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Low-Fat Vietnamese Sausage (*Lap Xuong*) Formulated with Passion-Fruit Peel Pectin as a Sustainable Fat Replacer

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This study developed a low-fat Vietnamese sausage (*Lap Xuong*) by simultaneously reducing pork back fat and reinforcing its structure with high-methoxyl pectin derived from passion fruit peel (*Passiflora edulis*), a sustainable byproduct of fruit processing. Three lean-meat/back-fat ratios (68 : 15, 73 : 10 and 78 : 5 % w/w) were produced under identical seasoning without pectin and dried at 60 °C for 24 h. Sensory evaluation indicated that the 78 : 5 formulation delivered the highest overall acceptance. This lean baseline was fortified with 0–5 % (w/w) pectin. Texture-profile analysis showed that 0.5 % pectin provided the optimum balance of hardness, cohesiveness, and springiness, as well as promoted a continuous protein–water network that mimicked fat functionality, as confirmed by SEM. The optimized product (77.5 % lean meat, 5 % fat, 0.5 % passion-fruit-peel pectin) delivers 262 kcal, 27.8 g protein, 8.31 g lipid, 19.1 g carbohydrate and 3.53 g dietary fiber per 100 g, cutting fat by 66.8–81.7 % relative to three leading commercial brands, yet boosting protein by 60–180 %. Adding a small amount of pectin from passion fruit peel can replace most of the fat, allowing manufacturers to create a much leaner sausage that still tastes and feels like the traditional product, while offering an eco-friendly way to produce healthier meat products.

1. Introduction

The fruit-processing industry generates vast streams of solid residues (principally peels and seeds) that are commonly discarded despite containing high concentrations of bioactive compounds such as polyphenols, dietary fiber, pigments, flavor volatiles, proteins, essential oils, and enzymes (Trigo et al., 2020). Among these constituents, pectin is one of the most economically important, and optimizing its extraction and recovery is regarded as critical for fully valorizing fruit-processing biomass.

Passion fruit (*Passiflora edulis*) is cultivated worldwide, and its pulp is widely processed into juices, jams, and concentrates. During pulping, the peel, representing 50–60 % of the whole fruit mass, accumulates as a low-value byproduct. Commercial pectin is still sourced predominantly from citrus peel and apple pomace, yet passion-fruit peel is both abundant and inexpensive. In Vietnam, the cultivated area reached approximately 9,500 ha, yielding more than 188,900 t of fresh fruit (Do, 2024). Reported pectin extraction yields from dried passion fruit peel typically range from 6 % to 18 %, depending on the extraction method employed (Freitas et al., 2020). Harnessing this resource would diversify the pectin supply chain and convert a growing agro-industrial residue into value-added ingredients, advancing circular economy goals. In a recent study, our group applied ultrasound-assisted acid extraction (5 min of ultrasonication at 550 W and 60 °C) to passion fruit peel, achieving a 12 % high methoxyl pectin yield with an exceptionally high Anhydrouronic acid (AUA) content (Huynh et al., 2024). These optimized conditions provide a reliable source of high-purity, high-methoxyl pectin (HMP). Beyond its gelling properties, HMP can function as a fat replacer in comminuted meat products. Wongkaew et al. (2020) demonstrated that replacing 5% pork fat with mango-peel pectin enhanced color retention and preserved both physicochemical and sensory qualities in Chinese dry sausage. Méndez-Zamora et al. (2015) further demonstrated that in combination with inulin, pectin could replace fat in frankfurter sausages to yield healthier, functional products without compromising textural integrity. Silva-Vazquez et al. (2018) also reported that pectin supplementation maintained water-holding capacity and reduced overall lipid content in emulsified meat systems. To date, no work has yet explored the incorporation of passion-fruit-rind pectin into Vietnamese

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sausage (*lap xuong*). Passion-fruit peel pectin in Huynh's work showed a degree of esterification (DE) above 80 %, markedly higher than that of Vietnamese mango-peel pectin (50-56 %, Nguyen et al., 2019), making it a distinctly superior source of high-methoxyl pectin. This very high DE might accelerate the formation of a stronger hydrophobic gel network, promisingly allowing passion-fruit peel pectin to mimic solid fat and reduce purge loss in low-fat sausages more effectively than its mango-derived pectin. This gap is especially notable given the increasing availability of passion-fruit processing residues in Vietnam.

Pursuing the fruit waste valorization strategies previously reported (Huynh et al., 2024) in response to a practical demand from local juice manufacturers seeking sustainable ways to valorize passion-fruit peel waste, this study builds upon our optimized extraction protocol to evaluate the performance of passion-fruit pectin as a structure-reinforcing fat replacer in the formulation of low-fat *Lap Xuong*, linking waste valorization with the development of healthier, value-added traditional meat products.

2. Materials and Methods

2.1 Materials and Chemicals

Fresh passion-fruit peels were collected from a factory of DNTP Agribusiness Investment Joint Stock Company (JSC) (Dak Lak, Vietnam). The peels were cleaned of pulp and seeds, rinsed, and cut into about 1 cm strips. The strips were dried at 60 °C to a constant weight, then milled and sieved (40–60 mesh) to produce a uniform powder, then sealed in moisture-proof pouches and stored below 25 °C. Unless stated otherwise, the following chemicals were used: ethanol (96 %, Fisher; USA), hydrochloric acid (37 % w/w, Xilong; China), sodium-hydroxide pellets (≥ 98 %, Xilong; China), citric acid monohydrate (≥ 99.5 %, Xilong; China), and phenol-red indicator (Merck; USA). CP Vietnam Livestock JSC supplied lean pork thighs and back fat. Collagen casings (20–24 mm) were provided by Viscofan Vietnam. Food-grade salt was purchased from Bac Lieu Salt JSC, food-grade sucrose from Thanh Thanh Cong Bien Hoa Sugar JSC, food-grade monosodium glutamate from Ajinomoto Vietnam, and food-grade sodium nitrite from Navico Investment and Development Trading Co., Ltd.

2.2 Pectin Recovery from Passion-fruit Peels

Pectin was extracted using a citric acid solvent with ultrasound assistance, according to Huynh et al. (2024). Approximately 10 g of finely milled, dried passion-fruit-peel powder was suspended in a 5 % (w/v) citric-acid solution at a solid-to-liquid ratio of 1 : 20 (g/mL). The slurry was placed in an Elmasonic S ultrasonic bath operating at 550 W and treated at 60 °C for 5 min; ultrasonic cavitation combined with mild heating disrupts the cell wall and accelerates pectin release. Immediately after sonication, the hot extract is filtered through muslin cloth to remove insoluble residues, and the clear filtrate is mixed with 96 % (v/v) ethanol at a 1 : 1 volume ratio. Gentle stirring followed by a 30-min rest precipitates the pectin as a fibrous gel, which is collected and washed twice with a minimal volume of 96 % ethanol to eliminate residual sugars and acids. Finally, the wet pectin is dried in a hot-air oven at 55 °C to a constant mass and ground into a uniform powder. The methoxyl (MeO) content, degree of esterification (DE), and anhydrouronic-acid (AUA) content of pectin were determined by titration, following the method of José et al. (2022). Fourier-transform infrared spectroscopy (FTIR) was recorded on a Jasco spectrometer (FTIR-4700A) to determine the unique structure of pectin.

2.3 *Lap Xuong* Preparation

Vietnamese Sausage (*Lap Xuong*) was prepared following Tran et al. (2022) and Wongkaew et al. (2020), with minor modifications. Lean and back fat were first trimmed of connective tissue. Three meat-fat blends (68 : 15, 73 : 10 and 78 : 5 w/w lean: back-fat) were prepared under identical seasoning and processing without pectin. The pork is ground through a 6 mm plate, while the fat is cut into roughly 5 mm cubes. In a chilled bowl chopper (or planetary mixer), the ground meat and diced fat are combined with 0.5, 1, 3 or 5 wt% pectin from passion-fruit peel and a precise seasoning blend consisting of sugar (14 wt%), salt (2 wt%), monosodium glutamate (0.7 wt%), sodium nitrite (0.01 wt%), black pepper (0.29 wt%). The mixture is emulsified at medium speed for 3–5 minutes until a smooth, sticky batter forms. This batter is then stuffed into collagen casings (20–24 mm diameter) using a manual sausage stuffer, and the links are formed by twisting or clipping at 8–10 cm intervals. The sausages are hung on stainless steel rods and dried in a convection oven at 60 °C for 24 h. Once fully dried and cooled to room temperature (25 ± 2 °C), the sausages are vacuum-packed in food-grade pouches and stored at 4 °C for up to two weeks (or frozen for extended shelf life). As a control, a traditional *Lap Xuong* batch was prepared using meat at 63 wt% and fat at 20 wt%, with the same seasoning, processing, and no pectin.

2.4 Quality Assessment of *Lap xuong*

2.4.1 Sensory Evaluation

Following TCVN 3215-79, 12 trained assessors (6 Male, 6 Female, 22–23 years old, non-smokers screened for

good taste–color–texture discrimination) attended four training sessions on attribute definitions and scale application before rating flavor, color, and texture on a five-point scale (0–5). 30 semi-trained panelists (15 Male, 15 Female, 20–22 years, non-smokers) underwent two introductory sessions and scored their overall liking on a seven-point hedonic scale. Each formulation was coded with a random three-digit number, then fried, sliced, and served in balanced order under uniform lighting, with palate cleansers offered between samples. Scores were subjected to one-way ANOVA, followed by Tukey's HSD test ($p = 0.05$) to identify significant differences among formulations.

2.4.2 Texture Profile Analysis (TPA)

The structural properties of the sausage were assessed using Texture Profile Analysis (TPA) with a Texture Analyzer (Zwick/Roell 1.0) to determine hardness, cohesiveness, springiness, and chewiness. Cooked sausage samples were trimmed into cylinders 30 mm in height at their original diameter. A 40 mm-diameter platen was used at a crosshead speed of 60 mm/min, with each sample subjected to two compression cycles to 40 % deformation of their original height. Results were subjected to one-way ANOVA, followed by Tukey's HSD test.

2.4.3 Morphological analysis

Scanning Electron Microscopy (SEM) was employed to visualize the protein–water–pectin network and assess how pectin content influences the microstructure (HR–SEM Mira, Tescan). Samples were secured to the stage using conductive double-sided carbon tape and examined under 10 keV accelerating voltage at a 50 µm magnification.

3. Results and Discussion

3.1 Pectin Recovery from Passion-fruit Peels

Passion-fruit-peel pectin extracted via ultrasound-assisted citric-acid extraction (UA) (5 min ultrasonication at 550 W and 60 °C) exhibited excellent quality metrics. The product showed a high DE of 83.67 %, a MeO content of 13.35 %, and an exceptionally pure backbone, as evidenced by an AUA content of 90.55 % (meeting the JECFA specification (FAO/WHO) for food-grade pectin). These values confirm that the ultrasound-assisted protocol accelerates pectin release, yielding a highly esterified, high-purity pectin suitable for food-grade applications. The FTIR spectrum of pectin obtained by UA displays the characteristic polysaccharide bands with notably enhanced signal intensity (Figure 1). A broad O–H stretching band appears near 3,356 cm^{-1}, while stretching of aliphatic $–CH_2–$groups is observed at 2,930 cm^{-1}. The ester carbonyl (C=O) peak at 1,733 cm^{-1} confirms high methoxylation, and the carboxylate (COO^-) band at 1,620 cm^{-1} indicates non-esterified uronic acid. Peaks at 1,441 cm^{-1} and 1,362 cm^{-1} further support the carboxylate functionality and the backbone vibrations of galacturonic acid. Fingerprint region (900–500 cm^{-1}) reflects the uniqueness of pectin's homogalacturonan backbone. These findings are consistent with those of Huynh et al. (2024).

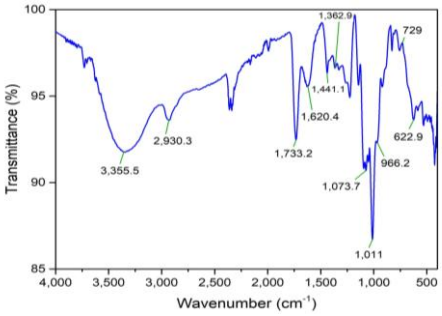

Figure 1: FTIR spectra of passion-fruit pectin

3.2 Quality Assessment of *Lap Xuong*

To develop a low-fat *Lap Xuong* formulation, the seasoning components were fixed at sugar, sodium nitrite, salt, monosodium glutamate, and white pepper. Two sequential screening steps were then performed: Three lean-to-fat blends (68:15, 73:10, and 78:5 (w/w)) were evaluated by sensory testing to identify the ratio yielding the highest overall acceptability; Using the most preferred fat content, high-methoxyl pectin (HMP) was varied at 0.5, 1, 3, and 5 wt%, and each formulation was characterized to determine the optimal pectin concentration for texture, microstructure and sensory acceptance. The 0.5–5 wt% range was chosen to encompass the typical commercial level (0.5 wt%) and to probe the upper functional limit at which pectin still forms a stable matrix without collapse.

3.2.1 Effect of lean-to-fat ratios on Sensory Properties

Sensory evaluation of three Lean-to-Fat blends (68:15, 73:10, and 78:5 (w/w)) is indicated in Table 1. The sensory data show that reducing fat from 15 % to 5 % (moving from 68 : 15 to 78 : 5 lean : fat) did not compromise color (3.40-3.77) or flavor (4.01–4.47). The intermediate 73 : 10 blend suffered a noticeable drop in texture (2.93 vs. 4.17), which dragged its overall liking down to 4.47. In contrast, the 78 : 5 formulation matched the highest texture score (4.27) and delivered the strongest "overall acceptance" rating (5.43), significantly above the other two ($p < 0.05$). Even with minimal fat, the 78 : 5 sausages retained a desirable mouthfeel, likely due to the structuring effect of protein–water network, and achieved the best balance of sensory attributes, making it the optimal base for subsequent pectin-level trials.

Table 1: Sensory evaluation of samples with different Lean-to-Fat Ratios

Pectin level (wt%)	Lean : back-fat ratio (w/w)	Sensory Evaluation			
		color	flavor	texture	overall liking
0	68 : 15	3.50±0.94^{a}	4.23±0.73^{a}	4.17±0.95^{a}	5.03±0.85^{ab}
	73 : 10	3.40±0.97^{a}	4.01± 0.91^{a}	2.93±1.34^{b}	4.47±1.07^{b}
	78 : 5	3.77±1.22^{a}	4.47±0.63^{a}	4.27±1.01^{a}	5.43±1.25^{a}

3.2.2 Effect of pectin content on sensory, microstructural, and textural properties

The data in Table 2 show that increasing pectin beyond a minimal level has a clear, dose-dependent impact on sensory quality, particularly with the meat-to-fat ratio of 78:5. The control (no pectin) scored highest for color (4.08), flavor (4.92), texture (4.83), and overall liking (6.42). Introducing only 0.5 % HMP produced slight declines (3.08, 4.08, 4.25, and 5.08 for the four sensory attributes), but all of these scores still fell within the "like slightly" to "neither like nor dislike" range and were statistically indistinguishable from the control. At 1 % pectin, all scores drop further (color 2.25, flavor 3.50, texture 3.58, liking 4.00), and by 3–5 % pectin, the sausages are rated as "dislike slightly" to "dislike moderately" for every attribute. These trends indicate that while HMP can successfully replace a portion of fat, exceeding about 0.5 wt% causes unacceptable changes in appearance, taste, and mouthfeel. Thus, 0.5 wt% pectin represents the practical upper limit for fat replacement in *Lap Xuong* without compromising consumer acceptance.

Table 2: Effect of pectin content on Sensory evaluation

Pectin level (wt%)	Lean : back-fat ratio (w/w)	Sensory Evaluation			
		color	flavor	texture	overall liking
0	63 : 20 (control)	4.08±0.67^{a}	4.92±0.29^{a}	4.83±0.34^{a}	6.42±0.87^{a}
0.5*	77.5 : 5	3.08±1.16^{ab}	4.08±0.51^{ab}	4.25±0.87^{ab}	5.08±0.79^{ab}
1*	77 : 5	2.25±0.97^{bc}	3.50±1.09^{b}	3.58±0.67^{bc}	4.00±1.04^{b}
3*	75 : 5	1.25±0.62^{cd}	2.08±1.08^{c}	2.67±0.78^{c}	2.42±1.00^{c}
5*	73 : 5	1.00±0.00^{d}	1.92±1.00^{dc}	2.75±0.97^{c}	2.33±1.30^{c}

(*) The lean-to-fat ratio was proportionally adjusted to accommodate the added pectin, ensuring the total formulation sums to 100 wt% .

TPA in Table 3 revealed that adding 0.5 % ultrasound-extracted pectin to the 77.5 : 5 lean-to-fat formulation almost fully preserved the textural properties of the traditional control (63 : 20). Hardness remained virtually unchanged (131.3 ± 12.4 N vs. 132.7 ± 16.1 N), springiness even increased slightly (0.79 ± 0.02 vs. 0.76 ± 0.02), while gumminess (30.2 ± 8.5 N vs. 29.9 ± 6.1 N) and chewiness (21.2 ± 7.9 N vs. 22.9 ± 4.9 N) were likewise comparable. Cohesiveness likewise remained stable at low replacement (0.23 ± 0.04 vs. 0.22 ± 0.02), indicating that the internal bonding strength of the meat–water network was maintained, a phenomenon attributed to the reinforcing gel matrix formed by pectin (Sharefiabadi and Serdaroğlu, 2021) and observed in frankfurter sausages with pectin–inulin blends (Méndez-Zamora et al., 2024). In contrast, higher pectin levels (1–5 %) produced progressively softer, less elastic sausages: at 1 % pectin, hardness fell by 31 % and chewiness by about 39 % relative to the 0.5 % sample, while springiness dropped to 0.69. At 3 % and 5 % pectin, hardness declined by more than 50 % and gumminess by over 65 %, yielding a markedly weaker, pasty texture. Excessive polysaccharide networks can disrupt the meat matrix and degrade textural quality (Sharefiabadi and Serdaroğlu, 2021). These findings confirm that a low dosage of 0.5 % pectin is sufficient to mimic fat functionality, maintaining firmness, cohesiveness, and chewiness, while higher concentrations compromise the sausage matrix. A similar retention was observed by Wongkaew et al. (2020) when replacing 5 % fat with mango-peel pectin in dried Chinese sausage, preserving hardness and chewiness equivalent to those of the full-fat control.

Table 3: Effect of pectin content on Texture-profile analysis

Pectin level (wt%)	Lean : back-fat ratio (w/w)	Texture-profile analysis				
		Hardness	Springiness	Gumminess	Chewiness	Cohesiveness
0	63 : 20	132.67± 16.07^{a}	0.76 ± 0,02^{ac}	29.91 ± 6.09^{a}	22.87 ± 4.86^{a}	0.22 ± 0.02^{a}
0.5*	77.5 : 5	131.33 ± 12.35^{a}	0.79 ± 0,02^{a}	30.19 ± 8.48^{a}	21.19 ± 7.92^{a}	0.23 ± 0.04^{ab}
1*	77 : 5	91.78 ± 11.88^{b}	0.69 ± 0,01^{c}	20.20 ± 5.09^{b}	13.99 ± 3.50^{ab}	0.22 ± 0.04^{a}
3*	75 : 5	57.18 ± 1.97^{c}	0.43 ± 0,02^{b}	9.82 ± 1.67^{c}	4.68 ± 0.96^{bc}	0.17 ± 0.03^{a}
5*	73 : 5	52.70 ± 2.68^{c}	0.41 ± 0,03^{b}	8.04 ± 1.03^{c}	3.36 ± 0.67^{c}	0.16 ± 0.02^{b}

(*) The lean-to-fat ratio was proportionally adjusted to accommodate the added pectin, ensuring the total formulation sums to 100 wt%.

Figure 2 presents representative SEM micrographs of low-fat *Lap Xuong* samples containing 0–5 % pectin, illustrating the progressive changes in microstructure with increasing pectin levels. SEM of the control sample (no pectin) revealed a relatively smooth and homogeneous protein–water matrix with minimal porosity, reflecting a structure held together primarily by meat proteins and discrete fat droplets. When 0.5 % pectin was incorporated, the micrographs showed fine fibrous strands and numerous small voids, indicative of a three-dimensional gel network that closely mimics dispersed fat globules and promotes moisture retention, similar to observations in mango-peel pectin–fortified sausages reported by Wongkaew et al. (2020). At 1 % pectin, these voids became larger and interconnected, suggesting an optimally developed gel network that enhances water-holding capacity and elasticity (Sharefiabadi and Serdaroğlu, 2021), which aligns with the increased cohesiveness and springiness observed in TPA. Samples containing 3 % and 5 % pectin exhibited progressively denser and coarser gels. At 3 %, the network appeared irregular with oversized voids, and at 5 %, the pectin gel filled virtually all pore space, resulting in a compact, pore-free matrix. Such overly continuous gels lack the pseudo-fat pockets necessary for a juicy mouthfeel (corresponding to the decreased hardness) and diminished sensory appeal recorded at higher pectin levels, a phenomenon similarly described by Calvo et al. (2008) in meat analogs. These observations confirm that pectin levels of 0.5–1 wt% strike the best balance between structural reinforcement and porosity, effectively replacing fat functionality in low-fat *Lap Xuong*.
All key metrics were statistically compared with the control (no pectin), ensuring consistent benchmarking. Distinct superscripts confirm concentration-dependent effects on texture and sensory properties, with 0.50% pectin yielding optimal values. The close agreement among instrumental data, sensory scores, and SEM inspection supports the reliability of the results.

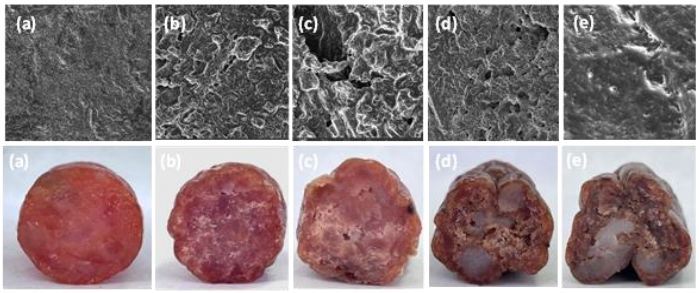

Figure 2: SEM of low-fat Lap Xuong samples containing: (a) no pectin, (b) 0.5 %, (c) 1 %, (d) 3 %, (e) 5 % pectin

3.3 Nutritional Profile and Comparative Analysis of the Optimized Low-Fat *Lap Xuong*

The final optimized low-fat *Lap xuong* formulation is as follows: a lean-to-fat ratio of 77.5:5 (w/w) and a 0.5 wt% pectin content. Table 4 highlights the nutritional improvements achieved in our optimized low-fat *Lap Xuong* (77.5:5 lean-to-fat, 0.5 wt% pectin) compared to three leading commercial products. At only 262 kcal per 100 g, our formulation reduces the caloric load by 35–53 % compared to the commercial range of 400–557 kcal. The low-fat sausage delivers 27.8 g of protein, 60–180 % more than the commercial samples (10–17.4 g), increasing its value as a high-protein snack. Fat falls to 8.31 g, a reduction of 67–82 % versus the commercial lipid contents (25–45.5 g), demonstrating the efficacy of pectin as a fat (rather than water) mimetic. At 19.1 g, the carbohydrate level is comparable to commercial brands (15–19.6 g), ensuring a familiar mouthfeel and caloric distribution. Regarding dietary fiber, our product contains 3.53 g of fiber per 100 g, but none of the commercial sausages declare any fiber content. This added fiber contributes to reduced net calories and may improve satiety and gut health. By substituting 0.5 wt% HMP for the fat, the study achieved a semi-dry sausage that retains its desirable texture and flavor while halving its energy density and reducing its lipid content. The simultaneous protein boost and introduction of dietary fiber convert a traditionally indulgent product into a more balanced, high-protein, high-fiber snack, aligning with consumer demand for healthier meat products without sacrificing sensory quality.

Table 4: Nutritional composition per 100 g of the optimized low-fat Lap Xuong compared with three leading commercial brands: (1) VISSAN, (2) CP Vietnam Livestock JSC, (3) Tan Hue Vien Meat Processing Co., Ltd

Nutrition values per 100 g	Low-fat *Lap xuong*†	Brand (1)††	Brand (2)††	Brand (3)††
Energy (kcal)	262	557.12	410	400
Protein (g)	27.80	17.37	15	10
Lipids (g)	8.31	45.48	39	25
Carbohydrates (g)	19.10	19.58	19	15
Fibers (g)	3.53	-	-	-

(†) Accredited laboratory results (TCVN 7088:2015, 8134:2009, 8136:2009, 4594:1988, 9050:2012); (††) Label-declared values.

4. Conclusions

This study demonstrates that high-methoxyl pectin recovered from pure passion-fruit peel via a 5-minute, 60 °C, 550 W ultrasound-assisted citric-acid extraction serves as an effective fat replacer in traditional Vietnamese sausage. *Lap Xuong* formulated with 0.5 wt% pectin and a 77.5:5 lean-to-fat ratio, matched the control in terms of hardness, springiness, gumminess, chewiness, cohesiveness, and overall acceptability, findings corroborated by SEM and TPA. The formula achieved dramatic nutritional improvements, including a 35–53 % reduction in energy, a 67–82 % reduction in lipid, and a 60–180 % increase in protein, as well as 3.53 g of dietary fiber per 100 g, compared to leading commercial brands. By valorizing passion-fruit processing waste and integrating pectin into meat reformulation, this work offers a sustainable route to healthier, high-protein, high-fiber meat products without compromising sensory quality. Future research will focus on addressing shelf-life stability, scale-up feasibility, and broader consumer acceptance to facilitate industrial adoption.

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