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ARTICLE

Evaluating the Potential of Vegetable Powders as Nitrite Replacements in Cured Pork Sausages: Effects of Different Processing Methods to Produce Chinese Cabbage and Radish Powders

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Abstract This study investigated the potential of Chinese cabbage and radish powders as natural sources of nitrite in ground pork sausages. Four vegetable powders from Chinese cabbage and radish, depending on the processing method, were prepared for evaluation: filtered Chinese cabbage juice powder (FCJP), crushed Chinese cabbage powder (CCP), filtered radish juice powder (FRJP), and crushed radish powder (CRP). Both FCJP and FRJP from filtered juice of Chinese cabbages and radishes had higher total soluble solids and water soluble index compared to CCP and CRP from crushed Chinese cabbages and radishes. Additionally, FRJP and CRP showed a higher nitrate content than CCP and FCJP. The evaluation of vegetable powders against products containing sodium nitrite (control) or commercial vegetable powder in ground pork sausages showed that the use of FRJP and CRP resulted in similar levels of CIE a* compared to the control, whereas those cured with FCJP or CCP resulted in lower CIE a* values. However, regardless of the type and processing method of vegetables, all sausages treated with vegetable powders were similar in terms of cured pigment, total pigment, curing efficiency, and lipid oxidation compared with the control. Although lower hardness was observed in sausages treated with FRJP, no other treatments affected textural attributes. These results indicate that FRJP and CRP have great potential as natural curing agents for replacing nitrite in cured sausages. The use of powders obtained from filtered juices may provide extended utility as vegetable-based curing methods for other meat products.

Keywords vegetable powder, Chinese cabbage, radish, curing, pork sausages

Introduction

Meat curing, an established method in which nitrite and salt are added to perishable meat or poultry for preservation (Sebranek, 2009), has long been used in the meat industry. Nitrites, which are considered essential for curing meat, contribute to the cured color and flavor of meat products, exhibit antimicrobial effects, and suppress lipid oxidation (Parthasarathy and Bryan, 2012; Sindelar and Milkowski, 2011; Terns et al., 2011). Despite the benefits associated with nitrites, the negative perception of synthetic additives (Aschemann-Witzel et al., 2019; Jo et al., 2020) has led to an increased consumer interest in improved products that utilize natural materials (Asioli et al., 2017).

To produce nitrite using natural materials, nitrate-reducing bacteria are typically applied to plant sources that contain high levels of nitrates. Celery, a representative natural source of nitrate, has been extensively used commercially as a substitute for synthetic nitrites (Yong et al., 2021). However, according to the European Food Safety Authority regulations (Regulation No. 1169/2011), celery is known to contain allergenic substances, leading to the search for other plant sources, including spinach, red beets, Swiss chard, kimchi, Chinese cabbage, and radish to cure meat products (Choi et al., 2020; Jeong et al., 2020a; Pádua et al., 2019; Shin et al., 2017; Sucu and Turp, 2018). Plant-based materials as natural nitrate sources have been reported to exhibit quality and sensory properties similar to those of conventional synthetic nitrites (Guimarães et al., 2022; Jeong et al., 2020a; Sindelar et al., 2007).

Chinese cabbage (*Brassica rapa* L. ssp. *pekinensis*) and radish (*Raphanus sativus* L.) are inherently abundant in nitrates and bioactive compounds and have not been linked to allergies (Goyeneche et al., 2015; Seong et al., 2016; Suh et al., 2013). Therefore, these vegetables are considered suitable candidates for use as natural additives in meat products. According to Bae et al. (2020), ground radish powder has emerged as a more effective alternative to synthetic nitrite for achieving better curing results than celery powder, which is a commonly utilized commercial substitute. Jeong et al. (2020a) reported that crushed and dried Chinese cabbage powder had a curing efficiency similar to that of sodium nitrite when used to cure pork sausages.

Processing methods, such as juicing and grinding, which are applied prior to powdering vegetables, can also influence the nitrate content and other physicochemical properties of the final products. Vasconcellos et al. (2016) found that juiced beets had higher levels of nitrate and antioxidants than beet products obtained via other processing methods. Similarly, Kolte (2014) found that the pretreatment, juicing, and heating methods used can result in different characteristics in terms of nitrate and other components in vegetable juices. However, no studies have compared the characteristics of Chinese cabbage and radish powders subjected to different pretreatment methods prior to pulverization for nitrite/nitrate replacement. Understanding the properties and potential applications of powders derived from these processing techniques is crucial for the development of naturally cured meat products.

Therefore, this study investigated the physicochemical characteristics of powders from Chinese cabbage and radish processed using different methods, with the goal of determining their suitability for incorporation into ground pork sausage as substitutes for commercially available vegetable powder (CVP) and synthetic nitrites.

Materials and Methods

Preparation of Chinese cabbage and radish powders using different processing procedures

Fresh Chinese cabbages and radishes were procured from a local market. The initial procedures used to produce Chinese cabbage and radish powders, that is, washing under running water and the removal of inedible parts and excess water, are illustrated in Fig. 1. The vegetables were then cut into uniform pieces of approximately 4×4 cm^2 and randomly assigned to two groups for processing: juicing (Group A) or crushing (Group B). To produce filtered Chinese cabbage juice powder (FCJP) and filtered radish juice powder (FRJP), vegetables in Group A were juiced (Juice extractor #68, Santos, Vaulx-en-Velin, France) to separate the pulp, centrifuged, and filtered using a 75 μm mesh to remove any remaining solids. The vegetables in group B were ground to approximately 2×2 mm^2 using a chopper (C6 VV, Sirman, Curtarolo, Italy) to produce

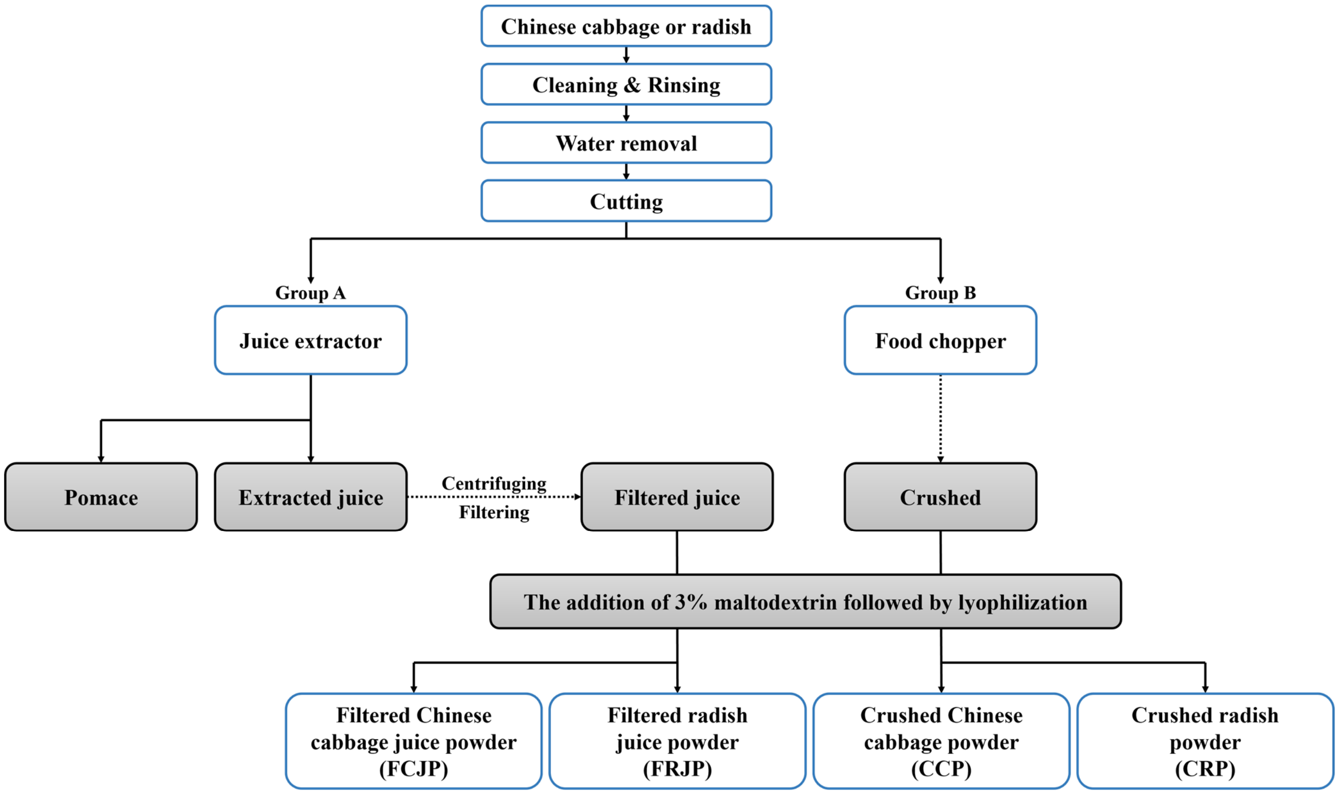

Fig. 1. Schematic diagram of manufacturing Chinese cabbage and radish powders using different processing methods.

crushed Chinese cabbage powder (CCP) and crushed radish powder (CRP). Samples from groups A and B were subsequently mixed with 3% maltodextrin (based on sample weight) and stored in a deep freezer (MDF-U700VX, PHC Holdings, Tokyo, Japan) at –80℃. The samples were subsequently dried in a vacuum freeze-dryer (Lyoph-Pride 20, Ilshinbiobase, Dongducheon, Korea) for three days at 0.67 Pa. The dried samples were subsequently processed using a blender and sieve to produce powder with a particle size of 600 μm. The prepared powders were vacuum-packed in oxygen-impermeable bags and stored in the dark at –24℃ until use.

Analysis of physicochemical characteristics of vegetable powders as replacements for synthetic nitrite

The drying yield was calculated as the percentage change in weight after drying, with respect to the initial weight before drying. To measure the pH, titratable acidity, and total soluble solids (TSS) of the vegetable powders, 5 g of each powder was mixed with 25 g of distilled water using a vortex mixer (VM-30, Daihan Scientific, Wonju, Korea). The mixtures were then centrifuged at 3,400×g for 10 min and the supernatant was filtered using Whatman No.1 filter paper (Cytiva, Little Chalfont, UK) for analysis. The pH of the sample solution was determined using a pH meter (Accumet® AB150, Thermo Fisher Scientific, Singapore). The titratable acidity was determined using the AOAC method 942.15 (AOAC, 2016) and the results were presented as a percentage. TSS were measured using a reflectometer (Atago® N1, Atago, Tokyo, Japan) and expressed as °Brix. Moisture content was evaluated using the AOAC method 930.04 (AOAC, 2016), and water activity was measured using a water activity analyzer (HP23-AW-A, Rotronic AG, Bassersdorf, Switzerland) at 25℃ on a 3 g sample in a plastic container. The color of the vegetable powder was measured using a CR-400 color meter (Konica Minolta, Osaka, Japan; illuminant C and 2° observer angle) attached to an 8 mm aperture after calibration with a white plate (No. 20333081). The water solubility index (WSI) and water absorption index (WAI) were evaluated using the method described by Anderson

(1982). The nitrite and nitrate ion contents in the powders were analyzed using the zinc reduction method described by Merino (2009). Standard curves were obtained by diluting $NaNO_2$ or KNO_3 with distilled water to concentrations ranging from 0 to 1.2 mg NO_2^-/L. The vegetable powders were diluted with distilled water to bring them within the detection range of standard curves. The diluted sample solution was reacted with sulfanilamide and N-(1-naphthyl)-ethylenediamine (NED) dihydrochloride and the absorbance of the resulting solution was measured using a spectrophotometer at 540 nm. The results obtained using standard curves were converted to sodium nitrite and sodium nitrate (mg/kg).

Preparation of pork sausages cured with sodium nitrite or vegetable powders

To compare the quality characteristics of pork sausages prepared with Chinese cabbage and radish powders, samples with 0.01% sodium nitrite (control) or 0.4% CVP (VegStable® 502 celery juice powder, Florida Food Products, Eustis, FL, USA) were prepared (Table 1). The FCJP, CCP, FRJP, and CRP treatments were supplemented with 0.4% of each vegetable powder derived from Chinese cabbages and radishes prepared using different processing methods. The use of celery powder in excess of 0.4% may result in an undesirable flavor in the final product (Alahakoon et al., 2015; Horsch et al., 2014). Based on this, a maximum limit of 0.4% vegetable powder was established. A starter culture consisting of 0.04% Bactoferm® CS-300 (Chr. Hansen, Milwaukee, WI, USA) was used to reduce naturally occurring nitrates in vegetable powder treatments. Prior to the production of sausages, pork ham and back fat were purchased from a local processor within 48 h post-mortem. Excessive muscle fat and connective tissue were removed, and the raw meat and back fat were chopped using a grinder with 3 mm plates. The mixture samples were allocated randomly into six separate groups, and each batch was subsequently

Table 1. Formulation for ground pork sausages cured with vegetable powders and starter culture to replace synthetic nitrite

Materials and ingredients (%, w/w)	Treatments[1)]					
	Control	CVP	FCJP	CCP	FRJP	CRP
Pork ham	70.00	70.00	70.00	70.00	70.00	70.00
Pork back fat	15.00	15.00	15.00	15.00	15.00	15.00
Ice/water	15.00	15.00	15.00	15.00	15.00	15.00
Sub total	100.00	100.00	100.00	100.00	100.00	100.00
Sodium chloride	1.50	1.50	1.50	1.50	1.50	1.50
Sodium tripolyphosphate	0.30	0.30	0.30	0.30	0.30	0.30
Dextrose	1.00	1.00	1.00	1.00	1.00	1.00
Sodium ascorbate	0.05	0.05	0.05	0.05	0.05	0.05
Sodium nitrite	0.01	-	-	-	-	-
Commercial vegetable powder	-	0.40	-	-	-	-
Filtered Chinese cabbage juice powder	-	-	0.40	-	-	-
Crushed Chinese cabbage powder	-	-	-	0.40	-	-
Filtered radish juice powder	-	-	-	-	0.40	-
Crushed radish powder	-	-	-	-	-	0.40
Starter culture[2)]	-	0.04	0.04	0.04	0.04	0.04

[1)] Control, 0.01% sodium nitrite; CVP, 0.4% commercial vegetable powder+0.04% starter culture; FCJP, 0.4% filtered Chinese cabbage juice powder+0.04% starter culture; CCP, 0.4% crushed Chinese cabbage powder+0.04% starter culture; FRJP, 0.4% filtered radish juice powder+0.04% starter culture; and CRP, 0.4% crushed radish powder+0.04% starter culture.

[2)] *Staphylococcus carnosus* and *Staphylococcus carnosus* subsp.

blended with ingredients using a mixer (5K5SS, Whirlpool, St. Joseph, MI, USA) for a duration of six min. The resulting mixtures were subsequently placed within a stuffer and filled with 24 mm diameter cellulose casings. The groups containing vegetable powder were then incubated at 40℃ for 2 h for alternative curing, and the control samples were maintained at 3℃ for 2 h for traditional curing. The samples were then cooked in a water bath (MaXturdy 45, Daihan Scientific, Wonju, Korea) at 90℃ until the internal temperature reached 75℃, placed in ice-cold water for 20 min, and stored overnight at 3℃ prior to analysis. The sausage processing was repeated three times.

Determination of pH values and cooking loss

The pH values were determined using an Accumet® pH meter following homogenization of the sausage sample (5 g) and addition of distilled water (25 mL). The percentage of cooking loss in pork sausages was determined based on the discrepancy in weight between the initial and cooled samples after cooking, expressed as a percentage of the initial weight.

Color measurement

The CIE color system-based assessment of pork sausages was performed using a color meter (CR-400, Konica Minolta), as described in the vegetable powder analysis section. Sausage samples were sliced longitudinally and the color of the cut surfaces was obtained from four readings for each replicate treatment. To avoid fading, color measurements were performed immediately after the sample was cut (King et al., 2023).

Determination of residual nitrite

The residual nitrite content in the pork sausages was analyzed using the AOAC method 973.31 (AOAC, 2016). A total of 5 g of the sample was combined with 150 mL of preheated distilled water at 80℃ and homogenized using a homogenizer (DI-25 basic, IKA-Werke, Staufen, Germany) at 10,000 rpm. The homogenized samples were decanted to 200 mL with distilled water and heated in a water bath at 80℃ for 2 h. After cooling, the sample solution was made up to 250 mL with distilled water and filtered using a filter paper (Whatman No.1, Cytiva). Then, 20 mL of filtrate was added to a 50 mL volumetric flask, followed by 2.5 mL of sulfanilamide, and reacted for 5 min. Next, 2.5 mL of NED dihydrochloride solution was added, made up to 50 mL with distilled water, and allowed to react for 15 min. The absorbance of the resulting solution was measured at 540 nm using a spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan). The nitrite content of the samples was determined using a standard curve for sodium nitrite (S2252, Sigma-Aldrich, St. Louis, MO, USA) and was expressed in mg/kg.

Determination of cured pigment, total pigment, and curing efficiency

The cured and total pigments were analyzed according to the method described by Hornsey (1956). Briefly, extraction was performed using 80% acetone for the cured pigment, and acidified acetone for the total pigment. The absorbance of the filtrate in the extract was measured at 540 nm for the cured pigment and 640 nm for the total pigment using a spectrophotometer (UV-2600i, Shimadzu), and the results are expressed as mg/kg (King et al., 2023). The curing efficiency was determined by calculating the percentage of cured pigment relative to the total pigment content (King et al., 2023).

Analysis of lipid oxidation

The thiobarbituric acid reactive substance (TBARS) values of the pork sausages were evaluated based on the distillation method described by Tarladgis et al. (1960). Briefly, the sample solution was extracted through distillation and mixed with a 0.02 M solution of 2-thiobarbituric acid in a 1:1 ratio. The mixture was heated in boiling water for 35 min. Subsequently, the resulting solution was cooled for 10 min and the absorbance at a wavelength of 538 nm was measured using a spectrophotometer. The results were calculated as mg of malondialdehyde (MDA) per kg of sample.

Texture profile analysis

Texture profile analysis of the pork sausages was performed using a texture analyzer (TA-XT2*i*, Stable Micro Systems, Godalming, UK) equipped with a cylindrical probe (50 mm in diameter). The sausage sample was prepared to a height of 2.5 cm and subjected to cyclic compression at 40% of its original height. The test speed was set at 5 mm/s, and the hardness, cohesiveness, springiness, gumminess, and chewiness were assessed (Bourne, 1978).

Statistical analysis

All experimental procedures were repeated thrice on separate and individual days. Statistical analysis of all data was performed using the Generalized Linear Model procedure in SAS software (version 9.4, SAS Institute, Cary, NC, USA) in accordance with a randomized block design. If the analysis of variance produced a statistically significant outcome, Duncan's multiple range test was performed to determine the disparities ($p<0.05$) in the means of the dependent variables across the various treatments.

Results and Discussion

Physicochemical characteristics of vegetable powders for replacing nitrite

The quality characteristics of the Chinese cabbage and radish powders prepared using different processing methods are shown in Table 2. The drying yield of vegetable powders ranged from 7.39% to 9.55% and decreased ($p<0.05$) in the order of CCP, CRP, FCJP, and FRJP. Our preliminary experiments showed that filtered radish juice had the lowest total dietary fiber content before being powdered, implying that differences in the total dietary fiber content based on the juicing or crushing processing method may affect the drying yield. The pH was higher for FCJP and FRJP ($p<0.05$) than CCP and CRP, with FRJP showing the highest pH ($p<0.05$). Among the various vegetable powders processed using the different methods, the lowest pH value was observed for CRP ($p<0.05$). Similarly, Jeong et al. (2020a) reported that the pH of powders derived from ground radish was lower than that of powders derived from ground Chinese cabbage. However, the pH values of all vegetable powders (FCJP, CCP, and FRJP) prepared in this study were higher ($p<0.05$) than that of CVP. With regards to alternative curing, the reducing activity of nitrate-reducing bacteria can be influenced by pH (Rodríguez-Daza et al., 2019). However, as can be observed from the cured pigment and total pigment results in this study, the levels of vegetable powders and nitrate-reducing bacteria added to the meat products were not affected by pH. In this study, FCJP had a higher ($p<0.05$) titratable acidity than the other vegetable powders (CCP, FRJP, and CRP). Conversely, the titratable acidity of the other vegetable powders did not differ ($p>0.05$) from that of the CVP. Indeed, the filtering process had a notable impact on the TSS content. The TSS content was found to be lower ($p<0.05$) in both CCP and CRP than in FCJP and FRJP. However, no notable differences ($p>0.05$) were detected in the TSS of the FCJP, FRJP, and CVP. The moisture content of the powders prepared in this study ranged from 5.02% to 6.34%, which was higher ($p<0.05$) than that of CVP (3.83%). Additionally, CCP and CRP prepared from crushed vegetables exhibited higher ($p<0.05$) moisture content and water activity than FCJP and FRJP

Table 2. Quality characteristics of vegetable powders as natural nitrate sources prepared using different processing methods

Dependent variables	Vegetable powders[1)]				
	CVP	FCJP	CCP	FRJP	CRP
Drying yield (%)	-	8.35±0.04^{C}	9.55±0.11^{A}	7.39±0.05^{D}	8.63±0.01^{B}
pH	6.01±0.00^{D}	6.20±0.00^{B}	6.18±0.01^{C}	6.27±0.01^{A}	5.94±0.00^{E}
Titratable acidity (%)	1.52±0.16^{B}	2.03±0.01^{A}	1.61±0.06^{B}	1.67±0.01^{B}	1.49±0.08^{B}
Total soluble solids (°Brix)	10.04±0.03^{A}	9.87±0.04^{A}	8.00±0.20^{B}	9.73±0.04^{A}	7.65±0.24^{B}
Moisture (%)	3.83±0.07^{C}	5.51±0.09^{B}	6.34±0.11^{A}	5.02±0.29^{B}	6.30±0.06^{A}
Water activity	0.18±0.00^{B}	0.14±0.01^{C}	0.21±0.01^{A}	0.13±0.01^{C}	0.21±0.01^{A}
CIE L*	68.09±0.31^{E}	84.50±0.26^{C}	79.44±0.15^{D}	90.27±0.16^{B}	91.29±0.58^{A}
CIE a*	6.11±0.10^{A}	−9.68±0.08^{D}	−11.79±0.13^{E}	−1.93±0.04^{C}	−1.36±0.05^{B}
CIE b*	28.33±0.43^{A}	22.73±0.19^{C}	26.65±0.33^{B}	15.90±0.10^{D}	11.64±0.10^{E}
WSI (%)	92.11±0.8^{A}	90.59±0.66^{A}	55.77±1.16^{B}	90.17±0.42^{A}	50.57±0.74^{C}
WAI	0.27±0.01^{C}	0.25±0.01^{C}	3.73±0.11^{B}	0.18±0.01^{C}	4.74±0.13^{A}
Sodium nitrite (mg/kg)	26.45±0.31^{A}	0.14±0.00^{B}	0.14±0.00^{B}	0.14±0.00^{B}	0.14±0.00^{B}
Sodium nitrate (mg/kg)	31,735±138^{C}	39,009±211^{B}	29,720±271^{D}	65,608±280^{A}	65,316±830^{A}

The results are presented as mean±SE of triplicate experiments.
[1)] Commercial vegetable powder (CVP), filtered Chinese cabbage juice powder (FCJP), crushed Chinese cabbage powder (CCP), filtered radish juice powder (FRJP), and crushed radish powder (CRP).
[A–E] Different superscript letters within a row indicate significant differences ($p<0.05$).
WSI, water solubility index; WAI, water absorption index.

powdered with filtered vegetables juice, regardless of the vegetable type. This difference can be ascribed to the exclusion of solids such as insoluble dietary fiber during filtering prior to pulverization. As illustrated in Fig. 2, the colors of the vegetable powders used in this study differed visually from their plant origins. Specifically, powders derived from Chinese cabbage, a leafy vegetable, displayed a greenish color, with CCP being the greenest. Conversely, the radish powders exhibited a yellowish-white color. The differences in color were further validated using instrumental color measurements. As shown in Table 2, the CIE L* values of the Chinese cabbage and radish powders were higher ($p<0.05$) than those of CVP. Notably, FRJP and CRP samples were higher ($p<0.05$) the CIE L* values compared to other powders. This could be attributed to the presence of anthoxanthin, a white flavonoid pigment found in radishes (Thakur and Sharma, 2018). Among the vegetable powders, CRP exhibited the highest ($p<0.05$) CIE L*. Positive CIE a* values indicate red when positive and green when

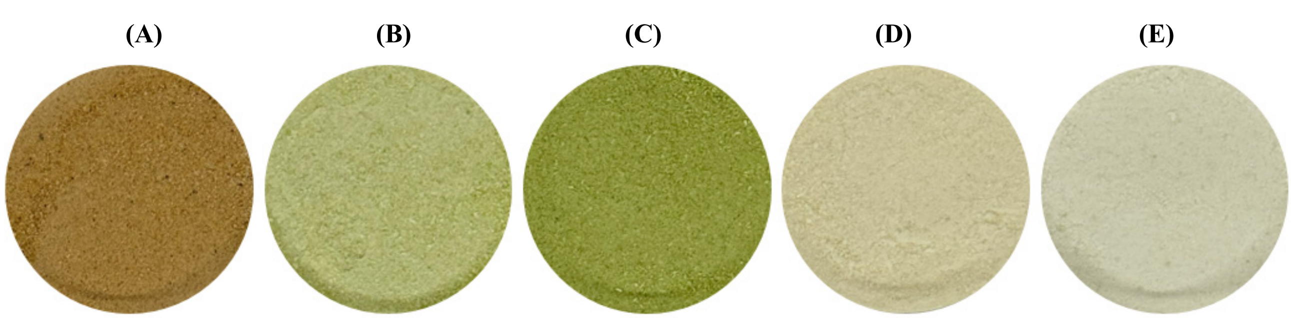

Fig. 2. Photographs of different vegetable powders for replacing sodium nitrite in ground pork sausages. (A) Commercial vegetable powder (CVP), (B) filtered Chinese cabbage juice powder (FCJP), (C) crushed Chinese cabbage powder (CCP), (D) filtered radish juice powder (FRJP), and (E) crushed radish powder (CRP).

negative (King et al., 2023). CVP showed the highest ($p<0.05$) CIE a* values, with positive values (CIE a* +6.11), whereas the other powders showed negative CIE a* values. Regardless of the processing method, the CIE a* values of the Chinese cabbage powders (FCJP and CCP) were lower ($p<0.05$) than those of the radish powders (FRJP and CRP), and CCP exhibited lower ($p<0.05$) CIE a* values than FCJP. The relatively low CIE a* values observed for the Chinese cabbage powder may indicate the presence of chlorophyll (Managa et al., 2020). The incorporation of Chinese cabbage powder may present limitations that could adversely affect the color of cured meat, thereby potentially limiting its usability. In this study, CVP showed the highest ($p<0.05$) CIE b* values, whereas CRP exhibited the lowest values ($p<0.05$). The addition of natural ingredients can affect the final color of meat products, potentially leading to unfavorable consumer perceptions due to significant differences in color (Ahn et al., 2007; Horsch et al., 2014; Lee et al., 2015). In terms of alternative curing, several studies (Bae et al., 2020; Guimarães et al., 2021; Guimarães et al., 2022; Jeong et al., 2020a) have indicated that the color attributes of radish-derived powders make them suitable alternatives for synthetic nitrites. WSI and WAI are important factors that indicate the suitability of a particular powder in the food industry (Moon et al., 2010). In this study, the WSI values of FCJP and FRJP from filtered juice of Chinese cabbages and radishes were comparable ($p>0.05$) to those of CVP. However, the WSI values of CCP and CRP from crushed Chinese cabbages and radishes were lower ($p<0.05$) than those from FCJP and FRJP, with reductions of 38.4% and 43.9%, respectively. The solubility of ingredients is a critical aspect in the production of meat items, particularly hams and bacons, which often involves the application of curing brine. This study did not examine the effects of FCJP and FRJP on the production of these items, but they may offer significant advantages in this regard. A higher WAI was observed ($p<0.05$) for CCP and CRP than for FCJP and FRJP, regardless of the type of vegetable used, and CRP was higher ($p<0.05$) than that of CCP. WAI has been found to have a significant relationship with total dietary fiber content in processed meat products, which may enhance their water-holding capacity (Lario et al., 2004; Lee et al., 2008). Nitrite content of 0.14 mg/kg was obtained for FCJP, CCP, FRJP, and CRP, regardless of the processing methods and vegetable types used. Nevertheless, it is noteworthy that the CVP sample contained a greater amount of nitrite (26.45 mg/kg) than the other powders prepared in this study. This result could be due to the manufacturing date and distribution environment of the CVP. Although the presence of nitrite in the powder was not initially detected, it was found to be within the range of 128–189 mg/kg after 10 days at room temperature, as previously noted by Sebranek and Bacus (2007). The nitrate content in the radish powders (FRJP and CRP) was higher ($p<0.05$) at 65,608 mg/kg and 65,316 mg/kg, respectively, than that in the Chinese cabbage powders (FCJP and CCP), which contained 39,009 mg/kg and 29,720 mg/kg, respectively. It should be noted that the radish powders had approximately twice the amount of nitrate as the celery-based CVP, which had 31,735 mg/kg of nitrate. The nitrate concentration in the powders derived from Chinese cabbage is similar to that found in commercial products, which typically contain around 30,000 mg/kg of nitrate (Sindelar and Houser, 2009). These findings imply that vegetable powders prepared using different processing methods could potentially be used as plant-based substitutes for nitrites in processed meat items.

Quality characteristics of pork sausages cured with different vegetable powders

Table 3 shows the pH, cooking loss, and instrumental color of pork sausages cured with sodium nitrite or vegetable powders using different processing methods. The pH values of the FCJP, CCP, FRJP, and CRP treatments were higher ($p<0.05$) than those of the control and CVP treatment. However, there were no significant differences ($p>0.05$) between these treatments. Jeong et al. (2020b) found that the use of vegetable powder for alternative curing did not affect the pH of pork sausages. In this study, the incorporation of vegetable powders into ground pork sausages led to greater ($p<0.05$) cooking loss compared to the

Table 3. Effects of different vegetable powders on pH, cooking loss, and CIE color of alternatively cured pork sausages

Treatments[1)]	pH	Cooking loss (%)	CIE L*	CIE a*	CIE b*
Control	6.20±0.01^{B}	0.96±0.04^{C}	68.92±0.22^{A}	9.34±0.06^{A}	6.00±0.07^{B}
CVP treatment	6.23±0.01^{B}	1.56±0.03^{A}	68.34±0.18^{AB}	9.04±0.06^{AB}	6.80±0.08^{A}
FCJP treatment	6.29±0.01^{A}	1.57±0.08^{A}	68.23±0.23^{B}	8.96±0.12^{B}	6.21±0.09^{B}
CCP treatment	6.28±0.01^{A}	1.27±0.08^{B}	67.97±0.17^{B}	7.98±0.06^{C}	6.76±0.10^{A}
FRJP treatment	6.30±0.02^{A}	1.52±0.06^{A}	68.02±0.26^{B}	9.22±0.09^{AB}	6.21±0.10^{B}
CRP treatment	6.30±0.02^{A}	1.37±0.08^{B}	68.00±0.25^{B}	9.25±0.08^{AB}	6.18±0.10^{B}

The results are presented as mean±SE of triplicate experiments.

[1)] The sausages were prepared using different curing agents, including 0.01% sodium nitrite (Control), 0.4% commercial vegetable powder (CVP treatment), filtered Chinese cabbage juice powder (FCJP treatment), crushed Chinese cabbage powder (CCP treatment), filtered radish juice powder (FRJP treatment), or crushed radish powder (CRP treatment), respectively.

[A–C] Different superscript letters within a column indicate significant differences (p<0.05).

control. The high levels of cooking loss observed in naturally cured sausages are attributed to acidity resulting from the organic acids present in the vegetable powders (Vasconcellos et al., 2016), as shown in Table 2. Similarly, Yoon et al. (2021) reported that substituting nitrite with white kimchi powder in pork sausages led to a lower cooking yield than traditional curing methods. Nevertheless, both CCP and CRP treatments exhibited a reduction (p<0.05) in cooking loss compared to FCJP and FRJP treatments, which is likely due to the increased moisture retention of the final products resulting from the relatively high WAI of the crushed vegetable powders (CCP and CRP). In instrumental color, no differences (p>0.05) were found in the CIE L* values for any of the vegetable powder treatments, including CVP. However, sausages containing Chinese cabbage and radish powders had lower CIE L* values (p<0.05) compared to those treated with sodium nitrite. Moreover, both FCJP and CCP treatments exhibited lower (p<0.05) CIE a* values than the control, and the CCP treatment had the lowest CIE a* values (p<0.05). This finding is likely attributable to the relatively low CIE a* of the Chinese cabbage powders, as indicated in Table 2. In addition, in this study, although the cured pigment did not differ among all sausages (Table 4), the probable reason for the noticeably reduced CIE a* of the FCJP and CCP treatments is the inherent plant pigment found in the vegetable powders used, rather than the curing process (Horsch et al., 2014). However, there were no differences (p>0.05) in the CIE a* values of FRJP and CRP treatments compared with the control or CVP treatment. Similar to our results, Jeong et al. (2020a) reported that pork sausages cured with radish powder did not differ in CIE a* from the nitrite-added control; however, products treated with Chinese cabbage powder showed significantly lower CIE a* values. In terms of CIE b* values, there were no differences (p>0.05) between the CVP and CCP treatments. Nevertheless, both of these treatments displayed higher (p<0.05) CIE b* values compared to the control and other treatments. Similarly, Jeong et al. (2020b) showed that the CIE b* values of pork products cured with 0.35% ground Chinese cabbage powder increased. However, the CIE b* values of the FRJP and CRP treatments did not differ (p>0.05) from those of the control, which aligns with the previous findings by Yoon et al. (2023) for pork sausages cured with ground radish powder. Sebranek and Bacus (2007) suggested that plant powders with less distinctive pigments would more effectively facilitate the supply of natural sources of nitrate. Thus, the findings of this study imply that in addition to the nitrate concentration in vegetables used as nitrite substitutes, their intrinsic color also plays a crucial role. Consequently, the use of radishes may be a more suitable option.

The residual nitrite, cured pigment, total pigment, curing efficiency, and TBARS values of ground pork sausages cured with sodium nitrite or vegetable powders using different processing methods are shown in Table 4. All sausages treated with vegetable powders exhibited significantly lower (p<0.05) residual nitrite content compared to the control. In line with this

Table 4. Effects of different vegetable powders on residual nitrite, cured pigment, total pigment, curing efficiency, and TBARS of alternatively cured pork sausages

Treatments[1)]	Residual nitrite (mg/kg)	Cured pigment (mg/kg)	Total pigment (mg/kg)	Curing efficiency (%)	TBARS (mg MDA/kg)
Control	54.39±1.40^{A}	29.69±0.36^{A}	39.27±0.43^{A}	75.79±1.41^{A}	0.11±0.01^{A}
CVP treatment	32.43±2.02^{B}	29.54±0.33^{A}	39.02±0.29^{A}	75.77±0.93^{A}	0.12±0.01^{A}
FCJP treatment	32.25±1.25^{B}	29.22±0.44^{A}	38.93±0.29^{A}	75.04±0.95^{A}	0.10±0.01^{A}
CCP treatment	27.87±1.61^{C}	28.78±0.61^{A}	39.02±0.53^{A}	73.73±1.02^{A}	0.12±0.01^{A}
FRJP treatment	36.85±1.33^{B}	29.33±0.48^{A}	38.34±0.45^{A}	76.73±1.81^{A}	0.10±0.01^{A}
CRP treatment	35.08±1.74^{B}	29.22±0.42^{A}	38.85±0.41^{A}	75.33±1.31^{A}	0.12±0.01^{A}

The results are presented as mean±SE of triplicate experiments.

[1)] The sausages were prepared using different curing agents, including 0.01% sodium nitrite (Control), 0.4% commercial vegetable powder (CVP treatment), filtered Chinese cabbage juice powder (FCJP treatment), crushed Chinese cabbage powder (CCP treatment), filtered radish juice powder (FRJP treatment), or crushed radish powder (CRP treatment), respectively.

$^{A–C}$ Different superscript letters within a column indicate significant differences ($p<0.05$).

TBARS, thiobarbituric acid reactive substance; MDA, malondialdehyde.

observation, several studies have reported lower nitrite content in alternatively cured products (Alahakoon et al., 2015; Choi et al., 2020; Sebranek and Bacus, 2007). In the present study, CCP treatment exhibited the lowest ($p<0.05$) residual nitrite content among the treatments with vegetable powders tested. This finding could be ascribed to the lower nitrate content of the added ingredients. However, no discrepancies in the residual nitrite content were detected ($p>0.05$) among the CVP, FCJP, FRJP, and CRP treatments. Cured meat pigment, also known as nitrosyl hemochrome, is a heat-stable pink pigment produced when nitrogen monoxide in nitrite reacts with myoglobin (King et al., 2023). Typically, a residual nitrite content of 10–15 mg/kg is required for cured meat pigments (Rivera et al., 2019). In this study, the incorporation of vegetable powders, such as FCJP, CCP, FRJP, and CRP, led to cured pigments that were comparable ($p>0.05$) to those of the control and CVP treatments. The findings of this study agree with those of Jeong et al. (2020a), who found no significant discrepancy in nitrosyl hemochrome content between sausages made with powder sourced from ground Chinese cabbage or radish and those made with sodium nitrite. Furthermore, the incorporation of vegetable powders in the curing process of sausages did not yield differences ($p>0.05$) in the total pigment content compared with that of the control. Bae et al. (2020) found a similar result, indicating that pork sausages cured with ground radish powder possessed comparable total pigment contents to those cured with sodium nitrite. It is commonly understood that the total pigment content in cured meat products is proportional to nitrosyl hemochrome (Jeong et al., 2020a; Shin et al., 2017), which was also observed in our study. The study revealed that curing efficiencies varied between 73.73% and 76.73% for treatments involving FCJP, CCP, FRJP, and CRP. This result aligns with the findings of Choi et al. (2020), who used white kimchi powder as a substitute curing agent in ground pork products. Additionally, the curing efficiency of pork sausages treated with Chinese cabbage and radish powder did not differ ($p>0.05$) from that of the control or the CVP treatment. Thus, the findings of this study suggest that Chinese cabbage and radish powders are suitable for curing meat products regardless of the processing method employed before pulverization. One of the primary functions of nitrite is to restrict lipid oxidation (Alahakoon et al., 2015; Sindelar and Milkowski, 2011). In this study, the TBARS levels in the control and all vegetable powder treatments were similar ($p>0.05$). This outcome may be linked to the antioxidant activity and conversion of nitrite from natural sources, which inhibit lipid oxidation in meat products (Magrinyà et al., 2016; Park et al., 2019).

Table 5 presents the textural properties of the ground pork sausages cured with sodium nitrite or vegetable powders using

Table 5. Effects of different vegetable powders on texture profile of alternatively cured pork sausages

Treatments[1)]	Hardness (N)	Cohesiveness	Springiness	Gumminess (N)	Chewiness (N)
Control	57.76±0.95[A]	0.74±0.00[A]	0.92±0.00[A]	42.96±0.71[A]	39.40±0.73[A]
CVP treatment	57.46±0.68[A]	0.74±0.00[A]	0.92±0.00[A]	42.68±0.50[A]	39.40±0.50[A]
FCJP treatment	56.18±0.61[A]	0.74±0.00[A]	0.92±0.00[A]	41.52±0.42[A]	38.34±0.39[A]
CCP treatment	56.16±0.79[A]	0.74±0.00[A]	0.92±0.00[A]	41.63±0.56[A]	38.50±0.53[A]
FRJP treatment	53.58±0.72[B]	0.74±0.00[A]	0.92±0.00[A]	39.82±0.41[B]	36.80±0.33[B]
CRP treatment	54.49±0.60[AB]	0.74±0.00[A]	0.92±0.00[A]	40.25±0.43[AB]	36.90±0.42[AB]

The results are presented as mean±SE of triplicate experiments.
[1)] The sausages were prepared using different curing agents, including 0.01% sodium nitrite (Control), 0.4% commercial vegetable powder (CVP treatment), filtered Chinese cabbage juice powder (FCJP treatment), crushed Chinese cabbage powder (CCP treatment), filtered radish juice powder (FRJP treatment), or crushed radish powder (CRP treatment), respectively.
[A,B] Different superscript letters within a column indicate significant differences ($p<0.05$).

different processing methods. The FRJP treatment did not show a difference ($p>0.05$) in hardness compared to the CRP treatment, but it was lower ($p<0.05$) than that of the control and other treatments. The reason for the low hardness in the FRJP treatment may be related to the presence of dietary fiber, which contributes to the hardness of meat products (Barbut, 2023; Fernández-Ginés et al., 2004). Gwak (2023) found that a larger amount of dietary fiber was eliminated when radish juice was filtered before powdering. This may explain why FRJP treatment resulted in lower hardness. However, in this study, the influence of other vegetable powders on hardness was not statistically significant ($p>0.05$) compared to the control. Preliminary findings prior to powdering indicate that this may be attributed to the difference in total dietary fiber content between filtered Chinese cabbage juice and crushed Chinese cabbage being less than the difference in total dietary fiber content between filtered radish juice and crushed radish (data not shown). This is likely why the hardness values of the FCJP and CCP treatments were similar. Additionally, no notable disparities ($p>0.05$) in cohesiveness or springiness were detected across treatments. The pork sausages exhibited a similar trend in terms of gumminess and chewiness, as they did for hardness. This could be due to the secondary nature of gumminess and chewiness, which are affected by primary textural properties, such as hardness (Bourne, 1978; Cáceres et al., 2006). Recently, Yoon et al. (2023) examined the textural properties of pork products cured with either sodium nitrite or powders derived from ground radish, and their findings indicated that there was no apparent influence on ground pork products. This is consistent with our observation that CRP treatment resulted in a texture profile comparable to that of the control.

Conclusion

In conclusion, the use of radish powders, regardless of whether the vegetables are filtered or crushed, may have the potential to produce cured pork sausages with desirable color and pigment properties. Conversely, Chinese cabbage powder showed limited potential because of its low CIE a* in the final product, particularly when the powder derived from crushed Chinese cabbage was used. Nevertheless, the potential use of filtered vegetable juice powders in other cured meat products, such as hams and bacons, could be extended owing to their high levels of nitrate content, TSS, and water soluble index. To determine the suitability of vegetable powders for alternative curing in industrial applications, additional research is required to assess their microbiological safety and sensory attributes during storage of meat products.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Gwak SH, Jeong JY. Data curation: Gwak SH, Bae SM. Formal analysis: Gwak SH, Bae SM. Methodology: Gwak SH, Bae SM, Jeong JY. Software: Gwak SH. Validation: Gwak SH. Investigation: Gwak SH, Jeong JY. Writing - original draft: Gwak SH. Writing - review & editing: Gwak SH, Bae SM, Jeong JY.

Ethics Approval

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

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