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ARTICLE

The Potential Substitution of Oyster Shell Powder for Phosphate in Pork Patties Cured with Chinese Cabbage and Radish Powder

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Abstract The use of natural ingredients in meat processing has recently gained considerable interest, as consumers are increasingly attracted to clean-label meat products. However, limited research has been conducted on the use of natural substitutes for synthetic phosphates in the production of clean-label meat products. Therefore, this study aimed to explore the potential of oyster shell powder as a substitute for synthetic phosphates in pork patties cured with Chinese cabbage or radish powders. Four different groups of patties were prepared using a combination of 0.3% or 0.6% oyster shell powder and 0.4% Chinese cabbage or radish powder, respectively. These were compared with a positive control group that contained added nitrite, phosphate, and ascorbate and a negative control group without these synthetic ingredients. The results showed that patties treated with oyster shell powder had lower ($p<0.05$) cooking loss, thickness and diameter shrinkage, and lipid oxidation than the negative control but had lower ($p<0.05$) residual nitrite content and curing efficiency than the positive control. However, the use of 0.6% oyster shell powder adversely affected the curing process, resulting in a decreased curing efficiency. The impact of the vegetable powder types tested in this study on the quality attributes of the cured pork patties was negligible. Consequently, this study suggests that 0.3% oyster shell powder could serve as a suitable replacement for synthetic phosphate in pork patties cured with Chinese cabbage or radish powders. Further research on the microbiological safety and sensory evaluation of clean-label patties during storage is required for practical applications.

Keywords oyster shell powder, Chinese cabbage powder, radish powder, nitrite alternative, phosphate replacement

Introduction

Nitrite is a widely used curing agent in the meat industry and offers several advantages, including the development of color, flavor, and antimicrobial and antioxidant effects (Alahakoon et al., 2015; Jo et al., 2020). However, concerns about the potential health risks associated with nitrite use have prompted researchers to explore alternative agents, such as natural ingredients (Delgado-Pando et al., 2021). In the meat processing industry, two alternative curing methods are commonly employed to replace synthetic nitrites. One method involves the use of vegetable powders rich in nitrate with starter cultures that possess nitrate-reducing activity. The other method involves the utilization of naturally occurring nitrite in products by applying pre-converted vegetable powders in which nitrate has already been converted to nitrite (Flores and Toldrá, 2021; Siekmann et al., 2021). The use of celery powder as a natural source of nitrate/nitrite is widely accepted as an alternative curing agent for meat products (Sebranek et al., 2012). However, some studies have investigated alternative sources of natural materials such as red beets, Chinese cabbage, radish, spinach, and parsley (Guimarães et al., 2021; Jeong et al., 2020a; Riel et al., 2017; Sucu and Turp, 2018). Vegetables such as Chinese cabbage (*Brassica rapa* L. ssp. pekinensis) and radish (*Raphanus sativus* L.) contain many naturally occurring nitrates, which have attracted attention as natural agents for alternative curing of meat products (Jeong et al., 2020a; Jeong et al., 2020b; Suh et al., 2013). Jeong et al. (2020a) conducted a study explored the use of Chinese cabbage, radish, and spinach powders as potential alternatives to sodium nitrite in sausage production. Among these powders, the radish powder (RP) demonstrated properties similar to those of sodium nitrite, suggesting its potential as a substitute. Guimarães et al. (2021) investigated the potential of natural curing agents, such as Japanese radish extracts, in the production of restructured ham and found that ham products containing these extracts exhibited color properties comparable to those of nitrite-cured products. However, natural substitutes for synthetic phosphates in the production of meat products with clean-labels have not yet been comprehensively examined in relation to research on alternatives for curing meat.

Phosphates are commonly employed in the manufacture of meat products, often in conjunction with salt, to achieve pH stability, improve texture and sensory attributes, inhibit fat oxidation, and preserve color, while enhancing water retention (Ellinger, 2018; Petracci et al., 2013). Nevertheless, concerns have been raised regarding the potential negative effects of phosphates on human health. Consequently, the demand for clean-label meat products has increased, leading to the replacement of synthetic phosphates with natural alternatives (Lee et al., 2023; Molina et al., 2023; Thangavelu et al., 2019). Oyster shells, primarily composed of calcium carbonate, are processed into powder by calcination and serve as a source of calcium. Oyster shells are a type of biowaste that can be obtained at relatively low cost, making them a viable and sustainable option for a variety of applications (Bonnard et al., 2020; Chilakala et al., 2019). As a result, the use of these powders as substitutes for phosphate in meat products has been the focus of continuous research (Cho and Jeong, 2018; Choi et al., 2014; Yoon et al., 2023). Previous studies have shown that incorporating oyster shell powder (OP) into pork sausages can improve water retention and texture, thereby enhancing the quality of the product and making it a potential substitute for sodium tripolyphosphate (STPP; Cho and Jeong, 2018; Jeong, 2018). However, the use of OP as a phosphate substitute in naturally cured meat products, particularly with respect to patties, has not been widely investigated. Previous studies have focused primarily on sausages, which have a different structure than that of patties. The open structure of patties made from coarsely ground meat may lead to unique quality attributes, such as color and pigment properties, which could be influenced by reducing conditions (King et al., 2023). Furthermore, there is a lack of information on the effects of OP on the properties of cooked frozen patties. While OP can be used as a substitute for phosphate in alternatively cured patties, its impact on the characteristics of cooked patties, including shrinkage, water holding capacity, and texture, is not fully understood. Therefore, the potential of OP to maintain the desired characteristics of cooked patties remains unclear, and further research is required to confirm this hypothesis.

Therefore, the objective of this study was to determine the effectiveness of OP as a phosphate replacement for pork patties cured with Chinese cabbage or RP as natural curing agents.

Materials and Methods

Preparation of chemicals and materials

Chinese cabbage powder (CP) and RP, used as natural nitrate sources in this study, were prepared as previously reported by Jeong et al. (2020a). Vegetables, including Chinese cabbages and radishes, sourced from local markets in Korea, were processed into powders. The vegetables were cut into appropriate sizes and the inedible portions were removed. They were then sliced and washed before blending for 10 min using a food processor. The resulting mixture was packaged and frozen at −18℃. It was then dried for 12 h at 60℃, pulverized, and sieved using a 30-mesh. The dried vegetables were placed in vacuum-sealed packages and stored at −18℃ until needed. Maltodextrin was added to the powders to standardize a nitrate content of 30,000 mg/kg and used on pork patties processing. OP was purchased from JK Biochem (Oyster Shell Calcium 40, Seoul, Korea), containing 52% calcium and less than 0.1% other minerals. The starter culture comprising *Staphylococcus canosus* was obtained from a supplier (Bactoferm® S-B-61, Chr Hansen, Milwaukee, WI, USA). Sodium ascorbate (#35268) and sodium nitrite (S2252) were obtained from Sigma-Aldrich (St. Louis, MO, USA) and Acros Organics (Geel, Belgium), and acerola juice powder was procured from Diana Food (Antrain, France).

Processing of pork patties

The preparation of patties necessitated the use of 15 kg of pork ham and back fat per batch of production. These materials were procured from a local supplier within 48 h of slaughter and their fat content was determined before processing. The amount of fat added was adjusted to attain the target fat content of 15% in the final product. Raw meat and back fat were subsequently processed using a chopper equipped with an 8 mm hole plate and a 4.5 mm hole plate, respectively, and then randomly assigned to six groups according to the formulation ratio (Table 1). Based on the weight of the ground pork and fat, basic ingredients, including 10% water, 1% NaCl, and 1% dextrose, were equally served in each batch and individually mixed using a mixer for 7 min. For the control (−), no additional additives were added beyond the basic ingredients, whereas the control (+), synthetic additives group, was supplemented with 0.3% STPP, 0.01% sodium nitrite, and 0.05% sodium ascorbate. In contrast, clean-label patties were tested using four different treatments. Treatment 1 included 0.4% CP and 0.3% OP, whereas treatment 2 contained 0.4% CP and 0.6% OP. Treatment 3 included 0.4% RP and 0.3% OP, whereas treatment 4 included 0.4% RP and 0.6% OP. The four treatments were supplemented with 0.04% starter culture to facilitate the conversion of nitrate to nitrite in the vegetable powders. Furthermore, these treatments received 0.295% acerola juice powder as a natural alternative to sodium ascorbate, serving as a curing accelerator. After mixing all batches, 90 g of each mixture was sequentially placed in Petri dishes (90×15 mm). All patties were then held at 40℃ for 2 h for curing before freezing at −24℃. On the designated day of analysis, the patties were thawed at 5℃ for 20 min prior to cooking and placed on an electric grill (GS6/C, Lincat, Lincoln, UK) preheated to 170℃ for cooking per group. During cooking, the patties were flipped every two min they reached a core temperature of 75℃. After cooking, the samples were cooled to room temperature for one hour before analysis. This process was repeated thrice for both preparation and analysis.

pH and cooking loss determination

The pH values were measured using a pH meter (Accumet® AB150, Thermo Fisher Scientific, Singapore) following the method described by Yoon et al. (2023). The samples were blended with distilled water at a ratio of 1:5. Cooking loss was determined by measuring the weight of patties before and after cooking and expressing the difference as a percentage.

Table 1. The formulation for preparing traditional patties or phosphate-free patties cured with Chinese cabbage or radish powder

Materials and ingredients (%)	Control (−)	Control (+)	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Ground pork ham (8 mm)	87.5	87.5	87.5	87.5	87.5	87.5
Ground backfat (4.5 mm)	12.5	12.5	12.5	12.5	12.5	12.5
Water	10.0	10.0	10.0	10.0	10.0	10.0
NaCl	1.0	1.0	1.0	1.0	1.0	1.0
Dextrose	1.0	1.0	1.0	1.0	1.0	1.0
Sodium tripolyphosphate	-	0.30	-	-	-	-
Oyster shell powder	-	-	0.30	0.60	0.30	0.60
Sodium nitrite	-	0.01	-	-	-	-
Chinese cabbage powder[1)]	-	-	0.40	0.40	-	-
Radish powder[2)]	-	-	-	-	0.40	0.40
Starter culture[3)]	-	-	0.04	0.04	0.04	0.04
Sodium ascorbate	-	0.05	-	-	-	-
Acerola juice powder[4)]	-	-	0.295	0.295	0.295	0.295

[1)] Chinese cabbage powder contained 32,020 mg/kg $NaNO_3$ (n=5).
[2)] Radish powder contained 32,283 mg/kg $NaNO_3$ (n=5).
[3)] Starter culture contained *Staphylococcus carnosus*.
[4)] Acerola juice powder contained 17.1% vitamin C (0.295% acerola powder, equivalent to 0.05% sodium ascorbate).

Patty shrinkage measurement

The shrinkage of patties was determined as described by Jeong et al. (2016). The initial thickness or diameter of the raw patties was measured using Vernier calipers (#530-101, Mitutoyo, Kawasaki, Japan). Following cooking and subsequent cooling, the patties were reassessed to determine the percentage reduction in their thickness or diameter relative to the original uncooked state.

Shear force measurement

The shear force of patties was evaluated according to the method described by Jeong et al. (2009). After cooking and cooling, the patties were divided into two sections measuring 2.5 cm in width. Five patties were used for each experimental group. The measurement obtained from the texture meter (TA-XT2*i*, Stable Micro System, Godalming, UK) equipped with a Warner-Bratzler blade, which indicates the maximum force required to shear the sample, was expressed in Newtons. The crosshead speed in the texture analyzer was determined to be 5 mm/s.

Instrumental color measurement

The patties were divided horizontally to their full height to evaluate the color of their cross-sections. The CIE L*a*b* values of the internal surfaces were measured using a color meter (CR-400, Konica Minolta, Osaka, Japan; illuminant C) equipped with an aperture (Φ 8 mm). Four readings were recorded for each treatment. A white standard plate (No. 20333081) was used to calibrate the color meter prior to the measurement.

Residual nitrite analysis

The residual nitrite content in the cooked patties was analyzed using the AOAC method 973.31 (AOAC, 2016). A standard curve for sodium nitrite was employed to determine the nitrite content of the samples, and the results were reported in milligrams per kilogram.

Cured meat pigment, total pigments, and curing efficiency analyses

The analysis of cured meat pigment and total pigments in cooked patties was conducted in accordance with the method outlined by Hornsey (1956), and the results were reported in milligrams per kilogram. The curing efficiency was calculated as the percentage of cured pigment in relation to the total pigment content, as described by King et al. (2023).

Thiobarbituric acid reactive substance analysis

Thiobarbituric acid reactive substance (TBARS) analysis was conducted according to Tarladgis et al. (1960) to evaluate the malondialdehyde (MDA) content of the patties. The results obtained from TBARS analysis were presented in milligrams of MDA per kilogram of sample.

Statistical analysis

The present investigation was conducted using a completely randomized block design comprising six distinct groups. Data collected from three separate trials were statistically analyzed using the Proc GLM procedure within the SAS program (SAS Institute, Cary, NC, USA). A statistical model with a significance level of $p<0.05$ was applied to separate the mean differences between the groups for the dependent variables using Duncan's multiple range test.

Results and Discussion

pH and cooking loss

There were no differences ($p>0.05$) in the pH values between treatments 1 and 3 or between treatments 2 and 4 (Table 2). This finding indicates that the type of vegetable powder used did not have a notable influence on the pH of the pork patties. However, the treatments exhibited higher pH values ($p<0.05$) than those of the control samples (Table 2). The elevated pH

Table 2. The pH, cooking loss, reduction in thickness, reduction in diameter, and shear force of traditional patties or phosphate-free patties cured with Chinese cabbage or radish powder

Treatments[1)]	pH	Cooking loss (%)	Reduction in patty thickness (%)	Reduction in patty diameter (%)	Shear force (N)
Control (−)	6.21 ± 0.02^{D}	24.09 ± 0.61^{A}	10.36 ± 0.65^{A}	12.09 ± 0.35^{A}	18.07 ± 0.46^{B}
Control (+)	6.39 ± 0.02^{C}	13.99 ± 0.33^{D}	6.93 ± 0.45^{B}	10.15 ± 0.23^{B}	19.81 ± 0.33^{A}
Treatment 1	6.64 ± 0.02^{B}	19.07 ± 0.53^{B}	7.85 ± 0.55^{B}	10.93 ± 0.43^{B}	18.76 ± 0.34^{AB}
Treatment 2	6.81 ± 0.04^{A}	17.26 ± 0.40^{C}	7.59 ± 0.63^{B}	10.71 ± 0.27^{B}	19.72 ± 0.30^{A}
Treatment 3	6.65 ± 0.02^{B}	17.73 ± 0.40^{C}	7.87 ± 0.55^{B}	10.91 ± 0.31^{B}	19.01 ± 0.52^{AB}
Treatment 4	6.81 ± 0.04^{A}	16.97 ± 0.54^{C}	7.54 ± 0.41^{B}	10.72 ± 0.30^{B}	19.73 ± 0.37^{A}

All values are presented as the mean±SE.

[1)] Treatments: control (−), no synthetic or natural additives; control (+), synthetic additives; treatment 1, 0.4% CP+0.3% OP; treatment 2, 0.4% CP+0.6% OP; treatment 3, 0.4% RP+0.3% OP; and treatment 4, 0.4% RP+0.6% OP.

$^{A–D}$ Superscript letters within a column indicate statistically significant differences ($p<0.05$).

CP, Chinese cabbage powder; OP, oyster shell powder; RP, radish powder.

observed in these patties may be due to the high pH (pH 9.84) of the OP added. Previous studies have suggested that the addition of oyster shell calcium to conventional meat products can cause an increase in pH (Cho and Jeong, 2018; Choi et al., 2014). This observation was corroborated by the present study using natural curing methods involving CP and RP. Additionally, as the amount of OP added to pork patties cured with vegetables increased, a significant increase ($p<0.05$) in the pH was observed (Table 2).

The use of OP in combination with CP or RP in cured pork patties resulted in lower ($p<0.05$) cooking loss than that of the control (−) (Table 2), suggesting that the addition of these natural additives contributed to increased water retention. In contrast, treatments 1–4, which used natural additives, demonstrated higher ($p<0.05$) cooking loss than the control (+) (Table 2). Previous research conducted by Choi et al. (2014) and Yoon et al. (2023) indicated that replacing phosphate with OP in pork ham or sausages did not result in a significant difference in cooking loss compared with conventional meat products. However, the findings from this study on pork patties differ from these previous results, suggesting that the replacement of phosphate with OP may have a different effect on cooking loss for this particular type of product. However, in this study, there was no difference ($p>0.05$) in cooking loss among treatments 2–4, but cooking loss was lower ($p<0.05$) than that in treatment 1 (Table 2). Therefore, the combination of 0.4% CP and 0.3% OP in clean-label patties was less effective at reducing cooking loss.

Reduction in patty thickness and diameter

Phosphate is widely recognized for its capacity to minimize shrinkage of meat products during cooking (Anjaneyulu et al., 1990; Long et al., 2011). Interestingly, there was no significant difference ($p>0.05$) in the reduction of thickness and diameter between the control (+) with synthetic additives and all treatments with natural additives (Table 2). Moreover, the treatments showed a smaller reduction ($p<0.05$) in both diameter and thickness than the control (−) without any additives. These results suggest that OP may serve as an alternative to phosphate as it achieved a similar level of shrinkage as the control group (+) when incorporated into patties at a concentration of 0.3%, regardless of the vegetable powder used in combination.

Shear force

Shear force refers to the force that a meat product can withstand when subjected to shearing, and serves as an indicator of its hardness (Novaković and Tomašević, 2017). Despite the variation in OP concentration and the type of vegetable powder used, no differences ($p>0.05$) were observed in shear force values between the different treatments and the control (+) (Table 2). However, among the various treatments, those containing 0.6% OP (treatments 2 and 4) had higher ($p<0.05$) shear force values than the control (−). In a previous investigation of pork sausages, Jeong (2018) found that a combination of 0.2% OP and 0.3% eggshell powder led to a significant improvement in hardness. Typically, the binding capacity of meat products is improved by increasing their ionic strength via the addition of phosphate and salt (Sebranek, 2009). In this study, the precise cause of the increase in shear force values owing to the use of OP is unknown. Nonetheless, it is conceivable that calcium in OP, functioning as a divalent cation, may facilitate protein bonding in meat, ultimately leading to the formation of a strong protein network (Cáceres et al., 2006; Lau et al., 2000). Although there was a trend towards higher shear forces in treatments 2 and 4 compared to treatments 1 and 3, statistical significance was not achieved (Table 2).

Instrumental color

The control (+) showed no difference ($p>0.05$) in CIE L* values from all treatments or the control (−) (Table 3). However,

Table 3. The internal color of traditional patties or phosphate-free patties cured with Chinese cabbage or radish powder

Treatments[1)]	Internal color		
	CIE L*	CIE a*	CIE b*
Control (−)	68.80±0.30^{A}	5.78±0.12^{C}	10.37±0.21^{A}
Control (+)	68.34±0.23^{AB}	10.02±0.09^{AB}	7.43±0.08^{C}
Treatment 1	67.45±0.38^{B}	9.84±0.18^{AB}	8.35±0.16^{B}
Treatment 2	67.52±0.30^{B}	9.62±0.14^{B}	8.50±0.09^{B}
Treatment 3	67.54±0.35^{B}	10.09±0.14^{A}	8.51±0.29^{B}
Treatment 4	67.67±0.24^{B}	9.86±0.14^{AB}	8.07±0.13^{B}

All values are presented as the mean±SE.
[1)] Treatments: control (−), no synthetic or natural additives; control (+), synthetic additives; treatment 1, 0.4% CP+0.3% OP; treatment 2, 0.4% CP+0.6% OP; treatment 3, 0.4% RP+0.3% OP; and treatment 4, 0.4% RP+0.6% OP.
$^{A–C}$ Superscript letters within a column indicate statistically significant differences ($p<0.05$).
CP, Chinese cabbage powder; OP, oyster shell powder; RP, radish powder.

the treatments showed lower ($p<0.05$) CIE L* values than the control (−). Additionally, the type of vegetable powder used and the amount of OP added did not have an impact ($p>0.05$) on the CIE L* values of pork patties within the treatment groups.

Efficient assessment of the curing process in meat products can be achieved by evaluating critical indicators, including CIE a* and cured pigment levels in cured meat (Feng et al., 2016; King et al., 2023). In this study, there was no significant difference ($p>0.05$) in the CIE a* values between the control (+) and all treatments (Table 3). Furthermore, the inclusion of OP in patties containing various vegetable powders did not affect ($p>0.05$) CIE a* values. Additionally, Lee et al. (2011) reported that adding OP to pork sausages did not result in a difference in CIE a* values compared with sausages containing phosphate. Although not statistically significant, the general pattern of CIE a* values decreased as the OP concentration in patties cured with CP or RP increased from 0.3% to 0.6% (Table 3). These findings may be attributed to the decrease in cured meat pigment, as shown in Table 4. As anticipated, the control (−) had the lowest ($p<0.05$) CIE a* values among all the patties tested because of the absence of nitrite or natural curing agents.

The control (−) exhibited the highest CIE b* values ($p<0.05$), whereas the control (+) had the lowest values ($p<0.05$; Table 3). However, among the treatments, vegetable powder type and OP did not significantly affect the CIE b* values ($p>0.05$). According to various studies, the use of plant-based powders as natural curing agents can affect the color of the final products, particularly when they originate from different sources (Jeong et al., 2020b; Riel et al., 2017; Sebranek and Bacus, 2007). In a related study, Jeong et al. (2020a) found that products using powders from leafy vegetables often exhibit higher levels of CIE b* compared to those using RP. Nevertheless, in this study, no significant difference ($p>0.05$) was observed in CIE b* values across the different vegetable sources used in the treatments (Table 3). One potential explanation for this result may be the incorporation of OP, which is typically white in color, along with CP or RP, resulting in a dilution effect on the CIE b* of the pork patties.

Residual nitrite

Treatments 1 to 4 had similar ($p>0.05$) residual nitrite content (Table 4). However, the treatments exhibited a lower ($p<0.05$) residual nitrite content than that of the control (+). This finding is consistent with several previous studies showing that clean-label or alternatively cured products generally have lower levels of residual nitrite than those containing sodium

Table 4. The residual nitrite, cured meat pigment, total pigments, curing efficiency, and TBARS of traditional patties or phosphate-free patties cured with Chinese cabbage or radish powder

Treatments[1)]	Residual nitrite (mg/kg)	Cured meat pigment (mg/kg)	Total pigments (mg/kg)	Curing efficiency (%)	TBARS (mg MDA/kg)
Control (−)	0.35±0.03^{C}	0.63±0.08^{D}	52.13±1.14^{BC}	1.20±0.15^{D}	0.52±0.03^{A}
Control (+)	44.01±1.01^{A}	39.05±0.52^{AB}	51.45±0.60^{C}	75.89±0.24^{A}	0.09±0.01^{B}
Treatment 1	33.62±2.07^{B}	40.26±0.60^{A}	56.55±0.96^{A}	71.70±0.65^{B}	0.09±0.01^{B}
Treatment 2	34.51±1.20^{B}	37.85±0.71^{BC}	54.68±0.69^{A}	69.22±1.06^{C}	0.10±0.01^{B}
Treatment 3	31.43±2.27^{B}	40.19±0.60^{A}	54.40±0.56^{AB}	73.52±0.74^{B}	0.10±0.01^{B}
Treatment 4	33.14±1.33^{B}	36.95±0.65^{C}	54.29±0.78^{AB}	67.86±1.42^{C}	0.10±0.01^{B}

All values are presented as the mean±SE.
[1)] Treatments: control (−), no synthetic or natural additives; control (+), synthetic additives; treatment 1, 0.4% CP+0.3% OP; treatment 2, 0.4% CP+0.6% OP; treatment 3, 0.4% RP+0.3% OP; and treatment 4, 0.4% RP+0.6% OP.
$^{A–D}$ Superscript letters within a column indicate statistically significant differences ($p<0.05$).
TBARS, thiobarbituric acid reactive substances; MDA, malondialdehyde; CP, Chinese cabbage powder; OP, oyster shell powder; RP, radish powder.

nitrite (Riel et al., 2017; Siekmann et al., 2021; Yong et al., 2021). This difference may be attributed to the reduction of nitrite to nitric oxide, which is influenced by the addition of a starter culture for alternative curing, resulting in its depletion (Ras et al., 2017; Wang et al., 2016). Another possible reason for the low levels of residual nitrite in meat products produced using alternative curing methods could be the presence of bioactive substances in plant sources (Viuda-Martos et al., 2010).

Cured meat pigment, total pigments, and curing efficiency

The results indicated that the amounts of cured meat pigment in treatments 2 and 4 were lower ($p<0.05$) than those in treatments 1 and 3 (Table 4). This outcome is attributed to the higher concentration of OP in pork patties, which significantly affects pH levels and thereby reduces cured meat pigment (Sebranek, 2009). Research has consistently emphasized the significance of pH in meat curing. Numerous studies, including those conducted by Fox (1966), Kim et al. (2019), and Sebranek (2009), have found that acidic conditions promote the reaction between reductants and nitrite, resulting in the rapid formation of nitric oxide, which is responsible for the coloration of cured meat. However, in this study, the relatively high pH in treatments 2 and 4, which contained 0.6% OP, delayed the nitrite curing reaction. Therefore, extending the curing time for these treatments may be necessary to produce sufficient amounts of nitric oxide (Sebranek, 2009). This may account for the lower CIE a* values observed in treatments 2 and 4 in our study (Table 3). However, treatments 1–3 did not differ ($p>0.05$) from the control (+) for the cured meat pigment (Table 4).

All four treatments showed significantly higher ($p<0.05$) total pigments than the control (+) (Table 4). The higher overall pigment level may be attributed to the influence of elevated pH levels in the treatments, which is in line with the findings of Fraqueza et al. (2006) and Hornsey (1959). Nevertheless, there were no significant differences ($p>0.05$) in total pigment content across all treatments or between the control groups (Table 4).

The results of this study indicate that the use of OP in curing meat patties has a negative impact on curing efficiency. Specifically, naturally cured patties containing varying levels of OP had a lower ($p<0.05$) curing efficiency than the control (+) (Table 4). Furthermore, among the treatments, treatments 2 and 4 had significantly lower ($p<0.05$) curing efficiency. This was likely due to the increased use of OP, as was observed for the cured meat pigment in this study. These results indicate that the effect of OP with high pH on the curing efficiency of pork patties is more pronounced than that of vegetable powders in the study conducted. According to Sebranek (2009), elevated pH levels can negatively affect the curing process of meat by slowing down the reaction.

Thiobarbituric acid reactive substance

As expected, the highest TBARS values ($p<0.05$) were observed in the control (−) (Table 4). However, the combination of CP, RP, and OP in pork patties did not have a significant impact ($p>0.05$) on TBARS values compared to the control (+). This is consistent with the findings of Yoon et al. (2023), who reported similar TBARS values for pork sausages cured with 100 ppm sodium nitrite or 0.4% RP, and suggested that the antioxidative activity of nitrite converted from the added nitrate source, RP, may have inhibited lipid oxidation. Furthermore, Yoon (2021) investigated the efficacy of citrus fiber, dried plum powder, and oyster shell calcium as alternatives to phosphates in pork sausages. The results indicate that oyster shell calcium exhibited no significant differences in TBARS values throughout the storage period, suggesting an antioxidant effect attributable to the presence of CaO. Therefore, our results suggest that the natural ingredients used in clean-label pork patties effectively inhibit lipid oxidation in the final product.

Conclusion

This study found that OP could be used as a viable substitute for phosphate in the production of pork patties cured with CP or RP. The results of this study suggest that 0.3% OP may be sufficient to replace synthetic phosphate in pork patties cured with CP or RP. In particular, the findings indicate that patties with OP exhibit similar thickness and diameter shrinkage, and shear force values as those with phosphate addition when frozen patties were cooked. However, the effect of the type of vegetable powder combined with OP on the physicochemical properties of the patties was negligible. This study was limited to the use of OP as a natural substitute for synthetic phosphates in cured pork patties, and it did not explore other vegetable powders or combinations of powders. Therefore, further studies are needed to determine the optimal combination of natural additives for cured meat products and to explore the potential use of natural additives in other types of meat products.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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