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Effects of the Addition Levels of White Kimchi Powder and Acerola Juice Powder on the Qualities of Indirectly Cured Meat Products

Abstract

This study investigated the effects of the addition levels of white kimchi powder and acerola juice powder, as natural sources of sodium nitrite and sodium ascorbate, on the quality of cooked ground pork products. Freeze-dried white kimchi powder (WKP) was prepared and used after fermentation for 2 wk. Six treatments were included: control (100 ppm sodium nitrite and 500 ppm sodium ascorbate), treatment 1 (0.2% WKP, 0.02 % starter culture, and 0.1% acerola juice powder), treatment 2 (0.2% WKP, 0.02% starter culture, and 0.2% acerola juice powder), treatment 3 (0.4% WKP, 0.04% starter culture, and 0.1% acerola juice powder), treatment 4 (0.4% WKP, 0.04% starter culture, and 0.2% acerola juice powder), and treatment 5 (0.4% celery powder, 0.04% starter culture, and 0.2% acerola juice powder). The pH values were decreased ($p<0.05$) because of lower pH of acerola juice powder, resulting in lower cooking yields ($p<0.05$) in these treatments. CIE L* and CIE a* values of indirectly cured meat products were not different ($p>0.05$) from the sodium nitrite-added control. However, indirectly cured meat products showed lower ($p<0.05$) residual nitrite contents, but higher ($p<0.05$) nitrosyl hemochrome contents and cure efficiency than the control. Treatments 2 and 4 had higher ($p<0.05$) total pigment contents and lipid oxidation than the control. This study indicates that white kimchi powder coupled with acerola juice powder has substantial potential to substitute synthetic nitrite to naturally cured meat products, which could be favored by consumers seeking clean label products.

Key words: cured meat, clean label, white kimchi powder, acerola juice powder, starter culture

Introduction

In the meat processing industry, meat curing is the oldest method of preserving meat and poultry; it is defined as the addition of salt with nitrite. Nitrite has a microbiological preservative effect, particularly against *Clostridium botulinum*, and it contributes to flavor, color properties, and inhibition of lipid oxidation in cured meat products (Cassens, 1995; Sindelar and Milkowski, 2011; Pegg and Shahidi, 2000). Nitric oxide reduced from nitrite reacts with myoglobin to form nitrosyl myoglobin, which is converted to a stable nitrosohemochrome during thermal processing. However, although nitrite has many benefits, consumer demand for natural products continues to grow because of perceptions and concerns for health risks related to the consumption of nitrite in conventionally cured meat products (Sebranek et al., 2012). Thus, many meat processors have attempted to develop and produce meat products cured with natural ingredients that meet the needs of consumers by replacing synthetic nitrite with natural ingredients containing nitrogen compounds, such as celery, spinach, lettuce, and beets (Bedale et al., 2016; Jeong, 2016; Sebranek et al., 2012). In the food industry, there is now a “clean label” trend, which refers to the production of foods without the addition of harmful ingredients or additives or through “natural” production methods, such as organic farming (Asioli et al., 2017). Some consumers select clean label products that are labeled as additive-free, preservative-free, natural, or organic rather than products with food additives on the product label, and there are increasing sales and marketing of these clean label products (Lee, 2015).

For an alternative meat curing method to replace synthetic nitrite, vegetables with a high content of nitrate and starter cultures such as *Staphylococcus carnosus* and *Staphylococcus xylosus* are commonly used (Alahakoon et al., 2015; Li et al., 2013b; Sindelar and Houser, 2009). Currently, celery is the most widely used as an alternative source of nitrate for curing meat products (Jeong, 2016; Sebranek and Bacus, 2007; Sindelar et al., 2007a; Sindelar et al., 2007b). In addition to celery, vegetables, such as spinach, lettuce, radish, cabbage, and red beet, are known to contain considerable amounts of nitrate (Bahadoran et al., 2016; Siciliano et al., 1975; Tamme et al., 2006; White, 1975). Kimchi, which is a traditional Korean fermented food, is primarily manufactured using Chinese cabbage and radish, which have high nitrate contents, and garlic, ginger, green onion, and red pepper, which also contain some nitrate (Kim and Shin, 1997). Moreover, kimchi has been recognized as containing bioactive substances, such as dietary fiber, minerals, lactic acid bacteria, phenolic compounds, and vitamins, especially vitamin B, ascorbic acid, and carotene. These substances are effective in preventing cancer, antioxidant activity, and constipation (Levy, 1981; Park et al., 2014). For these reasons, it is thought that kimchi has the potential to replace nitrite in naturally cured meat products. Acerola, which is also called West Indian cherry or Barbados cherry, has high contents of ascorbic acid and contains antioxidant compounds, such as carotenoid and anthocyanin, which can be used as functional foods (Assis et al., 2001; Rosso and Mercadante, 2005; Vendramini and Trugo, 2000). Reducing agents such as sodium ascorbate and sodium erythorbate are commonly used in traditional meat products to accelerate the rate of nitrite reduction to nitric oxide during meat curing (Honikel, 2008; Sebranek et al., 2012). Thus, acerola is a good candidate for replacing such cure accelerators in naturally curing meat because of its high ascorbic acid content. Terns et al. (2011) suggested that using cherry powder, with a high ascorbic acid content, increased the reduction of nitrite to nitric oxide and rapidly decreased the residual nitrite contents of indirectly cured, emulsified cooked sausages. Moreover, because of the effects of nutrients, such as ascorbic acid and polyphenols, in acerola powder, it can play crucial roles in suppressing the formation of nitrosamines by reducing the residual nitrite content of cooked meat (Neaud and Laroque, 2015). Lee et al. (2018) showed that kimchi extracts have the potential to reduce color deterioration and lipid oxidation in ground pork meat. In addition, Bae et al. (2019) reported that nitrate ion in fermented kimchi ranged from 1,450 to 1,801 ppm after 1 wk of fermentation. Kang et al. (2017) also found that nitrate contents of 2,248.5 mg/kg were detected in commercially available white kimchi in Korea. However, no information is available about using kimchi as a natural source for nitrite in indirectly cured, processed meat products. Kimchi is commonly prepared and fermented Chinese cabbage with varying seasonings including salt, garlic, ginger, red pepper powder, and other ingredients. However, white kimchi is produced without red pepper powder. Therefore, white kimchi was selected in this study to eliminate the confounding effect caused by the red color of red pepper itself and was dried to increase its nitrate concentrations. Therefore, this study investigated the applicability of white kimchi powder and acerola powder as sodium nitrite and sodium ascorbate replacements and evaluated their effects in naturally cured meat production by comparing them with conventionally cured products and products cured with commercially available celery powder.

Materials and Methods

White kimchi and kimchi powder preparation

Chinese cabbages and radishes grown in the five provinces of South Korea (Gyeonggi-do, Gyeongsang-do, Jeolla-do, Chungcheong-do, and Gangwon-do) were purchased, randomly selected, and used as the main ingredients for the production of white kimchi in this study. Moreover, Chinese cabbages, radishes, garlic, and ginger were prepared by trimming, washing, shredding, or cutting (Table 1). White kimchi was manufactured using a slight modification of the standardized recipe for the Korean food (Institute of Traditional Korean Food, 2008). The

Chinese cabbages were cut in half and solar salts were spread on the cut side of them, and then, they were soaked in water for 6 h. After soaking, the Chinese cabbages were rinsed under running water three to four times, and then, the water was drained for 1 h using a strainer. The seasoning ingredients (Table 1) were prepared and added to the Chinese cabbages in containers, and then, the pickling solution was poured into the containers. After 2 wk of fermentation in a kimchi refrigerator (K413SS13, LG Electronics, Changwon, Korea) at 0°C, the liquid was drained from the fermented white kimchi, and it was blended with a cutter (C6 VV, Sirman, Marsango, Italy). The ground white kimchi was vacuum-packed in nylon/polyethylene bags of ~500 g each and then stored in a deep freezer (HKF-51, HFK, Wonju, Korea) at −80°C before freeze drying. After opening the packages, the frozen white kimchi was dried at −40°C in a vacuum freeze dryer (PVTFD10R, Ilshinbiobase, Yangju, Korea) for 2 d. The dried white kimchi was pulverized with a blender (51BL30, Waring Commercial, Torrington, USA) for 3 min and then screened using a 30 mesh (Test sieve BS0600, Chunggye Sieve, Gunpo, Korea). The white kimchi powder was vacuum-packed in nylon/polyethylene bags and stored in a freezer at −18°C until further use.

Preparation and processing of ground pork products

Raw pork ham (*M. biceps femoris, M. semitendinosus*, and *M. semimembranosus*) muscles and back fat used in this study were obtained from a local meat processor (Pukyung Pig Farmers Livestock Co., Kimhae, Korea) at 24–48 h postmortem. After trimming the intermuscular fat and visible connective tissues from the fresh ham, the lean pork meat was cut into squares. The pork meat and back fat (total batch size of 20 kg per trial in three trials) were sequentially ground using a chopper (TC-22 Elegant plus, Tre Spade, Italy) with an 8 mm and 3 mm plate, respectively. Celery powder (SD00350002KL, Diana Food SAS, Antrain, France), with a nitrate ion content of 16,889 ppm (equivalent to 23,151 ppm sodium nitrate), starter culture (CS 299, CHR Hansen, Milwaukee, USA), acerola juice powder (SD00030013LP, Diana Food SAS, Antrain, France), containing a vitamin C content of 17.1%, sodium nitrite (S2252, Sigma-Aldrich, St. Louis, USA), and sodium ascorbate (#35268, Acros Organics, Geel, Belgium) were purchased from commercial suppliers. Different amounts of white kimchi powder, acerola juice powder, and starter culture were tested to investigate the suitability of white kimchi powder and acerola juice powder as natural sources for sodium nitrite/nitrate and sodium ascorbate for meat curing (Table 2). Ground pork meat and back fat were randomly assigned to a control and five treatment batches. All batches included 1.5% NaCl and 1.0% dextrose with the ground pork meat mixture (75% pork, 15% fat, and 15% ice/water). The control was prepared by adding 100 ppm sodium nitrite and 500 ppm sodium ascorbate. Five treatments were produced, with different amounts of vegetable powder, acerola juice powder, and starter culture (Table 2): the control, 0.01% sodium nitrite and 0.05% sodium ascorbate; treatment 1, 0.2% white kimchi powder, 0.02% starter culture, and 0.1% acerola juice powder; treatment 2, 0.2% white kimchi powder, 0.02% starter culture, and 0.2% acerola juice powder; treatment 3, 0.4% white kimchi powder, 0.04% starter culture, and 0.1% acerola juice powder; treatment 4, 0.4% white kimchi powder, 0.04% starter culture, and 0.2% acerola juice powder; and treatment 5, 0.4% celery powder, 0.04% starter culture, and 0.2% acerola juice powder. In treatment 5, the usage level of celery powder was chosen based on the supplier’s recommendation to compare with the white kimchi powder treatments (treatments 1 to 4) because celery juice and celery powder is commercially available and widely used as a natural source of nitrate in processed meat products (Sebranek and Bacus, 2007). Moreover, phosphates were not intentionally added to the samples because the use of phosphates in organic and natural meat products is limited. To prepare the samples, ground pork meat and back fat were added to a mixer (5K5SS, Whirlpool, St. Joseph, MI, USA) with NaCl and sodium nitrite for a control, or NaCl and white kimchi powder or celery powder for the indirectly cured treatments, and half of the ice/water, and this was mixed for 5 min. After that, the meat mixtures were added with dextrose, starter culture, acerola juice powder or sodium ascorbate, and the remaining ice/water, and then, the mixture was mixed again for 5 min. The meat mixture from each batch was stuffed into conical tubes in 50 g samples. The stuffed tubes were then centrifuged at 2,000 × g for 10 min (Combi R515, Hanil Science Industrial Co., Incheon, Korea) to remove any air pockets. After centrifuging, all tubes were closed with caps and placed on racks. Control samples were held at 10°C for 1 h in a refrigerator (C110AHB, LG Electronics, Changwon, Korea). Indirectly cured samples were incubated at 40°C for 2 h in an incubator (C-IB4, Changshin Science, Pocheon, Korea). When incubation was completed, all tubes, including the control and treatment samples, were cooked to an internal temperature of 75°C in a 90°C water bath (MaXturdy 45, Daihan Scientific Co., Wonju, Korea). The temperature was monitored using a 4-channel digital thermometer (Tes-1384, Ketech Scientific Instrument, Kaohsiung, Taiwan). After cooking, samples were immediately cooled for 20 min on slurry ice and stored at 2°C–3°C in the dark before analyzing. Experiments were performed in triplicate.

Moisture content determination

The moisture content of white kimchi powder was determined using the drying method (AOAC, 2016a).

Salinity measurement

The salt concentrations of white kimchi powder were determined according to the standard method of the Korea Food Code (Ministry of Food and Drug Safety, 2020). Salinity was calculated as follows:

$$\text{Salinity (\%)} = \frac{0.02\ \text{N AgNO}_3\ \text{(mL)} \times 0.00117 \times \text{AgNO}_3\ \text{factor} \times \text{dilution factor}}{\text{Sample (g)}} \times 100.$$

The pH values and cooking yield determination

The pH of white kimchi powder and cooked meat products was measured using a pH meter (Accumet AB150, Thermo Fisher Scientific, Inc., Singapore) following 5 g of samples being blended with 45 mL of distilled water for 1 min in a homogenizer (DI 25 basic, IKA®-Werke GmbH & Co. KG, Germany). The weight of each 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.

Nitrate and nitrite analysis

The contents of nitrate ion (NO_3^-) and nitrite ion (NO_2^-) of white kimchi powder were determined by the zinc reduction method described by Merino (2009). Results were reported as parts per million (ppm). The residual nitrite content in cooked meat products was analyzed according to the procedure of AOAC (2016b). A calibration curve was prepared using sodium nitrite (S2252, Sigma-Aldrich, St. Louis, USA), and the residual nitrite content was reported as parts per million (ppm).

Nitrosyl hemochrome, total pigment, and cure efficiency determination

Nitrosyl hemochrome and total pigment was determined using a method described 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 (Polytron PT10-35, Kinematica AG, Switzerland). The samples were kept in the dark for 15 min and filtered through a Whatman No. 1 filter paper, and then, 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 $A_{640} \times 680$. Cure efficiency (%) was calculated as (ppm of nitrosyl hemochrome) ÷ (ppm of total pigment) × 100.

Thiobarbituric acid reactive substances (TBARS) determination

Malondialdehydes (MDA) was measured by 2-thiobarbituric acid reactive substances (TBARS) values using a distillation method reported by Tarladgis et al. (1960) to determine lipid oxidation. The TBARS values were reported as mg MDA per kg of cooked samples.

Statistical analysis

All experiments were performed in triplicate. Data were statistically analyzed as a randomized block design with six treatments (control and five 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

The physicochemical properties of prepared white kimchi powder

The white kimchi powder prepared for meat product processing had a pH of 6.33 and moisture content of 5.37%. In the prepared white kimchi powder, the nitrate ion content was 16,778 ppm (equivalent to 22,999 ppm sodium nitrate), nitrite ion content was 0.72 ppm (equivalent to 1.08 ppm sodium nitrite), and salinity was 27.25%. In preliminary experiments, fermented white kimchi had nitrate ion contents of 1,247 ppm, nitrite ion contents of 0.31 ppm, and salinity of 2.07%, suggesting that these components in its powder form were concentrated following the drying process.

pH values, cooking yield, and CIE color values

The indirectly cured products (treatments 1 to 5) had lower pH values ($p<0.05$) than the control produced with sodium nitrite and sodium ascorbate (Table 3). As the addition levels of acerola juice powder increased in treatments 2 and 4 of the indirectly cured products, the pH values of the meat products decreased ($p<0.05$). This result was probably affected by the lower pH (3.33) of acerola juice powder. This is in agreement with Xi et al. (2012), who have reported similar findings of the pH values of naturally cured frankfurters decreasing as concentrations of cranberry powder, with a pH of 2.2, were increased. Interestingly, treatment 5 containing celery powder had lower pH values ($p<0.05$) than the control and the treatments with white kimchi powder, except for treatment 2. This result indicates that celery powder, with a pH 5.07, had an effect on relatively lowering the pH of treatment 5, compared with the white kimchi powder, with a pH of 6.33. The cooking yields of the indirectly cured meat products followed the same trends as the pH results of this study (Table 3). The control samples had higher ($p<0.05$) cooking yields compared with the indirectly cured treatments with white kimchi powder or celery powder. For the products containing white kimchi powder, treatments 2 and 4 with 0.2% acerola juice powder had lower cooking yields ($p<0.05$) than treatments 1 and 3, with 0.1% acerola juice powder. These results are slightly in contrast to those of Lee et al. (2008), who reported that incorporating kimchi powder at either 1% or 2% into breakfast sausages produced significantly higher cooking yields than the control without kimchi powder. However, unexpectedly, it seems that the effect of acerola powder on decreasing the pH value and cooking yields of naturally cured meats was very strong, compared with the conventionally cured meat products (control). These results are probably a result of phosphate not being added to the indirectly cured treatments in this study. Sebranek and Bacus (2007) indicated that the addition of curing accelerators, such as vinegar, lemon powder, and cherry powder, has the potential to accelerate nitrite reactions in natural or organic meat products. However, it has been suggested that lowering the pH of these products can result in the reduction of moisture retention because phosphates and some water binders cannot be used for them (Sebranek and Bacus, 2007). Consequently, there is a need for a supplementary approach to increase water binding, which is one of the essential functions of phosphates in cured meat products. Compared with the products with celery powder (treatment 5), the products with white kimchi powder (treatments 1 to 4) showed higher ($p<0.05$) cooking yields (Table 3). In this study, the cooking yields of treatment 5 (83.46%) were lower than those reported by Cropp (2018) in bologna sausages containing celery and cherry powder (91.6%). These results may be related to differences in product formulations and the celery powder used. For CIE L^* values, the five treatments were not significantly different ($p>0.05$) from the control (Table 3). Similarly, Sindelar et al. (2007b) reported that the addition of celery juice powder to ham, regardless of the addition level and incubation time, did not significantly change ($p>0.05$) the CIE L* values compared with those from the sodium nitrite control. In this study, the CIE a^*values ranged from 10.59 to 10.73, and no differences were found ($p>0.05$) between the control and all five treatments (Table 3), suggesting that the addition levels of nitrate from white kimchi powder or celery powder have been shown to be sufficient for developing the cured color of final products. Terns et al. (2011) obtained similar results for indirectly cured emulsified sausages. These results suggest that although only a small amount of white kimchi powder and acerola juice powder was added to treatments 1 and 3, they produced similar effects ($p>0.05$) on redness to the control and the other treatments. Therefore, the white kimchi powder prepared for this study could have the potential to substitute synthetic nitrite or commercial celery powder as a nitrate source for producing organic meat products. However, all treatments containing the vegetable powders had higher CIE b^* values ($p<0.05$) than the control (Table 3), but no difference in CIE b^* values ($p>0.05$) were found among products with the white kimchi powder or celery powder (treatments 1 to 5). Similarly, Krause et al. (2011) found that hams with vegetable juice powder and starter culture were more yellow (higher b* values) than the control cured with sodium nitrite. This is most likely because plant-derived powders include plant pigments (Horsch et al., 2014).

Residual nitrite, nitrosyl hemochrome, total pigments, cure efficiency, and TBARS

The residual nitrite contents were highest ($p<0.05$) in the control (21.65 ppm) and decreased by 78.4% of the added amount during product manufacturing (Table 4). This depletion is higher than the findings of ~65% for dry-cured sausages (Li et al., 2013a) and ~75% for frankfurters (Xi et al., 2012). The reduction of residual nitrite is affected by factors, such as the type of raw meat, pH of the meat, initial nitrite content, cooking temperature, and reducing agents (Cassens et al., 1978; Honikel, 2008; Xi et al., 2011). Among naturally cured products, when comparing treatments with the same amount of acerola powder, treatments 4 and 5 had higher residual nitrite contents ($p<0.05$) than other treatments (Table 4). It is possible that higher natural nitrate from vegetable powder along with the starter culture, *Staphylococcus carnosus*, which has nitrate reductase activity, resulted in more reduction of nitrate to nitrite in the meat curing system. However, as the amount of acerola juice powder increased, the residual nitrite contents decreased ($p<0.05$) in treatments 2, 4, and 5. Acerola is recognized as having high ascorbic acid, which has been found to be a curing accelerator that helps the conversion of nitrite to nitric oxide, and therefore is responsible for the faster development of the cured meat color (Sebranek et al., 2012). Gabaza et al. (2013) reported that ascorbic acid provides reducing conditions that increase the rate of nitric oxide formation, which accelerates the reduction of residual nitrite content. Sullivan et al. (2012a) and Terns et al. (2011) also found that the addition of cherry powder, which has high ascorbic acid content, reduces the residual nitrite content by increasing the reduction rate of nitrite to nitric oxide in indirectly cured sausages and hams. Thus, the lower residual nitrite of treatments 2, 4, and 5 could be related to the lower pH and ascorbic acid levels from the acerola powder added in this study, which was consequently available for the reduction of nitrite to nitric oxide. This explanation supports the findings for the nitrosyl hemochrome and total pigment contents (Table 4). The nitrosyl hemochrome and total pigment contents were higher ($p<0.05$) in treatments 2, 4, and 5 with 0.2% acerola juice powder than in the control and treatments 1 and 3 containing 0.1% acerola juice powder, regardless of the amounts of white kimchi or celery powder. These results suggest that cured color could rapidly develop through the addition of acerola juice powder as a source of ascorbic acid. Since pH and reductants are known to be the most important factors that influence nitrite reactions during meat curing (Sebranek, 2009). Especially, the pH can offer the basis for formulating acidulants to accelerate this process (Fox, 1974; Soltanizadeh and Kadivar, 2012). According to Fox et al. (1967) and Sebranek (1979), a small decrease in pH in the meat curing system can be quite important, and a pH decrease of 0.2 units can lead to double the rate of cured color formation because of nitrite–myoglobin interaction. The pH differences between treatments 2, 4, and 5 and the control and treatments 1 and 3 were about 0.16–0.39 pH units. Therefore, these pH differences might explain why treatments 2, 4, and 5 showed lower residual nitrite contents, but higher nitrosyl hemochrome and total pigment contents compared with the other treatments. However, cure efficiency was higher ($p<0.05$) in the indirectly cured treatments (treatments 1 to 5) than the control (Table 4). Treatment 2 had a higher ($p<0.05$) cure efficiency than the control and treatments 1 and 3, but it was not significantly different ($p>0.05$) from treatments 4 and 5. Interestingly, in treatment 2, kimchi powder, celery powder, and starter culture were added in half the concentrations of treatments 4 and 5, and acerola juice powder was added in equal concentrations. Such high cure efficiencies are thought to indicate the possibility that, coupled with acerola juice powder, prepared white kimchi powder is a very effective substitute for nitrite in an indirectly cured meat system. Other studies have also found high cure efficiencies for naturally cured meats. Sullivan et al. (2012b) found higher cure efficiencies for commercially available naturally cured brands of frankfurters, hams, and bacons collected from retail establishments, which were also redder as the cured pigments had increased. However, these trends on a relationship between redness and cured pigments were different from those observed in this study, which could have resulted from differences in nitrite/nitrate content derived from natural sources. Moreover, Shin et al. (2017) reported that cure efficiency was more than 80% when pork patties added with 2% pre-converted nitrite from Swiss chard powder, which was significantly higher compared with those produced with 2% pre-converted nitrite from celery powder. Treatments manufactured with white kimchi powder or celery powder had higher TBARS values ($p<0.05$) than the control with sodium nitrite (Table 4), and no differences ($p>0.05$) were observed in the TBARS values among the naturally cured products. Lower TBARS values in the control were expected to be due to higher residual nitrite contents in this study because nitrite contributes to antioxidant effects (Pegg and Shahidi, 2000). Although the addition of vegetable powders was expected to inhibit lipid oxidation because kimchi, celery, and acerola contain natural antioxidants, such as several polyphenols, flavonoids, and carotenoids, as well as high ascorbic acid content (Kooti and Daraei, 2017; Lee et al., 2018; Rufino et al., 2010; Woo and Jeong, 2006), this effect against lipid oxidation did not occur. A possible explanation for the higher TBARS values in the treatments with vegetable powder appears to be the effect of the lower pH values. Yasosky et al. (1984) found that the TBARS values of ground pork increased as pH values decreased. Kim et al. (2019) reported similar results for meat products cured with spinach and starter culture and found that pH values decreased with the addition of 10% spinach extract, whereas the TBARS values increased. Besides this, the TBARS values in this study were less than 0.15 mg MD/kg, which was lower than the 0.5–1.0 mg MD/kg suggested by Tarladgis et al. (1960) as a threshold range for detecting off-odor in cooked pork.

Conclusions

Although there was a detrimental effect on the cooking yield due to the lowered pH from the acerola juice powder added to replace sodium ascorbate, there was no difference in the redness of cured color development when compared with the sodium nitrite-added control. Furthermore, meat products indirectly cured with white kimchi powder or celery powder showed higher nitrosyl hemochrome and cure efficiency than the control. When 0.2% acerola juice powder was added, cooked products with white kimchi powder (0.2% or 0.4%) had a similar color and cured pigment qualities than those with 0.4% celery powder which is commercially available as a source of natural nitrate. Therefore, this study indicates that white kimchi powder has substantial potential to replace synthetic nitrite for naturally cured meat products and suggests that when a reductant with a low pH, such as acerola juice powder, is used for curing reactions with vegetable powder in clean label products, supplementary ingredients with buffering capacity for pH are required. In addition, further studies are warranted to reduce lipid oxidation in naturally cured meat products. The findings of this study indicate that the use of white kimchi powder in the production of indirectly cured meats could provide a product that is desirable for consumers who favor clean label products.

Conflicts of interest

The authors declare no potential conflict of interest.

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Table 1. Ingredients and seasoning used for preparing white kimchi

Ingredients for soaking[1]	Amount (g)	Seasoning ingredients[2]	Amount (g)	Pickling solution[3]	Amount (g)
Chinese cabbage	24,000	Shredded radish (4 × 0.5 cm)	3,000	Water	9,000
Water	20,000	Ground garlic	150	Salt	120
Solar salt	3,500	Ground ginger	50		
		Fermented shrimp	500		
		Salt	100		

[1] Chinese cabbages were cut in half, and solar salt was spread on the inside of them. Then, they were soaked in water for 6 h, rinsed under running water, and then drained of water.

[2] Seasoning ingredients were prepared and added to the Chinese cabbages after the cabbages were soaked.

[3] Pickling solution was poured onto Chinese cabbages containing seasoning in containers, and the white kimchi was fermented for 2 wk in a kimchi refrigerator at 0°C.

Table 2. The formulation for cooked ground pork products formulated with natural ingredients

Ingredients (%)	Treatments[1]					
	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
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
NaCl	1.50	1.50	1.50	1.50	1.50	1.50
Dextrose	1.00	1.00	1.00	1.00	1.00	1.00
Sodium nitrite	0.01	-	-	-	-	-
White kimchi powder	-	0.20	0.20	0.40	0.40	-
Celery powder	-	-	-	-	-	0.40
Starter culture	-	0.02	0.02	0.04	0.04	0.04
Sodium ascorbate	0.05	-	-	-	-	-
Acerola juice powder	-	0.10	0.20	0.10	0.20	0.20
Total	102.56	102.82	102.92	103.04	103.14	103.14

[1] Treatments: control, 0.01% sodium nitrite + 0.05% sodium ascorbate; treatment 1, 0.2% white kimchi powder + 0.02% starter culture + 0.1% acerola juice powder; treatment 2, 0.2% white kimchi powder + 0.02% starter culture + 0.2% acerola juice powder; treatment 3, 0.4% white kimchi powder + 0.04% starter culture + 0.1% acerola juice powder; treatment 4, 0.4% white kimchi powder + 0.04% starter culture + 0.2% acerola juice powder; and treatment 5, 0.4% celery powder + 0.04% starter culture + 0.2% acerola juice powder.

Table 3. Effects of natural ingredients on cooking yield, pH values, and CIE color of indirectly cured meat products

Traits	Treatments[1]					
	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
Cooking yield (%)	95.67 ± 0.21^{A}	91.18 ± 0.42^{B}	85.59 ± 0.66^{C}	91.25 ± 0.37^{B}	85.44 ± 0.70^{C}	83.46 ± 0.69^{D}
pH	6.26 ± 0.03^{A}	6.09 ± 0.02^{B}	5.92 ± 0.01^{CD}	6.10 ± 0.02^{B}	5.93 ± 0.00^{C}	5.87 ± 0.02^{D}
CIE L^*	67.83 ± 0.25	67.51 ± 0.22	67.91 ± 0.38	67.56 ± 0.18	67.90 ± 0.28	67.53 ± 0.44
CIE a^*	10.59 ± 0.23	10.73 ± 0.16	10.59 ± 0.20	10.73 ± 0.18	10.66 ± 0.13	10.71 ± 0.15
CIE b^*	7.37 ± 0.36^{B}	8.32 ± 0.18^{A}	8.61 ± 0.14^{A}	8.24 ± 0.15^{A}	8.62 ± 0.16^{A}	8.20 ± 0.32^{A}

All values are means ± standard errors.

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

[1] Treatments: control, 0.01% sodium nitrite + 0.05% sodium ascorbate; treatment 1, 0.2% white kimchi powder + 0.02% starter culture + 0.1% acerola juice powder; treatment 2, 0.2% white kimchi powder + 0.02% starter culture + 0.2% acerola juice powder; treatment 3, 0.4% white kimchi powder + 0.04% starter culture + 0.1% acerola juice powder; treatment 4, 0.4% white kimchi powder + 0.04% starter culture + 0.2% acerola juice powder; and treatment 5, 0.4% celery powder + 0.04% starter culture + 0.2% acerola juice powder.

Table 4. Effects of natural ingredients on residual nitrite, nitrosyl hemochrome, total pigment, and cure efficiency of indirectly cured meat products

Traits	Treatments[1]					
	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
Residual nitrite contents (ppm)	21.65 ± 0.44^{A}	2.32 ± 0.13^{C}	0.92 ± 0.06^{E}	3.98 ± 0.06^{B}	1.60 ± 0.05^{D}	1.76 ± 0.06^{D}
Nitrosyl hemochrome (ppm)	34.03 ± 0.81^{C}	37.14 ± 0.57^{B}	41.83 ± 0.99^{A}	38.16 ± 0.72^{B}	41.42 ± 1.07^{A}	42.46 ± 1.10^{A}
Total pigment (ppm)	47.83 ± 0.93^{C}	49.36 ± 0.56^{C}	52.59 ± 1.23^{AB}	48.98 ± 0.55^{BC}	53.10 ± 1.19^{A}	54.12 ± 0.94^{A}
Cure efficiency (%)	71.16 ± 1.03^{D}	75.26 ± 0.77^{C}	79.55 ± 0.34^{A}	76.34 ± 1.04^{BC}	78.08 ± 1.34^{ABC}	78.44 ± 1.30^{AB}
TBARS (mg MDA/kg)	0.10 ± 0.01^{B}	0.13 ± 0.01^{A}	0.13 ± 0.01^{A}	0.12 ± 0.01^{AB}	0.14 ± 0.01^{A}	0.12 ± 0.00^{AB}

All values are means ± standard errors.

$^{A-E}$ Means within a row with different superscript letters are significantly different ($p<0.05$).

[1] Treatments: control, 0.01% sodium nitrite + 0.05% sodium ascorbate; treatment 1, 0.2% white kimchi powder + 0.02% starter culture + 0.1% acerola juice powder; treatment 2, 0.2% white kimchi powder + 0.02% starter culture + 0.2% acerola juice powder; treatment 3, 0.4% white kimchi powder + 0.04% starter culture + 0.1% acerola juice powder; treatment 4, 0.4% white kimchi powder + 0.04% starter culture + 0.2% acerola juice powder; and treatment 5, 0.4% celery powder + 0.04% starter culture + 0.2% acerola juice powder.