

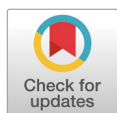
Effects of partial substitution of nitrites with purple-fleshed sweet potato powder on physicochemical characteristics of sausages

Sang-Keun Jin^{1#}, Teak-Soon Shin^{2#} and Dong-Gyun Yim^{3*}

¹Department of Animal Resources Technology, Gyeongnam National University of Science and Technology, Jinju 52725, Korea

²Department of Animal Science, Pusan National University, Miryang 50463, Korea

³Department of Agricultural Biotechnology and Research Institute of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Korea



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#These authors contributed equally to this work.

*Corresponding author

Dong-Gyun Yim
Department of Agricultural Biotechnology and Research Institute of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Korea.
Tel: +82-2-880-4820
E-mail: tousa0994@naver.com

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ORCID

Sang-Keun Jin
<https://orcid.org/0000-0002-8983-5607>
Teak-Soon Shin
<https://orcid.org/0000-0001-5362-9206>
Dong-Gyun Yim
<https://orcid.org/0000-0003-0368-2847>

Competing interests

No potential conflict of interest relevant to this article was reported.

Abstract

Synthetic nitrite imparts a reddish-pink color to meat and a distinct flavor to meat products, delays lipid oxidation, and inhibits microbial growth and pathogens. However, excessive intake of nitrite might result in the production of carcinogenic nitrosamine, which might increase the risk of cancer in humans. Therefore, we aimed to find an alternative natural colorant for pork sausages. Pork sausages were mixed with 0.014% sodium nitrite (NaNO₂) alone (CON), without either NaNO₂ or purple-fleshed sweet potato powder (PP; CON1), 0.5% PP alone (PP1), 1% PP (PP2) alone, 0.011% NaNO₂ and 0.5% PP (SP1), and 0.011% NaNO₂ and 1% PP (SP2). The sausages were then cooked and stored for physicochemical analysis on days 0, 5, 10, 15, and 20. The a* and W* values were the greatest and lowest in the SP2 and CON1 treatments, respectively ($p < 0.05$). The concentrations of residual nitrite in the sausages at 20 days decreased in the order of CON > SP1, SP2 > PP2 > PP1, CON1. The fatty acid content was higher, and flavorful amino acids were more in PP2 ($p < 0.05$). The fatty acid composition was comparable between the SP2 and CON groups, but the contents of glutamic acid and alanine were greater in the SP2 group. In conclusion, SP2 (0.011% NaNO₂ with 1% PP) could be added as a natural colorant for pork sausage production, and NaNO₂ could be substituted with up to 20% PP without detrimental effects on sausage appearance and/or quality.

Keywords: Purple sweet potato, Sausage, Nitrite, Physicochemical characteristic

INTRODUCTION

Synthetic nitrite imparts a reddish-pink color to meat and a distinct flavor to meat products, delays lipid oxidation, and inhibits microbial growth and pathogens [1,2]. However, the possible generation of carcinogenic nitrosamine due to excessive nitrite intake might be associated with an increased risk of cancer [3], which is an important concern in the meat industry. Consumers now prefer safe foods without synthetic ingredients or additives that might endanger health [4]. The development and utilization

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Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions

Conceptualization: Jin SK.
Data curation: Jin SK.
Formal analysis: Jin SK.
Methodology: Jin SK.
Software: Jin SK.
Validation: Shin TS.
Investigation: Shin TS.
Writing - original draft: Jin SK, Yim DG.
Writing - review & editing: Jin SK, Yim DG.

Ethics approval and consent to participate

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

of natural additives have recently attracted attention. Most natural additives that are used in sausages are sourced from herbs, spices, fruits, and vegetables [5].

Sweet potato (*Ipomea batatas* L.) is an abundant source of anthocyanins, vitamins, fiber, and minerals that can inhibit colon cancer, diverticular disease and constipation, decrease blood cholesterol, and help digestion [6–8]. Purple sweet potato is a source of abundant β -carotene, anthocyanins, and starch and has inherent water retention properties [9]. Anthocyanin and other polyphenols in purple sweet potatoes are powerful antioxidants [8], and anthocyanins can serve as a natural colorant, imparting a red-violet color to food [10]. However, only a few studies have addressed the impact of incorporating purple sweet potato powder (PP) on the physicochemical characteristics of sausages. Therefore, the present study aimed to determine whether PP could minimize the amount of sodium nitrite (NaNO_2) that is normally added to pork sausages without compromising quality, appearance and nutritional value.

MATERIALS AND METHODS

Sample preparation

Lean pork (~20 kg) and its fat were taken from a butcher, then the meat was coarsely pulverized in a grinder (Model 200, Lasar, Los Angeles, CA, USA), and categorized into six treatments (3 kg/group).

Preparation of cooked pork sausages

Table 1 shows the amounts of additives mixed with the meat in each group as follows: 0.014% NaNO_2 (Sewoo, Seoul, Korea), no NaNO_2 or PP, 0.5% PP, 1% PP, 0.011% NaNO_2 and 0.5% PP

Table 1. Composition of cooked pork sausage blends¹⁾

Ingredients	Composition (%)					
	CON	CON1	PP1	PP2	SP1	SP2
Meat ingredients						
Pork loin meat	72.266	72.28	71.78	71.28	71.769	71.269
Pork fat	11.18	11.18	11.18	11.18	11.18	11.18
Nonmeat ingredients						
Ice	13.78	13.78	13.78	13.78	13.78	13.78
Salt ²⁾	1.4	1.4	1.4	1.4	1.4	1.4
Sodium nitrite (NaNO_2) ³⁾	0.014	-	-	-	0.011	0.011
Phosphate ⁴⁾	0.2	0.2	0.2	0.2	0.2	0.2
Sugar ⁵⁾	0.5	0.5	0.5	0.5	0.5	0.5
MSG ⁶⁾	0.06	0.06	0.06	0.06	0.06	0.06
Spice ⁷⁾	0.6	0.6	0.6	0.6	0.6	0.6
Purple-fleshed sweet potato powder	-	-	0.5	1	0.5	1
Total	100	100	100	100	100	100

¹⁾Treatments: CON (control), 0.014% sodium nitrite; CON1 (control1); no sodium nitrite and purple-fleshed sweet potato powder combination; PP1, no sodium nitrite and 0.5% purple-fleshed sweet potato powder; PP2, no sodium nitrite and 1% purple-fleshed sweet potato powder; SP1, 0.011% sodium nitrite and 0.5% purple-fleshed sweet potato powder combination; SP2, 0.011% sodium nitrite and 1% purple-fleshed sweet potato powder combination.

²⁾Refined salt (Woo-II S&F, Ulsan, Korea).

³⁾Sodium nitrite (Duksan, Gyeonggi, Korea).

⁴⁾FOS/ENR (Taewon Food, Gyeonggi, Korea).

⁵⁾Beksul white sugar (CJ cheiljedang, Incheon, Korea).

⁶⁾Monosodium L-Glutamate (Shinwon Chemical, Seoul, Korea).

⁷⁾Bologna (Taewon Food, Gyeonggi, Korea).

(Jisanfood, Jinju, Korea), and, 0.011% NaNO₂ and 1% PP. The meat and additives were mixed for 120 sec to obtain uniform distribution of the additives in an A-20 matrix (Ramon, Oiartzun, Spain).

Meat mixtures (~160 g) were stuffed into E-25 fibrous casings (Sewoo, Seoul, Korea) to result in 120 mm sausages. The sausages were cooked in a water bath (100 °C) until the core temperature reached 75 °C and then cooled at 5 °C for 59 min. Each sausage was vacuum packed with polyvinyl chloride film (Krehalon UK, Beverley, UK). All experimental sausages were stored at 4 °C for 0, 5, 10, and 20 days and they were then analyzed on different days. The fatty acid and amino acid composition of the sausages was conducted on day 0. Each treatment was replicated four times.

Physicochemical analysis

The color values for L* (lightness), a* (redness), and b* (yellowness) were measured using colorimeter (CR-310, Minolta Inc., Tokyo Japan). It was standardized using a calibration plate ($Y = 93.5$, $X = 0.3132$, $y = 0.3198$). Color parameters are expressed as: Whiteness (W) was calculated according to the following formula: $W = L^* - 3b^*$. Cooked sausages (4 g) were disrupted in distilled water (36 mL) at 3,000×g for 30 s with a homogenizer (Ultra-Turrax T-50, IKA, Staufen, Germany). The pH of the sausages was conducted with a pH meter (Model 440, Mettler-Toledo GmbH, Greifensee, Switzerland). The water-holding capacity (WHC) of samples was measured as described by Joo [11], with modifications. Briefly, samples (3.0 g) of intact meat were placed between two thin plastic films on weighed using Whatman No. 1 filter papers (diameter, 11 cm), then compressed for 5 min between Plexiglas plates with a 2.5 kg load. After removing all of the compressed meat samples, the damp filter paper and the plastic films were immediately weighed, and WHC (%) was determined as:

$$\text{WHC (\%)} = \frac{(\text{Damp filter paper and plastic film weight}) - (\text{Filter paper and plastic film weight})}{\text{Meat sample weight}} \times 100$$

Six 1.5 × 1.5 × 1.5 cm samples of cooked pork sausage were sheared with an Instron 3343 (US/MX40, A&D, Norwood, MA, USA) to provide a crosshead speed of 100 mm/min. The shear force values from each sample were obtained and expressed as kg/cm². Volatile basic nitrogen (VBN) was obtained with the method of Conway micropipette diffusion as modified by Pearson [12] is expressed as mg VBN/100 g of sausage. Residual nitrite was calculated using spectrophotometry as described by AOAC [13].

Analysis of fatty acid content

Total fat was extracted as described by Folch et al. [14]. Samples (5 g) were thawed, and then lipids were extracted in chloroform/methanol (2:1) using BHT as an antioxidant [15]. Fatty acid methyl esters were quantified using an Agilent 7890N gas chromatograph (Agilent Technologies GmbH, Waldbronn, Germany) equipped with a flame ionization detector and fused silica capillary column (40 m, 0.28 mm) with 0.3 mm film thickness (Agilent Technologies GmbH). The carrier gas was helium (5 mL/min), and the injection volume was 1 µL. The temperature of the oven was initially kept at 190 °C for 60 sec, then maintained at 280 °C for 15 min. Linoleic acid (C18:2) was the internal standard (catalog number H3500, Sigma-Aldrich, St. Louis, MO, USA). Contents of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) are expressed as ratios (%) of total fatty acids, and PUFA/SFA and n-6/n-3 ratios were counted.

Analysis of protein and free amino acid content

Protein content was obtained with a slight modification of AOAC [13]. For analysis of free amino acids, a modification of the HPLC method described by Bidlingmeyer et al. [16] was given. The samples were delipidized by solvent extraction, then hydrolyzed with 6 N HCl in vacuum-packed tubes for 23 h at 108 °C. The hydrolyzed amino acids were sedimented by centrifugation at 5,000×g, and dried under vacuum for at least 1.5 h. The pH was adjusted by adding 20 mL of ethanol: water: triethylamine (2:2:1) and the samples were dried as described above. The samples were derivatized in 20 µL of ethanol:water:triethylamine:phenylisothiocyanate (7:1:1:1) at room temperature (26 °C) for 10 min, then dried under vacuum for at least 3 h. The samples were resuspended in 200 µL Pico Tag® diluent (Waters GmbH, Haan, Germany), then 8 µL was injected into a Nova-Pak C18 HPLC column (60 Angstroms, 4 µm, 3.9 × 150 mm; Waters GmbH.) attached to a 1525 HPLC (with binary gradient delivery, 717 auto-sampler and injector, 1500 column heater, and a 2487 dual wavelength UV detector). Amino acids were separated using buffers comprising sodium acetate (pH 6.4), EDTA 5,000 ppm, triethylamine (1:2,000), acetonitrile 6% v/v (buffer A) and acetonitrile 60% v/v, and EDTA 5,000 ppm; buffer B). A control sample was analyzed with the samples before hydrolysis to ensure accuracy and reproducibility. Data were analyzed using Breeze software Z (Waters GmbH).

Sensory color score determination

Seven panelists (age range 20–30 years) participated in sensory evaluations of the sausages at 5-day intervals during the 20 days of storage. All panelists were trained based on procedures published by [17,18]. The sausages were cooked at 102 °C for 4 min. Samples of the sausages were then cut into 1.5 × 1.5 × 1.5 cm cubes, coded with three-digit numbers and served to the panelists. Color was assessed based on a 9-point scale from 0 (extremely dislike) to 9 (extremely like). Two consecutive tasting sessions of three treated samples and a control sample proceeded with a 10-min break in between.

Statistical analysis

Data were collected in duplicate from the sausage samples (3 replicates × 6 samples × 3 treatments). Treatments and storage days were analyzed using one-way analysis of variance (ANOVA) and Duncan's multiple range test. All data were statistically analyzed using the general linear model procedure of the SAS statistical package [19] (SAS Institute, Cary, NC, USA). Values with $p < 0.05$ were considered statistically significant.

RESULTS AND DISCUSSION

Table 2 shows the impacts of PP on the color of sausages during storage (Fig. 1). Lightness and yellowness values were significantly higher in sausages treated with CON1 than with PP plus NaNO₂ (SP1, SP2) and PP alone (PP1, PP2) ($p < 0.05$). Kim and RYU [20] also found lower L* and b* values in sausages containing PP and NaNO₂ than in controls. The CIE a* values were positively affected by PP with NaNO₂. The CIE a* values were the highest and lowest after storage for 20 days, respectively, in sausages with, not without, added 0.011% NaNO₂ and 1% PP ($p < 0.05$). The higher redness values in the sausages of SP1 and SP2 were due to synergistic effects between NaNO₂ pigments derived from the PP and formed nitrosohemochrome, which resulted in a pink-red color during cooking [21]. This difference in meat color might be due to the non-enzymatic browning reaction between sugars in the PP and meat protein [22]. These results of including PP as a NaNO₂ replacement in sausages are consistent with those of Lee et al. [23]. Adding both sodium

Table 2. Color characteristics of cooked pork sausages containing two different percentages of purple sweet potato combined with nitrite during storage

Items	Treatments ¹⁾	Storage (days)				
		0	5	10	15	20
L* ²⁾	CON	79.20 ± 0.15 ^B	79.04 ± 0.13 ^A	78.69 ± 0.34 ^B	79.01 ± 0.27 ^B	78.70 ± 0.73 ^A
	CON1	79.85 ± 0.08 ^A	79.54 ± 0.78 ^A	80.14 ± 0.32 ^A	80.11 ± 0.21 ^A	79.13 ± 1.10 ^A
	PP1	75.79 ± 0.24 ^{Cb}	76.66 ± 0.48 ^{Ba}	76.38 ± 0.21 ^{Cab}	76.72 ± 0.19 ^{Ca}	76.47 ± 0.52 ^{Ba}
	PP2	75.40 ± 0.35 ^C	75.72 ± 0.13 ^C	75.44 ± 0.10 ^D	75.32 ± 0.41 ^D	75.60 ± 0.10 ^B
	SP1	75.68 ± 0.15 ^C	76.17 ± 0.05 ^{BC}	75.80 ± 0.12 ^{CD}	75.67 ± 0.50 ^D	76.03 ± 0.44 ^B
	SP2	72.92 ± 0.38 ^{Db}	73.87 ± 0.33 ^{Da}	73.48 ± 0.69 ^{Eab}	73.15 ± 0.42 ^{Eab}	73.59 ± 0.18 ^{Cab}
a*	CON	7.08 ± 0.04 ^{Cc}	7.33 ± 0.12 ^{Cb}	6.89 ± 0.06 ^{Cd}	7.65 ± 0.09 ^{Ca}	7.32 ± 0.07 ^{Cb}
	CON1	2.66 ± 0.15 ^{Fa}	2.26 ± 0.11 ^{Fb}	2.02 ± 0.27 ^{Fbc}	1.69 ± 0.07 ^{Fcd}	1.79 ± 0.19 ^{Fcd}
	PP1	5.14 ± 0.06 ^{Ea}	4.30 ± 0.29 ^{Eb}	3.99 ± 0.41 ^{Eb}	4.26 ± 0.66 ^{Eb}	3.73 ± 0.25 ^{Eb}
	PP2	5.51 ± 0.10 ^D	5.53 ± 0.22 ^D	4.93 ± 0.31 ^D	5.54 ± 0.68 ^D	5.07 ± 0.55 ^D
	SP1	8.49 ± 0.04 ^{Bbc}	8.59 ± 0.11 ^{Bb}	8.38 ± 0.13 ^{Bc}	8.93 ± 0.10 ^{Ba}	8.47 ± 0.10 ^{Bbc}
	SP2	9.53 ± 0.10 ^A	9.85 ± 0.44 ^A	9.43 ± 0.18 ^A	9.71 ± 0.48 ^A	9.54 ± 0.40 ^A
b*	CON	8.19 ± 0.02 ^{Bb}	8.22 ± 0.05 ^{Cb}	8.65 ± 0.20 ^{Ca}	8.07 ± 0.09 ^{Cb}	8.18 ± 0.04 ^{Cb}
	CON1	10.41 ± 0.10 ^{Ac}	10.56 ± 0.18 ^{Abc}	10.83 ± 0.30 ^{Ab}	11.27 ± 0.04 ^{Aa}	11.13 ± 0.07 ^{Aa}
	PP1	8.19 ± 0.15 ^{Bb}	8.94 ± 0.28 ^{Bab}	9.48 ± 0.44 ^{Ba}	9.23 ± 0.75 ^{Ba}	9.58 ± 0.15 ^{Ba}
	PP2	7.82 ± 0.26 ^{Cab}	7.75 ± 0.38 ^{Cb}	8.53 ± 0.38 ^{Ca}	8.22 ± 0.45 ^{Cab}	8.30 ± 0.48 ^{Cab}
	SP1	6.93 ± 0.11 ^{Dab}	6.54 ± 0.02 ^{Dcd}	7.02 ± 0.18 ^{Da}	6.36 ± 0.15 ^{Dd}	6.76 ± 0.11 ^{Dbc}
	SP2	5.82 ± 0.32 ^E	5.29 ± 0.42 ^E	5.93 ± 0.10 ^E	5.38 ± 0.23 ^E	5.52 ± 0.51 ^E
W*	CON	54.62 ± 0.14 ^{Aa}	54.38 ± 0.24 ^{Ba}	52.73 ± 0.47 ^{Bb}	54.80 ± 0.22 ^{Ba}	54.16 ± 0.75 ^{Ba}
	CON1	48.63 ± 0.21 ^{Ca}	47.86 ± 1.31 ^{Ea}	47.66 ± 0.62 ^{Dab}	46.29 ± 0.21 ^{Dbc}	45.74 ± 0.94 ^{Ec}
	PP1	51.22 ± 0.65 ^{Ba}	49.85 ± 0.43 ^{Dab}	47.95 ± 1.47 ^{Db}	49.04 ± 2.21 ^{Cab}	47.73 ± 0.98 ^{Db}
	PP2	51.93 ± 1.11 ^{Bab}	52.48 ± 1.22 ^{Ca}	49.84 ± 1.18 ^{Cb}	50.67 ± 0.97 ^{Cab}	50.70 ± 1.42 ^{Cab}
	SP1	54.90 ± 0.48 ^{Ac}	56.54 ± 0.05 ^{Aa}	54.75 ± 0.45 ^{Ac}	56.59 ± 0.10 ^{ABa}	55.75 ± 0.15 ^{ABb}
	SP2	55.46 ± 0.87 ^{Ab}	58.01 ± 1.15 ^{Aa}	55.70 ± 0.83 ^{Ab}	57.00 ± 1.10 ^{Aab}	57.03 ± 1.37 ^{Aab}
Sensory color score ³⁾	CON	7.17 ± 0.68 ^{ABC}	7.14 ± 0.80	7.06 ± 0.62 ^{AB}	6.75 ± 0.89	6.88 ± 0.99
	CON1	6.50 ± 0.32 ^C	6.57 ± 0.53	6.13 ± 0.79 ^C	6.06 ± 0.94	6.13 ± 1.06
	PP1	6.67 ± 0.61 ^{BC}	6.50 ± 0.58	6.38 ± 0.64 ^{BC}	6.13 ± 0.95	6.06 ± 1.12
	PP2	6.58 ± 0.66 ^C	6.50 ± 0.82	6.25 ± 0.93 ^C	6.31 ± 0.75	6.00 ± 1.41
	SP1	7.33 ± 0.68 ^{AB}	7.29 ± 0.49	7.31 ± 0.53 ^A	6.94 ± 0.62	7.13 ± 0.64
	SP2	7.67 ± 0.41 ^A	7.07 ± 0.45	7.31 ± 0.70 ^A	7.00 ± 0.65	7.13 ± 0.64

Data represent mean ± SD.

¹⁾Treatments: CON (control), 0.014% sodium nitrite; CON1 (control1), no sodium nitrite and purple-fleshed sweet potato powder combination; PP1, no sodium nitrite and 0.5% purple-fleshed sweet potato powder; PP2, no sodium nitrite and 1% purple-fleshed sweet potato powder; SP1, 0.011% sodium nitrite and 0.5% purple-fleshed sweet potato powder combination; SP2, 0.011% sodium nitrite and 1% purple-fleshed sweet potato powder combination.

²⁾W = L* - 3b*.

³⁾Sensory color score were evaluated based on a 9-point scale, 0 = extremely dislike and 9 = extremely like.

^{A-F}Means in the same column within the same aging period with different letters are significantly different (*p* < 0.05).

^{a-d}Means in the same row within the same aging condition with different letters are significantly different (*p* < 0.05).

nitrite and PP affected the whiteness values of the sausages, because the SP1 and SP2 samples were whiter than all other treated samples (*p* < 0.05). These results agreed with those of Jin et al. [24], who showed that adding NaNO₂ positively affected sausage whiteness. As shown in Fig. 1, color significantly differed between 0 and 10 days of storage, as panelists favored SP1 and SP2 to CON1, PP1, and PP2 (*p* < 0.05).

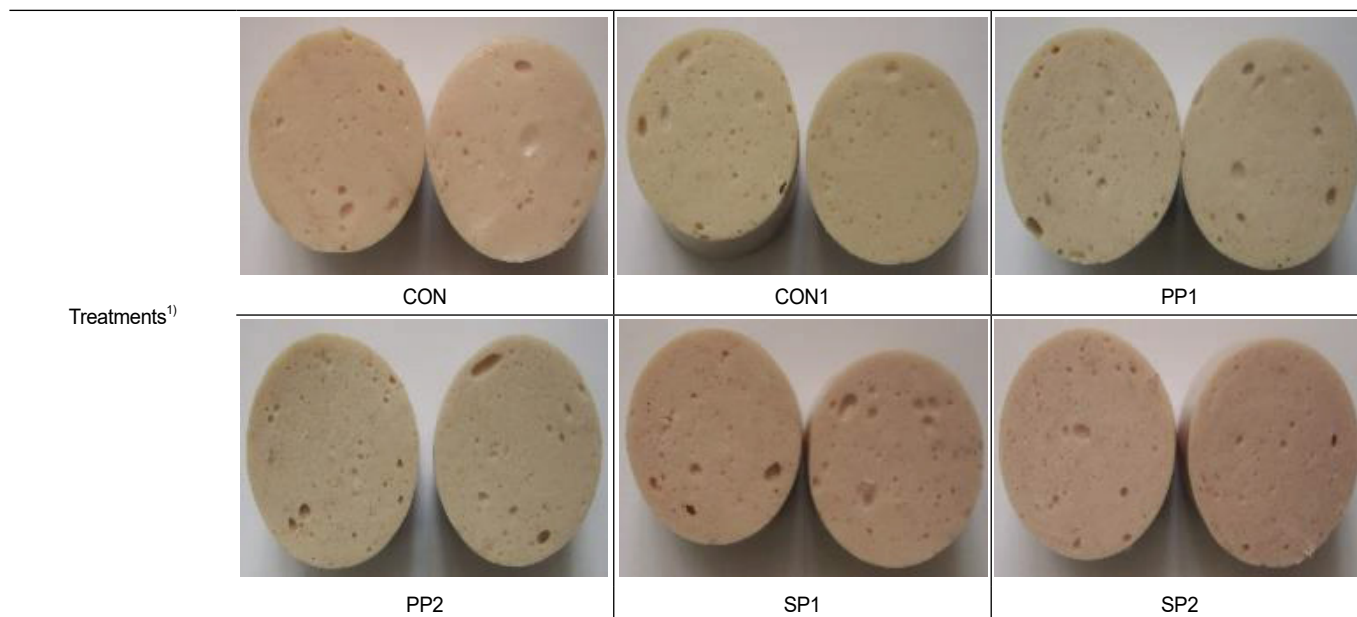


Fig. 1. Section color of cooked pork sausages containing two different percentages of purple sweet potato combined with nitrite. ¹⁾Treatments: CON (control), 0.014% sodium nitrite; CON1 (control1), no sodium nitrite and purple-fleshed sweet potato powder combination; PP1, no sodium nitrite and 0.5% purple-fleshed sweet potato powder; PP2, no sodium nitrite and 1% purple-fleshed sweet potato powder; SP1, 0.011% sodium nitrite and 0.5% purple-fleshed sweet potato powder combination; SP2, 0.011% sodium nitrite and 1% purple-fleshed sweet potato powder combination.

Table 3 highlights the effects of adding PP on the physicochemical characteristics and NaNO_2 retention in sausages during storage. The pH values were lower in sausages with added PP ($p < 0.05$), which concurred with the findings of [24,25]. The decrease in the pH value of sausages containing PP might be due to the depolymerization of starch granules caused by cooking, resulting in acidic terminal residues in starch molecules [26]. A lower pH causes an acidic environment in sausages, thus suppressing bacterial growth [27]. In this study, the pH of sausages was affected by the addition of PP. Furthermore, the pH of the PP samples slightly increased over time in storage ($p < 0.05$). The VBN content was comparable between the SP2 and CON groups, and lower in the PP2 than in the CON group on days 10 and 20 ($p < 0.05$). These findings agree with those of [23,24]. The low VBN values in the sausages were due to antimicrobial properties of PP. However, dramatic results were not observed in VBN measurement of this study. Our study found that the addition of PP might delay or inhibit spoilage (as indicated by VBN) in sausages. However, further study is needed.

All samples with added NaNO_2 retained the most nitrite by day 20 (CON, SP1, and SP2) (Table 3). The concentration of residual nitrite in sausages at 20 days decreased in the order of CON > SP1 and SP2 > PP2 > PP1 and CON1. More residual nitrite was found in the CON than in the SP1 and SP2 samples on day 20 of storage ($p < 0.05$). Levels of residual nitrite were significantly lower in samples containing both PP and added NaNO_2 , which concurred with the results of Lee et al. [23]. Marco et al. [28] found that the amount of nitrite in sausages rapidly decreases, owing to the higher reactivity of added nitrite compared with added nitrate. Thus, a low pH can affect the reactivity of nitrite and decrease the amount of residual nitrite in stored sausages. The present study also found decreased residual nitrite content in sausages with added PP during prolonged storage.

Table 4 describes the influence of PP on the fatty acid composition of sausages. Most of the detected fatty acids were MUFA, but the PUFA oleic acid (C18:1) was the most abundant in all treated samples. Saturated fatty acids were the next most abundant, with palmitic acid as its major

Table 3. Physico-chemical traits and residual nitrite of cooked pork sausages containing two different percentages of purple sweet potato combined with nitrite during storage

Items	Treatments ¹⁾	Storage (days)				
		0	5	10	15	20
pH	CON	6.06±0.01 ^{Ad}	6.07 ± 0.00 ^{Dd}	6.16 ± 0.02 ^{Ab}	6.26 ± 0.02 ^{Aa}	6.10 ± 0.01 ^{Cc}
	CON1	6.03 ± 0.01 ^{ABd}	6.12 ± 0.01 ^{Bb}	6.16 ± 0.01 ^{Aa}	6.12 ± 0.00 ^{Db}	6.10 ± 0.01 ^{Cc}
	PP1	6.01 ± 0.01 ^{Bc}	6.05 ± 0.01 ^{Eb}	6.08 ± 0.01 ^{Ca}	6.08 ± 0.01 ^{Ea}	6.08 ± 0.01 ^{Da}
	PP2	6.01 ± 0.01 ^{Bc}	6.04 ± 0.00 ^{Ec}	6.09 ± 0.01 ^{Ca}	6.09 ± 0.01 ^{Da}	6.09 ± 0.01 ^{Da}
	SP1	6.04 ± 0.02 ^{ABc}	6.17 ± 0.01 ^{Aa}	6.11 ± 0.01 ^{Bb}	6.11 ± 0.01 ^{Db}	6.18 ± 0.02 ^{Aa}
	SP2	6.05 ± 0.04 ^{Ac}	6.10 ± 0.01 ^{Cb}	6.15 ± 0.00 ^{Aa}	6.14 ± 0.00 ^{Ca}	6.12 ± 0.02 ^{Bab}
WHC (%)	CON	79.04 ± 2.39 ^{Aa}	68.84 ± 0.05 ^{Db}	70.95 ± 2.10 ^{Bb}	52.87 ± 0.62 ^{Cc}	71.68 ± 1.52 ^b
	CON1	74.99 ± 0.44 ^{BCa}	70.48 ± 0.96 ^{CDb}	71.04 ± 2.20 ^{Bb}	61.74 ± 1.59 ^{Ac}	72.58 ± 0.54 ^{ab}
	PP1	68.90 ± 2.34 ^{Db}	72.17 ± 0.98 ^{BCa}	74.48 ± 2.36 ^{ABa}	56.24 ± 1.34 ^{Bc}	72.52 ± 0.42 ^a
	PP2	72.32 ± 0.88 ^{Cb}	73.67 ± 0.71 ^{ABab}	75.78 ± 1.79 ^{Aa}	57.17 ± 2.06 ^{Bc}	73.66 ± 1.00 ^{ab}
	SP1	73.80 ± 0.76 ^{BCa}	70.55 ± 1.40 ^{CDb}	71.82 ± 1.74 ^{Bab}	58.77 ± 1.15 ^{Bc}	71.78 ± 0.61 ^{ab}
	SP2	75.75 ± 0.70 ^{Ba}	75.43 ± 1.40 ^{Aa}	73.95 ± 0.52 ^{ABab}	58.24 ± 1.60 ^{Bc}	72.16 ± 0.45 ^b
Shear force (kg/cm ²)	CON	1.34 ± 0.04 ^{bc}	1.27 ± 0.14 ^c	1.25 ± 0.02 ^{Dc}	1.47 ± 0.04 ^{Cab}	1.50 ± 0.10 ^{Ca}
	CON1	1.36 ± 0.12 ^c	1.36 ± 0.04 ^c	1.64 ± 0.04 ^{Ab}	1.43 ± 0.05 ^{Cc}	1.91 ± 0.08 ^{Aa}
	PP1	1.47 ± 0.06 ^{bc}	1.40 ± 0.05 ^c	1.40 ± 0.06 ^{Cc}	1.54 ± 0.11 ^{BCb}	1.85 ± 0.05 ^{ABa}
	PP2	1.38 ± 0.06 ^c	1.39 ± 0.06 ^c	1.55 ± 0.03 ^{Bb}	1.58 ± 0.02 ^{Bab}	1.67 ± 0.08 ^{BCa}
	SP1	1.44 ± 0.09 ^b	1.38 ± 0.15 ^b	1.43 ± 0.02 ^{Cb}	1.53 ± 0.07 ^{BCb}	1.96 ± 0.05 ^{Aa}
	SP2	1.40 ± 0.06 ^b	1.38 ± 0.07 ^b	1.37 ± 0.03 ^{Cb}	1.73 ± 0.03 ^{Aa}	1.84 ± 0.16 ^{Aa}
VBN (mg%)	CON	4.20 ± 0.28 ^{Aa}	2.99 ± 0.16 ^c	3.17 ± 0.16 ^{ABbc}	3.45 ± 0.16 ^b	3.36 ± 0.28 ^{ABc}
	CON1	3.73 ± 0.16 ^{ABa}	2.89 ± 0.16 ^b	3.08 ± 0.00 ^{Bb}	3.08 ± 0.28 ^b	2.99 ± 0.16 ^{ABb}
	PP1	3.17 ± 0.16 ^{cBab}	2.71 ± 0.16 ^c	3.45 ± 0.16 ^{Aa}	3.36 ± 0.28 ^a	2.89 ± 0.32 ^{Bbc}
	PP2	3.36 ± 0.28 ^{Ba}	2.80 ± 0.28 ^b	2.61 ± 0.16 ^{Cb}	3.08 ± 0.28 ^{ab}	2.89 ± 0.16 ^{Bb}
	SP1	4.11 ± 0.81 ^{Aa}	2.99 ± 0.32 ^b	2.99 ± 0.16 ^{Bb}	3.17 ± 0.16 ^b	3.08 ± 0.00 ^{ABb}
	SP2	3.27 ± 0.16 ^{Bab}	2.89 ± 0.16 ^b	3.08 ± 0.28 ^{Bab}	3.36 ± 0.28 ^a	3.17 ± 0.16 ^{ABab}
Residual nitrite (ppm)	CON	13.35 ± 0.62 ^A	ND	ND	ND	11.64 ± 1.40 ^A
	CON1	4.31 ± 1.16 ^B	ND	ND	ND	3.72 ± 0.63 ^D
	PP1	6.77 ± 2.59 ^B	ND	ND	ND	3.54 ± 0.77 ^D
	PP2	5.62 ± 1.34 ^B	ND	ND	ND	6.91 ± 0.25 ^C
	SP1	12.85 ± 0.88 ^{Aa}	ND	ND	ND	9.83 ± 0.17 ^{Bb}
	SP2	15.37 ± 0.42 ^{Aa}	ND	ND	ND	10.23 ± 0.20 ^{Bb}

Data represent mean ± SD.

¹⁾Treatments: CON (control), 0.014% sodium nitrite; CON1 (control1), no sodium nitrite and purple-fleshed sweet potato powder combination; PP1, no sodium nitrite and 0.5% purple-fleshed sweet potato powder; PP2, no sodium nitrite and 1% purple-fleshed sweet potato powder; SP1, 0.011% sodium nitrite and 0.5% purple-fleshed sweet potato powder combination; SP2, 0.011% sodium nitrite and 1% purple-fleshed sweet potato powder combination.

^{A-D}Means in the same column within the same aging period with different letters are significantly different ($p < 0.05$).

^{a-d}Means in the same row within the same aging condition with different letters are significantly different ($p < 0.05$).

component. The most abundant PUFA was linoleic acid. The PP2 sausages had the most PUFA, essential fatty acids (EFA), unsaturated fatty acids (UFA), ratios of UFA to SFA and of EFA to UFA, n-3 and n-6 fatty acids among the treated samples ($p < 0.05$). However, the composition of major fatty acids did not significantly differ between the CON and SP2 groups. A lower ratio (%) of SFA in the PP2 samples was responsible for the reduced amount of palmitic and stearic acids, which are associated with an increased risk of cardiovascular disease [29]. The most abundant fatty acid in the PP2 samples was linoleic acid (C18:2n-6), which differed from all other samples. Many studies have shown that replacing dietary saturated fat with oils abundant in linoleic acid helps to

Table 4. Fat and fatty acid composition of cooked pork sausages containing two different percentages of purple sweet potato combined with nitrite

	Treatments ¹⁾					
	CON	CON1	PP1	PP2	SP1	SP2
Fat	8.84 ± 0.51	8.77 ± 0.54	8.41 ± 0.37	8.53 ± 0.35	8.23 ± 0.37	8.45 ± 0.27
Capric acid (C10:0)	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00
Lauric acid (C12:0)	0.09 ± 0.01	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.01	0.09 ± 0.00	0.10 ± 0.01
Myristic acid (C14:0)	1.69 ± 0.01 ^A	1.62 ± 0.01 ^C	1.57 ± 0.01 ^D	1.59 ± 0.00 ^D	1.65 ± 0.01 ^B	1.59 ± 0.03 ^D
pentadecanoic acid (C15:0)	0.09 ± 0.00 ^A	0.09 ± 0.00 ^A	0.08 ± 0.00 ^C	0.08 ± 0.01 ^{BC}	0.09 ± 0.01 ^{AB}	0.08 ± 0.00 ^C
palmitic acid (C16:0)	23.93 ± 0.06 ^A	22.76 ± 0.09 ^D	22.68 ± 0.10 ^D	22.62 ± 0.01 ^D	23.71 ± 0.03 ^B	23.30 ± 0.19 ^C
Palmitoleic acid (C16:1)	2.86 ± 0.01 ^A	2.81 ± 0.01 ^B	2.63 ± 0.02 ^F	2.77 ± 0.01 ^C	2.71 ± 0.01 ^D	2.68 ± 0.02 ^E
Magaric acid (C17:0)	0.43 ± 0.00 ^C	0.43 ± 0.01 ^C	0.45 ± 0.01 ^B	0.42 ± 0.00 ^D	0.47 ± 0.00 ^A	0.47 ± 0.00 ^A
Magaolic acid (C17:1)	0.48 ± 0.00 ^B	0.48 ± 0.01 ^B	0.48 ± 0.01 ^B	0.48 ± 0.01 ^B	0.50 ± 0.01 ^A	0.51 ± 0.01 ^A
Stearic acid (C18:0)	10.96 ± 0.05 ^B	10.40 ± 0.02 ^C	11.00 ± 0.14 ^B	10.34 ± 0.04 ^C	11.45 ± 0.09 ^A	11.38 ± 0.11 ^A
Oleic acid (C18:1)	48.21 ± 0.06 ^B	47.49 ± 0.17 ^D	47.46 ± 0.16 ^D	47.55 ± 0.05 ^D	47.93 ± 0.08 ^C	48.56 ± 0.16 ^A
Linoleic acid (C18:2, n-6)	9.36 ± 0.08 ^C	11.61 ± 0.23 ^A	11.33 ± 0.21 ^B	11.77 ± 0.02 ^A	9.52 ± 0.05 ^C	9.43 ± 0.10 ^C
Linolenic acid (C18:3, n-3)	0.42 ± 0.01 ^C	0.64 ± 0.03 ^A	0.61 ± 0.03 ^B	0.65 ± 0.01 ^A	0.42 ± 0.01 ^C	0.41 ± 0.01 ^C
Arachidic acid (C20:0)	0.16 ± 0.01 ^A	0.15 ± 0.00 ^B	0.16 ± 0.01 ^A	0.15 ± 0.00 ^B	0.16 ± 0.01 ^A	0.17 ± 0.00 ^A
Eicosenoic acid (C20:1)	1.04 ± 0.01 ^B	0.96 ± 0.02 ^E	0.99 ± 0.01 ^D	0.98 ± 0.00 ^D	1.03 ± 0.01 ^C	1.06 ± 0.01 ^A
Eicosatrienoic acid (C20:4, n-6)	0.19 ± 0.01 ^B	0.40 ± 0.05 ^A	0.40 ± 0.05 ^A	0.42 ± 0.01 ^A	0.20 ± 0.01 ^B	0.20 ± 0.01 ^B
SFA	37.43 ± 0.10 ^{AB}	35.61 ± 0.11 ^D	36.10 ± 0.24 ^C	35.37 ± 0.04 ^D	37.69 ± 0.12 ^A	37.16 ± 0.26 ^B
MUFA	52.60 ± 0.06 ^A	51.75 ± 0.20 ^C	51.56 ± 0.19 ^C	51.78 ± 0.06 ^C	52.17 ± 0.08 ^B	52.81 ± 0.17 ^A
PUFA	9.97 ± 0.09 ^C	12.65 ± 0.30 ^{AB}	12.34 ± 0.28 ^B	12.84 ± 0.02 ^A	10.14 ± 0.06 ^C	10.03 ± 0.11 ^C
EFA	9.97 ± 0.09 ^C	12.65 ± 0.30 ^{AB}	12.34 ± 0.28 ^B	12.84 ± 0.02 ^A	10.14 ± 0.06 ^C	10.03 ± 0.11 ^C
UFA	62.57 ± 0.10 ^{CD}	64.39 ± 0.11 ^A	63.90 ± 0.24 ^B	64.63 ± 0.04 ^A	62.31 ± 0.12 ^D	62.84 ± 0.26 ^C
UFA/SFA	1.67 ± 0.01 ^{CD}	1.81 ± 0.01 ^A	1.77 ± 0.02 ^B	1.83 ± 0.01 ^A	1.65 ± 0.01 ^D	1.69 ± 0.02 ^C
EFA/UFA	0.16 ± 0.00 ^C	0.20 ± 0.01 ^{AB}	0.19 ± 0.01 ^B	0.20 ± 0.00 ^A	0.16 ± 0.00 ^C	0.16 ± 0.00 ^C
n-3	0.42 ± 0.01 ^C	0.64 ± 0.03 ^A	0.61 ± 0.03 ^B	0.65 ± 0.01 ^A	0.42 ± 0.01 ^C	0.41 ± 0.01 ^C
n-6	9.55 ± 0.08 ^C	12.01 ± 0.28 ^{AB}	11.73 ± 0.26 ^B	12.19 ± 0.02 ^A	9.72 ± 0.06 ^C	9.62 ± 0.10 ^C
n-6/n-3	22.61 ± 0.24 ^B	18.89 ± 0.43 ^D	19.46 ± 0.42 ^C	18.76 ± 0.20 ^D	23.38 ± 0.31 ^A	23.74 ± 0.20 ^A

¹⁾Treatments: CON (control),= 0.014% sodium nitrite, CON1 (control1), no sodium nitrite and purple-fleshed sweet potato powder combination; PP1, no sodium nitrite and 0.5% purple-fleshed sweet potato powder; PP2, no sodium nitrite and 1% purple-fleshed sweet potato powder; SP1, 0.011% sodium nitrite and 0.5% purple-fleshed sweet potato powder combination; SP2, 0.011% sodium nitrite and 1% purple-fleshed sweet potato powder combination.

^{A-F}Means in the same column within the same aging period with different letters are significantly different ($p < 0.05$).

SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EFA, essential fatty acids; UFA, unsaturated fatty acids.

lower cholesterol [30]. Adding PP to sausages also increased in the amount of linolenic acid in the sausages in the present study. This might be due to the high abundance of linolenic acid in purple sweet potatoes [20].

Adding PP caused changes in the levels of several amino acids in the pork sausages (Table 5), even though the total protein contents did not significantly differ ($p > 0.05$). The abundance of free glutamic acid was high. Glutamic acid is associated with the flavor called umami, which has a slightly sweet and sour taste [31]. The samples with purple-fleshed sweet potatoes contained significantly more glutamic acid, alanine, histidine, lysine, and arginine, and lower ratios of aspartic acid and cysteine ($p < 0.05$). Purple sweet potatoes are abundant in aspartic acid, glutamic acid, serine, alanine, valine, and other amino acids [20,32]. Changes in the levels of glutamic acid in the samples with PP can be attributed to the high amounts of similar amino acids extant in purple sweet potatoes. Levels of glutamic acid and alanine were higher in the SP2 than in the CON group ($p < 0.05$).

Table 5. Protein and amino acid composition of cooked pork sausages containing two different percentages of purple sweet potato combined with nitrite

	Treatments ¹⁾					
	CON	CON1	PP1	PP2	SP1	SP2
Protein	17.76 ± 0.58	17.40 ± 0.16	18.09 ± 0.48	17.79 ± 0.38	18.28 ± 1.14	17.99 ± 0.23
Aspartic acid	9.38 ± 0.12 ^A	9.22 ± 0.00 ^A	7.40 ± 0.09 ^B	6.82 ± 0.93 ^B	7.50 ± 0.20 ^B	7.51 ± 0.08 ^B
Threonine	4.65 ± 0.00	4.59 ± 0.00	4.60 ± 0.06	4.65 ± 0.10	4.67 ± 0.02	4.50 ± 0.01
Serine	3.87 ± 0.10	3.75 ± 0.00	4.06 ± 0.18	4.07 ± 0.21	4.07 ± 0.14	4.08 ± 0.18
Glutamic acid	14.91 ± 0.43 ^B	14.77 ± 0.00 ^B	16.00 ± 0.01 ^A	16.11 ± 0.14 ^A	15.67 ± 0.30 ^A	15.59 ± 0.30 ^A
Proline	4.29 ± 0.06	4.40 ± 0.00	4.43 ± 0.26	4.45 ± 0.05	4.42 ± 0.28	4.58 ± 0.16
Glycine	4.89 ± 0.25	4.81 ± 0.00	5.13 ± 0.05	4.95 ± 0.11	4.97 ± 0.02	5.10 ± 0.07
Alanine	5.86 ± 0.09 ^B	5.85 ± 0.00 ^B	6.18 ± 0.06 ^A	6.25 ± 0.15 ^A	6.21 ± 0.11 ^A	6.17 ± 0.03 ^A
Cysteine	1.37 ± 0.11 ^A	1.20 ± 0.00 ^B	0.00 ± 0.00 ^D	0.21 ± 0.00 ^C	0.00 ± 0.00 ^D	0.00 ± 0.00 ^D
Valine	5.48 ± 0.05	5.54 ± 0.00	5.58 ± 0.06	5.67 ± 0.16	5.73 ± 0.01	5.68 ± 0.18
Methionine	2.40 ± 0.74	2.94 ± 0.00	2.71 ± 0.02	2.59 ± 0.23	2.51 ± 0.62	2.76 ± 0.19
Isoleucine	5.08 ± 0.09	5.06 ± 0.00	5.11 ± 0.07	5.24 ± 0.22	5.34 ± 0.13	5.18 ± 0.18
Leucine	8.40 ± 0.02	8.42 ± 0.00	8.50 ± 0.04	8.64 ± 0.17	8.68 ± 0.06	8.61 ± 0.18
Tyrosine	3.32 ± 0.28	3.55 ± 0.00	3.51 ± 0.05	3.42 ± 0.16	3.31 ± 0.23	3.55 ± 0.15
Phenylalanine	4.17 ± 0.01	4.19 ± 0.00	4.27 ± 0.02	4.35 ± 0.10	4.29 ± 0.04	4.31 ± 0.06
Histidine	4.85 ± 0.09 ^B	4.68 ± 0.00 ^C	5.03 ± 0.08 ^A	5.12 ± 0.04 ^A	5.02 ± 0.05 ^A	4.98 ± 0.08 ^{AB}
Lysine	9.08 ± 0.02 ^{BC}	9.04 ± 0.00 ^C	9.29 ± 0.04 ^A	9.32 ± 0.06 ^A	9.30 ± 0.13 ^A	9.21 ± 0.01 ^{AB}
Ammonia	1.53 ± 0.01	1.52 ± 0.00	1.54 ± 0.12	1.58 ± 0.09	1.66 ± 0.06	1.60 ± 0.01
Arginine	6.52 ± 0.11 ^B	6.47 ± 0.00 ^B	6.72 ± 0.07 ^A	6.71 ± 0.10 ^A	6.70 ± 0.00 ^A	6.63 ± 0.02 ^{AB}
FAA	14.91 ± 0.43 ^B	14.77 ± 0.00 ^B	16.00 ± 0.01 ^A	16.11 ± 0.14 ^A	15.67 ± 0.30 ^A	15.59 ± 0.30 ^A
STAA	19.26 ± 0.45	19.00 ± 0.00	19.96 ± 0.35	19.92 ± 0.15	19.91 ± 0.26	19.85 ± 0.30
SAA	3.78 ± 0.84	4.14 ± 0.00	2.71 ± 0.02	2.63 ± 0.00	2.51 ± 0.62	2.76 ± 0.19
AAA	7.49 ± 0.26	7.73 ± 0.00	7.77 ± 0.06	7.77 ± 0.06	7.60 ± 0.19	7.85 ± 0.21
BAA	31.08 ± 0.97	32.43 ± 0.00	32.92 ± 0.04	33.09 ± 0.22	32.88 ± 0.71	33.06 ± 0.66
EAA	50.60 ± 0.68	50.93 ± 0.00	51.79 ± 0.04	52.29 ± 0.70	52.20 ± 0.27	51.84 ± 0.69
TAA	100	100	100	100	100	100

¹⁾Treatments: CON (control), 0.014% sodium nitrite; CON1 (control1), no sodium nitrite and purple-fleshed sweet potato powder combination; PP1 = no sodium nitrite and 0.5% purple-fleshed sweet potato powder; PP2, no sodium nitrite and 1% purple-fleshed sweet potato powder; SP1, 0.011% sodium nitrite and 0.5% purple-fleshed sweet potato powder combination; SP2, 0.011% sodium nitrite and 1% purple-fleshed sweet potato powder combination.

^{A-D}Means in the same column within the same aging period with different letters are significantly different ($p < 0.05$).

FAA, flavourous amino acid; STAA, sweet taste amino acid; SAA, sulfur-containing amino acid; AAA, aromatic amino acid; BAA, bitter amino acid; EAA, essential amino acid; TAA, total amino acid.

CONCLUSION

The inclusion of 1% PP with 0.011% sodium nitrite as a colorant seemed to confer desirable subjective and objective qualities on sausages. The residual nitrite content in sausages with added PP decreased over time in storage. The addition of 1% PP produced major changes in the fatty acid profiles of the sausages, reduced the ratios of SFA and MUFA, and increased PUFA levels. Adding PP also tended to increase the content of flavourous amino acids. The fatty acid composition was comparable between the SP2 and CON groups, but the SP2 groups contained more flavourous and sweet-tasting amino acids than the CON group. Therefore, including up to 1% of PP along with 0.011% NaNO₂ could serve as a natural colorant for pork sausages without any detrimental effects on quality. We also found that 20% PP might be able to replace NaNO₂. However, further investi-

gation is needed to determine the effects of partially substituting NaNO₂ with PP on the oxidative and microbiological stability of meat products.

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