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ARTICLE

Effects of *Dongchimi* Powder as a Natural Nitrite Source on Quality Properties of Emulsion-Type Sausages

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Abstract The use of nitrite as a conventional curing agent is decreasing because of the negative consumer perception of synthetic compounds in foods. Therefore, this study was conducted to investigate the efficacy of *dongchimi* as an alternative to synthetic nitrite and its effect on the qualitative properties of emulsion-type sausages. Under all tested fermentation conditions, both nitrite and nitrate contents were the highest when *dongchimi* was fermented at 0°C for 1 wk. The fermented *dongchimi* was powdered and added to the sausages. Emulsion-type sausages were prepared with 0.25% (treatment 1), 0.35% (treatment 2), 0.45% (treatment 3), or 0.55% (treatment 4) *dongchimi* powder, with 0.01% sodium nitrite-treated (control 1) and 0.40% celery powder-treated (control 2) sausages as controls. There were not different ($p>0.05$) in the pH, cooking yield, CIE L*, and CIE a* between the control 1 and treatments 2, 3, and 4. CIE b* was significantly higher ($p<0.05$) in the control 2 and lower ($p<0.05$) in the control 1 than that in the other groups. Treatment 4 and control 1 had similar contents of residual nitrite, nitrosyl hemochrome, and total pigment. Additionally, treatment 4 exhibited a significantly better ($p<0.05$) curing efficiency than the control 1. However, naturally cured sausages showed higher ($p<0.05$) lipid oxidation than the control 1. This study suggests that the use of more than 0.35% *dongchimi* powder could replace sodium nitrite or celery powder as curing agents for emulsion-type sausages.

Keywords fermented *dongchimi*, *dongchimi* powder, nitrite replacement, emulsion-type sausages

Introduction

Nitrite has been used as a conventional curing agent to improve the color and flavor of meat products as well as to inhibit lipid oxidation and growth of pathogenic bacteria (Alahakoon et al., 2015; Sebranek and Bacus, 2007). However, considering the negative consumer perception of foods containing synthetic compounds (Carocho et al., 2014; Shim et al., 2011), several studies have been attempted to identify potential replacements for synthetic nitrite in meat products (Jeong et al., 2020; Riel et al., 2017;

Sindelar et al., 2007a). An alternative method for the synthetic production of nitrite is the treatment of natural ingredients containing high concentrations of nitrate with nitrate-reducing bacteria, such as *Staphylococcus carnosus* and *Staphylococcus xylosus* (Sindelar and Houser, 2009). Natural ingredients with high nitrate contents include cabbage, celery, radish, spinach, parsley, and beetroot (Bahadoran et al., 2016; Gassara et al., 2016; Prasad and Chetty, 2008). Meat products using these natural ingredients to replace synthetic additives are preferred associated with the health concerns of consumers (Aschemann-Witzel et al., 2019; Delgado-Pando et al., 2021). However, celery powder, which is commercially used in the meat industry as a synthetic nitrite replacement (Sebranek et al., 2012), and several other synthetic nitrite substitutes may be offensive to consumers because of their inherent color and flavor (Sebranek and Bacus, 2007).

Kimchi is a traditional food in Korea (Jang et al., 2015), and its flavor is familiar to Korean consumers. Kimchi contains vitamins, organic acids, minerals, dietary fiber, probiotics, and unique flavoring compounds, which can help improve its nutritional, functional, and sensory properties (Cheigh et al., 1994; Park et al., 2014). Additionally, napa cabbage and radish, which are the main ingredients of kimchi, are known for their high nitrate contents (Bahadoran et al., 2016; Prasad and Chetty, 2008). In particular, radish root, which is the main ingredient for *dongchimi*, is generally white in color (Goyeneche et al., 2015) and has a high nitrate ion content of 1,939–6,260 mg/kg (Munekata et al., 2021). *Dongchimi* has various advantages of kimchi and can suppress the unique spicy taste of radish by reducing isothiocyanate during aging (Lee and Rhee, 1990). Owing to these properties, *dongchimi*, possessing various health benefits, has the potential to be an alternative ingredient for synthetic nitrite. However, because *dongchimi* may have different compositions based on fermentation conditions, such as the temperature and aging period (Cho and Na, 2020; Noh et al., 2008), it is necessary to examine the possibility of *dongchimi* powder as an alternative to synthetic nitrite in meat products.

Therefore, this study investigated the qualities of emulsion-type sausages after treatment with different concentrations of *dongchimi* powder, which was employed as an alternative natural curing agent.

Materials and Methods

Preparation of *dongchimi* powder

Dongchimi was prepared using a recipe for kimchi (Institute of Traditional Korean Food, 2013; Table 1) and fermented at 0℃ or 20℃ for 4 wk. Our preliminary analyses of *dongchimi* fermented at different temperatures and for different aging

Table 1. Formulation of the *dongchimi* preparation used in this study

Ingredients	% (w/w)
Radish	24.13
Solar salt	0.36
Refined salt	1.65
Green onion	0.35
Garlic	0.69
Ginger	0.41
Pear	3.45
Water	68.96
Total	100.00

periods revealed that *dongchimi* fermented at 0°C for 1 wk had the highest nitrate and nitrite ion contents (average 2,051 and 7.56 ppm, respectively). Therefore, *dongchimi* fermented at 0°C for 1 wk was powdered and used as a synthetic nitrite substitute in emulsion-type sausages.

Dongchimi ground for 5 min was dried in a hot-air dryer (EN-FO-392S, Enex Science, Goyang, Korea) set at 60°C for 12 h. The dried *dongchimi* was pulverized and screened with a sieve (600 μm), and then *dongchimi* powder was stored at −18°C. The pH and moisture content of the *dongchimi* powder used in this study were 4.75% and 2.92%, respectively. The concentrations of nitrate and nitrite ions were 16,905 ppm (23,158 ppm sodium nitrate) and 1.04 ppm (1.57 ppm sodium nitrite), respectively.

Manufacture of emulsion-type pork sausages

Six experimental groups were included in this study, as follows: Control 1 (0.01% sodium nitrite), control 2 (0.40% celery powder), treatment 1 (0.25% *dongchimi* powder), treatment 2 (0.35% *dongchimi* powder), treatment 3 (0.45% *dongchimi* powder), and treatment 4 (0.55% *dongchimi* powder; Table 2). Control 2 was prepared using celery powder (Vegstable 502, Florida Food Products, Eustis, FL, USA; 22,049 ppm nitrate ion and 11.53 ppm nitrite ion), which is a commercially available natural source of nitrate, for comparison with the samples produced using *dongchimi* powder prepared in this study. Celery powder was used at a maximum concentration of 0.4% by the supplier's recommendation as excessive use of celery powder may cause off-flavors in meat products. The experimental groups treated with celery powder or *dongchimi* powder (control 2 and treatments 1 to 4) were also treated with 0.03% mixed-strain starter culture (TEXEL® NatuRed LT; *S. carnosus* and *Staphylococcus vitulinus*, Danisco France, Paris, France) to convert nitrate to nitrite.

Fresh pork ham and fat were purchased from a local market. The raw materials were separately ground to a size of 3 mm using a chopper and then randomly separated into six batches to form the six experimental groups. The ground meat, sodium

Table 2. Formulation of naturally cured emulsion-type pork sausages treated with *dongchimi* powder

Ingredients (%, w/w)	Treatments[1]					
	Control 1	Control 2	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Pork ham (3 mm)	60.00	60.00	60.00	60.00	60.00	60.00
Pork backfat (3 mm)	20.00	20.00	20.00	20.00	20.00	20.00
Ice/water	20.00	20.00	20.00	20.00	20.00	20.00
Subtotal	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	-	-	-	-	-
Celery powder	-	0.40	-	-	-	-
Dongchimi powder	-	-	0.25	0.35	0.45	0.55
Stater culture	-	0.03	0.03	0.03	0.03	0.03
Total	102.86	103.28	103.13	103.23	103.33	103.43

[1] Treatments: Control 1 (0.01% sodium nitrite), control 2 (0.40% celery powder+0.03% starter culture), treatment 1 (0.25% *dongchimi* powder+0.03% starter culture), treatment 2 (0.35% *dongchimi* powder+0.03% starter culture), treatment 3 (0.45% *dongchimi* powder+0.03% starter culture), and treatment 4 (0.55% *dongchimi* powder+0.03% starter culture).

chloride, sodium tripolyphosphate, and half of the ice were placed in a food cutter and chopped. And then backfat, dextrose, sodium nitrite or the alternative curing ingredients (celery powder or *dongchimi* powder with a starter culture), sodium ascorbate, and the remaining ice were added to the food cutter and emulsified until the temperature of the meat batter reached 12℃. The meat batter was stuffed into 24 mm cellulose casings. Before cooking, samples with the starter culture (control 2 and treatments 1–4) were placed for 2 h at 40°C to allow for the conversion of nitrate into nitrite, whereas control 1 was left at 4℃ for 2 h. All samples were then cooked to 75℃ in a 90℃ water bath. The cooked samples were rapidly cooled and stored at 2℃–3℃ in the dark until analyses.

Determination of pH values and cooking yields

After homogenizing 5 g of the sample in 45 mL of distilled water, the pH values of the homogenized sausages were measured using a pH meter. The cooking yield was determined using the differences of sample weight before and after cooking.

Color measurements

Color measurements (CIE L*, CIE a*, and CIE b*) were performed using a chromameter (CR-400, Konica Minolta Sensing, Osaka, Japan) set at illuminant C and an observer angle of 2°. The chromameter was calibrated using a white calibration plate prior to measuring. The surface color of the samples was measured following immediately cutting.

Residual nitrite, nitrosyl hemochrome, total pigment, and curing efficiency determination

The residual nitrite content of the sausages was measured using the AOAC method 973.31 (AOAC, 2016) and reported in ppm. Nitrosyl hemochrome and total pigment contents were measured using the method described by Hornsey (1956), respectively. The curing efficiency was expressed using the percentage of nitrosyl hemochrome to total pigment (AMSA, 2012).

Thiobarbituric acid reactive substances (TBARS) values

Lipid oxidation of the samples was analyzed using the method described by Tarladgis et al. (1960). TBARS values were reported as mg malondialdehyde (MDA)/kg of sample.

Statistical analysis

Data were analyzed using general linear models employing the SAS software (SAS, 2012). Differences in the model were considered significant at $p<0.05$. Differences in means were compared using the Duncan's multiple range test.

Results and Discussion

pH values and cooking yields

The pH values of the samples treated with *dongchimi* powder (treatments 1 to 4) was similar to those of the control groups ($p>0.05$; Table 3). The concentration of *dongchimi* powder used for the treatment did not affect the pH values of sausages ($p>0.05$). In a previous study, Choi et al. (2020) found no changes in the pH values of naturally cured sausages treated with

Table 3. Effects of different concentrations of *dongchimi* powder on the pH, cooking yield, and CIE color in emulsion-type sausages

Treatments[1)]	Dependent variables				
	pH	Cooking yield (%)	CIE L*	CIE a*	CIE b*
Control 1	6.22±0.03^{A}	98.59±0.04^{A}	75.07±0.13^{A}	8.45±0.06^{A}	7.04±0.03^{D}
Control 2	6.21±0.02^{A}	98.66±0.04^{A}	74.76±0.13^{AB}	8.07±0.03^{B}	8.13±0.03^{A}
Treatment 1	6.26±0.02^{A}	98.12±0.14^{B}	74.23±0.28^{B}	8.51±0.09^{A}	7.47±0.02^{C}
Treatment 2	6.24±0.02^{A}	98.45±0.09^{A}	74.67±0.15^{AB}	8.37±0.07^{A}	7.49±0.02^{C}
Treatment 3	6.24±0.02^{A}	98.46±0.06^{A}	74.50±0.21^{AB}	8.40±0.03^{A}	7.57±0.03^{B}
Treatment 4	6.24±0.02^{A}	98.53±0.08^{A}	74.51±0.15^{AB}	8.36±0.03^{A}	7.60±0.03^{B}

All values are means±SEs.
[1)] Treatments: Control 1 (0.01% sodium nitrite), control 2 (0.40% celery powder+0.03% starter culture), treatment 1 (0.25% *dongchimi* powder+ 0.03% starter culture), treatment 2 (0.35% *dongchimi* powder+0.03% starter culture), treatment 3 (0.45% *dongchimi* powder+0.03% starter culture), and treatment 4 (0.55% *dongchimi* powder+0.03% starter culture).
[A–D] Within a column, different superscripts indicate the significant difference ($p<0.05$).

varying concentrations of white kimchi powder.

Treatment 1 showed the lowest cooking yield among all experimental groups ($p<0.05$; Table 3), although the numerical difference was small. Naturally cured sausages from other groups (control 2 and treatments 2 to 4) showed no difference in the cooking yield, compared to control 1 ($p>0.05$). This result was consistent with those of Bae et al. (2020) and Jeong et al. (2020), who obtained similar results for pork products treated with radish powder as a nitrite replacer.

CIE color

The CIE L*, CIE a*, and CIE b* of the emulsion-type sausages are listed in Table 3. Except for treatment 1, naturally cured sausages (control 2 and treatments 2 to 4) did not differ in CIE L* from control 1 ($p>0.05$). However, treatment 1 showed lower CIE L* than control 1 ($p<0.05$). Similarly, other studies on synthetic nitrite replacement using vegetable-based ingredients have shown that the CIE L* of the final products was not affected, even with high concentrations of substitutes (Riel et al., 2017; Sindelar et al., 2007b). However, results from several studies have shown that decreases in CIE L* could occur because of the difference in the color of synthetic nitrite substitutes (Kim et al., 2019; Ko et al., 2017). The *dongchimi* powder used in this study was white in color and therefore may not reduce the CIE L* of emulsion-type sausages.

Regardless of the concentration of *dongchimi* powder added, treatments 1 to 4 had CIE a* similar to that of control 1 ($p>0.05$). Previously, Bae et al. (2020) reported that the CIE a* of pork products did not change, regardless of the level of radish powder added. The lowest CIE a* were found in the control 2 ($p<0.05$). Jeong et al. (2020) showed that pork products treated with Chinese cabbage or spinach exhibited lower CIE a* than sodium nitrite-treated products. It may be possible that leafy vegetables, such as celery, spinach, and Chinese cabbage, are rich in chlorophyll (Bohn et al., 2004; Butnariu and Butu, 2015), which is the main green pigment in plants and may reduce the CIE a* of meat products.

All naturally cured sausages (control 2 and treatments 1 to 4) had higher CIE b* compared to control 1 ($p<0.05$), and CIE b* was the highest in control 2 ($p<0.05$). This may be due to differences in chlorophyll and carotenoid contents between celery powder and *dongchimi* powder. Celery has a higher chlorophyll and carotenoid contents than radish root (Cho et al., 2007; Kim et al., 2007). Similarly, Jeong et al. (2020) had reported that meat products treated with leafy vegetable powders had higher CIE b* than those with radish powder. Nevertheless, in this study, CIE b* increased with the concentration of *dongchimi* powder ($p<0.05$), as was previously reported by Lee et al. (2008) for sausages with kimchi powder.

Residual nitrite

The residual nitrite content of *dongchimi*-treated samples increased as the concentration of *dongchimi* powder increased ($p<0.05$; Table 4). A similar result was found by Riel et al. (2017), who reported that treatment with higher levels of parsley extract increased a residual nitrite content in sausages. Control 2 had a higher residual nitrite content than treatments 1–3 ($p<0.05$). With the exception of treatment 4, the residual nitrite content was lower in naturally cured sausages (control 2 and treatments 1 to 3) than that in control 1. Sindelar et al. (2007b) showed that hams cured with 0.2% and 0.35% celery powder exhibited a lower residual nitrite content (19.3 to 36.0 ppm) than 200 ppm sodium nitrite added hams (63.4 ppm residual nitrite), which is consistent with our results. However, the residual nitrite content in treatment 4 was similar to that of control 1 ($p>0.05$). This may be caused by the high concentration of added *dongchimi* powder in treatment 4.

Nitrosyl hemochrome, total pigment, and curing efficiency

None of the emulsion-type sausages showed differences in nitrosyl hemochrome and total pigment contents ($p>0.05$; Table 4), as was previously noted by Sindelar et al. (2007b) for hams with vegetable juice powder. Treatment 2 showed no difference in the curing efficiency, compared to control groups ($p>0.05$), whereas treatments 3 and 4 showed higher curing efficiencies than control 1 ($p<0.05$; Table 4). Notably, Bae et al. (2020) found that the curing efficiency increased when the amount of radish powder added to meat products increased from 0.15% to 0.30%. The curing efficiency required to obtain well-cured meat has been found to be greater than 80% (AMSA, 2012). In this study, the curing efficiency of the *dongchimi* powder ranged from 80.50% to 84.23% (treatments 1 to 4). Therefore, it is possible to produce naturally cured meat products with an excellent curing efficiency using *dongchimi* powder. Our results showed that using a minimum *dongchimi* powder concentration of >0.35% in emulsion-type sausages, a curing efficiency comparable to that obtained with sodium nitrite treatment could be achieved.

Thiobarbituric acid reactive substances (TBARS) values

The naturally cured emulsion-type sausages (control 2 and treatments 1–4) had higher TBARS values than control 1

Table 4. Effects of different concentrations of *dongchimi* powder on residual nitrite, nitrosyl hemochrome, total pigment, curing efficiency, and TBARS in emulsion-type sausages

Treatments[1)]	Dependent variables				
	Residual nitrite (ppm)	Nitrosyl hemochrome (ppm)	Total pigment (ppm)	Curing efficiency (%)	TBARS (mg MDA/kg)
Control 1	59.35±3.87^{A}	32.58±0.37^{A}	39.55±0.48^{A}	82.37±0.30^{B}	0.042±0.002^{B}
Control 2	44.55±1.74^{B}	33.40±0.42^{A}	40.12±0.47^{A}	83.25±0.51^{AB}	0.049±0.002^{A}
Treatment 1	18.52±0.87^{D}	32.48±0.55^{A}	40.35±0.63^{A}	80.50±0.40^{C}	0.054±0.006^{A}
Treatment 2	29.15±2.33^{C}	33.21±0.25^{A}	39.78±0.54^{A}	83.55±0.55^{AB}	0.053±0.004^{A}
Treatment 3	34.73±1.19^{C}	33.55±0.32^{A}	40.01±0.65^{A}	83.96±0.66^{A}	0.052±0.002^{A}
Treatment 4	58.14±1.23^{A}	33.30±0.46^{A}	39.55±0.62^{A}	84.23±0.40^{A}	0.052±0.003^{A}

All values are means±SEs.

[1)] Treatments: Control 1 (0.01% sodium nitrite), control 2 (0.40% celery powder+0.03% starter culture), treatment 1 (0.25% *dongchimi* powder+0.03% starter culture), treatment 2 (0.35% *dongchimi* powder+0.03% starter culture), treatment 3 (0.45% *dongchimi* powder+0.03% starter culture), and treatment 4 (0.55% *dongchimi* powder+0.03% starter culture).

[A–D] Within a column, different superscripts indicate the significant difference ($p<0.05$).

TBARS, 2-thiobarbituric acid reactive substances; MDA, malondialdehydes.

($p<0.05$; Table 4). Based on results from previous studies, meat products cured with vegetables have higher TBARS values than traditionally cured products containing nitrite (Jeong et al., 2020; Kim et al., 2017; Kim et al., 2019). This may be due to the lower residual nitrite content in naturally cured products (7.04 ppm to 9.19 ppm) versus sodium nitrite added products (41.56 ppm; Bae et al., 2020). However, the sausages treated with *dongchimi* powder (treatments 1 to 4) showed similar levels of TBARS values as those of celery powder-treated sausages (control 2), regardless of the *dongchimi* powder concentration ($p>0.05$). In general, kimchi is known to contain antioxidants, but the amount of *dongchimi* powder used in this study did not seem to have sufficient antioxidant effect to reduce the TBARS value of emulsion-type sausages. However, Hwang et al. (2017) found no differences in TBARS values between frankfurters with fermented red beet extracts and synthetic nitrites. Additionally, Sindelar et al. (2007b) reported that celery powder-treated hams showed similar TBARS values as those of sodium nitrite-treated hams, although TBARS values decreased with the incubation time. The inconsistency in these results may be attributed to a variety of factors, such as the type of natural nitrite substitutes, their concentrations, and the manufacturing formulation and processes.

Conclusion

In conclusion, this study indicated that *dongchimi* powder can be a potential alternative to commercially available celery powder and synthetic sodium nitrite in meat processing. The use of more than 0.35% *dongchimi* powder could ensure a curing efficiency comparable to that obtained utilizing traditionally curing agents. Future studies in the field should focus on the safety aspect, particularly in regard to the growth of microorganisms during storage, and sensory properties of the cured meat products. Further research on these topics would be necessary to commercialize meat products treated with *dongchimi* powder for industrial applications.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

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

Ethics Approval

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

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