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Valorization of fish bone powder and tomato pomace pectin to produce alternative fat replacer in pork patty

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Abstract

Reducing fat in pork patties while maintaining quality is challenging due to their high fat content. A potential solution has been focused on substituting fat with fat replacers (FRs), particularly those derived from agricultural by-products. This study developed an alternative FR by inducing gelation of mixed pectin (from tomato pomace and commercial sources) with calcium from catfish bone powder and evaluated its application in pork patties. Pork patties with 0, 25, 50, 75, and 100% fat substitution by FR were analyzed for their qualities. Results showed a significant fat reduction from 23.72 to 7.44% with 100% FR substitution, accompanied by an increased calcium content, suggesting improved nutritional quality. However, FR substitution exceeding 25% led to color changes and reduced overall acceptance. Notably, after one week of storage at 4 °C, rancidity 2-thiobarbituric acid reactive substances (TBARS) value was significantly lower in patties with 25% FR substitution. Therefore, producing reduced-fat pork patties with a suitable level of fat replacer appears feasible for maintaining desirable quality.

Keywords: Low-fat patty, Fat replacer, Tomato pomace pectin, Natural calcium, Fish bone powder

1. Introduction

Catfish (*Carias macrocephalus*) is an economically important species in Thailand. The country has an annual production of about 99,344 metric tons [1]. It is processed into either fresh cut or other fishery products. These processes generated a significant amount of waste (e.g., heads, bones, and skin). This poses an environmental burden and represents inefficient utilization of fishery resources. Therefore, the recovery and upcycling of this waste into higher-value products has become a focus. Production of fish bone powder from catfish heads as a source of natural calcium was recently documented [2]. Liberated calcium ions from the bone powder are sufficient to generate functional properties in food, although the bone powder's solubility is limited [3]. Direct application of fish bone powder to activate an endogenous cross-linking enzyme, transglutaminase, in fish sausage has been observed [4]. Fish bone powder induced gelation of pectin (low methomyl type) has been proposed to produce an innovative low sugar jam [5]. Application of these gels in other food models should be elucidated for valorization of catfish by-products.

Tomato pomace (TP) is a by-product from tomato processing, such as canned tomatoes, ketchup, and tomato sauce [6]. During these processes, tomatoes are crushed and only their juice is collected for further processing. Then, its pomace is eliminated and sold as a low-value feed component. TP has received attention since it contains bioactive compounds such as carotenoids and pectin. Pectin was extracted from TP. It was reported to contain lycopene, which is beneficial for food applications as a natural colorant and antioxidant. Thus, gelation of pectin from TP induced by calcium from fish bone may be developed to create an innovative food or food ingredient. One application is the creation of an alternative fat replacer (FR) in high-moisture meat products such as patties. Patties are an interesting model since they are a popular product globally. They are made from comminuted meat and animal fat before adding specific organoleptic ingredients and shaping with a specific thickness. These patties are cooked by roasting/grilling before being served within a sandwich bread, known as a burger. Processing techniques can be modified by changing the meat and fat to create a variety of products suited for various consumers. Among those, pork patties are widely accepted in Eastern cultures. Back fat is used to maintain their juiciness and carry the pork flavor in the patty. However, pork back fat contains high saturated fatty acids and may be the source of risk for various chronic diseases [7-8]. A reduction of potential risk for those diseases could be successfully done through the consumption of low-fat meat products. However, simply reducing fat from meat products leads directly to changes in sensory characteristics, affecting consumer acceptability. Therefore, the development of low-fat products that maintain their overall qualities is challenging. One approach is using FRs [9].

FRs for meat products are developed based on the gelation of polysaccharides such as alginate, carrageenan, and pectin to build a juicy texture. Additionally, non-meat proteins (egg whites, soy protein isolates, and whey protein isolates) are normally added to maintain the mouth feel of animal fat. Alginate is used as an FR in meat emulsions [10], while carrageenan is reported to be better for burger patties [11]. Konjac flour containing galactomannan is used in combination with natural calcium from fish bone to reduce the fat content in pork emulsion Thai sausages (Mu Yor) [12]. Moreover, pectin from multiple sources could be employed as an FR for low-fat food products, e.g., yoghurt, muffins, and meat-based snacks [13-16]. Furthermore, in response to the growing market trends for low-fat food products, substituting fat with a FR in low-fat yogurt was explored to improve consumer perception [15]. Application of pectin from alternative sources, such as by-products from tomato processing industries, to reduce fat in meat products still faces challenges. Successfully overcoming such problems would change the image of these meat products, positioning them as healthier foods.

Therefore, the aim of this study was to prepare a fat replacer based on the gelation of pectin from TP induced by catfish bone powder and evaluate its potential application in pork patties without compromising overall quality. This approach offers a potential strategy for valorizing agricultural resources through fat replacer technology, contributing to zero-waste practices.

2. Materials and methods

2.1 Materials

Catfish heads were obtained from Pla Duk Nong Khai Farm (Nong Khai, Thailand). Commercial grades of low-methoxyl pectin and soy protein isolate were used. Fresh pork, animal fat, and other ingredients were obtained from a local market (Nong Khai, Thailand). TP was a kind gift from the Sri Chiang Mai Agro-Industries, Nong Khai, Thailand. This pomace was dried at 60 °C to a constant weight and kept in a desiccator before pectin extraction.

2.2 Methods

2.2.1 Preparation and characterization of fish bone powder

Fish bone powder was prepared from cat fish head according to the previously reported [2]. The obtained bone powder was used as catfish bone powder (CBP) exhibited particle size < 38 μm. This powder contains the total calcium content about 1.48% and its soluble calcium was found about 0.03%.

2.2.2 Extraction and characterization of pectin from TP

2.2.2.1 Extraction of pectin

Pectin was removed from TP using microwave-assisted extraction, following a previously described modified method [17]. TP was mixed with 2 M citric acid at a 1:30 (w/v) ratio before heating at 300 W for 10 min. The extract was filtered twice through cheesecloth to eliminate sediment. The filtrate was mixed with cold ethanol (99%) in a 1:1 (v/v) ratio before precipitating pectin in a cold room for 12 h. Precipitated pectin was recovered by centrifugation at 20,000 × g for 10 min. The sediment was retained for further studies and stored at 4 °C.

2.2.2.2 Determination of esterification (DE) *of pectin*

The degree of esterification (DE) of pectin was determined based on a titrimetric method. Dried pectin (0.1 g) was dissolved in DI-water (20 mL) and first titrated with sodium hydroxide (NaOH) using phenolphthalein as an indicator. Then, 10 mL of NaOH (0.5 M) was added, and the sample was allowed to stand for 20 min before adding 10 mL of 0.5 M hydrochloric acid (HCl). The final mixture was titrated with a 0.1 M NaOH solution, with the initial and final volumes of NaOH recorded as V_1 and V_2, respectively. The DE was calculated as:

$$DE\ (\%) = \frac{V_2}{(V_1+V_2)} * 100 \quad (1)$$

2.2.2.3 Determination of lycopene content

Lycopene content was spectrophotometrically estimated after extraction of a dried sample (0.09 g) with hexane (3 mL) for 24 h. The absorbance at 503 nm was recorded. Lycopene content was calculated using an extinction coefficient of 17.2×10^4.

2.2.3 Preparation of FR

A pectin mixture was prepared by mixing commercial pectin with TP pectin in a 3:1 ratio. This mixed pectin (2%) was dissolved in deionized water (DI) in the presence of soy protein isolate (1%) before heating at 90 °C for 30 min. Then, 0.5% CBP was added followed by continued heating for 5 min. After cooling, the obtained gel was used as an FR substitute in pork patty formulations.

2.2.4 Production of pork patty

Pork patty samples were produced according to a previous study with slight modification [18]. The fat content in the recipe was substituted with FR at 25, 50, 75, and 100% (Table 1). Pork mince and fat or FR were mixed using a meat chopper (Champ Amci TC12-C, Chonburi, Thailand) for 2 min to prepare the patties. After that, dry ingredients were added before continued chopping for 2 min. Finally, 50 g portions were separated for molding into 7 cm diameter round and 1 cm thick shapes. The molded patties were cooked under microwave heating (SAMSUNG model MS23K3555EW/ST, Chonburi, Thailand) at 900 W for 150 s before analysis.

Table 1 Experimental design and pork patty recipe.

Ingredient	Patty recipe				
(g)	CT	R25	R50	R75	R100
Pork	62.0	62.0	62.0	62.0	62.0
Fat	18.0	13.5	9.0	4.5	0.0
FR	0.0	4.5	9.0	13.5	18.0
Salt	0.8	0.8	0.8	0.8	0.8
Onion	10.0	10.0	10.0	10.0	10.0
Sugar	1.0	1.0	1.0	1.0	1.0
Oyster sauce	1.8	1.8	1.8	1.8	1.8
Egg white	5.0	5.0	5.0	5.0	5.0
Seasoning	1.4	1.4	1.4	1.4	1.4

CT = Control: R25, R50, R75, and R100 were patties with FR at 25, 50, 75, and 100% fat substitution, respectively.

2.2.5 Determination of patty color

Color values were determined with a colorimeter (Hunter Lab, Illinois, USA) using the standard illuminant D_{65}, calibrated with white and black standard plates. A 2° standard observer angle with an 8 mm aperture was applied. Color parameters, including L^*, a^*, and b^* values, were reported as averages from at least 5 measurements. The color difference (ΔE) was calculated as previously reported [19].

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

where L_0^*, a_0^*, b_0^* correspond to the control formulation.

2.2.6 Nutritional quality

The crude fat content was determined on a dry basis using Soxhlet extraction, with petroleum as a solvent. The wet basis fat content was calculated from the dry basis fat content considering the moisture level.

The energy from fat was calculated based on its caloric content, 9 kcal/g. The values were reported on a wet basis [20].

The calcium content was calculated based on that in CBP, 1.48%, as previously reported [2]. Then, the total Ca in a patty can be estimated as:

$$Calcium\ content\ (\%) = \frac{(X * 1.48)}{100} \quad (3)$$

where *x* is the percent of CBP in the patty formulation.

2.2.7 Texture profile analysis

The texture of the cooked samples was assessed using texture profile analysis (TPA) with a TA-XT Plus device (Stable Micro Systems, Ltd., Godalming, UK) as described in a previous study [21]. Briefly, the cooked samples were cored using a sterile 1.3 cm diameter cylindrical plastic borer, and the sample height was controlled at 1.0 cm. Each piece was compressed twice to 50% of its original height with a cylindrical aluminum probe. The pre-test and post-test speeds were maintained at 5 mm/s. The TPA values, including hardness, gumminess, springiness, cohesiveness, adhesiveness, and chewiness, were determined from 5 measurements.

2.2.8 Sensory evaluation

The cooked samples were evaluated for their attributes by 30 untrained panelists using a 9-point hedonic scale as previously reported [22]. The sensory attributes (color, flavor, taste, texture, and overall acceptability) were reported.

2.2.9 Oxidative stability of patties

Lipid oxidation in pork patties was assessed by measuring 2-thiobarbituric acid reactive substances (TBARS) according to a previously reported method with slight modification [23]. Samples (3 g) were mixed with TBA (3 mL) and TCA solutions (17 mL) before boiling and centrifugation at 1000 × g for 10 min. The supernatant was collected to measure an absorbance at 532 nm (PG model T80, Woodway Lane, United Kingdom) expressed as mg of malondialdehyde (MDA)/kg sample referencing an MDA standard.

2.3 Statistical analysis

International business machines (IBM) statistical package for the social sciences (SPSS) software (Version 28.0, IBM, USA) was utilized for all statistical analyses. A one-way analysis of variance (ANOVA) was conducted to determine the statistical significance of differences between multiple independent groups for a single factor. The F-value was calculated, while the *p*-value ($p<0.05$) was used to indicate statistical significance.

3. Results and discussion

3.1 Characteristic of TP pectin

Pectin extracted from TP was a powder with a yellow or orange color, while that of commercial pectin powder was white (Figure 1). The color difference is likely due to carotenoids, pigments in tomatoes, which remained after extraction.

(A) (B)

Figure 1 Physical appearance of TP pectin (A) and commercial pectin (B).

The extracted pectin was 39.71±3.28% carotenoids, confirming the presence of lycopene in this pectin. Similar results were previously reported [24]. Contamination of carotenoids in pectin extracted from tomatoes might not limit its use, but it can improve the color of some foods. The presence of lycopene in pectin extracted from TP could serve as a natural colorant with antioxidant properties for food applications. This pectin's degree of esterification was 8.52, making it a low-methoxyl pectin. Notably, this is slightly elevated compared to a previously reported value, 4.71 [25]. It is hypothesized that this pectin would gel after being activated by calcium from either chemical or natural sources. Therefore, changes in the flow behavior of pectin induced by calcium ions in CBP were evaluated. Unfortunately, gelation of TP pectin alone was not observed. This might have been due to fragmentation of long chain pectin molecules by acid hydrolysis during extraction with citric acid under microwave digestion. The viscosity of the pectin solution was 5.57±0.02 Cp. This value increased to 6.34±0.01 and 6.7 ±0.03 Cp, when 0.5 and 1.0% CBP was added, respectively. The increased viscosity of the pectin solution with higher CBP concentrations suggests that cross-linking of pectin chains likely occurred. However, the cross-linking of short-chain pectin might not be sufficient to form a complete 3-dimensional structure capable of trapping water molecules as a gel. The viscosity of the pectin solution plateaued at 0.5% CBP addition. Further increasing the CBP level to 1.0% did not significantly increase viscosity. Thus, 0.5% CBP addition was used in further development of a pectin gel to serve as a fat replacer in meat products. A combination of pectin from TP and commercial sources is necessary to extend the pectin chain before inducing formation of a gel network. TP pectin and commercial pectin in a 1:3 ratio with 2.0% total mixed pectin was also initially studied. Additionally, incorporating non-meat proteins, particularly soy protein, into this pectin gel is important for enhancing the texture and mouthfeel of fat. This enables it to replace fat in meat products, similar to the successful fat replacer prepared from konjac-carrageenan gel in a no-fat chicken sausage [26].

Although the preparation of pectin gel from TP combined with commercial pectin was successfully developed, the optimal ratio of pectin from different sources needs to be evaluated before scale-up. The availability of by-products (TP or catfish waste) must be assessed for practical application. Additionally, management of agricultural waste streams, with a focus on maintaining quality, is a vital concern. These aspects provide a more balanced view regarding the potential application and associated limitations.

3.2 Characteristic of pork patty substituted with different FR levels

3.2.1 Color

The color characteristics of pork patty were significantly influenced by the incorporation of FR, as outlined in Table 2. The lightness (L* value) demonstrated a significant decrease ($p < 0.05$) with increasing levels of fat replacement, ranging from 57.58 to 48.72. This indicated that the use of pectin-based gel FR contributed to a darker coloration of the patties. Similar findings have been reported by [27], which found a reduction in lightness of low-fat plant-based hamburger patties upon introduction of FR. In contrast, the a* value showed a notable increase ranging from 6.22 to 7.82 up on adding more FR. This suggested that pectin-based gel not only replaced the fat but also enhanced the redness of the pork patty ($p < 0.05$). Increasing redness up on adding FR prepared from rapeseed oil oleogels based on beeswax in beef heart patty [28]. The b* value, which represents yellowness, remained relatively unchanged in the values between 18.41 and 19.47. However, statistical analysis revealed that only the patty substituted with 25% FR displayed a significant increase compared to the control sample. Furthermore, the total color difference (ΔE) between the test samples and the control showed a statistically significant increase ($p < 0.05$) as the level of fat replacement increased. Although these color changes are scientifically measurable, their effect on consumer acceptance might be more consequential and should be discussed.

Table 2 Color values of pork patties substituted with various levels of FR.

Treatment	Color value			
	L^*	a^*	b^*	ΔE
CT	57.58 ± 0.26^a	6.22 ± 0.09^d	18.72 ± 0.04^{ab}	-
R25	55.36 ± 0.14^b	7.02 ± 0.13^c	19.47 ± 0.05^a	2.47 ± 0.18^d
R50	52.59 ± 0.24^c	7.48 ± 0.12^b	18.41 ± 0.13^{ab}	5.16 ± 0.25^c
R75	51.88 ± 0.46^d	7.10 ± 0.11^c	18.94± 0.23^{ab}	5.78 ± 0.46^b
R100	48.72 ± 0.05^e	7.82 ± 0.25^a	18.89± 0.39^{ab}	9.01 ± 0.02^a

Different letters ($^{a-e}$) within the same column indicate statistically different values (p <0.05).
Mean ± SE was based on 5 replications.

3.2.2 Fat content and energy from fat in pork patty

Fat content in pork patties decreased significantly, by up to 70.53% (wet basis) when 100% of the available fat was replaced with our FR. However, zero fat could not be achieved, although fat was not added to the formulation. The remaining fat likely originated from the intrinsic fat content of pork. This finding agrees with previous reports showing a reduction in fat content in frankfurter sausage when fat was entirely replaced with FRs, while residual fat was still observed [29]. Thus, only substantial fat reduction can be achieved in pork patties, contributing to a healthier nutritional profile.

Additionally, the energy from fat decreased from 240.02 to 70.75 kcal after substitution of fat with 100% FR (Table 3). This demonstrates a key advantage of fat substitutes in pork patty formulations, thereby improving the nutritional value of these products. Recent studies have shown that FRs can significantly reduce the energy of frankfurter sausage while maintaining sensory qualities [29]. Furthermore, this strategy supports a previous study emphasizing the improvement of the nutritional benefits of fat substitutes to balance the nutrient profiles of meat products.

Substituting FR made from pectin and fish bone powder in pork patties not only reduced the fat content and caloric value of the product, but also significantly improved its nutritional profile, especially the calcium content. The total calcium content of pork patties was increased (Table 3). Similar to the findings to this study demonstrates that adding fish bone powder to Mu Yor increases its calcium content [12]. Our FR is an effective ingredient for enhancing the calcium content of pork patties. Available calcium from fish bone (salmon and cod) has been reported to be absorbed effectively as $CaCO_3$ when assessed in young humans [30]. Sufficient calcium intake is crucial for maintaining bodily functions. The recommended daily calcium intake varies by age, gender, and health status. The Thai Recommended Dietary Allowance (RDA) suggests an intake ranging from 500 to 1,300 mg/day. Thus, by reducing fat and simultaneously increasing calcium levels, our FR improved the nutritional profile of the patties, promoting a healthier perception of these meat products.

Table 3 Nutritional quality of pork patties substituted with various levels of FR.

Nutritional quality	Patty recipe				
	CT	R25	R50	R75	R100
Fat (wet basis) (g/100g)	26.67 ± 0.43^a	24.36 ± 0.38^b	21.89 ± 0.46^c	16.83 ± 0.17^d	7.86 ± 0.05^e
Calories from fat (kcal/100g)	240.02 ± 3.91^a	219.24 ± 3.39^b	197.03 ± 4.12^c	151.46 ± 1.53^d	70.75± 0.48^e
Increased calcium (mg/kg)	0	3.33	6.66	9.99	13.32

Different letters ($^{a-e}$) within the same row indicate statistically different values (p<0.05).
Mean ± SE was based on 3 replications.

3.2.3 Textural properties

The reformulated patties with varying levels of FR in this study demonstrated some textural attributes (Table 4). Replacement of fat with FR resulted in a significant decrease (p <0.05) in hardness, springiness, gumminess, and chewiness when the fat replacement level was ≥25%. Increasing the fat replacement level beyond 25% had no additional significant effect on these parameters (p <0.05). In contrast, cohesiveness decreased at 25% fat replacement but tended to increase at higher replacement levels, reaching its highest value in the R100 sample. These findings indicated that fat replacement using our FR significantly influenced the texture of pork patties (p <0.05). This observation agrees with previous reports that attribute increased hardness and chewiness of low-fat burgers to a denser structure formed after substituting fat with a hydrogel made from chia and linseed oil [11].

Table 4 Textural properties of pork patties with different FR levels.

Textural property	Patty recipe				
	CT	R25	R50	R75	R100
Hardness (N)	18.74±1.90[a]	13.49±2.31[b]	12.14±1.11[b]	14.23±1.47[b]	13.83±3.26[b]
Springiness	0.67±0.06[a]	0.55±0.05[b]	0.50±0.05[b]	0.56±0.06[b]	0.58±0.10[b]
Cohesiveness	0.35±0.02[ab]	0.31±0.01[b]	0.33±0.04[ab]	0.34±0.03[ab]	0.36±0.04[a]
Gumminess (N)	6.54±0.62[a]	4.21±0.76[b]	4.02±0.31[b]	4.96±0.88[b]	4.99±1.54[b]
Chewiness (N)	4.35±0.54[a]	2.37±0.59[b]	2.02±0.31[b]	2.79±0.56[b]	2.98±1.42[b]

Different letters ([a-b]) within the same row indicate statistically significant differences (p<0.05).
Mean ± SE was based on 5 replications.

3.2.4 Sensory analysis

Although the nutritional value and oxidative stability of the patties were improved, consumer acceptance remains a crucial factor. Therefore, sensory evaluations were conducted on pork patties produced with FRs made from a pectin-fish bone powder mixture. Sensory evaluation revealed a reduction in consumer acceptability with increased FR substitution (Figure 2). This reduction resulted from texture and taste preferences. The reduced flavor score was attributed to a sour taste, based on the panel discussion. This might be due to the residual acid in TP pectin since citric acid was used as a solvent. Thus, fat reduction in acidic foods is another application of TP pectin. A reduction of fat from set yoghurt by low-methoxyl pectin has been reported [15]. Thus, application of an FR at a suitable level might be a crucial criterion to minimize adverse impacts on consumer acceptability. Substitution using FR at 25% would be possible since a significantly reduced acceptability was not observed. However, evaluating consumer acceptability in real-market conditions must be conducted to ensure the practical application of this FR.

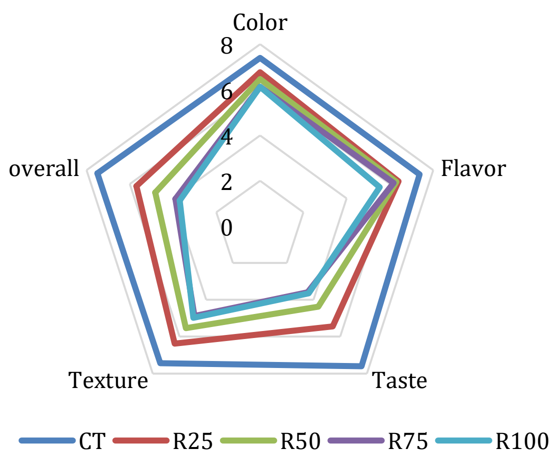

Figure 2 Sensory attributes of pork patties with various levels of FR.

3.2.5 Oxidative stability during storage

The differences in fat content among the samples are expected to affect the oxidative stability during storage, which can be assessed using the TBARS method. Before the cold storage study (Day 0), all patty samples exhibited lower oxidation values compared to the control (Table 5). This suggests that reducing the fat content, which acts as a reactant in lipid oxidation, by replacing it with FR, may help slow the formation of rancid products after preparation and cooking. This inhibitory effect may be attributed to the carotenoid and lycopene content remaining in the TP pectin present in FR. It has been reported that dried tomato powder can function as an antioxidant in meat products [31]. Oxidative rancidity becomes pronounced with increased storage times. Monitoring quality changes over the product shelf life will yield insightful information about shelf-life extension by active ingredients in food. However, storage studies for various periods could give information about the deterioration trends of a food product. Thus, storage of pork patties at 4 °C for a week was conducted. Lipid oxidation became more pronounced with increased storage time (Table 5). The oxidation values of patties substituted with 100% FR remained constant, demonstrating that FR effectively reduced lipid oxidation. Our FR is hypothesized to have the capability to extend the shelf life by retarding chemical deterioration. However, extending the storage period and monitoring other quality attributes must be fully studied to gain insightful information regarding the storage stability of low-fat pork patties.

Table 5 TBARS value (mg MDA/kg) of pork patties during storage at 4 °C for 7 days.

Treatment	Store time (days)	
	0	7
CT	4.63 ± 0.17^{a}	5.40 ± 0.07^{a}
R25	3.44 ± 0.32^{b}	4.59 ± 0.03^{b}
R50	3.43 ± 0.23^{b}	4.49 ± 0.07^{b}
R75	2.58 ± 0.07^{c}	3.71 ± 0.30^{c}
R100	2.19 ± 0.17^{d}	2.19 ± 0.06^{d}

Different letters ($^{a-d}$) within the same column indicate statistically different values (p <0.05).
Mean ± SE was based on 3 replications.

4. Conclusions

A fat replacer based on pectin gel (from tomato pomace mixed with a commercial brand) was successfully developed, using fish bone powder to induce gelation in the presence of soy protein isolate. Its application in pork patties demonstrated both benefits and challenges. FR substitution effectively reduced fat and caloric content, enhanced oxidative stability, and significantly increased calcium levels. However, it also unfavorably affected sensory attributes, limiting its use at higher substitution levels. Further research is needed to optimize the sensory properties of pork patties with this FR to facilitate its wider adoption in the meat industry.

5. Ethical approval

This study was conducted in accordance with the Declaration of Helsinki and was approved (Approval Number: HE672159) by the Center for Ethics in Human Research, Khon Kaen University. Informed consent was obtained for experimentation with human subjects. The privacy rights of human subjects must always be observed.

6. Acknowledgements

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7. Conflicts of interest

The authors declare there is no conflict of interest.

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