Effects of dietary supplementation of natural and fermented herbs on growth performance, nutrient digestibility, blood parameters, meat quality and fatty acid composition in growing-finishing pigs

Xin Jian Lei, Hyeok Min Yun and In Ho Kim

Department of Animal Resource and Science, Dankook University, Cheonan, Republic of Korea

ABSTRACT
The present experiment was conducted to determine effects of herbs (Artemisia capillaris and Acanthopanax senticosus) in natural and fermented forms on growth performance, nutrient digestibility, blood parameters, meat quality and fatty acid composition in growing-finishing pigs. A total of 96 pigs [(Landrace × Yorkshire) × Duroc] with an average initial body weight (BW) of 25.46 ± 1.07 kg were randomly allotted into one of three dietary treatments. The dietary treatments included: (1) CON (basal diet), (2) NH (basal diet + 0.05% natural herbs) and (3) FH (basal diet + 0.05% fermented herbs). Pigs fed NH and FH diets had greater final BW than those fed CON diet (p < .05). During the whole period of the experiment, pigs fed NH and FH diets had a greater average daily gain than those fed CON diet, and the average daily feed intake in FH dietary treatment was greater than CON dietary treatment (p < .05). The FH dietary treatment had improved apparent total tract digestibility (ATTD) of dry matter compared with CON and NH dietary treatments (p < .05). The ATTD of nitrogen in NH and FH dietary treatments was greater than that in CON dietary treatment (p < .05). Moreover, fermented herbs decreased saturated fatty acids (SFA) but increased polyunsaturated fatty acids (PUFA) and PUFA to SFA ratio in Longissimus dorsi muscle. In conclusion, natural or fermented herbs improved growth performance and nutrient digestibility in growing-finishing pigs. Additionally, fermented herbs supplementation positively changed fatty acid profiles in Longissimus dorsi muscle.

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Introduction
Phytophagic feed additives have gained much attention as alternatives to antibiotic growth promoters because of the ban of antibiotic growth promoters in many countries including European Union and South Korea (Windisch et al. 2008; Salim et al. 2013; Levy 2014). Various herbs and their extracts have been used as feed additives due to their anti-oxidative effect, anti-microbial effect and growth-promoting effect (Ozer et al. 2007; Wei and Shibamoto 2007; Windisch et al. 2008; Yang et al. 2014; Hanczakowska et al. 2015). Previous studies have reported that herbs and their extracts may be included in swine diets to improve growth performance, nutrient digestibility, immune function and meat quality (Yan et al. 2011a, 2011b; Huang et al. 2012; Yan et al. 2012a; Cheng et al. 2017).

It is suggested that fermentation could enhance the bioactivity of herbs (Hussain et al. 2016). Ahmed et al. (2016) reported that microbial fermentation process improved nutritional composition of herbs (pomegranate, Ginkgo biloba and licorice) but reduced anti-nutritional factors. Jeong and Kim (2015) and Zhao et al. (2016) reported that supplementation of fermented herbs (Gynura procumbens, Rehmannia glutinosa and Scutellaria baicalensis) improved growth performance, nutrient digestibility in weaning and growing pigs. In finishing pigs, Ahmed et al. (2016) observed that back-fat thickness and thiobarbituric acid reactive substances (TBARS) of meat were decreased, whereas immune function and meat fatty acid composition were improved when fermented herbs was included in diet.

Artemisia capillaris is a traditional herb used mainly as a hepatoprotective, analgesic and antipyretic agent (Jang et al. 2014; Son et al. 2017). Additionally, A. capillaris may also has various functions against inflammation, cancer and hepatotoxicity (Hong et al. 2004; Lee et al. 2011; Feng et al. 2013). Acanthopanax senticosus is known as a powerful tonic and medicinal herb,
which has immunomodulatory, anti-oxidant and anti-inflammatory activities (Huang et al. 2011; Kim et al. 2015). Previously, several studies have shown that A. senticosus and its extract have beneficial effects on intestinal microbiota, gut morphology and growth performance in pigs (Yin et al. 2008; Fang et al. 2009; Han et al. 2014). However, there is still limited information on the influence of the fermented A. capillaries and A. senticosus in pigs. The aim of this study was to evaluate the effects of natural or fermented herbs (A. capillaries and A. senticosus) on growth performance, apparent total tract digestibility (ATTD), blood parameters, meat quality and fatty acid composition in Longissimus dorsi muscle (LM) in growing-finishing pigs.

Materials and methods

The Animal Welfare Committee of Dankook University (Cheonan, Choongnam, South Korea) approved the animal care protocol used in this experiment.

Preparation of natural and fermented herbs

The leaves of A. capillaries and the leaves and roots of A. senticosus were washed, air-dried and powdered. Then, the powdered A. capillaries and A. senticosus were mixed thoroughly (1:1, w/w) to obtain the combination of herbs (natural herbs). For solid fermentation, natural herbs were mixed with Enterococcus faecium SLB 120 at 1.0 × 10⁸ colony-forming units (cfu)/g. Thereafter, the mixture was soaked in distilled water to maintain a 40% moisture concentration. Hydrated herbs were then fermented at 37 °C. After fermentation for 72 h, the fermented samples were dried at 35 °C in a forced-air oven (model FC-610, Advantec, Toyo Seisakusho Co. Ltd., Tokyo, Japan) for 3 days and ground to pass through a 0.15 mm sieve. The natural herbs contained 876.5 g/kg DM, 212.8 g/kg crude protein, 52.0 g/kg ether extract, 2342.45 mg/kg tannic acid and 4918.36 mg/kg total phenols. Fermented herbs contained 893.6 g/kg DM, 170.5 g/kg crude protein, 57.3 g/kg ether extract, 1053.92 mg/kg tannic acid and 7562.36 mg/kg total phenols.

Experimental design, animals, housing and diets

A total of 96 pigs ([Landrace × Yorkshire] × Duroc) with an average initial body weight (BW) of 25.46 ± 1.07 kg were randomly allotted into one of the three dietary treatments with eight replicates of four pigs (two gilts and two barrows) each, according to initial BW and sex. The dietary treatments included: (1) CON (basal diet), (2) NH (basal diet +0.05% natural herbs) and (3) FH (basal diet +0.05% fermented herbs). The basal diet (Table 1) was formulated to meet or exceed the nutrient requirements recommended by NRC (2012) nutrient requirements. Experimental diets were fed in two phases including phase I (weeks 0–8) and phase II (weeks 8–16). Diets were offered in meal form throughout the experiment. All pigs were housed in an environmentally controlled room with forced ventilation and completely slatted plastic flooring. Each pen was equipped with a nipple drinker and a metal feeder. Pigs were provided with free access to drinking water and feed throughout experimental period.

Growth performance and nutrient digestibility

Individual BW and feed consumption on a pen basis were measured at the beginning of the experiment and end of week 4, 8, 12 and 16 to calculate average daily gain (ADG), average daily feed intake (ADFI) and gain/feed ratio (G/F).

To determine the ATTD of dry matter (DM), nitrogen (N), 2 g/kg of chromium oxide (Cr₂O₃) was added to the experimental diets as an indigestible marker during the last week of this experiment. At the end of the experiment, faecal samples were collected from each pen via rectal massage. Faecal samples from the same pen were pooled and mixed immediately, after

Table 1. Basal diet composition for growing-finishing pigs (as-fed basis).

| Items                  | Phase I (weeks 0 to 8) | Phase II (weeks 8 to 16) |
|------------------------|-----------------------|-------------------------|
| Ingredients, g/kg      |                       |                         |
| Corn                   | 599.3                 | 674.5                   |
| Soybean meal           | 237.5                 | 181.4                   |
| Rice bran              | 50.0                  | 50.0                    |
| Molasses               | 40.0                  | 50.0                    |
| Animal fat             | 26.1                  | 20.0                    |
| Rapeseed meal          | 20.0                  | –                       |
| Dicalcium phosphate    | 11.6                  | 11.2                    |
| Calcium carbonate      | 4.4                   | 6.8                     |
| L-lysine-HCl           | 3.4                   | 2.0                     |
| α-methionine           | 1.0                   | –                       |
| Choline chloride       | 0.8                   | 0.4                     |
| L-Threonine            | 0.9                   | 0.2                     |
| Salt                   | 1.5                   | 1.5                     |
| Mineral premix         | 2.5                   | 1.5                     |
| Vitamin premix         | 1.0                   | 0.5                     |
| Calculated composition |                       |                         |
| Digestible energy, MJ/kg | 14.42               | 14.08                   |
| Analysed composition, g/kg |                   |                         |
| Crude protein          | 177.2                 | 148.0                   |
| Lysine                 | 10.2                  | 8.9                     |
| Calcium                | 7.0                   | 7.4                     |
| Phosphorus             | 5.9                   | 5.4                     |

*Provided per kilogram of complete diet: 12.5 mg Mn (as MnO₂), 179 mg Zn (as ZnSO₄), 5 mg Cu (as CuSO₄·5H₂O), 0.5 mg I (as KI) and 0.4 mg Se (as Na₂SeO₃·5H₂O), 175 Fe (as FeSO₄·7H₂O).

*Provided per kilogram of complete diet: 4800 U vitamin A, 960 U vitamin D₃, 20 U vitamin E, 2.4 mg vitamin K₃, 4.6 mg riboflavin, 1.2 mg vitamin B₆, 13 mg pantothene acid, 23.5 mg niacin, 0.02 mg biotin.

(b)Provided per kilogram of complete diet: 4800 U vitamin A, 960 U vitamin D₃, 20 U vitamin E, 2.4 mg vitamin K₃, 4.6 mg riboflavin, 1.2 mg vitamin B₆, 13 mg pantothene acid, 23.5 mg niacin, 0.02 mg biotin.

(2) NH (basal diet +0.05% natural herbs) and (3) FH (basal diet +0.05% fermented herbs). The basal diet (Table 1) was formulated to meet or exceed the nutrient requirements recommended by NRC (2012) nutrient requirements. Experimental diets were fed in two phases including phase I (weeks 0–8) and phase II (weeks 8–16). Diets were offered in meal form throughout the experiment. All pigs were housed in an environmentally controlled room with forced ventilation and completely slatted plastic flooring. Each pen was equipped with a nipple drinker and a metal feeder. Pigs were provided with free access to drinking water and feed throughout experimental period.
which samples were stored at −20 ºC until subsequent analysis were conducted. Faecal samples were dried at 60 ºC for 72 h. After that, faecal and feed samples were finely ground so that they could pass through a 1-mm screen for analysis of DM (method 930.15) and N (method 984.13) using the AOAC (2007) procedures. Chromium was analysed via UV absorption spectrophotometry (UV-1201, Shimadzu Corp., Kyoto, Japan), according to the method described by Kauffman et al. (1986). The ATTD was then calculated using the following formula:

$$\text{ATTD(\%)} = \left[1 - \left(\frac{\text{Nd} \times \text{Cd}}{\text{Nf} \times \text{Cf}}\right)\right] \times 100,$$

where Nf = nutrient concentration in faeces (% DM), Nd = nutrient concentration in diet (% DM), Cd = chromium concentration in diet (% DM) and Cf = chromium concentration in faeces (% DM).

**Blood parameters**

At the beginning and end of the study, 16 healthy pigs (two pigs per pen) were randomly chosen from each treatment to collect blood samples via jugular venipuncture. Blood samples were collected into both non-heparinised tubes (5 mL) and vacuum tubes (5 mL) containing K3EDTA (Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ) to obtain serum and whole blood, respectively. White blood cells (WBC), red blood cells (RBC) and lymphocyte concentrations in the whole blood were determined using an automatic blood analyser (ADVIA 120, Bayer, NY). One-half blood sample was centrifuged at 3000 × g for 15 min at 4 ºC to separate serum. The serum insulin-like growth factor I (IGF-I), tumour necrosis factor-α (TNF-α), interleukin-1β (IL-1β) and interleukin-6 (IL-6) were assessed using commercially available ELISA kits (Quantikine, R&D Systems, Minneapolis, MN) according to the manufacturer’s instructions. Superoxide dismutase (SOD), total antioxidant capacity (T-AOC), glutathione peroxidase (GSH-Px) and malondialdehyde (MDA) in serum were determined using commercial kits (Cell Biolabs, Inc. San Diego, CA) following the instructions.

**Meat quality**

At the end of the experiment, all pigs were slaughtered at a local commercial slaughterhouse. Following exsanguinations and evisceration, carcases were split down the midline. At 45 min post mortem, backfat thickness (between the third and fourth last ribs level) were measured using a real-time ultrasound instrument (Piglot 105; SFK Technology, Herlev, Denmark). Carcases were chilled at 2 ºC for 24 h and samples of LM were removed between the 10th and 11th ribs from the right side of the carcase. For meat quality, LM samples were thawed at room temperature before evaluation. Subjective meat colour, marbling and firmness scores were evaluated according to National Pork Producers Council (1991) standards. Immediately after the subjective tests were conducted, the lightness, redness and yellowness values were measured at three locations on the surface of each sample (Model CR-410 Chromameter, Konica Minolta Sensing Inc., Osaka, Japan). At the same time, duplicate pH values of each sample were directly measured using a pH metre (Fisher Scientific, Pittsburgh, PA). The water-holding capacity (WHC) was measured in accordance with the methods described by Kauffman et al. (1986). Briefly, a 0.3 g sample was pressed at 3000 × g for 3 min at 26 ºC on a 125-mm-diameter piece of filter paper. The areas of the pressed sample and the expressed moisture were delineated and then determined using a digitising area-line sensor (MT-10S, M.T. Precision Co. Ltd., Tokyo, Japan). The ratio of water:meat area was then calculated, giving a measure of WHC (a smaller ratio indicates increased WHC). Longissimus muscle area was measured by tracing the LM surface at the 10th rib, which was also conducted using the afore-mentioned digitising area-line sensor. Drip loss was measured using approximately 2 g of meat sample according to the plastic bag method described by Honikel (1998). Cook loss was determined as described previously by Sullivan et al. (2007).

The TBARS were determined using method described by Witte et al. (1970). The TBARS values were expressed as milligrams of malonaldehyde per kilogram of muscle. Trichloroacetic acid solution (20% w/v) was used for the extraction. Chromium was analysed via UV absorption spectrophotometry (UV-1201, Shimadzu Corp., Kyoto, Japan).

**Fatty acid content**

Lipid from LM was extracted with hexane/isopropanol (3:2 v/v). Fatty acids were converted into methyl esters. Briefly, 0.5 mL of toluene and 2 mL of 5% KOH-MeOH were added to the lipid. Samples were vortex-mixed and heated at 70 ºC for 8 min. After cooling down in cold water, 2 mL of 14% BF3-MeOH was added to the sample. After heating at 70 ºC for another 8 min, samples were cooled down with cold water. After that, 3 mL of 5% NaCl was added to the samples. After mixing well, 5 mL of distilled water and 0.5 mL of hexane were added to the samples to extract fatty acid methyl esters (FAMEs). The mixture
was vortexed and centrifuged at 3000 \times g for 5 min. The upper phase was collected and dried with sodium sulphate. Samples were analysed for total fatty acids using a HP5890 gas chromatograph with a flame ionisation detector (Hewlett Packard 5890 Series II, Hewlett Packard, Palo Alto, CA). The FAMEs were separated using a Supelcowax-10 fused silica capillary column (100 m 0.32 mm i.d., 0.25 μm film thickness; Supelco, Inc., Bellefonte, PA) at helium flow rate of 1.2 mL/min. Oven temperature was increased from 220 to 240 °C at the rate of 2 °C/min. Temperatures of the injector and detector were at 240 °C and 250 °C, respectively. One microlitre of sample was injected into the column in split mode (50:1). The peak of fatty acids was identified and quantified by comparing to the retention time and peak area of each fatty acid standard (Sigma, St. Louis, MO). Fatty acid content was expressed as percentage of total fatty acids. The recovery of methylated fatty acids compared to the internal standard was higher than 80%.

Statistical analysis

Data were statistically analysed using GLM procedure of SAS (SAS Institute 1996) with pen as experimental unit. Differences among treatments were determined using Tukey’s range test. Results are presented as means with their standard errors. Probability level less than .05 was considered as statistically significant.

Results

Growth performance

The growth performance of pigs fed diets supplemented with herbs in natural and fermented forms are presented in Table 2. At the end of week 8, pigs fed NH diet exhibited higher BW than those fed CON diet \( (p < .05) \). Pigs fed NH and FH diets had increased final BW compared with those fed CON diet \( (p < .05) \). The ADG and ADFI were higher for NH and FH dietary treatments compared with CON dietary treatment during weeks 4 to 8 \( (p < .05) \). During weeks 12 to 16 and 0 to 16, Pigs fed FH diet had increased ADFI compared with those fed CON diet \( (p < .05) \). Additionally, during weeks 0 to 16, the ADG of pigs in NH and FH dietary treatments was greater than that of pigs fed CON dietary treatment \( (p < .05) \). There were no significant differences on growth performance among dietary treatments during weeks 0 to 4 and 8 to 12 of the experiment \( (p > .05) \). The G/F showed no significant differences among dietary treatments throughout the experiment \( (p > .05) \).

| Dietary treatments | CON | NH | FH | SEM | \( p \) value |
|--------------------|-----|----|----|-----|------------|
| Body weight, kg    |     |    |    |     |            |
| Initial            | 25.34 | 25.62 | 25.51 | 0.07 | .985       |
| Week 4             | 44.79 | 45.87 | 44.52 | 0.77 | .890       |
| Week 8             | 63.95\(^{b}\) | 67.29\(^{a}\) | 66.28\(^{ab}\) | 1.16 | .001       |
| Week 12            | 83.43 | 84.92 | 90.13 | 2.28 | .075       |
| Final              | 102.87\(^{a}\) | 109.38\(^{b}\) | 113.27\(^{c}\) | 2.15 | .020       |
| Weeks 0 to 4       | ADG, g | 695 | 723 | 679 | 27 | .910       |
| ADFI, g            | 1473 | 1423 | 1402 | 59 | .999       |
| G/F                | 0.472 | 0.508 | 0.484 | 0.013 | .887       |
| Weeks 4 to 8       | ADG, g | 684\(^{a}\) | 765\(^{a}\) | 777\(^{a}\) | 26 | .001       |
| ADFI, g            | 1584\(^{a}\) | 1950\(^{a}\) | 1867\(^{a}\) | 53 | .002       |
| G/F                | 0.432 | 0.392 | 0.416 | 0.018 | .099       |
| Weeks 8 to 12      | ADG, g | 696 | 630 | 852 | 90 | .068       |
| ADFI, g            | 2453 | 2320 | 2712 | 123 | .097       |
| G/F                | 0.284 | 0.272 | 0.314 | 0.035 | .857       |
| Weeks 12 to 16     | ADG, g | 694 | 873 | 827 | 73 | .098       |
| ADFI, g            | 3169\(^{b}\) | 3228\(^{ab}\) | 3656\(^{c}\) | 143 | .001       |
| G/F                | 0.219 | 0.270 | 0.226 | 0.022 | .112       |
| Weeks 0 to 16      | ADG, g | 692\(^{a}\) | 748\(^{a}\) | 784\(^{a}\) | 19 | .002       |
| ADFI, g            | 2170\(^{a}\) | 2230\(^{ab}\) | 2409\(^{ab}\) | 61 | .010       |
| G/F                | 0.319 | 0.335 | 0.325 | 0.006 | .099       |

1The dietary treatments included: (1) CON (basal diets), (2) NH (basal diets +0.05% natural herbs) and (3) FH (basal diets +0.05% fermented herbs).

Table 2. Effects of natural and fermented herbs supplementation on growth performance in growing-finishing pigs.

| Items, % | Dietary treatments | CON | NH | FH | SEM | \( p \) value |
|----------|--------------------|-----|----|----|-----|------------|
| Dry matter |                  | 84.60\(^{b}\) | 84.46\(^{b}\) | 86.95\(^{a}\) | 0.96 | .002       |
| Nitrogen  |                  | 82.20\(^{b}\) | 85.78\(^{a}\) | 86.03\(^{a}\) | 1.05 | .001       |

1The dietary treatments included: (1) CON (basal diets), (2) NH (basal diets +0.05% natural herbs) and (3) FH (basal diets +0.05% fermented herbs)

Table 3. Effects of natural and fermented herbs supplementation on nutrient digestibility in growing-finishing pigs.

1The dietary treatments included: (1) CON (basal diets), (2) NH (basal diets +0.05% natural herbs) and (3) FH (basal diets +0.05% fermented herbs).

Apparent total tract digestibility

Effects of natural and fermented herbs on ATTD were summarised in Table 3. The ATTD of DM for pigs fed FH diet was greater than that of pigs fed CON and NH diets \( (p < .05) \). Compared with CON diet pigs, pigs fed NH and FH diets showed greater ATTD of N \( (p < .05) \).

Blood parameters

Effects of natural and fermented herbs on blood profiles are presented in Table 4. The determined blood parameters including RBC, WBC, lymphocyte, IGF-I, TNF-α, IL-1β, IL-6, GSH-Px and SOD were unaffected by dietary treatments \( (p > .05) \). However, dietary
supplementation with fermented herbs increased serum T-AOC but decreased MDA content in serum (p < .05).

**Meat quality and backfat thickness**

No significant effects were observed on sensory evaluation (colour, firmness and marbling), meat colour (L*, a* and b*), pH, WHC, drip loss, cooking loss, LM area, backfat thickness or TBARS (Table 5; p > .05).

**Fatty acid composition in LM**

Effects of dietary herbs and fermented herbs on fatty acid composition in LM are presented in Table 6. The concentration of C14:0 was decreased in FH dietary treatment compared with that in CON and NH dietary treatments (p < .05). The C18:0 and total saturated fatty acid (SFA) concentrations were lower in FH dietary treatment than those in CON dietary treatment (p < .05). FH dietary treatment had increased C18:3n-3 concentration compared with CON treatment. In addition, the polyunsaturated fatty acid (PUFA) to SFA ratio (PUFA/SFA) in FH dietary treatment was higher than that in CON and NH dietary treatments (p < .05).

**Discussion**

The fermentation process can improve the treatment efficacy of active ingredients and reduce the anti-nutritional effects of herbs, thereby enhancing the growth- and health-promoting properties of medicinal plants (Ahmed et al. 2016). Tannins are known to have a bitter or astringent taste which reduces palatability and hence feed intake (Jansman 1993). In this study, fermentation process reduced tannic acids concentration, which may mitigate the adverse effect of tannins present in natural herbs on feed intake. In the present study, pigs fed NH diet had increased ADG compared with those fed CON diet but there were no significant differences on ADFI and G/F during weeks 0 to 16, although numerical increases were observed. However, ADG and ADFI were increased in FH dietary treatment compared with those in CON dietary treatment during weeks 0 to 16. In agreement with our results, Yan et al. (2011a, 2011b) reported that herb extract mixture from buckwheat, thyme, curcuma, black pepper and ginger in growing pigs and herb extract from *Houttuynia cordata* or *Taraxacum officinale* in finishing pigs, improved growth performance indicated as increased ADG and ADFI but not G/F. Herb additives may improve the flavour and palatability of feed, stimulate the appetite of the animals, and then increase the feed intake (Wenk 2003; Frankic et al. 2009). Consequently, the increased feed intake may contribute to the improved ADG. However, discrepant results regarding the effects of herb additives on growth performance were reported in previous studies (Yu et al. 2017). Ahmed et al. (2016) demonstrated results regarding the effects of herb additives on feed intake. In the present study, pigs fed FH diets had increased ADG compared with those fed CON diet but there were no significant differences on ADFI and G/F during weeks 0 to 16. In agreement with our results, Yan et al. (2011a, 2011b) reported that herb extract mixture from buckwheat, thyme, curcuma, black pepper and ginger in growing pigs and herb extract from *Houttuynia cordata* or *Taraxacum officinale* in finishing pigs, improved growth performance indicated as increased ADG and ADFI but not G/F. Herb additives may improve the flavour and palatability of feed, stimulate the appetite of the animals, and then increase the feed intake (Wenk 2003; Frankic et al. 2009). Consequently, the increased feed intake may contribute to the improved ADG. However, discrepant results regarding the effects of herb additives on growth performance were reported in previous studies (Yu et al. 2017). Ahmed et al. (2016) demonstrated that dietary supplementation with herbs (pomegranate, *Gingko biloba* and licorice) in natural or fermented forms had no effects on BW and ADG, but reduced ADFI and increased G/F compared with unsupplemented diet in growing-finishing pigs. Jeong and Kim (2015) reported that no significant effect of fermented herbs combination (*G. procumbens*, *R. glutinosa*, and *S. baicalensis*) on feed intake of growing pigs with improvements on ADG and G/F. Similarly, in weaning pigs, Zhou et al. (2015) observed that dietary supplementation with fermented *G. biloba* L residues increased BW, ADG, and G/F, whereas ADFI was unaffected.
Hanczakowska et al. (2015) suggested that dietary inclusion of herbal extract mixture from *S. officinalis*, *U. dioica*, *M. officinalis* and *E. purpurea* had no significant effect on growth performance in finishing pigs. These contradictory results regarding the growth performance responses to natural, fermented, or extracted herbs may be due to different species of herbs, concentrations of herbs and processing methods of herbs (Wenk 2003; Windisch et al. 2008; Hashemi and Davoodi 2011; Costa et al. 2013; Embuscado 2015). Additionally, different physiological phases of pigs may respond differently to herb additives.

In the current experiment, the inclusion of natural herbs led to a higher ATTD of N than CON treatment at the end of the experiment. Meanwhile, the ATTD of DM and N were improved when fermented herbs were included in diets. The increased ATTD of DM and N maybe another reason for the improved growth performance in pigs fed diets supplemented with natural or fermented herbs. Similarly, Yan et al. (2012a), Jeong and Kim (2015), Zhou et al. (2015) and Zhao et al. (2016) previously observed increased ATTD of DM and N in pigs fed diets supplemented with herbs in natural or fermented forms. It is suggested that herbs may increase the activity of digestive enzymes, which may improve ATTD of DM and N (Chrubasik et al. 2005; Srinivasan 2005; Hashemi and Davoodi 2011).

Additionally, some previous studies suggested that the herbs could enhance the health status of gastrointestinal environment, thereby improve nutrient digestibility. (Benkeblia 2004; Choi et al. 2008; Yin et al. 2008; Fang et al. 2009; Seo et al. 2010; Huang et al. 2012). However, the influence of herbs on intestinal microbial population was not measured in the present study. Therefore, further studies are required to determine the effects of natural and fermented herbs on intestinal health of pigs.

### Table 5. Effects of natural and fermented herbs supplementation on meat quality and backfat thickness in growing-finishing pigs.

| Items                        | CON | NH  | FH  | SEM | p value |
|------------------------------|-----|-----|-----|-----|---------|
| Sensory evaluation           |     |     |     |     |         |
| Color                        | 2.00| 1.94| 1.84| 0.14| .990    |
| Marbling                     | 1.78| 1.75| 1.81| 0.13| .887    |
| Firmness                     | 1.72| 1.50| 1.63| 0.10| .099    |
| Meat colour                  |     |     |     |     |         |
| Lightness (L*)               | 46.44| 48.68| 49.77| 2.56| .070    |
| Redness (a*)                 | 16.17| 15.48| 15.98| 1.92| .698    |
| Yellowness (b*)              | 5.66 | 5.44| 5.88 | 0.40| .399    |
| pH                           | 5.30 | 5.28| 5.36 | 0.04| .549    |
| Water holding capacity, %    | 50.02| 50.42| 50.34| 2.15| .287    |
| Drip loss, %                 |     |     |     |     |         |
| Day 1                        | 7.49 | 6.05| 6.59 | 1.55| .099    |
| Day 3                        | 9.84 | 8.12| 8.30 | 1.52| .880    |
| Day 5                        | 13.03| 11.95| 10.13| 1.16| .845    |
| Day 7                        | 13.58| 12.52| 11.04| 1.10| .758    |
| Cooking loss, %              | 38.44| 40.50| 39.00| 1.02| .918    |
| Longissimus dorsi area, cm²  | 58.54| 59.50| 59.64| 2.47| .090    |
| TBARS, mg of malonaldehyde/kg | 0.025| 0.023| 0.021| 0.002| .391    |
| Backfat thickness, mm        | 27.80| 25.08| 27.00| 2.50| .070    |

*The dietary treatments included: (1) CON (basal diets), (2) NH (basal diets +0.05% natural herbs) and (3) FH (basal diets +0.05% fermented herbs).

### Table 6. Effects of natural and fermented herbs supplementation on fatty acid composition of *Longissimus dorsi* muscle.

| Items, %                   | CON | NH  | FH  | SEM  | p value |
|----------------------------|-----|-----|-----|------|---------|
| C14:0                      | 1.42| 1.33| 0.98| 0.09 | .002    |
| C16:0                      | 28.64| 28.01| 25.95| 1.39| .063    |
| C18:0                      | 13.02| 11.83| 11.46| 0.62| .011    |
| C20:0                      | 0.22 | 0.24| 0.19 | 0.03| .654    |
| Total SFA                  | 43.30| 41.41| 37.58| 2.16| .001    |
| C16:1n−7                  | 3.28 | 3.05| 2.44 | 0.56| .080    |
| C18:1n−9                  | 34.20| 37.02| 39.28| 1.80| .099    |
| C20:1n−9                  | 0.48 | 0.64| 0.54 | 0.11| .091    |
| Total MUFA                 | 38.02| 40.71| 42.26| 1.85| .899    |
| C18:2n−6                  | 9.71 | 9.14| 9.97 | 0.66| .067    |
| C20:2n−6                  | 0.26 | 0.29| 0.24 | 0.08| .091    |
| C20:4n−6                  | 1.50 | 1.56| 1.75 | 0.15| .081    |
| C18:3n−3                  | 0.11| 0.27| 0.37| 0.07| .005    |
| C22:6n−3                  | 3.33| 3.13| 4.46| 2.96| .066    |
| Total PUFA                 | 14.91| 14.39| 16.79| 2.48| .088    |
| Total UFA                  | 52.93| 55.10| 59.05| 2.59| .100    |
| PUFA/SFA                  | 0.34| 0.35| 0.43| 0.03| .019    |

*The dietary treatments included: (1) CON (basal diets), (2) NH (basal diets +0.05% natural herbs) and (3) FH (basal diets +0.05% fermented herbs).

**MUFA**: monounsaturated fatty acid; **PUFA**: polyunsaturated fatty acid; **PUFA/SFA**: PUFA to SFA ratio; **SEM**: standard error of the mean; **SFA**: saturated fatty acid; **UFA**: unsaturated fatty acid.

a,bMeans within the same row without the same superscript letter are significantly different (<.05).
Dietary supplementation with herbs may have beneficial effect on immune function of pigs (Yuan et al. 2006; Liu et al. 2011; Yeh et al. 2011; Yan et al. 2012b; Han et al. 2014). Han et al. (2012) indicated that *A. senticosus* polysaccharide increased WBC and lymphocyte concentrations in weanling pigs. Jeong and Kim (2015) found that fermented medicinal plants (*G. procumbens, R. glutinosa* and *S. baicalensis*) supplementation increased WBC concentration in growing pigs. Yan and Kim (2013) reported that dietary fermented garlic increased lymphocyte and RBC concentrations in growing pigs. However, in the present experiment, no significant differences on RBC, WBC, Lymphocyte, TNF-α, IL-1β and IL-6 concentrations were detected. In agreement with our results, Cho et al. (2012) reported that dietary supplementation with herbs (yellow ginger or hoantchy root) did not affect WBC, RBC or lymphocyte concentrations in growing-finishing pigs. In the present study, the lack of effect on WBC RBC, lymphocyte, TNF-α, IL-1β and IL-6 concentrations could be due to the maturation of pigs’ immune system in finishing phase or the low concentrations of herbs used. It is known that IGF-I may influence growth and metabolism of pigs (Hossner et al. 1997). In the current study, the concentration of IGF-I was unaffected by dietary treatments, suggesting that improved growth performance for pigs fed diets supplemented with natural or fermented herbs was not related to the concentration of IGF-I.

The T-AOC is considered to be the integrated action of all the antioxidants present in plasma and body fluids, thus providing an insight into the oxidation resistance capacity of the whole body (Ghiselli et al. 2000). MDA is one of the major final products of lipid peroxidation and is considered as a marker of oxidative stress (Lu et al. 2010). In the present study, the increased serum T-AOC activities and reduced MDA content may indicate the improvement in the antioxidant status of pigs fed diet supplemented with fermented herbs. It is suggested that herbs have strong antioxidant activity because of the presence of phenolic compounds (Wang et al. 2016). The increased phenols content in fermented herbs may help to explain the increased serum T-AOC activities and reduced MDA in pigs fed diet supplemented with fermented herbs.

Lan et al. (2017) suggested that *Astragalus membranaceus*, *Codonopsis pilosula* and allicin mixture supplementation increased meat colour and redness values but decreased lightness value of LM, although pH, WHC, drip loss, LM area, and backfat thickness were not affected. Liu et al. (2016) found that *S. baicalensis* and *Lonicera japonica* extract mixture supplementation exerted no effects on meat colour, cooking loss, drip loss, LM area and sensory evaluation of LM, whereas pH was increased and TBARS was decreased when *S. baicalensis* and *L. japonica* extract mixture was included in the diet. Hanczakowska et al. (2015) observed that herbal extract mixture (*S. officinalis*, *U. dioica*, *M. officinalis* and *E. purpurea*) had no effect on WHC, pH, lightness, redness, yellowness and TBARS values after 24 h cooling, but reduced TBARS, redness and yellowness after 5 months. However, in the present study, backfat thickness, LM area, sensory evaluation of LM, meat colour (lightness, redness and yellowness values), pH, drip loss and cooking loss were not affected by natural or fermented herbs. These inconsistent findings about meat quality may be due to the kinds of herbs used and the time of measurement.

Meat is a major source of fat in human diets. It has been demonstrated that SFA may increase cholesterol level and the risk of cardiovascular diseases (Siri-Tarino et al. 2015; Ruiz-NúñezOpens et al. 2016). However, monounsaturated fatty acids or PUFA may decrease cholesterol concentrations and exert benefit effects on human health (Richard et al. 2009; González et al. 2013). There has been a growing interest to manipulate the fatty acid composition of meat by diets (Wood et al. 2004). Zhou et al. (2013) reported that dietary supplementation of *Coptis chinensis* herb extract decreased total SFA concentration but increased total unsaturated fatty acids (UFA) concentration in LM of finishing pigs. Hanczakowska et al. (2015) observed that herbal extracts (*S. officinalis*, *U. dioica*, *M. officinalis* and *E. purpurea*) had beneficial effect on pork health-promoting properties, indicated as increased PUFA concentration and PUFA/SFA in *Longissimus thoracis* muscle. Ahmed et al. (2016) also suggested that herbs (*pomegranate + G. biloba + licorice*) in natural or fermented forms could modify the fatty acid composition in *Longissimus thoracis* muscle. They found that natural herbs reduced SFA (C20:0) level, but increased PUFA (C20:5n-3) concentration. Additionally, they observed that supplementation with fermented herbs decreased SFA (C15:0) and PUFA (C20:4n-6) and increased MUFA (C18:1 and total MUFA) and PUFA (C18:3n-3 and C20:5n-3) concentrations. In the present study, in agreement with those findings, dietary supplementation with fermented herbs reduced SFA (C14:0, C18:0, and total SFA) concentration but increased PUFA (C18:3n-3) concentration, and PUFA/SFA, although natural herbs had no effects on LM fatty acid composition. It is suggested that dietary phenolic compounds can positively modify the fatty acid composition via preventing the oxidation of unsaturated fatty acids.
(Cao et al. 2012; Ahmed et al. 2016; Hussain et al. 2016). Therefore, the changes in fatty acids composition of LM from pigs fed diet supplemented with fermented herbs may be related to the phenols in the fermented herbs. The lack of response to natural herbs on fatty acid composition was probably due to the relative low content of phenols in natural herbs. Further study is still warranted to investigate the exact mechanism of the effects of fermented herbs supplementation on fatty acid composition.

Conclusions

In conclusion, it can be concluded that supplementation with natural herbs increased growth performance and nutrient digestibility in growing-finishing pigs. Supplementation with fermented herbs enhanced growth performance, nutrient digestibility and serum antioxidant status, and positively modified fatty acid profiles in LM.

Disclosure statement

All authors have no conflicts of interest to declare. The authors alone are responsible for the content and writing of this article.

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