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Use of green tea extract and rosemary extract in naturally cured pork sausages with white kimchi powder

Abstract

The impact of green tea extract powder and rosemary extract powder, alone or in combination, on the quality characteristics of naturally cured pork sausages produced with white kimchi powder as a nitrate source was evaluated. Ground pork sausages were assigned to one of seven treatments: control (0.01% sodium nitrite and 0.05% sodium ascorbate), treatment 1 (0.3% white kimchi powder and 0.05% green tea extract powder), treatment 2 (0.3% white kimchi powder and 0.1% green tea extract powder), treatment 3 (0.3% white kimchi powder and 0.05% rosemary extract powder), treatment 4 (0.3% white kimchi powder and 0.1% rosemary extract powder), treatment 5 (0.3% white kimchi powder, 0.05% green tea extract powder, and 0.05% rosemary extract powder), and treatment 6 (0.3% celery juice powder, 0.05% green tea extract powder, and 0.05% rosemary extract powder). Naturally cured products had lower ($p<0.05$) cooking yield and residual nitrite content than control sausages. However, compared to the control, naturally cured products with white kimchi powder (treatments 1 to 5) showed similar ($p>0.05$) the pH, oxidation-reduction potential, CIE L* values, CIE a* values, nitrosyl hemochrome content, total pigment content, and curing efficiency to the control. When the amount of green tea extract powder or rosemary extract powder was increased to 0.1% (treatments 2 and 4), lipid oxidation was reduced ($p<0.05$). These results indicate that green tea extract powder, rosemary extract powder, and white kimchi powder may provide an effective solution to replace synthetic nitrite and ascorbate used in traditionally cured products.

Keywords: naturally cured meat, sodium nitrite, white kimchi powder, green tea extract powder, rosemary extract powder

Introduction

The demands of consumers interested in health are causing clean-label trends such as organic and preservative-free foods to emerge in the food industry (Asioli et al., 2017; Yong et al., 2020). In the meat-processing industry, nitrite is widely used as an essential food additive that develops the typical cured meat color and flavor, improves microbiological safety, and provides antioxidant activity (Honikel et al., 2008; Pegg and Shahidi, 2000; Sebranek, 2009; Sebranek and Bacus, 2007a). However, nitrite ($NaNO_2$ or KNO_2), which is traditionally used as a curing agent, is a chemical additive and has become a factor for consumers to avoid the consumption of processed meat products. Moreover, nitrite is difficult to replace because it has simultaneous multifunctional activity (Alahakoon et al., 2015). Thus, a new category of meat products has emerged, such as so-called "naturally cured meat products" or "indirectly cured meat products," which replace synthetic nitrite with plant-based ingredients such as vegetable powder or concentrate (Sebranek and Bacus, 2007a; Sebranek and Bacus, 2007b; Sindelar and Houser, 2009). Meat products in this category generally use vegetables that are rich in nitrate as a natural nitrate source. In this process, a starter culture such as *Staphylococcus carnosus*, which has nitrite-reducing activity, facilitates the production of nitrite from natural nitrate (Sebranek and Bacus, 2007a). As a result, naturally cured products have similar quality characteristics to traditionally cured products (Choi et al., 2020; Jeong et al., 2020a; Jeong et al., 2020b; Krause et al., 2011; Sebranek and Bacus, 2007a; Sucu and Turp, 2018). However, most naturally cured meat products generally have a lower residual nitrite concentration and relatively large variation compared to traditionally cured meat products (Sebranek and Bacus, 2007a; Sindelar et al., 2007; Yong et al., 2021). For this reason, products containing natural nitrite/nitrate derived from vegetables may have reduced antioxidant capacity and may be less able to inhibit the growth of pathogenic bacteria. Consequently, there is a need to overcome the challenge of reduced nitrate levels in meat products cured using natural ingredients rather than synthetic additives. Overcoming this challenge will improve the quality of clean-label meat products.

Reducing compounds such as sodium ascorbate and sodium erythorbate are widely used for meat curing. These compounds act as cure accelerators that promote the reduction of nitrite to nitric oxide during the meat-curing step (Sebranek, 2009). However, since most of these compounds are also chemical additives, it is necessary to find alternative means to produce clean-label meat products. In this respect, the application of plant extracts and ingredients may appear to be suitable solutions to replace nitrite and ascorbate in meat products (Ferysiuk and Wójciak, 2020, Kumar et al., 2015). Green tea extract is a natural antioxidant owing to the presence of polyphenols, including flavanols, flavadiols, flavonoids, and phenolic acids (Chacko et al., 2010). These polyphenolic compounds eliminate free radicals and chelate metals, thereby inhibiting lipid oxidation and extending the shelf life of meat and meat products (Shah et al., 2014). According to Choi et al. (2003), the use of green tea powder in pork sausages resulted in lower levels of thiobarbituric acid-reactive substances (TBARS) than in sausages with nitrite. Moreover, Price et al. (2013) found that green tea extract more effectively prevents lipid oxidation than sodium nitrite in cooked pork meatballs, suggesting that green tea extract could be a promising substitute to ascorbate in terms of antioxidant effects. Rosemary extract is another plant-based ingredient that contains high levels of phenolic substances such as phenolic diterpenes and phenolic acid, which confer strong antioxidant capacity (Brewer, 2011; Zhang et al., 2010). Thus, as an antioxidant and metal chelator, rosemary extract can be used to inhibit lipid oxidation and protect the flavor of meat products. Nissen et al. (2004) evaluated the antioxidative activity of rosemary, green tea, coffee, and grape skin in cooked pork patties and found that rosemary had the greatest antioxidative efficiency. Some bioactive compounds in plant extracts act as reducing agents to promote the curing reaction, while others exhibit a pro-oxidant effect in meat products (Lin et al., 2011; Viuda-Martos et al., 2009; Vossen et al., 2012). Although several studies have investigated the use of plant extracts in traditionally cured meat products, the effects of green tea extract, rosemary extract, and white kimchi powder (a natural nitrite/nitrate source) on the quality characteristics of naturally cured meat products have not been evaluated. A new approach is needed to enhance the function of nitrite in naturally cured meat products with less residual nitrite content and to utilize these natural ingredients that can be applied to clean-label meat products. Therefore, the purpose of this study was to evaluate whether green tea extract, rosemary extract, and white kimchi powder can be used to cure pork sausages without adding nitrite and ascorbate.

Materials and Methods

The preparation of white kimchi powder and materials

Chinese cabbages and radishes grown in South Korea were purchased from five regions (Chungcheong-do, Gangwon-do, Gyeonggi-do, Gyeongsang-do, and Jeolla-do) and were randomly selected for white kimchi production. Garlic, ginger, fermented shrimp, solar salt, and refined salt were purchased at local retail markets (Busan, Korea). Fermented white kimchi was prepared using the standard recipe (Institute of Traditional Korean Food, 2008), with a slight modification. After 2 wk of fermentation at 0°C, white kimchi was powdered, as described previously (Choi et al., 2020). The fermented white kimchi was crushed and stored in a deep freezer (HKF-51, HFK, Wonju, Korea) at −80°C prior to freeze-vacuum drying using a freeze vacuum dryer (PVTFD10R, Ilshinbiobase, Yangju, Korea) at −40°C for 48 h. Thereafter, the dried white kimchi was pulverized and passed through a #30 mesh sieve (Test sieve BS0600, Chunggye Sieve, Gunpo, Korea). The white kimchi powder was analyzed for pH (6.24) and nitrate content (19,634 ppm sodium nitrate), vacuum-packed, and stored in a freezer at −18°C until use as a nitrate source.

Celery powder (VegStable 502, Florida Food Products Inc., Eustis, FL, USA) with 35,281 ppm sodium nitrate, a starter culture (CS 299, Chr. Hansen Inc., Milwaukee, WI, USA) consisting of *S. carnosus*, sodium nitrite (S2252, Sigma-Aldrich, St. Louis, MO, USA), sodium ascorbate (#35268, Acros Organics, Geel, Belgium), green tea extract powder (Green Tea Extract, Phytotech Extracts Pvt. Ltd., Bengaluru, India), and rosemary extract powder (#19100003, Plantextrakt GmbH & Co. KG, Vestenbergsgreuth, Germany) were purchased from commercial suppliers. Other ingredients and spices were obtained from an ingredient supplier (Taewon Food Industry Co. Ltd., Ansan, Korea).

Ground pork sausage processing

Fresh pork muscles (*M. biceps femoris, M. semitendinosus*, and *M. semimembranosus*) and backfat were purchased from a local meat processor (Pukyung Pig Farmers Livestock, Gimhae, Korea) at 24–48 h post-mortem. After trimming, the raw materials were cut into squares of approximately 4–5 cm and stored in a –18°C freezer. All processing steps were performed within 1 month of storage. A batch of 35 kg per replicate was prepared for manufacturing ground pork sausages, and sausage processing was replicated three times. Before processing, frozen pork ham and backfat were completely thawed at 2–3°C and ground using a chopper (TC-22 Elegant plus, Tre Spade, Torino, Italy) equipped with an 8-mm plate. The meat was chopped again using a 3-mm plate. The ground materials were randomly assigned to one of seven treatments (Table 1): control (0.01% sodium nitrite and 0.05% sodium ascorbate), treatment 1

(0.3% white kimchi powder and 0.05% green tea extract powder), treatment 2 (0.3% white kimchi powder and 0.1% green tea extract powder), treatment 3 (0.3% white kimchi powder and 0.05% rosemary extract powder), treatment 4 (0.3% white kimchi powder and 0.1% rosemary extract powder), treatment 5 (0.3% white kimchi powder, 0.05% green tea extract powder, and 0.05% rosemary extract powder), and treatment 6 (0.3% celery juice powder, 0.05% green tea extract powder, and 0.05% rosemary extract powder). The nitrate content in white kimchi powder and celery juice powder was calculated as 60 ppm (treatments 1 to 5) and 105.8 ppm (treatment 6), respectively, for naturally cured sausages, which contained 0.03% starter culture to convert the nitrate in white kimchi powder and celery juice powder to nitrite. Phosphates were not added because the objective of this study was to evaluate meat products with a clean-label concept. The prepared pork meat and fat were mixed with 1.5% NaCl for 3 min using a mixer (5KSM7990, Whirlpool Corp., St. Joseph, MI, USA). Other ingredients and ice/water were added into the mixer, and the prepared meat product was mixed for seven additional minutes depending on the treatment (Table 1). Meat mixtures from each treatment were stuffed into 24-mm cellulose casings (NOJAX Cellulose Casings, Viskase Companies, Inc., Lombard, IL, USA) using a stuffer (TRE SPADE MOD.5/V Deluxe, FACEM S.p.A, Torino, Italy). The control samples were placed in a refrigerator (C110AHB, LG Electronics Inc., Changwon, Korea) at 2–3°C for 1 h, while the naturally cured samples were placed in an incubator (C-IB4, Changshin Science, Pocheon, Korea) at 38°C for 2 h (Bae et al., 2020; Sindelar et al., 2007). All samples were cooked to reach an internal temperature of 75°C in a water bath (MaXturdy 45, Daihan Scientific, Wonju, Korea) set at 90°C. After cooking, the products were immediately cooled for 20 min in an ice slurry and stored at 2−3°C in the dark until analysis. All dependent variables were measured in duplicate.

Cooking yield and pH measurements

The sausages were weighed before and after cooking to determine the cooking yield. The cooking yield was calculated using the following equation:

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

For pH measurement, 5 g of cooked sample was blended with 45 mL distilled water and homogenized for 1 min at 8,000 rpm using a homogenizer (DI 25 basic, IKA-Werke GmbH & Co. KG, Staufen, Germany). The pH of the homogenates was measured using a pH meter (Accumt AB150, Thermo Fisher Scientific Inc., Singapore).

Oxidation-reduction potential (ORP) determination

The ORP of cooked products was measured using a slight modification of the method described by Cornforth et al. (1986) and John et al. (2005). Briefly, 10 g of each sample was homogenized with 20 mL of 0.1 M sodium carbonate for 30 s at 13,000 rpm using a homogenizer (DI 25 basic, IKA-Werke GmbH & Co. KG, Staufen, Germany). Thereafter, 50 μL butylated hydroxytoluene (7.2% in ethanol) was added to minimize sample oxidation during blending. The samples were allowed to stabilize for 3 min. ORP values were determined using a platinum Ag/AgCl combination electrode (13-620-631, Thermo Fisher Scientific Inc., Singapore) mounted on a pH meter (Accumt AB150, Thermo Fisher Scientific Inc., Singapore) set to the millivolt scale.

Instrumental color measurements

The CIE L* (lightness), a* (redness), and b* (yellowness) values were measured on the cut surface of each sample using a chroma meter (CR-400, Konica Minolta Sensing Inc., Osaka, Japan; 8 mm aperture, illuminant C, 2° observer angle) calibrated with a white calibration plate (L* +94.90, a* −0.39, b* +3.88). Each cooked sample was cut parallel to the longitudinal axis and divided into two slices. Color measurements were taken on the fresh cut surface at two random locations on each sliced sample. Four readings were obtained per treatment.

Nitrate and residual nitrite content analysis

The nitrate ion (NO_3^-) content of the prepared white kimchi powder and commercial celery powder was analyzed using the zinc reduction method (Merino, 2009). The results were converted to concentrations of sodium nitrate (ppm). The residual nitrite content of the cooked meat sausages was analyzed by the AOAC method 973.31 (AOAC, 2016). The calibration curve was prepared using sodium nitrite as a standard (S2252, Sigma-Aldrich, St. Louis, MO, USA), and the residual nitrite content was reported in ppm.

Nitrosyl hemochrome content, total pigment content, and cure efficiency determination

Nitrosyl hemochrome and total pigment contents were measured using the method described by Hornsey (1956). Blended samples were mixed with 80% acetone and acidified acetone solution to measure nitrosyl hemochrome and total pigment contents, respectively. The absorbance of the filtrate was measured at wavelengths of 540 nm (A_{540}) and 640 nm (A_{640}), respectively, using a spectrophotometer (UV-1800, Shimadzu Corp., Kyoto, Japan). Nitrosyl hemochrome and total pigment concentrations were calculated using the following equations. Finally, curing efficiency was calculated as the ratio of nitrosyl hemochrome content to total pigment content in the meat.

$$\text{Nitrosyl hemochrome (ppm)} = A_{540} \times 290$$

$$\text{Total pigment (ppm)} = A_{640} \times 680$$

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

Thiobarbituric acid reactive substances (TBARS) determination

Lipid oxidation was analyzed using the distillation method described by Tarladgis et al. (1960). After reacting malondialdehyde (MDA) released by lipid oxidation with 0.02 M 2-thiobarbituric acid (TBA) solution, the absorbance was measured at 538 nm using a spectrophotometer (UV-1800, Shimadzu Corp., Kyoto, Japan). The obtained results were multiplied by a factor of 7.8 to calculate TBARS values (mg MDA/kg cooked sample).

Statistical analysis

The experimental design was a completely randomized design with seven treatment groups (one control and six naturally cured treatments). All experiments used three independent replicates, with each replicate manufactured on a different processing day. The data were analyzed using the Generalized Linear Model (GLM) included in the SAS software package (SAS, 2012). When significant differences were identified, the dependent variable means were analyzed using Tukey's multiple comparisons tests ($p<0.05$).

Results and Discussion

Cooking yield, pH, and ORP

The cooking yield was higher in the control than in naturally cured pork sausages (treatments

1 to 6) ($p<0.05$) (Table 2). Recently, Choi et al. (2020) investigated the effects of using acerola juice powder on the quality of meat products indirectly cured with white kimchi powder and found that pork products cured with white kimchi powder and acerola juice powder had a lower cooking yield than nitrite-added control, similar to our results. However, in this study, there were no differences ($p>0.05$) in cooking yield for products cured with white kimchi powder or celery juice powder, regardless of addition level or combinations of green tea extract powder and rosemary extract powder. Jeong et al. (2020b) found that pork sausages cured with 0.15% to 0.35% Chinese cabbage powders had a similar cooking yield to those cured with 0.4% commercial celery juice powders. Considering the quality of meat products and industrial use, a low cooking yield may have negative impacts on both manufacturers and consumers. Sebranek and Bacus (2007a) pointed out that moisture retention in natural or organic meat products may be reduced without the addition of phosphates or water-binding agents. In this study, alkali phosphate was not intentionally added to the products. Therefore, when producing meat products using natural ingredients, appropriate ingredients that replace phosphate may improve moisture retention. There was some evidence for this. Choi et al. (2020) reported that when phosphate was not added, pork products cured with white kimchi powder had a lower cooking yield than the nitrite-added control, whereas Bae et al. (2020) found that there were no differences in cooking yield between the control with sodium nitrite and pork products cured with radish powder when the samples were prepared with adding sodium tripolyphosphate.

The pH of meat products cured with plant-based natural ingredients (treatments 1 to 6) did not differ ($p>0.05$) from that of the control sausages containing sodium nitrite (Table 2). Moreover, no differences ($p>0.05$) in pH were observed among the naturally cured pork sausages, suggesting that green tea extract and rosemary extract did not affect the pH of pork products cured with white kimchi powder or celery juice powder. Similar to our results, Wenjiao et al. (2014) reported that the addition of tea polyphenol had no effect on the pH of pork sausages. However, Lara et al. (2011) found that the pH of cooked pork patties was significantly reduced by the addition of rosemary or lemon balm extract due to the acidic compounds present in the extracts. Jeong et al. (2020a) reported that the addition of Chinese cabbage, radish, or spinach powder to naturally cured pork products did not change the pH of cured pork products, which was in line with our results. In a preliminary test for this study, the pH values of raw pork meat, white kimchi powder, green tea extract powder, and rosemary extract powder were 5.80, 6.24, 4.45, and 5.42, respectively. The equivalent pH in all samples in this study may be attributed to the relatively high pH of white kimchi powder and the buffering capacity of meat (Krause et al, 2011; Li et al., 2012).

A low ORP promotes the color development of meat products because it contributes to a reducing environment in meat (Claus and Jeong, 2018; Cornforth et al., 1986). In this study, the ORP values of meat products ranged from −141.57 to −142.85 (Table 2). Generally, ascorbate can act as a reducing agent for myoglobin under certain conditions (Holownia et al., 2003). However, in this study, control sausages containing ascorbate showed no differences ($p>0.05$) in ORP from the products with the natural extracts. In previous research, Wójciak et al. (2011) showed that the addition of plant extracts (green tea, red pepper, rosemary) to meat products had significantly reduced ORP values. Therefore, our results suggested that the natural extracts used in this study may have acted as reducing agents in naturally cured pork sausages. In addition, differences in pH can alter the ORP (Antonni and Brunori, 1971). Thus, it may appear that the final products with similar pH values did not result in different ORP values, regardless of nitrite/nitrate sources and the addition of green tea extract or rosemary extract powder.

Instrumental color

The addition of green tea extract powder, rosemary extract powder, or a combination of the two did not significantly change ($p>0.05$) the CIE L* values of white kimchi powder-treated products (treatments 1 to 5), compared to control sausages (Table 2). Jin et al. (2016) found that the use of 1% and 2% thyme or rosemary powder did not change the CIE L* values of pork sausages at the beginning of storage. Similarly, Vossen et al. (2012) reported that the CIE L* values between frankfurters prepared with 0.5% dog rose extract and control frankfurters containing sodium nitrite and sodium ascorbate were not different. In this study, pork sausages prepared with celery juice powder (treatment 6) as a natural nitrate source had lower ($p<0.05$) CIE L* values compared to control sausages, which is inconsistent with the results of Choi et al. (2020), who reported that the CIE L* values of products prepared with 0.4% celery powder were not different from those of nitrite-supplemented controls. This may be attributed to the difference between the manufacturers and dosages of the celery product used in these studies.

Redness in cured meat products is an important index that is used to determine the degree of cured meat color and is related to nitrosyl hemochrome content (AMSA, 2012). Some studies found that green tea and rosemary treatments had no effect on the redness of meat products (Bozkurt, 2006; Rojas and Brewer, 2007). In this study, the CIE a* values of all products tested ranged from 8.40 to 8.71, and there were no differences ($p>0.05$) between the control and the treatments (Table 2). From the point of view of alternative curing, these results indicate that the amount of nitrate added in the form of white kimchi powder or celery powder is sufficient to develop the cured meat color of the final products. It should be noted that treatments 1 to 5 had a low nitrate content derived from white kimchi powder (approximately 60 ppm sodium nitrate). Even if nitrate was completely reduced to nitrite, the amounts of nitrite in white kimchi powder treatments would have been lower than that in the control (100 ppm sodium nitrite), but the cured color was comparable. Regarding the CIE a* values of naturally cured products, Terns et al. (2011) showed similar results using celery juice powder and cherry powder in indirectly cured sausages. Magrinyà et al. (2016) also found that cooked cured sausages prepared with vegetable concentrate and tocopherol extract had the same redness as products prepared with sodium nitrite. Thus, white kimchi powder has the potential to replace synthetic nitrite or commercial celery powder as a natural nitrate source for the production of naturally cured meat products. Furthermore, natural ingredients such as green tea extract powder and rosemary extract powder could be effectively used as sodium ascorbate alternatives. In addition, the role of natural ingredients as replacers of nitrite/nitrate or ascorbate is supported by the results of nitrosyl hemochrome content and curing efficiency in this study (Table 3).

The pork sausages containing natural vegetable powders (treatments 1 to 6) showed higher ($p<0.05$) CIE b* values than the control sausages (Table 2), probably because of the inherent pigments in the plant-derived powders (Bae et al., 2020; Jeong et al., 2020a). When the amount of green tea extract powder or rosemary extract powder increased from 0.05% to 0.1% (treatments 2 and 4) or when both were added in combination (treatments 5 and 6), the CIE b* value significantly increased ($p<0.05$). Several previous reports indicate that pigments in plant-based ingredients that replace nitrite/nitrate may affect the yellowness of the meat products (Bae et al., 2020; Horsch et al., 2014; Jeong et al., 2020b; Kim et al., 2019; Riel et al., 2017). Horsch et al. (2014) reported that yellowness in hams increased with increasing celery concentrate concentration, likely because the plant-derived concentrate includes plant pigments. Jin et al. (2016) and Nowak et al. (2016) also suggested that increased yellowness of sausages may have resulted from the color of the plant extracts. These previous findings are consistent with the results of our study.

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

The residual nitrite content was the highest ($p<0.05$) in the control (23.94 ppm), and approximately 76% of the initial nitrite amount reduced after product manufacturing (Table 3), similar to the result of a previous study showing that the residual nitrite content of frankfurters decreased to approximately 75% of initial nitrite levels (Xi et al., 2012). The depletion of residual nitrite is affected by factors such as meat type, pH, initial nitrite content, cooking temperature, and reducing agents (Cassens et al, 1978; Flores and Toldrá, 2021; Honikel, 2008; Sindelar and Milkowski, 2011). In this study, a lower residual nitrite content in all naturally cured sausages (treatments 1 to 6) was observed when compared to control sausages ($p<0.05$) (Table 3). Several previous studies using nitrate-rich plant substitutes as natural sources to replace synthetic nitrite in alternatively cured meat products have shown a similar trend (Bae et al., 2020; Jeong et al., 2020a; Jeong et al., 2020b; Sebranek and Bacus, 2007a; Yong et al., 2021). These results could be interpreted in two ways. First, the content of nitrate derived from white kimchi powder was relatively lower in treatments 1 to 6. Second, nitrite generated by nitrate-reducing bacteria during product processing prior to being cooked may have reacted with bioactive compounds present in natural ingredients, thereby resulting in lower residual nitrite levels in the finished products. There is some evidence that bioactive compounds play a role in residual nitrite content reduction (Lin et al., 2011; Viuda-Martos et al., 2009; Viuda-Martos et al., 2010; Zhou et al., 2020). Viuda-Martos et al. (2009) described that decreased residual nitrite content may have resulted from reactions with bioactive compounds such as polyphenols and flavonoids that are present in natural ingredients. Zhou et al. (2020) also reported decreased residual nitrite content when rosemary extract, grape seed extract, and green tea polyphenols were added to pork sausages. Nevertheless, among the products cured with white kimchi powder (treatments 1 to 5), the residual nitrite content was not affected ($p>0.05$)

by the addition of green tea extract powder and rosemary extract powder, either alone or in combination. Treatment 6, which contained celery juice powder as a natural source of nitrate, had higher ($p<0.05$) residual nitrite content than the kimchi powder counterpart (treatment 5), likely because the nitrate levels in the commercially available celery juice powder were relatively higher than those in the white kimchi powder prepared in this study, although the same concentration (0.3%) for both celery juice powder and white kimchi powder was included in the formulation.

In the manufacture of meat products, nitrosyl hemochrome is formed during the curing and cooking processes. It contributes to the distinctive pink color of meat products. In alternative curing methods, it has been proposed that *S. carnosus*, a starter culture with nitrate reductase activity, and high natural nitrate levels in vegetable powder, increase the rate of nitrate reduction to nitrite in the meat curing system (Alahakoon et al., 2015; Magrinyà et al., 2016; Sindelar and Houser, 2009). In particular, nitric oxide released from nitrite reacts with myoglobin to form nitrosomyoglobin. These curing reactions can be promoted by using cure accelerators such as sodium ascorbate or sodium erythorbate (Honikel, 2008; Sebranek, 2009; Sebranek et al., 2012). Although reducing agents such as sodium ascorbate were not used in the naturally cured products, the nitrosyl hemochrome content was similar ($p>0.05$) in treatments 1 to 5 or higher ($p<0.05$) in treatment 6 compared to the control sausages (Table 3). In addition, the nitrosyl hemochrome content was not affected ($p>0.05$) by the addition of green tea extract powder, rosemary extract powder, or their combination in naturally cured sausages. In agreement with our results, Terns et al. (2011) reported that indirectly cured sausages formulated with vegetable juice powder and cherry powder without reductants showed effective cured pigment development similar to that in control sausages with sodium ascorbate and sodium erythorbate. Choi et al. (2020) obtained similar results for cooked pork products that were cured with white kimchi powder and acerola juice powder. Wójciak et al. (2011) found that the use of green tea and rosemary helped to reduce nitrite to nitric oxide and form nitrosomyoglobin, thereby stabilizing the color of the cured meat products. Likewise, our results indicate that the green tea extract powder and rosemary extract powder may be involved in the curing reactions, acting as reducing agents that promote the release of nitric oxide from nitrite, thereby forming nitrosyl hemochrome in cooked sausages. This result was expected based on the results of residual nitrite content in this study.

In the cooked cured products tested in this study, there was no difference ($p>0.05$) in total pigment content, regardless of the nitrate/nitrite source and addition of natural extract powders (Table 3). Similar results were reported when using 0.15% to 0.30% radish powder with 0.05% sodium ascorbate in alternatively cured pork products (Bae et al., 2020). However, the total pigment content found in naturally cured sausages (from 51.68 ppm to 54.29 ppm) in this study was slightly higher than that obtained in pork sausages cured with Chinese cabbage powder (from 48.62 ppm to 49.13 ppm) (Jeong et al., 2020b) and in pork products cured with radish powder (from 45.73 ppm to 45.90 ppm) (Bae et al., 2020). In this sense, the addition of green tea extract powder and rosemary extract powder may have played a role in the formation of meat pigments in the final products.

Treatments using white kimchi powder (treatments 1 to 5) showed a curing efficiency similar ($p>0.05$) to that of control sausages (Table 3). However, treatment 6 had a higher ($p<0.05$) curing efficiency than that of the control group. The curing efficiency is the percentage of total pigment converted to nitroso pigment in cured meat (AMSA, 2012). Therefore, the high curing efficiency in treatment 6 may be the result of the high nitrosyl hemochrome content observed. Nevertheless, when the amount of green tea extract powder or rosemary extract powder was increased to 0.1% (treatments 2 and 4) or when the two extract powders are added together at

0.5% (treatment 5), the curing efficiency was not significantly different ($p>0.05$) from that of treatment 6. These results suggest that the use of green tea extract powder or rosemary extract powder alone or in combination provides equivalent or higher curing efficiency compared to traditionally cured products.

Thiobarbituric acid reactive substances (TBARS)

Across all products tested in this study, the TBARS values were considerably lower (<0.15 mg MDA/kg) than the threshold range (0.5–1.0 mg MDA/kg) for rancidity perception (Tarladgis et al., 1960). However, regardless of addition of green tea extract powder and rosemary extract powder, naturally cured products prepared with white kimchi powder or celery powder (treatments 1 to 6) were found to have higher ($p<0.05$) TBARS values than control sausages (Table 3). In alternative curing, vegetables that have characteristic flavors and colors are used as nitrite/nitrate alternatives (Jo et al., 2020). Because the excessive use of vegetable powders during curing may negatively affect sensory properties, the amount of vegetable powders used in alternatively cured meat products is limited, thereby resulting in a low residual nitrite content in the final products (Sebranek and Bacus, 2007a). Thus, the lower TBARS values in the control samples may result from their high residual nitrite content, which had an antioxidative effect on lipid oxidation. Previously, several studies on natural antioxidants showed that the application of green tea extract and rosemary extract inhibits lipid oxidation in meat and meat products as a function of associated phenolic compounds (Fernández-López et al., 2005; Hernández-Hernández et al., 2009; Lorenzo and Munekata, 2016; Nieto et al., 2018). In this regard, the TBARS values were expected to be lower in naturally cured sausages. However, the natural extract powders in this study did not completely compensate for the antioxidant activity in naturally cured products with low nitrite levels. A study by Lin et al.

(2011) confirmed that a small amount (0.009%) of sodium nitrite is more effective in preventing lipid oxidation than green tea extract at a low concentration (0.05%). Nevertheless, when the amount of green tea extract powder or rosemary extract powder was increased to 0.1% (treatments 2 and 4) or green tea extract powder, rosemary extract powder, and celery juice powder were used in combination (treatment 6), the TBARS values decreased ($p<0.05$) in the naturally cured products, suggesting that 0.1% green tea extract powder and rosemary extract powder have antioxidant effects that inhibit lipid oxidation in the sausages. Therefore, to enhance the antioxidant activity in naturally cured meat products, a substantial amount of these extracts should be added, higher than the concentration used in this study.

Conclusions

Green tea extract powder and rosemary extract powder, alone or in combination, are potential replacements for sodium ascorbate in the production of sausages naturally cured with white kimchi powder. These naturally cured products exhibited redness, nitrosyl hemochrome content, total pigment content, and curing efficiency comparable to those of products containing nitrite. However, 0.1% green tea extract powder and rosemary extract powder inhibited lipid oxidation in naturally cured products but showed higher TBARS values than control products. These results suggest that the use of green tea extract powder and rosemary extract powder (either alone or in combination) in sausages cured with white kimchi powder may provide an effective solution to replace synthetic nitrite and ascorbate used in traditionally cured products. To supplement the antioxidant activity from these two extract powders in naturally cured meat products with low nitrite content, addition of a sufficient amount (higher than 0.1%) should be considered.

Conflicts of interest

The authors declare no potential conflicts of interest.

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Table 1. Formulation for pork sausages naturally cured with white kimchi powder or celery powder

Ingredients (%)	Treatments[1]						
	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
Pork ham	70.00	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	15.00
Ice/water	15.00	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	100.00
NaCl	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Sugar	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mustard powder	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Pepper	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Onion powder	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Garlic powder	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Sodium nitrite	0.01	-	-	-	-	-	-
White kimchi powder	-	0.30	0.30	0.30	0.30	0.30	-
Celery juice powder	-	-	-	-	-	-	0.30
Starter culture	-	0.03	0.03	0.03	0.03	0.03	0.03
Sodium ascorbate	0.05	-	-	-	-	-	-
Green tea extract powder	-	0.05	0.10	-	-	0.05	0.05
Rosemary extract powder	-	-	-	0.05	0.10	0.05	0.05
Total	103.31	103.63	103.68	103.63	103.68	103.68	103.68

[1] Treatments: control, 0.01% sodium nitrite + 0.05% sodium ascorbate; treatment 1, 0.3% white kimchi powder + 0.05% green tea extract powder; treatment 2, 0.3% white kimchi powder + 0.1% green tea extract powder; treatment 3, 0.3% white kimchi powder + 0.05% rosemary extract powder; treatment 4, 0.3% white kimchi powder + 0.1% rosemary extract powder; treatment 5, 0.3% white kimchi powder + 0.05% green tea extract powder + 0.05% rosemary extract powder; and treatment 6, 0.3% celery juice powder + 0.05% green tea extract powder + 0.05% rosemary extract powder.

Table 2. Effects of green tea extract and rosemary extract on cooking yield, pH values, ORP, and CIE color values of pork sausages naturally cured with white kimchi powder or celery powder

Treatments[1]	Cooking yield (%)	pH	ORP[2] (mV)	CIE L^*	CIE a^*	CIE b^*
Control	94.13±0.31^{A}	6.07±0.04^{A}	-142.12±3.60^{A}	65.77±0.12^{A}	8.66±0.08^{A}	8.91±0.06^{D}
Treatment 1	90.60±0.47^{B}	6.00±0.04^{A}	-142.37±1.33^{A}	65.73±0.14^{A}	8.59±0.12^{A}	9.84±0.07^{C}
Treatment 2	90.98±0.56^{B}	5.97±0.05^{A}	-141.72±0.74^{A}	65.66±0.18^{AB}	8.71±0.13^{A}	10.31±0.08^{B}
Treatment 3	91.55±0.53^{B}	5.99±0.04^{A}	-142.85±0.43^{A}	65.45±0.13^{AB}	8.40±0.13^{A}	9.78±0.10^{C}
Treatment 4	91.41±0.43^{B}	5.99±0.04^{A}	-141.57±1.13^{A}	65.32±0.12^{AB}	8.43±0.13^{A}	10.32±0.06^{B}
Treatment 5	90.18±0.53^{B}	5.98±0.05^{A}	-142.82±1.36^{A}	65.45±0.10^{AB}	8.52±0.09^{A}	10.18±0.06^{B}
Treatment 6	90.46±0.48^{B}	6.01±0.02^{A}	-142.23±0.88^{A}	65.10±0.10^{B}	8.53±0.11^{A}	10.75±0.06^{A}

All values are means ± SE.

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

[1] Treatments: control, 0.01% sodium nitrite + 0.05% sodium ascorbate; treatment 1, 0.3% white kimchi powder + 0.05% green tea extract powder; treatment 2, 0.3% white kimchi powder + 0.1% green tea extract powder; treatment 3, 0.3% white kimchi powder + 0.05% rosemary extract powder; treatment 4, 0.3% white kimchi powder + 0.1% rosemary extract powder; treatment 5, 0.3% white kimchi powder + 0.05% green tea extract powder + 0.05% rosemary extract powder; and treatment 6, 0.3% celery juice powder + 0.05% green tea extract powder + 0.05% rosemary extract powder.

[2] ORP, Oxidation-reduction potential.

Table 3. Effects of green tea extract and rosemary extract on residual nitrite, nitrosyl hemochrome, total pigment, curing efficiency, and TBARS values of pork sausages naturally cured with white kimchi powder or celery powder

Treatments[1]	Residual nitrite (ppm)	Nitrosyl hemochrome (ppm)	Total pigment (ppm)	Curing efficiency (%)	TBARS[2] (mg MDA/kg)
Control	23.94±0.33^{A}	38.69±0.80^{B}	50.66±1.00^{A}	76.38±0.68^{B}	0.094±0.002^{C}
Treatment 1	6.82±0.13^{BC}	40.41±0.98^{AB}	52.25±0.97^{A}	77.25±0.50^{B}	0.142±0.007^{A}
Treatment 2	6.43±0.17^{C}	42.39±0.92^{AB}	54.29±1.10^{A}	78.06±0.19^{AB}	0.129±0.005^{B}
Treatment 3	7.13±0.41^{BC}	40.26±0.84^{AB}	51.68±0.94^{A}	77.87±0.40^{B}	0.140±0.007^{A}
Treatment 4	6.96±0.24^{BC}	41.04±0.84^{AB}	52.59±1.23^{A}	78.10±0.31^{AB}	0.130±0.004^{B}
Treatment 5	6.35±0.10^{C}	41.83±0.86^{AB}	53.38±1.02^{A}	78.34±0.22^{AB}	0.138±0.006^{A}
Treatment 6	7.89±0.48^{B}	43.11±1.18^{A}	53.83±1.03^{A}	79.96±0.78^{A}	0.126±0.005^{B}

All values are means ± SE.

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

[1] Treatments: control, 0.01% sodium nitrite + 0.05% sodium ascorbate; treatment 1, 0.3% white kimchi powder + 0.05% green tea extract powder; treatment 2, 0.3% white kimchi powder + 0.1% green tea extract powder; treatment 3, 0.3% white kimchi powder + 0.05% rosemary extract powder; treatment 4, 0.3% white kimchi powder + 0.1% rosemary extract powder; treatment 5, 0.3% white kimchi powder + 0.05% green tea extract powder + 0.05% rosemary extract powder; and treatment 6, 0.3% celery juice powder + 0.05% green tea extract powder + 0.05% rosemary extract powder.

[2] TBARS, 2-Thiobarbituric acid reactive substances; MDA, Malondialdehyde.