MS, rheology, and microscopy could provide deeper insights into structure-function relationships. Moving from in-vitro to in-vivo digestion studies would also strengthen nutritional relevance.

7. Conclusion

1. The chemical composition of sausages enriched with collagen hydrolysate 10% and cranberry powder 2% showed a protein increase from 10.91% to 13.68%, fat reduction from 9.1% to 6.7%, and moisture rise from 72.7% to 77.2%. These shifts indicate a nutrient-dense, elderly-oriented formulation with higher protein and lower fat content, explained by the replacement of part of the lipid fraction with protein- and water-rich additives.

2. The fatty-acid profile shifted toward slightly higher SFA C16:0 26.5%, C18:0 14.1% and lower MUFA C18:1 30.6%, while PUFA were largely maintained with a modest increase in ALA 0.8% to 1.2%. Trans isomers and short/medium-chain FA remained negligible < 0.1%. These changes are explained by partial fat displacement and the non-lipid nature of the additives.

3. Oxidative stability analysis revealed that after 10 days of storage, the enriched sample had a lower peroxide value 8.1 vs 9.8 meq/kg; –17%. The increase from baseline was also smaller + 3.6 vs + 5.7 meq/kg confirming that collagen hydrolysate combined with cranberry polyphenols slows lipid oxidation in cooked sausages.

4. Instrumental color analysis showed that the enriched sausages were lighter L^* 63.91 vs 61.14 and less red a^* 13.82 vs 17.82 at baseline, consistent with the presence of berry phenolics. After light exposure, redness was better preserved in the enriched sample Δa^* −0.07; −0.5% compared to the control Δa^* −1.36; –7.6%, while both exhibited a modest yellow shift. The overall color stability index remained comparable 94%, demonstrating that enrichment maintains photostability while improving redness retention.

5. In-vitro digestibility of sausages enriched with collagen hydrolysate (10%) and cranberry powder (2%) showed a notable improvement compared with the control. The release of soluble peptides increased by 21.2% during pepsin hydrolysis and by 10.3% during trypsin hydrolysis, indicating enhanced proteolytic breakdown and higher accessibility of protein fractions. These findings demonstrate that the addition of collagen hydrolysate and cranberry improves the digestibility of sausage proteins, making the product more suitable for elderly nutrition by facilitating protein utilization and absorption.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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