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Investigating the Effects of Chinese Cabbage Powder as an Alternative Nitrate Source on Cured Color Development of Ground Pork Sausages

Abstract

This study investigated the effects of Chinese cabbage powder as a natural replacement for sodium nitrite on the qualities of alternatively cured pork products. Chinese cabbages grown in Korea were collected and used for preparing hot air dried powder. Different levels of Chinese cabbage powder were added to pork products and evaluated by comparing these products to those with sodium nitrite or a commercially available celery juice powder. The experimental groups included control (100 ppm sodium nitrite added), treatment 1 (0.15% Chinese cabbage powder added), treatment 2 (0.25% Chinese cabbage powder added), treatment 3 (0.35% Chinese cabbage powder added), and treatment 4 (0.4% celery juice powder added). The cooking yields and pH values of treatments 1 to 3 were significantly lower ($p<0.05$) than the control. However, all of the alternatively cured products were redder (higher CIE a* values; $p<0.05$) than the control and this result was supported from higher nitrosyl hemochrome, total pigment, and curing efficiency. Furthermore, the inclusion of vegetable powders to these products resulted in considerably less residual nitrite content. However, Chinese cabbage powder (0.25% and 0.35%) was effective in producing alternatively cured meat products with a higher curing efficiency comparable to those of the traditionally cured control or the products with celery juice powder. Therefore, Chinese cabbage powder exhibited the efficacy for use as a natural replacer for alternatively cured meat products.

Keywords: alternatively cured meat, Chinese cabbage powder, sodium nitrite, color, cured

pigment

Introduction

Nitrite, which is essentially used for curing meat, is a typical synthetic additive to replace in processed meat products termed naturally cured meat products. Nitrite is a multifunctional ingredient in cured meat and contributes to the cured meat color and unique flavor, while effectively controlling rancidity by retarding lipid oxidation, and inhibiting the growth of microorganisms, particularly against *Clostridium botulinum* (Alahakoon et al., 2015; Sebranek, 2009; Sindelar and Houser, 2009; Sindelar and Milkowsk, 2012). Therefore, it is difficult to replace nitrite, and a complete replacement for nitrite has not yet been discovered that can serve similarly as a multifunctional ingredient (Alahakoon et al., 2015; Sindelar and Houser, 2009). In order to address this, the meat processing industry seeks to replace synthetic additives with natural sources (Alahakoon et al., 2015).

Novel food technology ideas designed to replace synthetic nitrite have focused on a method for producing naturally cured meat products by adding a vegetable powder with high nitrate content and a starter culture, such as *Staphylococcus carnosus*, *Staphylococcus vitulinus*, and *Staphylococcus xylosus*, possessing nitrate-reducing activity (Sebranek and Bacus, 2007a; Terns et al., 2011). Celery juice powder is the most widely used as a natural nitrate source for alternatively cured meat products. However, there is a limit to the amount of celery powder that can be used in product formulation as it may adversely affect the sensory attributes (Sindelar et al., 2007b). Therefore, in order to overcome this problem, some researchers have trialed other types of vegetables with high nitrate content such as white kimchi, red beet, parsley, spinach, and Swiss chard as potential natural sources for nitrite to produce naturally cured meat sausages (Choi et a., 2020; Riel et al., 2017; Riyad et al., 2018; Sucu and Turp, 2018). Riyad et al. (2018)

reported that the addition of red beet powder increased the redness of cooked sausages and demonstrated similar lipid oxidation to the nitrite-added control after 4 weeks of storage. However, Riel et al. (2017) found that compared with the traditionally nitrite-cured control, alternatively cured sausages with 0.49% parsley extract powder showed a reduced residual nitrite content (40%) and similar CIE a* values until 21 d of storage. Most of these studies appear to have achieved a successful outcome to replace nitrite because this indirect curing method is used mainly in comminuted meat products rather than the whole muscle products, including hams and jerkies. Since the naturally occurring nitrate is soluble and the starter culture is water insoluble, the results were ineffective in the whole muscle products (Sebranek and Bacus, 2007a; Sindelar et al., 2010).

Vegetable concentrates, or powders are advantageous as they can provide high concentrations of nitrate to produce naturally cured products. However, high levels of vegetable products may affect the sensory attributes, and therefore the specific vegetable used should not negatively influence the characteristic flavors and pigments of the cured meats or act as an allergen (Sebranek and Bacus, 2007a; Sebranek et al., 2012). Chinese cabbage is a green leafy vegetable and considered a good source for biologically active metabolites such as carotenoids, phenolic acids, flavonoids, and vitamins, which can act as antioxidants (Lee et al., 2015; Seong et al., 2016). Moreover, Chinese cabbage contains high concentrations of naturally occurring nitrate, which makes it a potential candidate for use as a natural alternative for meat products. Reportedly, the average nitrate content in fresh Chinese cabbage was 1,438.5 mg/kg (Kang et al., 2016) or 1,740 mg/kg (Chung et al., 2003) depending on the study. Thus, the nitrate concentration can increase following the drying process and a sufficient amount of nitrate will be supplied to the cured products in powder form (Choi et al., 2020; Sindelar, 2006). Therefore, Chinese cabbage powder was expected to show potential as a new natural alternative for synthetic nitrite as it is not associated with allergens. However, studies focusing on the compatibility of this ingredient in naturally cured meat sausages have not yet been elucidated. Therefore, this study investigated the effects of the addition levels of Chinese cabbage powder on the quality attributes of alternatively cured pork sausages and evaluated their effects by comparing them with products containing synthetic sodium nitrite or those cured with commercially available celery powder.

Materials and Methods

The preparation of raw materials

Chinese cabbages grown in five provinces of South Korea (Gyeonggi-do, Gyeongsang-do, Jeolla-do, Chungcheong-do, and Gangwon-do) were purchased, randomly selected (approximately 10 kg/region), and used for manufacturing Chinese cabbage powder in this study. Following removal of the non-edible portion of the cabbages such as the outside leaves and roots, the cabbages were cut (3 × 5 cm), rinsed in distilled, deionized water, and then drained for 1 h in a strainer. The excess water was further removed by (pressing 10 pumps) using a spinner (OXO Good Grips Salad Spinner, OXO International, Chambersburg, PA, USA). The rinsed Chinese cabbages were homogenized for 4 min using a food cutter (C6 VV, Sirman, Marsango, Italy). The sides of the food cutter were scraped periodically and the sample homogenized for an additional 2 min. This process was repeated until the sample was homogenized for a total of 10 min (Nuñez de González et al., 2015). The homogenized samples were vacuum-packed in nylon/polyethylene bags (~500 g each) and then stored in a freezer (C110AHB, LG Electronics, Changwon, Korea) at −18°C prior to hot air drying. Then the frozen samples were removed from the bags and dried at 60°C in a dryer (EN-FO-3925, Enex Science, Goyang, Korea) for 12 h. The dried samples were pulverized with a blender (51BL30, Waring Commercial, Torrington, CT, USA) for 3 min and screened using a 30 mesh sieve (Test sieve BS0600, Chunggye Sieve, Gunpo, Korea). The Chinese cabbage powder was vacuum-packed in nylon/polyethylene bags and stored in a freezer at −18°C until further use. The prepared Chinese cabbage powder had a nitrate ion content of 36,863 ppm (equivalent to 50,479 ppm sodium nitrate), a nitrite content of 0.2 ppm, a pH of 5.44, and a moisture content of 6.27%. Celery powder (VegStable 502, Florida Food Products, Inc., Eustis, FL, USA) with a nitrate ion content of 23,375 ppm (equivalent to 32,020 ppm sodium nitrate) and a starter culture (CS 299, CHR Hansen, Milwaukee, WI, USA) consisting of *Staphylococcus carnosus*, sodium nitrite (S2252, Sigma-Aldrich, St. Louis, MO, USA), and sodium ascorbate (#35268, Acros Organics, Geel, Belgium) were obtained from commercial suppliers.

The manufacturing process of ground pork sausages

The pork ham (*M. biceps femoris, M. semitendinosus*, and *M. semimembranosus*) muscles and back fat used in this study were purchased from a local meat processor (Pukyung Pig Farmers Livestock Co., Kimhae, Korea) at 24–48 h postmortem and. The intermuscular fat and visible connective tissues were trimmed from the fresh ham. The lean pork ham was cut into squares of approximately 4–5 cm, vacuum-packaged in nylon/polyethylene film bags, and then stored in a –18°C freezer until processing within 1 mon. The pork back fat was also prepared similarly. In order to manufacture the ground pork products (total batches of 30 kg per trial), frozen pork meat and back fat were thawed at 2–3°C for 24–36 h prior to processing and then sequentially ground with a chopper (TC-22 Elegant plus, Tre Spade, Torino, Italy) equipped with an 8-mm plate and 3-mm plate. The ground pork meat and back fat were randomly separated into five batches (Table 1) as follows: control, 0.01% sodium nitrite; treatment 1, 0.15% Chinese cabbage powder and 0.015% starter culture; treatment 2, 0.25% Chinese cabbage powder and 0.025% starter culture; treatment 3, 0.35% Chinese cabbage powder and 0.035% starter culture; and treatment 4, 0.4% celery juice powder and 0.04% starter culture. In the control samples, the addition of 100 ppm sodium nitrite was considered according to the regulations of The Korea Food Code (Ministry of Food and Drug Safety, 2020) in processed meat (< 70 ppm residual nitrite ion). The utilization level of the celery juice powder and starter culture was based on the suppliers' recommendations (Choi et al., 2020; Sindelar et al., 2007b). From the results of the nitrate analysis for Chinese cabbage powder (50,497 ppm nitrate) and celery juice powder (32,020 ppm nitrate), the various addition levels of Chinese cabbage power in treatments 1–3 were selected based on the target nitrate concentration in 0.4% celery juice powder. The ingoing nitrate concentrations from the vegetable powders were calculated as 75.75 ppm, 126.24 ppm, 176.74 ppm, and 128.08 ppm for treatments 1, 2, 3, and 4, respectively. For processing of the control samples, ground pork meat, pork fat, NaCl, dextrose, sodium tripolyphosphate, sodium nitrite, and sodium ascorbate were added to a mixer (5K5SS, Whirlpool, St. Joseph, MI, USA) with the ice/water and then mixed for 10 min (Table 1). For alternatively cured products, Chinese cabbage powder or celery juice powder and starter culture were incorporated in the same ingredients and procedure of the control, but sodium nitrite was not included. Each batch was stuffed into conical tubes (approximately 50 g) using a stuffer (MOD.5/W Deluxe, Tre Spade, Torino, Italy). The stuffed tubes were then centrifuged at 2000

× g for 10 min (Combi R515, Hanil Science Industrial Co., Incheon, Korea) to remove any air pockets. All tubes were closed with caps and placed on racks in a refrigerator at 10°C for the control or incubated for 2 h at 40°C in an incubator (C-IB4, Changshin Science, Pocheon, Korea) for treatments 1 to 4. After incubation, the tubes from each batch were sequentially cooked to an internal temperature of 75°C in a 90°C water bath (MaXturdy 45, Daihan Scientific Co., Wonju, Korea) for approximately 9–12 min depending on the samples. The temperature was monitored using a 4-channel digital thermometer (Tes-1384, Ketech Scientific Instrument, Kaohsiung, Taiwan). Once cooked, the samples were immediately cooled for 20 min on slurry ice and stored at 2–3°C in the dark prior to analysis. Experiments were performed in triplicate.

Moisture content determination

The moisture content of the Chinese cabbage powder was determined using the drying method (AOAC, 2016).

The pH values determination

Five grams of Chinese cabbage powder or cooked meat products were homogenized with 45 mL of distilled water for 1 min in a homogenizer (DI 25 basic, IKA®-Werke GmbH & Co. KG, Staufen, Germany). The pH values of each sample were measured using a pH meter (Accumet AB150, Thermo Fisher Scientific, Inc., Singapore).

Cooking yield determination

The weight of each meat product sample in the conical tube was measured prior to cooking and then again after cooking and cooling to determine the cooking yield using the following equation:

$$\text{Cooking yield (\%)} = \frac{\text{Sample weight after cooking}}{\text{Sample weight before cooking}} \times 100$$

CIE color measurements

Color measurements were taken using a colorimeter (Chroma Meter CR-400, illuminant C, 2° standard observer; Konica Minolta Sensing Inc., Osaka, Japan) calibrated with a white plate (L* 94.90, a* –0.39, b* 3.88). The Commission Internationale de l'Eclairage (CIE) L* (lightness), a* (redness), and b* values (yellowness) system was used to determine the color of freshly cut surfaces of each cooked sample immediately after cutting.

Residual nitrite analysis

The nitrate ion (NO_3^-) and nitrite ion (NO_2^-) of the homogenized Chinese cabbage prior to drying and the powder following the drying process were determined by the zinc reduction method described by Merino (2009). Results were reported as ppm. The residual nitrite content in the cooked pork sausages was analyzed according to the procedure of the AOAC (2016). A calibration curve was prepared using sodium nitrite (S2252, Sigma-Aldrich, St. Louis, MO, USA), and the residual nitrite content was reported as ppm.

Nitrosyl hemochrome, total pigment, and curing efficiency determination

Nitrosyl hemochrome and total pigment were determined using a method by Hornsey (1956). For nitrosyl hemochrome determination, 10 g of each cooked sample was blended with 40 mL acetone and 3 mL distilled, deionized water using a homogenizer (DI 25 basic, IKA®-Werke

GmbH & Co. KG, Staufen, Germany). The samples were kept in the dark for 15 min and filtered through a Whatman No. 1 filter paper, and then, the absorbance of the filtrate at 540 nm (A_{540}) was determined using a spectrophotometer (UV-1800, Shimadzu Co., Kyoto, Japan). The nitrosyl hemochrome concentration (ppm) was calculated as $A_{540} \times 290$. For the total pigment measurement, 10 g of each cooked sample was blended with 40 mL acetone, 1 mL HCl, and 2 mL distilled, deionized water, which was allowed to stand in the dark at 2–3℃ for 1 h and then filtered through a Whatman No. 1 filter paper. Absorbance was measured at 640 nm (A_{640}). The total pigment concentration (ppm) was calculated as $A_{640} \times 680$. Curing efficiency (%) was calculated using the following equation:

$$\text{Curing efficiency (\%)} = \frac{\text{Nitrosyl hemochrome}}{\text{Total pigment}} \times 100$$

Statistical analysis

The experiment was replicated three times. Data were statistically analyzed as a randomized block design with five treatments (control and four nitrite-free treatments) using the Proc GLM (general linear model) procedure of the SAS program (SAS, 2012). If significance was determined ($p<0.05$) in the model, the significance of the means was further separated by Duncan's multiple range test.

Results and Discussion

Cooking yield, pH values, and CIE color values

The alternatively cured sausages (treatments 1 to 4) produced lower cooking yields ($p<0.05$) compared to the nitrite-added control (Table 2). However, there were no differences ($p>0.05$) in cooking yields by Chinese cabbage powder level or the addition of celery juice powder. Kim et al. (2019a) and Krause et al. (2011), who reported that the meat products cured with a natural nitrite source from vegetable juice showed no significant differences in cooking loss compared to the conventionally cured control. However, the effects of vegetable powder on cooking yields in this study are in agreement with Choi et al. (2020), who found that the naturally cured products with white kimchi powder or celery powder exhibited significantly lower cooking yields than the nitrite-added control.

Naturally cured sausages (treatments 1 to 3) with the Chinese cabbage powder had lower pH values ($p<0.05$) than the control (Table 2). Moreover, the pH values decreased ($p<0.05$) further as level of Chinese cabbage powder increased. These decreases in pH might be related directly to the vegetable powder or caused by the lactic acid produced by the starter culture during incubation (Gøtterup et al., 2008; Sebranek and Bacus, 2007a; Terns et al., 2011). Since the Chinese cabbage powder used in this study had a pH of 5.44, the powder could lower the pH of treatments 1 to 3. However, the pH values of treatment 4 were similar ($p>0.05$) to that of the control. This result was consistent with the findings of Sindelar et al. (2007b), who found that the addition of celery juice powder at various levels to hams did not change the pH of the products compared to the nitrite-added control.

No differences ($p>0.05$) in CIE L* values were observed between the control and the other treatments (Table 2). Krause et al. (2011) reported similar results for the CIE L* values in sliced hams with vegetable juice powder and Riyad et al. (2018) also found no differences in CIE L* values between the sodium nitrite-added control and beef sausages cured with celery, parsley, or spinach powder. Furthermore, the alternatively cured sausages (treatments 1 to 4) exhibited higher CIE a* values than the control; however, these differences were not for the significant ($p>0.05$) for the CIE a* values by any Chinese cabbage powder level used in treatments 1 to 3 (Table 2). Similar results were reported by Kim et al. (2019a), who found that when fermented spinach juice was added into pork loin along with organic acids, CIE a* values were higher than in the control marinated with nitrite and ascorbic acid. Similarly, Sucu and Turp (2018) reported that the inclusion of beetroot powder as a nitrite alternative resulted in an increase in redness (higher CIE a* values) in fermented beef sausages. In this study, treatment 2 and treatment 4 provided equivalent nitrates from vegetable powder, while treatment 1 had 40% lower nitrate than the two treatments. Interestingly, the CIE a * values for treatment 1 showed similar values to treatments 2 to 4 and higher values than control. Since the most important parameter in color is redness (a* value) for cured meat products (Feng et al. 2016), these results indicated that the Chinese cabbage powder was very effective at increasing redness in the naturally cured sausages and showed the potential of this power for use as a replacement for nitrite. Treatments 1 and 2 showed similar ($p>0.05$) CIE b* values to the control (Table 2). However, treatments 3 and 4 exhibited higher ($p<0.05$) CIE b* values compared to the control and other treatments. These results were similar to those of Riel et al. (2017), who found that higher ingoing amounts of parsley extract powder resulted in higher b* values compared to traditionally cured sausages. Horsch et al. (2014) also reported that celery concentrate treatments were significantly more yellow (higher b* values) than the hams cured with nitrite and an increase of the concentration of celery concentrate lead to increased yellowness in the final ham products. Riel et al. (2017) and Horsch et al. (2014) indicated that the higher b* values might be related to the plant pigments in the vegetable concentrates. Therefore, our results suggested that when vegetable powder with increased nitrate contents was added to the meat products, the effect of the color of the vegetable powder could be minimized, and similar yellowness to that of the nitrite added products might be obtained in the alternatively cured sausages.

Residual nitrite, nitrosyl hemochrome, total pigments, and curing efficiency

The residual nitrite contents of the cooked pork sausages was 37.32, 14.68, 16.58, 22.24, and 16.35 ppm for the control, treatment 1, treatment 2, treatment 3, and treatment 4 (Table 3). Previous researchers have found this depletion of nitrite during product manufacturing. Xi et al. (2012) found that the amount of nitrite had reduced by about 75% of the initial concentration for frankfurters. Choi et al. (2020) also reported about 78% of the nitrite had depleted in ground pork products following the cooking and chilling process. In this study, the addition of a starter culture (*S. carnosus*) converted the nitrate from vegetable powder to nitrite in alternatively cured products although the added amount of starter culture varied depending on the treatments. Terns et al. (2011) indicated that the level of starter culture did not improve the cured meat properties in the indirectly cured, emulsified sausages. Nevertheless, all alternatively cured sausages had lower ($p<0.05$) residual nitrite contents than the control. Sebranek and Bacus (2007a) found that the residual nitrite contents was lower in the naturally cured meat products than in the conventionally cured products. Similarly, Riel et al. (2017) reported that the residual nitrite contents of mortadella-type sausages produced with different levels of parsley extract powder were lower than the nitrite-added control. In this study, treatments 3 had higher ($p<0.05$) residual nitrite contents compared to other treatments. Higher residual nitrite contents in treatment 3 among the alternatively cured products were expected because the highest ingoing amounts of nitrate (176 ppm) were from the Chinese cabbage powder in this study.

Nitrosyl hemochrome is a stable pink pigment formed by the reaction of nitric oxide converted from nitrite with myoglobin, resulting in a typical cured meat color after the cooking process (Cassens, 1997; Suman and Joseph, 2013). In this study, similar to the results of the CIE a* values, the nitrosyl hemochrome contents were higher ($p<0.05$) for all of the alternatively cured sausages than the control (Table 3). However, treatment 1 showed lower ($p<0.05$) nitrosyl hemochrome contents than treatments 2 to 4, which exhibited similar results ($p>0.05$). This finding suggested that the increase in redness of the alternatively cured sausages might be associated with an increase in the nitrosyl hemochrome, and sufficient amounts of nitrite were facilitated for the curing reactions, which resulted in the reduction of residual nitrite as shown in this study. Similar to our results, Choi et al. (2020) found that the indirectly cured pork products with 0.2% or 0.4% white kimchi powder had a higher nitrosyl hemochrome contents than the conventionally cured control. Terns et al. (2011) also obtained similar results by adding celery juice powder and cherry powder to the indirectly cured, emulsified sausages. However, these results disagree with those of Sindelar et al. (2007b), who found no differences in the cured pigment contents between the nitrite-added control and the naturally cured hams treated with different concentrations of the celery juice powder and the incubation time. As a result, the results of the present study suggest that the addition of cabbage powder was very effective in the cured pigment formation in the alternatively cured products.

Total pigment contents of the products tested in this study ranged from 47.18 to 49.13 ppm and were lower than those found in previous research (Sindelar et al., 2007a) ranging from 58.1 to 92.5 ppm. However, compared to the control, the addition of Chinese cabbage powder or celery juice powder to the products increased ($p<0.05$) the total pigment contents. However, these increases were similar ($p>0.05$) to each other. These results clearly followed the same trends as our CIE a* values. The relationship between nitrosyl hemochrome and total pigment contents was supported by Ahn and Maurer (1989), who speculated that less nitrosyl hemochrome formation could be the primary cause of a low total pigment. This has been previously confirmed by Sullivan et al. (2012), who reported that naturally cured frankfurters collected from commercial brands had the greatest amount of cured pigment and the highest total pigment contents. Thus, our results suggested that nitrite derived from vegetable sources by the starter culture was rapidly converted to nitric oxide, resulting in more nitrosyl hemochrome and total pigment contents in final products. In addition, it might be possible that the curing reaction in the alternatively cured products could occur faster because the vegetables such as the Chinese cabbage powder and celery juice powder possess inherent ascorbic acid that functions as a curing accelerator facilitated the conversion of nitrite to nitric oxide enhancing color development (Li et al., 2018; Sebranek et al., 2012; Zhu et al., 2018).

Curing efficiency of the pork products tested in this study ranged from 72.70% to 82.93% (Table 3). Cured pork sausages with Chinese cabbage powder or 0.4% celery juice powder had a higher ($p<0.05$) curing efficiency than the control with sodium nitrite. Furthermore, no differences ($p>0.05$) in curing efficiency were found between treatments 2 to 4. Kim et al. (2019b) reported that pork loins cured with fermented Swiss chard showed curing efficiency of 62.9% to 90.19% with the concentrations of fermented Swiss chard solutions, which was lower or higher than that of the control cured with 120 ppm nitrite (86.03%). Choi et al. (2020) found that the curing efficiency of indirectly cured meat products with white kimchi powder ranged from 75.26% to 79.34%, resulting in higher curing efficiency than the nitrite control. However, the lower nitrosyl hemochrome contents in treatment 1 resulted in decreasing curing efficiency and treatments 1 had less ($p<0.05$) curing efficiency than treatments 2 to 4. Therefore, these results suggested that the 0.15% addition (75 ppm ingoing nitrate) of Chinese cabbage powder did not show sufficient cured pigment and curing efficiency in the alternatively cured products even when it showed a higher curing efficiency than the control. Importantly, the addition of more than 0.25% Chinese cabbage powder (126 ppm ingoing nitrate) increased both the cured pigment and curing efficiency in the alternatively cured meat products.

Conclusions

Although cooking yield was slightly lower in the alternatively cured pork sausages with Chinese cabbage powder or celery juice powder, higher redness was found compared with the nitrite control. Moreover, less residual nitrite content were found in the alternatively cured meat products. In addition, the nitrite derived from the vegetable powder and starter culture with nitrate-reducing activity was more effectively involved in the curing reaction and more effective at the conversion of nitrite to nitric oxide, thereby resulting in higher cured pigment, total pigment, and curing efficiency. However, among the meat products with Chinese cabbage powder, 0.15% addition of Chinese cabbage powder (treatment 1) exhibited less cured pigment and curing efficiency, while the addition of more than 0.25% Chinese cabbage powder (126 ppm ingoing nitrate) positively affect the cured meat sausages with an increase in the cured pigment and curing efficiency comparable to those of the traditionally cured control. Therefore, this study indicated that Chinese cabbage powder showed efficacy as a new natural ingredient to replace synthetic nitrite for alternatively cured meat sausages. Further research is needed to explore the effectiveness of Chinese cabbage powder on the sensory attributes and shelf life of naturally cured meat products during storage for industrial practice.

Conflicts of interest

The authors declare no potential conflict of interest.

Acknowledgments

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Table 1. The formulation for cooked ground pork products formulated with vegetable powders

Main materials (%)	Treatments				
	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Pork ham	70.00	70.00	70.00	70.00	70.00
Pork back fat	15.00	15.00	15.00	15.00	15.00
Ice/water	15.00	15.00	15.00	15.00	15.00
Ingredients (%)					
NaCl	1.50	1.50	1.50	1.50	1.50
Dextrose	1.00	1.00	1.00	1.00	1.00
Sodium tripolyphosphate	0.30	0.30	0.30	0.30	0.30
Sodium nitrite	0.01	-	-	-	-
Sodium ascorbate	0.05	0.05	0.05	0.05	0.05
Chinese cabbage powder	-	0.15	0.25	0.35	-
Celery powder	-	-	-	-	0.40
Starter culture	-	0.015	0.025	0.035	0.04
Total	101.860	103.015	103.125	103.235	103.29

Table 2. Effects of Chinese cabbage powder on cooking yield, pH values, and CIE color of alternatively cured meat products

Treatments[1]	Dependent variables				
	Cooking yield (%)	pH	CIE L^*	CIE a^*	CIE b^*
Control	99.64 ± 0.01^A	6.15 ± 0.009^A	68.79 ± 0.17	8.85 ± 0.14^B	6.98 ± 0.05^B
Treatment 1	99.24 ± 0.08^B	6.12 ± 0.003^B	68.41 ± 0.16	10.10 ± 0.10^A	6.97 ± 0.07^B
Treatment 2	99.24 ± 0.02^B	6.10 ± 0.002^C	68.28 ± 0.16	10.12 ± 0.09^A	7.04 ± 0.06^B
Treatment 3	99.19 ± 0.05^B	6.08 ± 0.003^D	68.44 ± 0.10	10.06 ± 0.07^A	7.39 ± 0.06^A
Treatment 4	99.20 ± 0.07^B	6.16 ± 0.005^A	68.29 ± 0.15	9.98 ± 0.08^A	7.52 ± 0.03^A

All values are means ± standard errors.

$^{A\text{-}D}$ Means within a column with different superscript letters are significantly different ($p<0.05$).

[1] Treatments: control, 100 ppm sodium nitrite; treatment 1, 0.15% Chinese cabbage powder; treatment 2, 0.25% Chinese cabbage powder; treatment 3, 0.35% Chinese cabbage powder; treatment 4, 0.4% celery juice powder.

Table 3. Effects of Chinese cabbage powder on residual nitrite, nitrosyl hemochrome, total pigment, and curing efficiency of alternatively cured meat products

Treatments[1]	Dependent variables			
	Residual nitrite (ppm)	Nitrosyl hemochrome (ppm)	Total pigment (ppm)	Curing efficiency (%)
Control	37.32 ± 0.53^{A}	34.29 ± 0.09^{C}	47.18 ± 0.18^{B}	72.70 ± 0.36^{C}
Treatment 1	14.68 ± 1.67^{C}	37.85 ± 0.24^{B}	48.79 ± 0.11^{A}	77.57 ± 0.50^{B}
Treatment 2	16.58 ± 1.62^{C}	39.73 ± 0.28^{A}	48.62 ± 0.22^{A}	81.73 ± 0.69^{A}
Treatment 3	22.24 ± 2.05^{B}	40.53 ± 0.09^{A}	49.13 ± 0.11^{A}	82.49 ± 0.09^{A}
Treatment 4	16.35 ± 2.13^{C}	40.60 ± 0.13^{A}	48.96 ± 0.18^{A}	82.93 ± 0.35^{A}

All values are means ± standard errors.

$^{A\text{-}C}$ Means within a column with different superscript letters are significantly different ($p<0.05$).

[1] Treatments: control, 100 ppm sodium nitrite; treatment 1, 0.15% Chinese cabbage powder; treatment 2, 0.25% Chinese cabbage powder; treatment 3, 0.35% Chinese cabbage powder; treatment 4, 0.4% celery juice powder.