Effect of *Allium hookeri* and whey powder in diet of pigs on physicochemical characteristics and oxidative stability of pork

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**ABSTRACT**

The objective of this study was to determine the effect of *Allium hookeri* supplementation with whey powder in pig diet on meat quality, oxidative stability and sensory characteristics of *Longissimus dorsi* muscle samples. A total of 60 pigs were randomly assigned into the following three groups (four replicate pens per group with five pigs per pen): CON group, basal diet; AH, dietary supplementation with 10 g *A. hookeri*/kg feed and AHW, dietary supplementation with 5 g *A. hookeri*/40 g whey powder/kg feed. Proximate composition of muscle sample was not significantly affected by *A. hookeri* supplementation. On average, the AHW group showed higher pH but less cooking loss than the CON group. However, the AH and AHW groups had lower (*p* < .05) collagen content and shear force than the CON group. Retardation of lipid oxidation was significantly higher in the AH compared to that in the CON group. However, fatty acid compositions were not significantly affected by *A. hookeri* or whey powder supplementation, the exceptions were the C18:0 and C18:3 that showed the highest and the C20:3 the lowest proportions in the AH group. The AH group exhibited higher free amino acid contents such as Glu, Asn, Thr, Arg, Tyr, Ile and Leu than the AHW or CON group. However, sensory characteristics were not significantly affected by supplementation with *A. hookeri* or whey powder. These findings demonstrate that *A. hookeri* might be a promising supplement for pigs diet to improve meat oxidative stability without negatively compromise the nutritional properties and sensory quality.

**ARTICLE HISTORY**

Received 29 November 2016
Revised 15 March 2017
Accepted 24 March 2017

**KEYWORDS**

*Allium hookeri*; pork; whey; meat quality; oxidative stability

**Introduction**

Substitution of feed additives in livestock with natural products has been widely discussed and argued to produce more healthy meat and reduce environmental problems. To minimise cost of feeding and maximise efficiency, optimal feeding system is needed. Feed additives including antibiotics, antioxidants and growth-promoting substances can increase the conversion ratio of muscle to meat. Currently, synthetic feed additives have been advocated to be replaced by natural feed additives such as those from plants like herbs and spices (Kim et al. 2009; Yan et al. 2011).

*Allium hookeri* has been successfully cultivated in South Korea in recent years. As part of the Korean folk medicine, *Allium* species have been traditionally used for medicinal purposes since ancient times. *Allium* species are fortified with sulphur-bearing compounds. They can be used as antioxidant and anti-inflammatory agents. They even have applications in toxicology (Nishimura et al. 2006). Sulphur-bearing compounds in *Allium* species include methiin, alliin, isoalliin, propiin and allicin, a representative component in garlic (Rhyu & Park 2013). In a previous study, Lee (2014) has demonstrated that 1% *A. hookeri* supplementation of guinea pig diet can inhibit the accumulation of fat and release free fatty acids in these animals.

Whey powder is considered as a valuable by-product in cheese industry. The main components of whey protein are lactose, protein, lipids and minerals. In particular, whey protein has some beneficial effects on protein synthesis, mineral absorption and blood glucose metabolism (Pal et al. 2010). Kim et al. (2016a) have reported that 1% whey powder supplementation can enhance the tenderness and redness of dry-aged pork which is vulnerable to lipid oxidation.

Given these traits of whey powder and *Allium* species, combining *A. hookeri* with whey powder as dietary supplementation might have synergistic effect on growth performance of pigs, meat quality and
oxidative stability. Therefore, the aim of this study was to determine the effect of supplementing 1% *A. hookeri* or 0.5% *A. hookeri* with 4% whey protein in pigs diet on sensory and texture characteristics, free amino acids, fatty acid composition and oxidative stability of *Longissimus dorsi* muscle.

**Materials and methods**

**Animals and experimental design**

The experimental design was approved by Konkuk University Institutional Animal Care and Use Committee (IACUC). A total of 60 three-way crossbred pigs (*Duroc × Landrace × Yorkshire*) with an average live weight of 55.0 ± 1.41 kg at the age of 90 d were randomly assigned to one of three treatment groups on the basis of weight. Each treatment group had 20 pigs during the growing phase (30 d) and fattening phase (90 d). Experimental unit was the pigs (*n* = 20). Each treatment group had four replicate pens with five pigs per pen (*n* = 20). *A. hookeri* was purchased from Samchaenara Co. (Gyeongsangnamdo, Korea). Whey powder was provided by Samik Dairy Co., Ltd. (Seoul, Korea). *A. hookeri* leaves and roots were purchased from Samchaenara Co. (Gyeongsangnamdo, Korea). They were subjected to vacuum and freeze-drying. The three treatment groups were: (1) CON, basal diet; (2) AH, basal diet supplementation with 10 g *A. hookeri* powder/kg and (3) AHW, basal diet supplementation with 5 g *A. hookeri* powder and 4 g whey powder/kg (as-fed basis, Table 1). Basal diet was formulated to contain similarly digestible crude protein (DCP) 14.5 g/kg and digestible energy 14.7 MJ/kg. Feed was offered *ad libitum*. The ambient temperature was kept at approximately 22°C. The relative humidity was 70–80%. Basal diet supplementation was conducted according to the recommendation for nutrients by the National Research Council (NRC) (1998). According to a previous study (Lee 2014), proximate compositions of freeze-dried *A. hookeri* were: moisture of 1.6%, crude protein of 12.7%, ash of 12.2%, fat of 0.5% and crude fibre of 31.7%. At 180 d of age, pigs were slaughtered with final live weight of 122.37 ± 0.84 kg. There was no significant (*p* > 0.05) difference in weight among the three groups. After the slaughtering process, carcases were stored at 2–4°C for 24 h for chilling. Samples from the *L. dorsi* were collected from each carcase and subsequently vacuum packaged and stored at −20°C for further analysis.

**Chemical analysis**

**Proximate composition and collagen content**

Moisture, crude protein, crude fat and ash contents were determined using the method of the Association of Official Analytical Chemists (AOAC 2000).
Collagen content was analysed using the method of Silva et al. (1999). Briefly, sample (4 g) was placed in a flask with 30 mL of 6 N HCl. Hydrolysis of the sample was performed at 110 °C in a drying oven for 16 h. The volume of the hydrolysed sample was adjusted to 500 mL with water. A 2 mL of the diluted sample was left to react with 1 mL of oxidant solution for 20 min. The oxidative sample was then mixed with 1 mL of colour reagent and left to react for 15 min at 60 °C in a water bath followed by cooling to room temperature. The absorbance was measured at wavelength of 550 nm to determine the amount of hydroxyproline in the sample.

Sample pH

Two grams of sample were homogenised in 18 mL of distilled water with a Bag Mixer 400 (Interscience Co., Saint-Nom-la-Bretêche, France). The pH of the sample was measured with a pH metre (pH 900, Precisa Co., Dietikon, Switzerland).

Colour

Colour measurement of meat was conducted using a colorimeter (NR-300, Nippon Denshoku, Tokyo, Japan). Calibration of the machine was conducted with a white plate (CIE L* = +94.48, a* = −0.67, b* = +3.31). After the sample was placed at room temperature for 30 min, values of CIE L* (lightness), CIE a* (redness) and CIE b*(yellowness) were measured.

Cooking loss

Cooking loss was measured as weight loss of sample during cooking. Each 500 g of sample (20 muscles per treatment) was cooked at 75 °C to reach an internal core temperature of 70 °C. Temperature profiles of samples were obtained using a thermocouple (Thermometer TES 1300, TES Electrical Electronic Co., Taipei, Taiwan). After boiling, the sample was cooled with ice-cold water for chilling. Sample was then dried to remove surface moisture and weighted.

Drip loss

Approximately 500 g of sample was sealed in transparent oxygen-permeable polyvinyl chloride film and stored at 4 °C for 24 h. Drip loss was measured from the observed weight loss of the sample during refrigerated storage. Drip loss (%) was calculated as follows:

\[
\text{Drip loss (\%)} = \left( \frac{\text{Weight loss after drip}}{\text{Initial sample weight}} \right) \times 100
\]

TBARS

Thiobarbituric acid reactive substances value (TBARS) of the sample was measured using the method of Witte et al. (1970). Briefly, samples were prepared as uncooked and cooked meat after cooking loss measurement. Uncooked and cooked meat samples were packaged in polyethylene plastic bags and stored in a refrigerated room at 4 °C for 24 h. To determine TBARS values, 2 g of either uncooked or cooked sample (0 and 24 h) was homogenised with 10 mL of 10% trichloroacetic acid (TCA) solution and 0.04 mL of 0.3% butylated hydroxytoluene (BHT) solution. Then, 5 mL of the homogenised sample was reacted with 5 mL of 2-thiobarbituric acid solution (TBA) to determine malondialdehyde (MDA) level present in the sample after heating the mixture in boiling water for 10 min. After chilling down, the absorbance value of sample was measured at wavelength of 532 nm using a spectrophotometer (Optizen 2120UV, Mecasys, Seoul, Korea). Data were expressed as levels of MDA in mg/kg of muscle. TBARS value was calculated using molar and extinction coefficient for MDA (1.56 × 10⁵ M⁻¹ C⁻¹).

Shear force measurement

After cooking loss measurement, strips were cut off from muscle samples using a sampling cylinder with diameter of 1 cm and length of 4 cm. Shear force was then measured on a texture analyser (TA-XT2, Stable Micro System, Scarsdale, NY) equipped with a triangle angular slot cutting edge under a crosshead speed of 2 mm/s.

Fatty acid analysis

For fatty acid analysis, lipids were extracted from muscle samples using the method of Folch et al. (1957). Afterwards, 10% boron trifluoride (BF3) in methanol was added to the lipid extract for methylation reaction. Briefly, after the addition of BF3, the sample was heated in a water bath (60 °C) for 40 min. After cooling, hexane and distilled water were added to the sample and mixed. The mixture was then centrifuged at 2000g for 15 min. The hexane layer was used for fatty acid analysis. Nonadecanoic acid methyl ester at 0.3 mg/mL was used as an internal standard, which was added prior to methylation. Fatty acids were analysed by gas chromatography (GC) (7,890A, Agilent Technologies, Santa Clara, CA) with a flame ionisation detector and a DB-23 capillary column (60 mm × 0.25 mm × 0.25 um, Agilent). Chromatographic conditions were as follows: initial oven temperature at
100 °C (held for 4 min) and ramping at 3 °C/min to 240 °C (held for 15 min). The injector and detector were maintained at 225 and 285 °C, respectively. The flow rate of helium was set at 0.75 mL/min. Then, 1 μL of the solution was injected in split mode (200:1). Supelco 37 component FAME mix standard (Sigma-Aldrich, Bellefonte, PA) was used for identification of fatty acids in the chromatogram. Total fatty acid content was expressed as mg per g of dry muscle and the fatty acid composition as % of total fatty acids in sample.

**Free amino acid analysis**

A given sample (5 g) was sonicated with 90 mL of 75% ethanol for an hour and allowed to stand for 24 h. Before amino acid analysis, the extract was filtered through 0.2 μm filter. Solvent and gradient conditions of free amino acid analysis were determined using the method of Henderson et al. (2000). Free amino acids (FAAs) were analysed by HPLC (Dionex Ultimate 3000, Waltham, MA) using Chromeleon 6.8 software and a VDSpher 100 C18-E column (4.6 mm × 150 mm, 3.5 μm, VDS Optilab, Berlin, Germany). Primary amino acids were detected as o-phthaldehyde (OPA) derivatives at wavelength of 338 nm while secondary amino acids were determined as 9-fluorenylmethyl chloroformate (FMOC) derivatives at 226 nm for excitation and 313 nm for emission. Free amino acids were identified using amino acid standard (AAS18, Sigma-Aldrich, Bellefonte, PA). Free amino acids were expressed in mg/kg dry muscle.

**Sensory evaluation**

After heating at 75 °C to reach core temperature of 70 °C to determine cooking loss, heated samples were immediately cut into 1.5 cm × 1.5 cm × 1.5 cm cubes and randomly assigned to nine trained panellists for sensory evaluation. The procedure of sensory evaluation was conducted with training and replicate measurements according to sensory evaluation method of the American Meat Science Association (AMSA 1978) with slight modification. Briefly, sample cubes were used for sensory evaluation. The amount of perceptible connective tissue, juiciness and flavour intensity were evaluated on a 9-point descriptive scale (9’ indicating extremely tender, no perceptible connective tissue, extremely juicy with intense meaty flavour, while ‘1’ indicating extremely tough, abundant connective tissue, extremely dry with a bland meaty flavour). In addition, 9-point hedonic scale (9, extremely desirable; 1, extremely undesirable) was used to evaluate taste, flavour and the overall palatability.

**Statistical analysis**

All data analyses were performed using SPSS 18.0 software (SPSS, Chicago, IL). Each treatment had four replicate pens with five pigs in each pen. Each pig was independently used for all experiments and considered as the experimental unit (n = 20). All experiments were analysed with model including dietary treatments as a fixed effect. Data were expressed as mean ± standard error of means. Statistically significant difference was defined at p < .05 following one-way analysis of variance (ANOVA) and Duncan multiple range test.

**Results**

**Proximate compositions and meat quality traits**

Proximate composition was not significantly affected by the treatments, so the mean compositions were: moisture: 72.03–72.55%; crude fat: 1.82–2.54%; crude protein: 26.71–26.92%; ash 1.40–1.80% (Table 2). Collagen content was significantly (p = .017) decreased by dietary supplementation with *A. hookeri* compared to that in the CON. The shear force values of the AH and AHW groups were lower (p < .05) than that of the CON group (Figure 1).

Linear increase in pH with increasing level of *A. hookeri* in the diet was noted (Table 2, p < .001). The pH after cooking followed the same pattern. Drip loss (range: 6.20–8.07%) was not significantly different among the three groups. However, cooking loss of AHW was significantly (p < .05) lower than that of the CON group (Table 2).

Lightness (L*) and redness (a*) values were not significantly affected by *A. hookeri* or whey powder supplementation. AHW and whey powder supplemented diet from weaning to slaughter.

| Table 2. Proximate composition (%) | CON | AH | AHW | SEM | p Value |
|------------------------------------|-----|----|-----|-----|---------|
| Moisture, %                        | 72.3 | 72.2 | 72.5 | 0.21 | .651    |
| Fat, %                             | 1.82 | 2.29 | 2.54 | 0.19 | .301    |
| Protein, %                         | 26.71| 26.92| 26.74| 0.25 | .285    |
| Ash, %                             | 1.80 | 1.57 | 1.40 | 0.09 | .946    |
| Collagen, g/kg                     | 7.00 | 3.99 | 4.88 | 0.49 | .017    |
| pH, 24 h                           | 5.37 | 5.57 | 5.48 | 0.02 | <.001   |
| Cooked meat pH                     | 5.59 | 5.69 | 5.63 | 0.01 | <.001   |

**Colour**

| Value | CON | AH | AHW | SEM | p Value |
|-------|-----|----|-----|-----|---------|
| L*     | 51.70| 51.16| 51.16| 0.44 | .861    |
| a*     | 8.39 | 8.35 | 9.69 | 0.28 | .076    |
| b*     | 4.94 | 4.11 | 6.00 | 0.26 | .009    |
| Drip loss | 8.07 | 7.25 | 6.20 | 0.97 | .121    |
| Cooking loss, % | 11.31 | 9.85 | 8.68 | 0.73 | .013    |

CON, basal diet fed pigs; AH, 1% *Allium hookeri* fed pigs; AHW, 0.5% *Allium hookeri* and 4% whey powder fed pigs. a–c, different superscript letters mean significant differences among groups (p < .05).
supplementation (Table 2). Even though the redness values of all groups were not significant different, *A. hookeri* with whey powder supplementation showed slightly increased value \((p < .1)\). Yellowness \((b^*)\) value of the AHW group was significantly \((p < .01)\) higher than that of the AH group.

**Lipid oxidation**

Effects of *A. hookeri* and whey powder supplementation on TBARS of raw meat, cooked meat at 0 h, and cooked meat at 24 h are shown in Table 3. In terms of raw meat, the AH group had the lowest TBA value \((0.07 \text{ MDA mg/kg meat})\) while the CON group had the highest TBA value \((0.13 \text{ MDA mg/kg meat})\). However, TBA value of raw meat of the AHW group was not significantly \((p > .05)\) different from that of the AH or CON group. Both cooked meats at 0 h and at 24 h tended \((p < .1)\) to show low TBA values in groups supplemented with *A. hookeri*.

**Fatty acid composition**

The effect of *A. hookeri* and whey powder supplementation on fatty acid composition is shown in Table 4. Supplementation failed to significantly affect total fatty acid content \((p > .05)\). In addition, SFA, MUFA and PUFA proportions were not significantly different among the three treatment groups. Regarding the fatty acid composition, only the proportions of C18:0, C18:3n – 3 and C20:3n – 3 in muscle were affect by diets. The C18:0 proportions increased by increasing the level of *A. hookeri* in diet, while the C18:3n – 3 showed the lowest proportions in the CON group and the highest in the AH group. The supplementation with *A. hookeri* decreased the proportions of C20:3n – 3 in muscle compared to the control.

**Free amino acid composition**

Effect of diet supplementation with *A. hookeri* and whey powder on free amino acids composition and concentration is summarised in Table 5. The concentrations of some free amino acids (glutamic acid, asparagine, threonine, arginine, tyrosine, isoleucine and leucine) in the AH group were considerably increased compared to those in other groups. In particular, 1% *A. hookeri* supplementation significantly decreased the proportions of C18:3n – 3 in muscle compared to the control.

### Table 3. TBARS (mg MDA/kg muscle) of Longissimus dorsi muscle in pig fed *Allium hookeri* and whey powder supplemented diet from weaning to slaughter.

| Value | CON | AH | AHW | SEM | p Value |
|-------|-----|----|-----|-----|---------|
| Raw meat  | 0.13 | 0.07 | 0.09 | 0.02 | .016 |
| Cooked meat | 0.92 | 0.86 | 0.85 | 0.24 | .063 |
| Cooked meat (24 h) | 1.11 | 0.96 | 1.06 | 0.11 | .071 |

CON, basal diet fed pigs; AH, 1% *Allium hookeri* fed pigs; AHW, 0.5% *Allium hookeri* and 4% whey powder fed pigs. a–c, different superscript letters mean significant differences among groups \((p < .05)\).

### Table 4. Fatty acid composition (% of total fatty acids) and total fatty acids (mg/g dry muscle) of Longissimus dorsi muscle in pig fed *Allium hookeri* and whey powder supplemented diet from weaning to slaughter.

| (% fatty acids) | C10:0 | C12:0 | C14:0 | C16:0 | C18:0 | C18:1 | C18:2 | C18:3 | C20:2 | C20:3 | C20:4 | C24:0 | SFAd | PUFAf |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| CON            | 0.13  | 0.13  | 0.13  | 0.02  | .004  | .495  | .325  | .535  | .258  | .254  | .419  | .351  | .957  | .312  | .016  |
| AH             | 0.09  | 0.09  | 0.09  | 0.04  | .049  | .975  | .325  | .535  | .258  | .254  | .419  | .351  | .957  | .312  | .016  |
| AHW            | 1.45  | 1.44  | 1.50  | 0.22  | .975  | .325  | .535  | .258  | .254  | .419  | .351  | .957  | .312  | .016  | .004  |
| SEM            | 0.06  | 0.08  | 0.06  | 0.01  | .319  | .325  | .535  | .258  | .254  | .419  | .351  | .957  | .312  | .016  | .004  |

\(\text{SFA}^a\), saturated fatty acids.

\(\text{MUFA}^b\), monounsaturated fatty acid.

\(\text{PUFA}^c\), polyunsaturated fatty acid.
enhanced glutamic acid content (449.23 mg/kg) compared to the CON or AHW. Aspartic acid content (42.97 mg/kg) of the AH was slightly ($p = .063$) higher than that of the CON or AHW. However, aspartic acid content of the AHW was not significantly ($p > .05$) different from that of the CON.

**Trained sensory panel analysis**

Results of sensory panel evaluation for meat of the CON, AH and AHW groups are shown in Table 6. Although shear force values of the AH and AHW groups were lower than that of the CON, connective tissue amounts were not significantly different among the three groups. However, dietary supplementation of 1% *A. hookeri* to pigs showed a tendency ($p < .1$) of enhancing flavour intensity compared to control diet, although sensory evaluation results for the AHW samples were not significantly ($p > .05$) different from those of the AH samples.

**Discussion**

Moisture, crude fat, crude protein and ash contents of muscle samples were not affected by the AH and AHW supplementations in this study. No significant effect of plant extract supplementation on proximate compositions of pork muscle was reported (Luhucky et al. 2010; Rossi et al. 2013). On the other hands, this result was different from results of Chen et al. (2008) and Yan et al. (2011) showing that garlic powder diets for pigs increased marbling score of pork.

**Table 5.** Free amino acids composition of *Longissimus dorsi* muscle in pig fed *Allium hookeri* and whey powder supplemented diet from weaning to slaughter.

| Unit: mg/kg (dry matter basis) | CON | AH | AHW | SEM | p Value |
|-------------------------------|-----|----|-----|-----|---------|
| Aspartic acid                 | 26.0| 43.0| 22.1| 5.56| .063    |
| Glutamic acid                 | 308.3$^{b}$| 449.2$^{a}$| 366.3$^{b}$| 22.12| .018    |
| Asparagine                    | 84.3$^{b}$| 128.1$^{a}$| 91.9$^{b}$| 10.26| .045    |
| Serine                        | 230.5| 322.9| 244.6| 24.08| .058    |
| Glutamate                     | 708.9| 740.85| 656.1| 170.33| .886    |
| Histidine                     | 86.9| 130.6| 102.4| 11.05| .063    |
| Glycine                       | 285.1| 362.0| 287.3| 32.24| .155    |
| Threonine                     | 179.4$^{b}$| 254.2$^{a}$| 184.1$^{b}$| 17.51| .039    |
| Arginine                      | 152.1$^{b}$| 230.5$^{a}$| 150.1$^{b}$| 11.16| .009    |
| Alanine                       | 600.3| 729.9| 646.1| 40.84| .106    |
| Taurine                       | 6583.3| 6604.4| 6963.9| 679.58| .838    |
| Tyrosine                      | 174.6$^{b}$| 254.7$^{a}$| 181.4$^{b}$| 15.39| .024    |
| Valine                        | 142.9| 207.6| 159.6| 17.03| .065    |
| Methionine                    | 158.2| 206.6| 157.5| 17.53| .107    |
| Tryptophane                   | 39.9| 57.8| 36.8| 7.66| .128    |
| Phenylalanine                 | 188.6| 246.2| 199.9| 14.31| .053    |
| Isoleucine                    | 132.1$^{b}$| 199.2$^{a}$| 142.2$^{b}$| 13.23| .028    |
| Leucine                       | 259.5$^{b}$| 394.2$^{a}$| 283.7$^{b}$| 20.49| .014    |
| Lysine                        | 165.8| 253.3| 177.5| 26.43| .082    |
| Proline                       | 93.2| 114.2| 100.9| 24.93| .723    |

CON: basal diet fed pigs; AH: 1% *Allium hookeri* fed pigs; AHW: 0.5% *Allium hookeri* and 4% whey powder fed pigs. a–c, different superscript letters mean significant differences among groups ($p < .05$).

**Table 6.** Sensory characteristics of pork loin from pigs fed with *Allium hookeri* and whey powder.

| CON | AH | AHW | SEM | $p$ Value |
|-----|----|-----|-----|---------|
| Juiciness | 4.86| 5.71| 4.57| .93| .454    |
| Tenderness | 4.00| 5.85| 4.71| .91| .150    |
| Connective tissue amount | 5.00| 3.42| 4.42| .92| .251    |
| Flavor intensity | 4.29| 5.29| 3.14| .91| .087    |
| Off-odor intensity | 4.14| 3.42| 3.50| 1.20| .574    |
| Overall acceptability | 4.14| 5.00| 4.43| .98| .154    |

CON: basal diet fed pigs; AH: 1% *Allium hookeri* fed pigs; AHW: 0.5% *Allium hookeri* and 4% whey powder fed pigs. All sensory characteristics was evaluated using an 9-point descriptive scale, where 9 = extremely desirable, 1 = extremely undesirable) was used to evaluate taste, flavour and the overall palatability.

Connective tissues are mainly composed of collagen protein, which negatively affected on tenderness (Lepetit et al. 2000). At cooking temperature above 65°C, increased toughness in cooked sample is due to shrinkage of collagen (Lepetit et al. 2000). However, *A. hookeri* root contains high levels of *allicin* (about 56.6 μg/g) that can act as an inhibitor of collagen synthesis since cysteine proteases are activated by *Allium* species both in *vitro* and in *vivo* (Paris et al. 2002; Sardari et al. 2006; Rhyu & Park 2013). Consequently, the low shear force values of samples from groups supplemented with *A. hookeri* might have been partly due to the activation of endogenous cysteine proteases.

The pH of meat is an important determinant of meat and it is generally determined during post-mortem. Similar result of pH has been reported by Chen et al. (2008) in a study where pig diet was
supplemented with 1 g/kg garlic powder. This study reported the beneficial effect of the garlic powder on pH and drip loss. It is known that sulphur compounds such as S-alllycysteine and quercetin from *Allium* spp. can decrease the activity of lactate dehydrogenase (Grisolia et al. 1975; Sheela & Augusti 1992). Thus, *A. hookeri* supplementation might have inhibited the accumulation of lactic acids in meat. Moreover, increasing pH after cooking might be due to transition of protein charges caused by the cooking process. Likewise, cooking loss of AH had a tendency to be less than that of the control group. Several factors can contribute to water-holding capacity of meat, including net charge effect for pH, proteolysis and protein oxidation (Huff-Lonergan & Lonergan 2005). The relative low drip loss and cooking loss in the AH and AHW muscles found in this study might be due to their relative high pH values. Decreased drip loss and cooking loss but increased pH of pork from 1 to 2 g/kg garlic powder fed pigs have also been reported by Kim et al. (2009).

The increasing tendency (*p* < .1) of redness values and significant high yellowness value of the AHW were consistent with the results of Kim et al. (2016a) showing that whey powder supplementation resulted in increased redness and yellowness values reflecting myoglobin content in pork. Lindahl et al. (2001) have stated that yellowness value of pork muscle is associated with a high ratio of oxymyoglobin to myoglobin.

Previously, dietary supplementation with *Allium sativum* to broilers has shown an inhibitory effect on lipid oxidation (Kim et al. 2009). *A. hookeri* contains abundant antioxidants such as phenols and organosulfur compounds (Kim et al. 2016b). Furthermore, it has been reported that total antioxidant ability of blood from pigs is increased after plant extract supplementation (Rossi et al. 2013). Moreover, Lee et al. (2014) have proved that *A. hooerki* has antioxidant because total phenol contents of water extracts from root and leaf of *A. hookeri* are 6 and 23 mg GAE/g, respectively. Although there was no significant difference in antioxidant ability among cooked samples, there was significantly difference in antioxidant ability between the AH and CON. This result suggests that the cooking process might have diminished the antioxidant effect of *A. hookeri* supplementation.

Morifuji et al. (2005) have explained that fatty acid synthesis can positively affect skeletal muscle due to whey protein supplementation. Nevertheless, whey powder supplementation failed to show significant effect on fatty acid composition or content in this study. Kim et al. (2009) have reported that unsaturated fatty acid contents are increased along with decreased saturated fatty acid contents due to garlic supplementation. A similar result of fatty acid composition changes has been reported by Choi et al. (2010) showing that unsaturated fatty acid levels are increased with increasing doses of garlic supplementation. However, C18:3n – 3 (linoleic acid) and C18:0 (stearic acid) contents in the AH were increased compared to those in the CON in the present study. Linoleic acid content of meat was seemed to be determined by feed intake since the linoleic acid was regarded as main fatty acids of *Allium* species (Kouba et al. 2003; Tsiaganis et al. 2006). Moreover, the increasing linoleic acid content can suppress stearoyl-CoA-desaturase activity to convert stearic acid into oleic acid (C18:1n – 9) (Kouba et al. 2003).

Glutamic acid and aspartic acid are considered as taste-active components. These acids can enhance the umami taste of meat (Fuke & Konosu, 1991). Increased levels of free amino acids in muscles of pigs with 0.5% garlic extract supplementation have been reported by Lee et al. (2012). They also reported that insulin, the levels of which were increased in garlic extract supplementation group, accelerated the absorption of free amino acids from blood into muscle and enhanced growth performance of pigs (Lee et al. 2012). Therefore, 0.5% *A. hooerki* with 4% whey supplementation did not affect free amino acid compositions. However, 1% *A. hookeri* supplementation might have improved meat flavour due to increased level of free amino acids. Kato et al. (1989) have demonstrated that the brothy flavour of pork is increased when free amino acid contents of pork is increased during storage. For this reason, the higher tendency of flavour intensity of AH might be due to its high free amino acid contents.

**Conclusions**

Different dose levels (0.5% and 1%) of *A. hookeri* supplementation and 4% whey protein significantly affected the quality and oxidative stability of fresh *L. dorsi* samples. Basal diet supplemented with *A. hookeri* enhanced the cooking yield and decreased shear force of pork. Some free amino acid contents were significantly affected by 1% *A. hookeri* supplementation. Therefore, *A. hookeri* supplemented diets might be useful natural antioxidants to retard lipid oxidation and enhanced meat quality for the meat industry. However, further research is required to determine the effects of *A. hookeri* supplementation on metabolic processes in pigs and protein characteristics of meat after such supplementation.
Acknowledgment

This research was supported by Technology Commercialization Support Program of Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry, and Fisheries funded by the Ministry of Agriculture, Food, and Rural Affairs, Republic of Korea.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

AMSA. 1978. Guidelines for cookery and sensory evaluation of meat. Chicago, IL, USA: American Meat Science Association National Live Stock and Meat Board.

AOAC. 2000. Official Methods of Analysis of the AOAC. Arlington, VA, USA: AOAC.

Chen YJ, Kim IH, Cho JH, Yoo JS, Wang Q, Wang Y, Huang Y. 2008. Evaluation of dietary L-carnitine or garlic powder on growth performance, dry matter and nitrogen digestibilities, blood profiles and meat quality in finishing pigs. Anim Feed Sci Tech. 141:141–152.

Choi IH, Park WY, Kim YJ. 2010. Effects of dietary garlic powder and α-tocopherol supplementation on performance, serum cholesterol levels, and meat quality of chicken. Poult Sci. 89:1724–1731.

Folch J, Lees M, Sloane-stanly GH. 1957. A simple method for the isolation and purification of total lipid from animal tissues. J Biol Chem. 226:497.

Fuke S, Konosu S. 1991. Taste-active components in some foods: a review of Japanese research. Physiol Behav. 49:863–868.

Grisolia S, Rubio V, Feijoo B, Mendelson J. 1975. Inhibition of lactic dehydrogenase and of pyruvate kinase by low concentrations of quercetin. Physiol Chem Phys. 7:473–475.

Henderson JW, Ricker RD, Bidlingmeyer BA, Woodward C. 2000. Rapid, accurate, sensitive and reproducible analysis of amino acids. Agilent Publication Number 5980-1193EN. Palo Alto, CA: Agilent Technology.

Huff-Lonergan E, Lonergan SM. 2005. Mechanisms of water-holding capacity of meat: the role of postmortem biochemical and structural changes. Meat Sci. 71:194–204.

Kato H, Ryue MR, Nishimura T. 1989. Flavor Chemistry: Chapter 13, Role of free amino acids and peptides in food taste; p. 158–174.

Kim JH, Yeon SJ, Hong GE, Park W, Lee CH. 2016a. Effects of whey powder supplementation on dry-aged meat quality. Korean J Food Sci Anim Resour. 36:397–404.

Kim S, Kim DB, Lee S, Park J, Shin D, Yoo M. 2016b. Profiling of organosulphur compounds using HPLS-PDA and GC/MS system and antioxidant activities in hooker chive (Allium hookeri). Nat Ford Res. 30:2798–2804.

Kim YJ, Jin SK, Yang HS. 2009. Effect of dietary garlic bulb and husk on the physicochemical properties of chicken meat. Poult Sci. 88:398–405.

Kouba M, Enser M, Whittington FM, Nute GR, Wood JD. 2003. Effect of a high-linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig. J Anim Sci. 81:1967–1979.

Lee DH, Lim SR, Ra CS, Kim JD. 2012. Effects of dietary garlic extracts on whole body amino acid and fatty acid composition, muscle free amino acid profiles and blood plasma changes in Juvenile Sterlet Sturgeon, Acipenser ruthenus. Asian Australas J Anim Sci. 25:1419–1429.

Lee NY. 2014. Effects of Allium hookeri root and processed sulfur on the fat accumulation and biochemical parameters in guinea pigs [Master thesis]. Seoul, KR: Konkuk University.

Lee KW, Kim YS, Park PJ, Jeong JH. 2014. Comparison of effect of water and ethanol extract from roots and leaves of Allium hookeri. J Korean Soc Food Sci Nutr. 43:1808–1816.

Lepetit J, Grajales A, Favier R. 2000. Modelling the effect of sarcomere length on collagen thermal shortening in cooked meat: consequence on meat toughness. Meat Sci. 54:239–250.

Lindahl G, Lundstrom K, Tornberg E. 2001. Contribution of pigment content, myoglobin forms and internal reflectance to the colour of pork loin and ham from pure breed pigs. Meat Sci. 59:141–151.

Luhucky R, Nuernberg K, Kovac L, Bucko O, Nuernberg G. 2010. Assessment of the antioxidant potential of selected plant extracts – in vitro and in vivo experiments on pork. Meat Sci. 85:779–784.

Morifuji M, Sakai K, Sanbongi C, Sugira K. 2005. Dietary whey protein downregulates fatty acid synthesis in the liver, but upregulates it in skeletal muscle of exercise-trained rats. Nutrition. 21:1052–1058.

NRC. 1998. Committee on Nutrient Requirements of Swine, National Research Council. Nutrient requirements of swine. 10th ed. Washington, DC: National Academy Press.

Nishimura H, Higuchi O, Tateshita K, Tomobe K, Okuma Y, Nomura Y. 2006. Antioxidative activity and ameliorative effects of memory impairment of sulfur-containing compounds in Allium species. Biofactors. 26:135–146.

Pal S, Elis V, Ho S. 2010. Acute effects of whey protein isolate on cardiovascular risk factors in overweight, post-menopausal women. Atherosclerosis. 212:339–344.

Parisi M, Moreno S, Fernandez G. 2002. Characterization of a novel cysteine peptidase from tissue culture of garlic (Allium Sativum L.). In Vitro Cell Dev Biol-Plant. 38:608–612.

Purslow PP. 2005. Intramuscular connective tissue and its role in meat quality. Meat Sci. 70:435–447.

Rhyu DY, Park SH. 2013. Characterization of alkyl thiosulfinate in Allium hookeri root using HPLC-ESI-MS. J Korean Soc Appl Biol Chem. 56:457–459.

Rossi R, Pastorelli G, Cannata S, Tavaniello S, Maiorano G, Corino C. 2013. Effect of long term dietary supplementation with plant extract on carcass characteristics meat.
quality and oxidative stability in pork. Meat Sci. 95:542–548.
Sardari K, Mirshahi A, Maleki M, Aslani MR, Barjasteh MN. 2006. Effects of topical allicin on second-intention wound healing in dogs (histological aspects). Comp Clin Path. 15:98–102.
Sheela CG, Augusti KT. 1992. Antidiabetic effects of S-allyl cysteine sulphoxide isolated from garlic *Allium sativum* Linn. Indian J Exp Biol. 30:523–526.
Silva J, Patarata L, Martins C. 1999. Influence of ultimate pH on bovine meat tenderness during ageing. Meat Sci. 52:453.

Tsiaganis MC, Laskari K, Melissari E. 2006. Fatty acid composition of *Allium* species lipids. J Food Compost Anal. 19:620–627.
Yan L, Meng QW, Ao X, Zhou TX, Yoo JS, Kim HJ, Kim IH. 2011. Effects of fermented garlic powder supplementation on growth performance, blood characteristics and meat quality in finishing pigs fed low-nutrient-density diets. Livet Sci. 137: 255–259.
Witte VC, Krause GF, Bailey ME. 1970. A new extraction method for determining 2-thiobarbituric acid values of pork. J Food Sci. 35:582–585.