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Effects of dietary addition of wormwood on growth performance, blood characteristics and meat quality in growing-fattening pigs

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Abstract: This study investigated the effects of the dietary addition of wormwood (*Artemisia montana* Pampan) on growth performance, blood characteristics, carcass traits, and meat quality in growing-fattening pigs. One hundred eighty crossed pigs (Landrace × Yorkshire × Duroc), weighing approximately 70 kg, were divided into four groups of 15 head (eight barrows and seven gilts) per pen, and the experiment was replicated thrice. The basal diet (C) was supplemented with 0.5% (T1), 1.0% (T2), and 1.5% (T3) of dried powdered wormwood, and the pigs were fed an experimental diet for six weeks. The average daily weight gain and feed efficiency were significantly higher ($P < 0.05$) in treatments than in C. On the contrary, the total cholesterol concentration was significantly lower ($P < 0.05$) in treatments than in C. Additionally, the high-density lipoprotein cholesterol concentration was significantly higher ($P < 0.05$), and the carcass grade was better ($P < 0.05$) in the treatments than in C. The ether extract content of the *longissimus dorsi* (LD) muscle was lower ($P < 0.05$) in T2 and T3 than that in C. In contrast, the unsaturated fatty acid (USFA) composition in LD muscle was higher ($P < 0.05$) in the treatments than in C. Additionally, the marbling and flavour of cooked meat were better ($P < 0.05$) in the treatments than in C. The dietary addition of wormwood increased ($P < 0.05$) lightness and yellowness of the surface meat colour and decreased ($P < 0.05$) juiciness of the LD sensory evaluation. Therefore, the dietary addition of wormwood improved growth performance, feed efficiency, carcass grade, USFA composition, and oxidation of protein and lipids in the LD muscle of growing-fattening pigs.

Keywords: *Artemisia montana* Pampan; feed efficiency; cholesterol; carcass grade; pork characteristics

Antibiotics have been widely used as feed additives for economic benefits in the pig industry. However, antibiotics increase bacterial resistance, which may lead to resistance to new drugs and may leave antibiotic residues in pork. Hence, the use of antibiotics in animal feeds is restricted.

Antibiotics have long been used to improve the growth performance and feed utilization during animal production. However, the problem with feeding antibiotics to pigs is antibiotic resistance and the detrimental effects that they have on human health (Li 2017). In the case of Korea, the Ministry of Agriculture, Food and Rural Affairs banned the use of antibiotics for feed additives in the manufacture of compounded feeds in July 2011, and it is regulated by the Feed Management Act. However, antibiotic-free feeding increases production costs, diseases, and mortality rates and decreases production. Therefore, feed additives, such as probiotics, prebiotics, and synbiotics, have been used as substitutes for antibiotics. Ziemer and Gibson (1998) reported that probiotics are live microbial feed additives that improve the intestinal microbial balance of the host animal. Furthermore, prebiotics are non-

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digestible food ingredients that stimulate bacterial growth and activity in the digestive system (Ziemer and Gibson 1998). Thus, the improvement of the host health requires a mixture of probiotics and prebiotics (synbiotics). Prebiotics increase growth performance, nitrogen retention, and protein and fat digestibility in pigs (Chu et al. 2011).

Wormwood (*Artemisia montana* Pampan) belongs to the family Compositae, which includes 300 aromatic and medicinal plant species in the Northern Hemisphere. In traditional medicine and phytotherapy, a wormwood extract aids digestion, kills parasites, and cures constipation and neuralgia. However, the wormwood extract contains essential oils, alkaloids, phenolic compounds, potentially psychoactive terpenes (thujone, which is toxic at high doses), and sesquiterpene lactones (absinthin and anabsinthin), which are responsible for its bitter taste. This bitter taste has discouraged researchers from examining the potential nutritional value of wormwood in animals for many years.

Ethno-veterinary medicine focuses on the animal keepers' knowledge and approaches to animal healthcare and production including information on diseases, their control (remedies and clinical practices for treatment), and prevention (management strategies and spiritual elements, among others). During the last century, the medical use of wormwood plants was seemingly on the decline due to fears of absinthism, a syndrome allegedly caused by the wormwood-flavoured spirit absinthe and as a result of thujone, a monoterpene ketone often present in the wormwood essential oil. In addition, wormwood contains 6,7-dimethylesculetin, capillarisin, and coumarin secreted as bile salts and lipolytic enzymes in the small intestine.

In the European Union, Chinese medicinal herbs have been used in livestock production as alternatives to antibiotics. Herbs may stimulate appetite, regulate digestion, and have anti-oxidative effects in pigs (Yan et al. 2011). Thus, several medicinal herbs have been used as feed additives in pigs to stimulate growth performance and prevent digestive tract diseases. We expect that wormwood may act as functional feed additive because it contains non-digestible components as a Chinese medicinal herb.

Park and Kim (2008) also reported that wormwood decreases protein and lipid oxidation in chickens by affecting lignan, flavonoids, phenolic compounds, and antioxidants. Furthermore, wormwood was also used as an additive for pigs and tested against meat quality and improved immune responses in fattening pigs (Chu and Song 2012). This study focused on wormwood as a feed additive and its effects on the growth performance, blood characteristics, carcass traits, and meat quality of growing-fattening pigs.

MATERIAL AND METHODS

Animals, treatments, and management

Experimental pigs approximately 120 days old with an average body weight (BW) of 70.3 ± 1.1 kg were used in this study. One hundred eighty crossed pigs (Landrace × Yorkshire × Duroc) were assigned to one of the four dietary treatments based on BW and sex. Each of the four dietary treatments contained 15 pigs (eight barrows and seven gilts) per pen, and each experiment was replicated thrice (15 pigs × four diets × three replicates). The pigs were given pre-feeding for three days, had free access to water and *ad libitum* feed, and were fed an experimental diet until they reached 106.4 ± 1.0 kg BW.

Basal diet contained approximately 51.51% and 51.43% maize, 18.78% and 19.62% soybean meal, and 15.00% and 15.00% wheat during the growing and fattening periods, respectively (Table 1). The chemical composition of the basal diet consisted of 14.53% and 15.34% crude protein (CP), 3.26 Mcal/kg and 3.28 Mcal/kg metabolizable energy, 0.80% and 0.86% lysine, and 0.50% and 0.52% total phosphorus in the growing and fattening periods, respectively. The wormwood plants were dried at 60 °C for 48 h before being crushed. After this, the wormwood plants were ready for use in this study. The pigs fed a basal diet were used as the controls (C) and those fed a basal diet supplemented with 0.5% (T1), 1.0% (T2), and 1.5% (T3) wormwood belonged to the treatment groups. The pigs were fed an experimental diet for six weeks.

Growth performance and carcass characteristics

BW was measured at the start and end of the present study. Consumed feed was recorded daily during the feeding trials. Feed efficiency was calculated based on the average daily gain (ADG) and feed intake.

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Table 1. Ingredients and chemical composition of experimental diet

Items	Growing	Fattening
Ingredients composition (%)		
Corn	51.51	51.43
Soybean meal	18.78	19.62
Wheat	15.00	15.00
Wheat bran	6.00	6.00
Animal fat	4.00	4.00
Molasses	0.52	0.40
Calcium phosphate	1.80	1.16
Limestone	1.00	1.00
Sodium chloride	1.00	1.00
L-lysine hydrochloride acid	0.16	0.16
Vitamin premix[1]	0.10	0.10
Trace mineral premix[2]	0.10	0.10
Methionine	0.03	0.03
Chemical composition (as-fed basis)		
Crude protein (%)	14.53	15.34
ME (Mcal/kg)	3.26	3.28
Lysine (%)	0.80	0.86
Calcium (%)	0.82	0.70
Total phosphorus (%)	0.50	0.52

[1]Supplied per kilogram of diet: 8 000 IU vitamin A, 1 500 IU vitamin D, 4 000 IU vitamin E, 150 mg vitamin K, 400 mg vitamin B_{12}, 20.0 mg niacin, 15.0 mg thiamine, 2.0 mg pantothenic acid, 8.0 mg riboflavin and 0.02 mg biotin

[2]Supplied per kilogram of diet: 60 mg Zn, 60 mg Fe, 25 mg Mn, 15 mg Cu, 0.25 mg Se and 0.20 mg I

The pigs weighed approximately 106 kg on average at the end of this study. The experimental animals were fasted for 12 h before the transport, and were transported approximately 20 km for 1 h to a local abattoir near the experimental station, then the animals stayed in a lairage area for 3 h until slaughtered. The experimental animals were slaughtered by stunning with electrical tongs at 300 V for 3 s and shocked pigs were exsanguinated while hanging. Carcasses were dehaired using a dehairer (Bagon Equipment Co., Zhengzhou, China) at 62 °C for 5 minutes. The remaining hair was removed using a knife and flame. Carcasses were eviscerated, split, and placed in a chiller at 5 °C for 12 hours. One hundred eighty pigs were slaughtered in one day.

The dressing percentage was calculated as the ratio of cold carcass weight to live weight. Backfat thickness in the Korean carcass grading system (2018) is measured as the fat thickness in the midline of between the 11th and 12th rib. The carcass grade of pork was examined according to the Korean carcass grading system (Ministry of Agriculture, Food and Rural Affairs; MAFRA 2017), which grades pork carcasses considering quality and conformation. The quality of pork carcasses was graded as 1+, 1, 2, and 3 based on marbling, lean colour, and condition of belly streaks. Additionally, the conformation of pork carcasses was graded as A, B, C, and D by assessing carcass weight, backfat thickness, eye-muscle area, and fat condition, as the covering condition of backfat and subcutaneous fat. Furthermore, the carcass quality grades in this study were expressed as 1 (extremely good), 2 (good), 3 (bad), and 4 (extremely bad) instead of 1+, 1, 2, and 3.

Blood metabolites and chemical composition of *longissimus dorsi* muscle

Three hours after the end of the last feeding in this study, blood samples were collected from the jugular vein of 12 pigs (two barrows and two gilts per each pen × three pens) in each treatment group. Blood corpuscles, such as leukocytes, erythrocytes, haemoglobin, haematocrit, and platelets were determined using an automatic haematological analyzer (VET abc, Montpellier, France) within 2 h from blood sampling. The plasma was obtained by centrifugation at 2 500 × *g* for 30 min at 4 °C and stored at −20 °C until plasma chemical composition analysis. The chemical composition, comprising total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, total protein, triglyceride, and blood urea nitrogen (BUN) concentrations, was determined using a blood analyzer (Express Plus, Bayer, MA, USA).

The *longissimus dorsi* (LD) (6th to 13th rib) muscle was cut and collected from 12 pigs (two barrows and two gilts per each pen × three pens), stored at 5 °C from each treatment and used to determine the chemical composition. The LD muscle was divided into four parts for physical and chemical analyses, as described by Jin et al. (2009) (Figure 1). Approximately 24 h after slaughter, the moisture, CP, EE (ether extract), and ash contents of LD muscle were determined according to the methods of the Association of Analytical Chemists (AOAC 2005).

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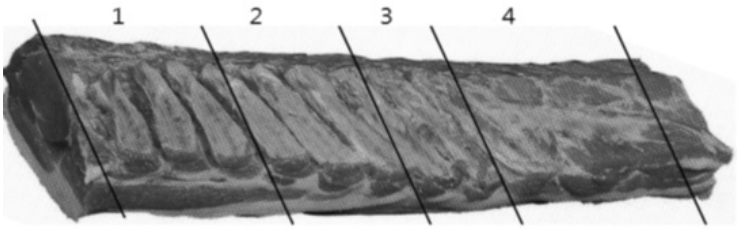

Figure 1. Diagram of the fillet distribution on the pork loin used for physical and chemical analyses (Jin et al. 2009)
Each number indicates the part of the fillet used for the different analyses: (1) chemical composition; (2) pH, volatile basic nitrogen, thiobarbituric acid reactive substances and water holding capacity; (3) fresh meat analysis and meat colour; (4) cooking loss, sensory analysis and texture analysis

Water holding capacity, pH, protein oxidation, shear force, and lipid oxidation

The LD muscle samples of approximately 24 h after slaughter were used for determination of pH, water holding capacity (WHC), shear force, meat colour and sensory evaluation. Additionally, to determine the thiobarbituric acid reactive substances (TBARS), volatile basic nitrogen (VBN) and fatty acid composition, every sample was vacuum packaged, stored at 4 °C, and then used on day 7 of storage.

To determine pH, a 5 g sample was homogenized approximately 24 h postmortem in 10 volumes of distilled water (DW) using a Polytron homogenizer (MSE, Orlando, FL, USA). Double DW used in this research was purified in a water purification system with Millipore Direct-Q® 5 UV (Merck KGaA, Darmstadt, Germany). Measurements were performed using a Hanna HI 9025 pH meter (Hanna Instruments, Woonsocket, RI, USA) with an Orion 8163 glass electrode (Orion Ross, Beverly, MA, USA). The WHC was determined using the centrifugal method according to Honikel (1998). Samples of approximately 2.0 × 0.4 × 0.4 cm in cross-sectional area were weighed and placed in tubes with filters (pore size 90 µm) to separate the meat from the expelled liquid at the bottom of the tubes. The samples were then centrifuged at 40 × *g* for 1 h at 4 °C. After centrifugation, the water loss was calculated as a difference in weight before and after centrifugation. Each sample was measured thrice and averaged.

The LD muscle for determined shear force was cut into cubes of approximately 4 × 2.5 × 1.5 cm (i.e., length × width × height), and the samples were cooked in a water bath at 75 °C until the internal temperature of LD muscle reached 70 °C. Next, the samples were cooled for 4 h at 25 °C, and the shear force was measured using an Instron 3343 (US/MX50, A&D Co., Ann Arbor, MI, USA) equipped with one Warner-Bratzler shear blade (crosshead speed of 1 mm/s; Willrich Precision Instruments, Cresskill, NJ, USA). Each sample was measured thrice and averaged.

Lipid oxidation was determined by thiobarbituric acid analysis, according to the iron-induced TBARS procedure described by Huang and Miller (1993). Meat samples (3 g) were weighed into centrifuge tubes with screw caps. Further, 57 ml of cold phosphate buffer (pH 7.0) was added, and the contents were homogenized at 12 000 × *g* for 1 minute. The homogenized samples were incubated at 37 °C in a water bath with $FeSO_4 \cdot 7H_2O$ for 30 min and then centrifuged for 15 minutes. The absorbance of supernatants was read at 532 nm using a spectrophotometer (EZ-210; Perkin Elmer Lambda, Shelton, CT, USA). Liquid malondialdehyde (MDA) (Aldrich Chemical Co. Ltd., Dorset, UK) was used as the standard to determine the standard response and recovery. TBARS values were expressed as mg of MDA per kg of muscle tissue.

Protein oxidation was determined by VBN analysis. The VBN is used as a biomarker of protein and amine degradation by the action of microorganisms and endogenous enzymes during meat storage (Bekhit et al. 2021). Meat samples (10 g) were mixed in 90 ml of DW and transferred to a distillation flask containing 100 ml of DW. After the addition of 2 g MgO and an antifoaming agent, the mixture was distilled using a Kjeldahl distillation apparatus (PLT Scientific Instruments, Selangor, Malaysia). The distillate was collected into 25 ml/100 g H_3BO_3 for 25 min, and five drops of Tashiro's indicator (Honeywell Research Chemicals, Seelze, Germany) were added. The solution was titrated using 0.1 M hydrochloric acid to calculate the total VBN in the sample in terms of mg VBN/100 g of stored meat.

Surface colour of LD muscle

The surface colour of LD muscle was evaluated on a freshly cut surface (3 cm thick slice) after 20 min

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at room temperature using a CR-300 Chroma Meter (Minolta, Osaka, Japan). Three colour measurements were performed across individual sample surfaces, and the average of five replicates was expressed as CIE L*, CIE a*, and CIE b*. The CR-300 Chroma Meter (Minolta) was calibrated against a white tile (L* = 93.30, a* = 0.32, b* = 0.33) and Illuminant D65, a 10° standard observer, and an 8-mm viewing aperture were used.

Fatty acid composition of LD muscle

To determine the fatty acid composition of wormwood and LD muscle, fat was extracted from the ground wormwood or muscle using a modified Folch wash method. Fatty acids were quantified as fatty acid methyl esters and prepared by acid-catalyzed methanolysis. The fatty acid methyl esters in the hexane layer were analyzed using an Agilent chromatograph (Agilent 6890+; Agilent Technologies, Santa Clara, CA, USA) with a mass spectrometry detector (Shenzhen ThreeNH Technology, Shenzhen, China) and a split (50 : 1) injector (SRI Instruments, Torrance, CA, USA). The samples were methylated in duplicate and injected twice into a gas-liquid chromatography (GLC) column (Agilent Technologies, Santa Clara, CA, USA). The separation of the fatty acid methyl esters was performed on an HP-5MS capillary GLC column (30 m × 0.32 mm i.d.; 0.25 mm film thickness; Agilent Technologies, Santa Clara, CA, USA) with helium as the carrier gas.

The mass spectrometry interface and injector temperatures were fixed at 270 and 260 °C, respectively. Oven temperature was set to 160 °C for 2.5 min, 160 °C to 260 °C at 4 °C per min, and 260 °C for 5 minutes. The data were recorded and analyzed using ChemStation G1701CA software, vC.00 (Agilent ChemStation, Santa Clara, CA, USA).

Sensory evaluation of LD muscle

For the sensory evaluation of LD muscle, 35 panellists were used to evaluate the sensory quality of the cooked samples. Sensory evaluations were performed in duplicate for each sample. Panellists were trained according to sensory evaluation procedures.

Meat samples of approximately 100 g were cooked to an internal temperature of 70 °C in a water bath and cut into 10 × 3 × 25 mm pieces. The pieces were placed on white plastic trays covered with aluminium foil and served immediately to each panellist. The cooked meat samples were evaluated for colour (1 = very unacceptable and 9 = very acceptable), marbling (1 = very unacceptable and 9 = very acceptable), aroma (1 = very unacceptable and 9 = very acceptable), tenderness (1 = very tough and 9 = very tender), juiciness (1 = very dry and 9 = very juicy), flavour (1 = very unacceptable and 9 = very acceptable), and overall acceptability (1 = very unacceptable and 9 = very acceptable).

Statistical analyses

The current experiments of growth performance and carcass characteristics had 180 observations (15 pigs × four diets × three replicates). Additionally, the current experiments of blood metabolites and meat quality parameters of LD had 48 observations (12 pigs × four diets). Statistical analyses of all experimental data as growth performance, carcass characteristics, blood metabolites and meat quality parameters were performed using one-way analysis of variance (ANOVA). All analyses were conducted using the general linear model (GLM) with Statistical Analysis Software v9.4 (SAS Institute, Cary, NC, USA). For all evaluations, a significance level of $P < 0.05$ was used. Also, Duncan's multiple range test was used to detect significant differences between means within dietary factor.

RESULTS

Growth performance

The effects of dietary addition of wormwood on growth performance and feed efficiency of pigs are shown in Table 2. The final BW and ADG were increased in all treatments compared to C ($P < 0.05$), and there was no consistent trend according to the addition level of wormwood. The average daily feed intake was not affected by the addition of wormwood, but feed efficiency was increased in the treatments compared to C regardless of the addition level ($P < 0.05$).

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Table 2. The effects of dietary addition of wormwood on the growth performance and feed efficiency of growing-fattening pigs[1]

	C	T1	T2	T3	SEM
Initial body weight (kg)	70.50	70.33	70.33	70.10	1.07
Final weight (kg)	104.83^{b}	106.41^{a}	106.78^{a}	107.59^{a}	1.03
Average daily gain (kg/day)	0.817^{b}	0.859^{a}	0.867^{a}	0.892^{a}	0.013
Average daily feed intake (kg)	3.03	3.00	2.99	2.98	0.14
Feed efficiency ratio	0.271^{b}	0.287^{a}	0.291^{a}	0.299^{a}	0.028

C = basal diet; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood

[1]Mean of 45 pigs housed in each treatment

[a,b]Values in the same row with different superscripts differ at $P < 0.05$

Table 3. The effects of dietary addition of wormwood on the carcass traits and meat grades of pigs[1]

	C	T1	T2	T3	SEM
Carcass traits					
Carcass weight (kg)	81.00^{b}	81.00^{b}	83.33^{ab}	86.33^{a}	1.67
Dressing (%)	77.27	76.12	78.04	80.24	1.36
Back-fat thickness (mm)	24.67^{a}	23.00^{ab}	22.67^{b}	21.33^{c}	1.52
Meat grade					
Carcass grade score[2]	2.96^{a}	2.24^{b}	2.22^{b}	2.04^{c}	0.08
Incidencidence of high grade (%)[3]	52.0	58.0	64.0	68.0	–

C = basal diet; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood

[1]Mean of 45 pigs housed in each treatment

[2]The carcass grades were assessed on a 4-point scale: 1, extremely good; 2, good; 3, bad and 4, extremely bad

[3]The high grade rate was calculated as 1+ plus 1 of quality grade

[a–c]Values in the same row with different superscripts differ at $P < 0.05$

Carcass characteristics

The effects of dietary addition of wormwood on the carcass traits and meat grades of pigs are shown in Table 3. Carcass weight in T3 was significantly higher ($P < 0.05$) than that in C or T1. However, the dressing percentage was not significantly different between C and treatments. The backfat thickness was decreased in T2 and T3 compared to C ($P < 0.05$), and the reduction effect was greater as the wormwood addition level increased. Thus, the conductor grade was improved in all treatments compared to C ($P < 0.05$), and the improvement effect was larger in T3, which had the highest amount of wormwood, especially compared to T1 and T2 ($P < 0.05$).

Blood metabolites

The effects of dietary addition of wormwood on the concentration of blood corpuscles and plasma chemical composition of pigs are shown in Table 4. Blood corpuscles, such as leukocytes, erythrocytes, haemoglobin, haematocrit, and platelets, were not significantly affected ($P > 0.05$) by the dietary addition of wormwood. The total cholesterol and triglyceride concentrations in the plasma in T2 and T3 were significantly lower ($P < 0.05$) than those in C and T1. Additionally, the HDL-cholesterol concentration in the plasma in the treatments was significantly higher ($P < 0.05$) than that in C. However, there was no significant difference in HDL-cholesterol concentration between C and treatments. The triglyceride concentration was decreased in T2 and T3 compared to C, and in particular, as the level of dietary wormwood increased, the decreasing effect was greater ($P < 0.05$). Although there was no difference in plasma TP concentration between C and treatments, plasma BUN concentration was significantly decreased only in T3 compared to C.

Chemical composition and physiological characteristics of LD muscle

The effects of dietary addition of wormwood on the chemical composition and physiological characteristics in LD muscle of pigs are shown in Table 5. The dietary addition of wormwood did not affect the moisture and CP contents in LD mus-

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Table 4. The effects of dietary addition of wormwood on the blood corpuscle concentration and chemical composition in the plasma of growing-fattening pigs[1]

Items	C	T1	T2	T3	SEM
Blood corpuscles					
Leukocytes (10^3/mm^3)	17.70	17.98	18.90	17.33	1.33
Erythrocytes (IU/dl)	8.02	7.92	7.76	7.57	0.42
Hemoglobin (IU/dl)	14.70	14.98	15.35	15.43	0.67
Hematocrit (IU/dl)	41.88	41.93	42.15	43.65	0.24
Platelets (10^3/mm^3)	105.5	113.5	117.5	115.3	4.41
Chemical composition of plasma					
Total cholesterol (mg/dl)	120.00^{a}	119.50^{a}	110.33^{b}	108.33^{b}	2.00
HDL-cholesterol (mg/dl)	72.17^{b}	79.50^{a}	78.83^{a}	79.00^{a}	2.02
LDL-cholesterol (mg/dl)	31.90	31.63	30.58	28.78	1.75
Total protein (g/dl)	8.75	8.45	8.25	8.20	0.44
Triglyceride (mg/dl)	55.21^{a}	51.72^{a}	42.82^{b}	33.74^{c}	4.27
Blood urea nitrogen (mg/dl)	10.42^{a}	9.82^{a}	9.96^{a}	7.37^{b}	0.74

C = basal diet; HDL-cholesterol = high density lipoprotein cholesterol; LDL-cholesterol = low density lipoprotein cholesterol; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood

[1]Mean of 12 pigs housed in each treatment

[a–c]Values in the same row with different superscripts differ at $P < 0.05$

cle. However, the EE concentration was increased in T2 and T3 compared to C ($P < 0.05$), and the ash concentration increased compared to C only in T3 ($P < 0.05$). The dietary addition of wormwood did not affect pH or WHC. The shear force was improved in all treatment groups compared to C ($P < 0.05$), and the improvement effect tended to increase as the wormwood addition level increased. The TBARS and VBN concentration significantly decreased by the addition of wormwood ($P < 0.05$), but there was not any linear effect according to the wormwood level.

Surface colour of LD muscle

The effects of the dietary addition of wormwood on the surface colour in the fresh LD muscle of pigs are shown in Table 6. CIE L* (lightness) only increased in T2 and T3 compared to C ($P < 0.05$), but CIE b* (yellowness) decreased in T2 and T3 compared to C, but T2 was comparable to C ($P < 0.05$). As a result, the lightness and yellowness tended to increase as the amount of added wormwood increased.

Table 5. The effects of dietary addition of wormwood on the chemical composition and physiological characteristics in LD muscle of pigs[1]

Items	C	T1	T2	T3	SEM
Chemical composition					
Moisture (%)	73.31	73.26	72.65	72.57	0.24
Crude protein (%)	22.68	22.80	22.90	23.27	0.49
Ether extract (%)	3.67^{a}	3.31^{ab}	3.03^{b}	3.01^{b}	0.17
Ash (%)	1.03^{b}	1.47^{ab}	1.34^{ab}	1.90^{a}	0.09
Physiological characteristics					
pH	5.80	5.77	5.74	5.71	0.18
Water holding capacity (%)	63.04	62.16	61.64	61.61	2.69
Shear force (kg/cm^2)	5.83^{c}	6.27^{b}	6.65^{b}	7.23^{a}	0.07
TBARS (MDA mg/kg)	0.21^{a}	0.15^{b}	0.13^{b}	0.12^{b}	0.03
VBN (mg/100g)	9.94^{a}	8.92^{b}	8.87^{b}	8.53^{b}	0.13

C = basal diet; MDA = malondialdehyde; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood; TBARS = thiobarbituric acid reactive substances; VBN = volatile basic nitrogen

[1]Mean of 12 pigs housed in each treatment

[a–c]Values in the same row with different superscripts differ at $P < 0.05$

Table 6. The effects of dietary addition of wormwood on the surface colour in LD muscle of pigs[1]

Items	C	T1	T2	T3	SEM
CIE L*	42.80^{b}	43.78^{b}	49.09^{a}	50.12^{a}	1.41
CIE a*	3.85	4.17	4.54	4.28	0.33
CIE b*	3.53^{a}	3.34^{a}	2.09^{b}	1.87^{b}	0.50

C = basal diet; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood

[1]Mean of 12 pigs housed in each treatment.

[a,b]Values in the same row with different superscripts differ at $P < 0.05$

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Fatty acid composition of LD muscle

The fatty acid composition of wormwood was 3.88% capric acid, 0.41% lauric acid, 0.39% myristic acid, 22.75% palmitic acid, 1.26% palmitoleic acid, 2.86% stearic acid, 35.23% linoleic acid, 0.77% arachidic acid, 0.41% eicosenoic acid, 0.58% arachidonic acid, 0.96% behenic acid, 0.77% erucic acid, and 0.87% tetracosanoic acid. Additionally, the wormwood also contained 67.11% unsaturated fatty acids (USFA) and 32.89% saturated fatty acids (SFA) (data not shown).

The effects of the dietary addition of wormwood on the fatty acid composition in the LD muscle of pigs are shown in Table 7. The composition of myristic, stearic, and oleic acids was similar across treatments. Palmitic acid was decreased only in T1 compared to C. Palmitoleic acid was increased in all treatments compared to C ($P < 0.05$), and in particular, it was highest in T1 regardless of the wormwood addition level ($P < 0.05$). Linoleic acid was significantly increased only in T3 compared to C ($P < 0.05$), whereas arachidonic acid was significantly decreased only in T3 compared to C ($P < 0.05$). The SFA were decreased only in T1 compared to C ($P < 0.05$), and USFA were increased in all wormwood added treatments compared to C ($P < 0.05$). Also, the USFA/SFA ratio was significantly higher in all treatment groups compared to C ($P < 0.05$). However, there was no linear or consistent trend according to the level of wormwood addition.

Table 7. The effects of dietary addition of wormwood on the fatty acid composition in LD muscle of pigs[1]

	C	T1	T2	T3	SEM
Myristic acid (%)	1.38	1.36	1.31	1.25	0.03
Palmitic acid (%)	18.57^{a}	15.80^{b}	16.55^{ab}	16.55^{ab}	0.31
Palmitoleic acid (%)	4.09^{c}	5.13^{a}	4.59^{b}	4.95^{b}	0.23
Stearic acid (%)	4.53	4.53	4.95	4.77	0.25
Oleic acid (%)	56.31	58.11	58.27	57.37	1.57
Linoleic acid (%)	13.39^{ab}	13.74^{ab}	13.18^{b}	14.49^{a}	0.28
Arachidonic acid (%)	1.73^{a}	1.33^{a}	1.15^{a}	0.62^{b}	0.02
Saturated fatty acid (SFA, %)	24.48^{a}	21.69^{b}	22.81^{ab}	22.57^{ab}	0.23
Unsaturated fatty acid (USFA, %)	75.52^{b}	78.31^{a}	77.19^{a}	77.43^{a}	0.56
Essential fatty acid (EFA, %)	15.12	15.07	14.33	15.11	0.23
USFA/SFA	3.085^{b}	3.610^{a}	3.384^{a}	3.431^{a}	0.12
EFA/USFA	0.200	0.192	0.186	0.195	0.09

C = basal diet; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood

[1]Mean of 12 pigs housed in each treatment

[a–c]Values in the same row with different superscripts differ at $P < 0.05$

Sensory evaluation of LD muscle

The effects of the dietary addition of wormwood on the sensory evaluation in the cooked LD muscle of pigs are shown in Table 8. All sensory evaluations were affected by the addition of wormwood. The colour and aroma were not different between C and T1, but were high in T2 and T3 ($P < 0.05$). Marbling was increased in all treatments compared to C ($P < 0.05$), but tenderness was decreased in all treatments compared to C ($P < 0.05$). Juiciness was decreased only in T3 compared to C ($P < 0.05$). Flavour and overall acceptability were improved in all treatments compared to C ($P < 0.05$), and as the amount of added wormwood increased, it was numerically increased, but there was no significant difference.

Table 8. The effects of dietary addition of wormwood on the sensory evaluation[1] in LD muscle of pigs[2]

	C	T1	T2	T3	SEM
Color	5.81^{b}	6.02^{b}	7.64^{a}	7.82^{a}	0.17
Marbling	5.28^{b}	6.21^{a}	6.34^{a}	6.35^{a}	0.13
Aroma	5.22^{b}	5.57^{b}	6.77^{a}	6.98^{a}	0.21
Tenderness	6.23^{a}	5.76^{b}	5.70^{b}	5.62^{b}	0.11
Juiciness	6.34^{a}	6.31^{a}	6.28^{a}	5.72^{b}	0.21
Flavor	5.97^{b}	6.32^{a}	6.75^{a}	6.79^{a}	0.13
Overall acceptability	5.99^{b}	6.44^{a}	6.78^{a}	6.79^{a}	0.20

C = basal diet; T1 = basal diet supplemented with 0.5% of dried powdered wormwood; T2 = basal diet supplemented with 1.0% of dried powdered wormwood; T3 = basal diet supplemented with 1.5% of dried powdered wormwood

[1]Sensory evaluation was scored on a 9-point scale based on 1 (extremely bad) to 9 (extremely good)

[2]Mean of 12 pigs housed in each treatment

[a,b]Values in the same row with different superscripts differ at $P < 0.05$

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DISCUSSION

In this study, the dietary addition of wormwood increased the growth performance and feed efficiency of growing-fattening pigs. In previous studies, dietary supplementation of extracts from wormwood also increased ADG in chickens (Kim et al. 2010). Phytochemicals in plants have been reported to positively affect growth performance and daily gain owing to their ability to stimulate appetite, increase feed intake (Gill 2000), and increase endogenous digestive enzyme activity. Additionally, the phytochemical constituents of plants also include antiviruses and antioxidants that improve the intestinal immune system by eliminating pathogenic microbes and increasing the beneficial bacterial population. Some or all of these phytochemical effects might be an explanation why the dietary addition of wormwood increased the growth performance and feed efficiency of growing-fattening pigs during this study.

Kim et al. (2004) observed that dietary wormwood decreased the carcass weight and backfat thickness in gilts and growing-fattening pigs because the extracts from wormwood accelerated protein synthesis by increasing insulin-like growth factor-1 in the plasma (Kwon et al. 2005). Moreover, diets containing 5% and 10% olive leaves contained up to 10% polyphenols, which decreased backfat and LD muscle thickness in pigs and affected meat quality parameters (Paiva-Martins et al. 2009). In this study, a diet containing 1% or 1.5% wormwood decreased the backfat thickness of growing-fattening pigs, consistent with the findings of Kwon et al. (2005). However, based on the reports above, the effects of dietary wormwood on carcass traits of pigs are still unclear.

Baker et al. (1984) reported that total cholesterol in plasma causes hyperlipidaemia, cardiovascular disorders, and arteriosclerosis. LDL-cholesterol in the plasma causes hyperlipidaemia and is transferred from the plasma to blood vessels. On the contrary, HDL-cholesterol in the plasma transfers cholesterol from blood vessels to the liver, where the transferred cholesterol is decomposed. Therefore, LDL-cholesterol is considered injurious, while HDL-cholesterol is beneficial to human health. Han et al. (2009) reported that extracts from some plants, such as wormwood, decreased the total cholesterol and triglyceride concentrations in the plasma of rats, which was attributed to the phenols, terpenoids, and dietary fibre in wormwood. Extracts from green tea also arrested cholesterol biosynthesis and increased faecal fat due to suppressed lipid absorption by suppressed micelles in the small intestine (Ikeda 2008). Moreover, plant extracts such as anthocyanin, coumarin, catechin, and caffeic acid are also known to improve the liver function and protect it from damage because these chemicals suppress free radicals and lipid peroxidation and increase the activity of glutathione reductase in the blood (Lee et al. 1999). In the present study, the dietary addition of wormwood decreased the concentration of total cholesterol and triglycerides. Still, it increased the concentration of HDL-cholesterol in the plasma, which may be attributed to the active compounds extracted from wormwood in the digestive system, consistent with the aforementioned studies. It has been suggested that wormwood is beneficial to pig health and can be considered an environmentally friendly product for pigs and functional meat. Functional meat might be advantageous for the meat industry and consumers for chronic disease prevention.

It has also been reported that dietary mugwort decreases EE content in the LD muscle of fattening pigs (Kim et al. 2004), leading to delayed damage of intestinal endothelial cells due to decreased lipid content. Moreover, a diet containing oligosaccharides from wormwood decreased the accumulation of celiac fat in obese rats (Jang and Choi 2003). The findings of our study which showed that the dietary addition of 1.0% or 1.5% wormwood decreased EE content in LD muscle, which might result from wormwood interference with lipid metabolism, are consistent with those of previous studies.

Byrne et al. (2000) reported that meat pH is closely related to slaughter and processing, meat quality, and WHC. The rapid change in pH after slaughter causes high tenderness of meat due to the degradation of actin and myosin. In this study, all treatments showed normal values for pH and WHC, in accordance with the literature (Paiva-Martins et al. 2009), indicating that all animals in this experiment were in the good pre-slaughter condition.

Literature on the relationship between wormwood and shear force of meat is not yet available. Generally, shear force is affected by the content of EE, connective tissues, and muscle tissues in meat (Kim et al. 2009). The dietary addition of wormwood might have caused the toughness

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of pork, which showed an increased shear force of LD muscle in this study.

Lipid oxidation by TBARS is affected by various factors such as storage period, storage temperature, fatty acid composition, and oxygen and antioxidant activation (Chen and Wailmaleongora-Ek 1981). Usually, diets with high polyunsaturated fatty acid (PUFA) contents are more prone to oxidation. However, dietary antioxidants, such as vitamins, carotenoids, and flavonoids, protect the meat against oxidation because antioxidants delay or prevent lipid oxidation by reducing free radical activities in meat (Paiva-Martins et al. 2009). Therefore, antioxidant supplementation in the diet is an efficient method to increase meat oxidative stability. In this study, the dietary addition of wormwood decreased lipid oxidation in pork, which may be due to polyphenols and their antioxidant activities. Therefore, the differences in oxidative stability can only be explained by differences in the antioxidant content of meat (Paiva-Martins et al. 2009). In this study, the dietary addition of wormwood decreased protein oxidation (VBN) and increased the protein oxidative stability of meat, indicating the antioxidant activity of wormwood.

Many factors affect meat colour, including oxygen volume in myoglobin, enzyme activity in meat, storage temperature, microorganism pollution of meat, and pH. Myoglobin, oxygen, and enzyme activity also affect meat colour. Kim et al. (2004) showed that the diet with wormwood increased the lightness and decreased the yellowness of pork colour, which is consistent with the results of this study, which showed that dietary addition of wormwood above 1.0% increased the lightness and decreased the yellowness of LD muscle. However, the literature contains little information regarding the wormwood metabolism or its compounds. Moreover, in previous studies, it has been found that dietary antioxidant compounds, such as vitamin E, improved meat colour and lipid stability of fresh pork (Asghar et al. 1991).

Fat content and fatty acid composition affect marbling, meat grade, taste, flavour, quality, and storage, and the health of meat consumers. The meat fatty acid composition is affected by the fatty acid composition of the diet of monogastric animals (Pascual et al. 2007). We analyzed the fatty acid composition in wormwood and not in the experimental diet. Wormwood contains large quantities of oleic, linoleic, linolenic and palmitic acid that may have increased the oleic, palmitic and linoleic acid content of meat from 56.31% to 58.27%, 15.80% to 18.57%, and 13.18% to 14.49%, respectively. Moreover, lipid oxidation in tissues depends on the proportion of PUFA in lipid bilayers, amount of reactive oxygen species produced, and antioxidant levels. Wormwood polyphenols can represent antioxidants for animal nutrition because they can be readily produced at a low cost. Polyphenols are strong antioxidants that exhibit a wide action spectrum, and they are getting more attention in reducing lipid oxidation (Gladine et al. 2007). Kang et al. (2007) reported that the total fatty acid content of pork is affected by the composition of oleic, palmitic, and linoleic acid. Park and Kim (2008) reported that fatty acids in chicken meat are affected by wormwood fatty acids, which increase USFA and decrease SFA, consistent with the results of this study. Dietary oleic acid, a monounsaturated fatty acid in olive and rapeseed oils, prevents arteriosclerosis and adult diseases by decreasing the cholesterol and triglyceride plasma concentrations (Grundy 1986). The dietary intake of wormwood in growing-fattening pigs might have increased the USFA and oleic acid and decreased the SFA of meat. Pork with high USFA and low SFA in LD muscle might be more appealing to consumers and more beneficial to human health because SFA consumption has been shown to increase plasma LDL-cholesterol and is associated with coronary heart diseases in humans (Mattson and Grundy 1985).

In the present study, the sensory evaluation of marbling, tenderness, and flavour of cooked meat was improved in all treatments. Additionally, the colour and aroma of cooked meat were improved by adding 1.0% and 1.5% wormwood. Sensory evaluation is an important factor in determining meat quality parameters because of its importance to consumers. Tenderness and juiciness of meat are correlated with WHC and cooking loss (Wood et al. 2008). The wormwood polyphenols affect the meat aroma of native Korean goats (Lee et al. 1998). Furthermore, a wormwood diet increases the tenderness and aroma of pork (Kim et al. 2004). Therefore, polyphenols in wormwood could also be the reason for the improved sensory evaluations of cooked meat from growing-fattening pigs.

CONCLUSION

In this study, the addition of wormwood improved the ADG and feed efficiency of finisher pigs, and

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reduced blood cholesterol and triglycerides by affecting the lipid metabolism. In addition, this effect not only improved carcass grade by increasing carcass weight and reducing backfat thickness, but also had a positive effect on meat quality. Dietary wormwood improved marbling and flavour of cooked meat, increased lightness and yellowness, and decreased juiciness. Therefore, the dietary addition of wormwood improved growth performance, feed efficiency, carcass grade, USFA composition, and oxidation of protein and lipids in the LD muscle of growing-fattening pigs.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

AOAC – Association of Official Analytic Chemists. Official methods of analysis. Method 996.11. Maryland, USA: AOAC international; 2005.

Asghar A, Gray JI, Booren AM, Gomaa EA, Abouzied MM, Miller ER, Buckley DJ. Effects of supranutritional dietary vitamin E levels on subcellular deposition of α-tocopherol in the muscle and on pork quality. J Sci Food Agric. 1991 Apr 24;57(1):31-41.

Baker DP, Van Lenten BJ, Fogelman AM, Edwards PA, Kean C, Berliner JA. LDL, scavenger, and beta-VLDL receptors on aortic endothelial cells. Arteriosclerosis Offic J Am Heart Assoc. 1984 May;4(3):248-55.

Bekhit AEDA, Holman BW, Giteru SG, Hopkins DL. Total volatile basic nitrogen (TVB-N) and its role in meat spoilage: A review. Trends Food Sci Technol. 2021 Mar;109:280-302.

Byrne CE, Troy DJ, Buckley DJ. Postmortem changes in muscle electrical properties of bovine M. longissimus dorsi and their relationship to meat quality attributes and pH fall. Meat Sci. 2000 Jan;54(1):23-34.

Chen TC, Waimaleongora-Ek C. Effect of pH on TBA values of ground raw poultry meat. J Food Sci. 1981 Jun 18;46(6):1946-7.

Chu GM, Song YM. Effect of dietary addition of wormwood (Artemisia montana Pampan) on performance of fattening pigs and selected hematological and immunological indices. Livest Sci. 2012 Aug;147(1-3):188-91.

Chu GM, Lee SJ, Jeong HS, Lee SS. Efficacy of probiotics from anaerobic microflora with prebiotics on growth performance and noxious gas emission in growing pigs. Anim Sci J. 2011 Feb 23;82(2):282-90.

Gill C. Botanical feed additives. Feed Int. 2000 Apr;21:14-7.

Gladine C, Morand C, Rock E, Gruffat D, Bauchart D, Durand D. The antioxidative effect of plant extracts rich in polyphenols differs between liver and muscle tissues in rats fed n-3 PUFA rich diets. Anim Feed Sci Technol. 2007 Dec 15;139(3-4):257-72.

Grundy SM. Comparison of monounsaturated fatty acids and carbohydrates for lowering plasma cholesterol. N Engl J Med. 1986 Mar 20;314(12):745-8.

Han EK, Jin YX, Yoo YS, Jung EJ, Lee JY, Chung CK. Effect of Artemisia capillaris and Paecilomyces japonica on the reduction of hepatotoxicity and lipid metabolism induced by ethanol. Journal of the Korean Society of Food Science and Nutrition. 2009 Aug 31;38(8):1016-23.

Honikel KO. Reference methods for the assessment of physical characteristics of meat. Meat Sci. 1998 Aug 1; 49(4):447-57.

Huang YX, Miller EL. Iron-induced TBARS as an indicator of oxidative stability of fresh chicken meat. In: Colin P, Culioli F, Ricard H, editors. Proceedings of the 11th European Symposium on the Quality of Poultry meat; 1993 Oct. p. 430-4.

Ikeda I. Multifunctional effects of green tea catechins on prevention of the metabolic syndrome. Asia Pac J Clin Nutr. 2008 Jan 1;17(S1):273-4.

Jang JY, Choi HJ. Effects of Artemisia iwayomogi oligosaccharide on the blood lipids, abdominal adipose tissues and leptin levels in the obese rats. Korean J Nutr. 2003 Jun;36(5):437-45. Korean.

Jin SK, Kim IS, Song YM, Kang SN, Je YJ, Oh HS, Min CS. The effect of ion water and premixed mineral supplementation on the growth performance, carcass, and meat quality parameters in finishing pigs. Food Sci Anim Res. 2009 Apr 30;29(2):252-9. Korean.

Kang SN, Kim JD, Kim IS, Jin SK, Lee M. Effect of replacing antibiotics by herb extracts and digestive enzymes containing vitamin E and oriental medicinal plants byproduct on blood serum cholesterol and meat qualities in the hog loin meat. Food Sci Anim Res. 2007 Mar 31; 27(1):87-94. Korean.

Kim IS, Jin SK, Song YM, Hah KH, Kim HY, Nam KY, Lyou HJ, Ha JH. The quality properties of pork meat by feeding mugwort powder during chilling storage. J Korean Soc Internat Agric. 2004 Dec;16:319-24. Korean.

Kim IS, Jin SK, Kang SN. Effects of mugwort powder supplementation on carcass and meat characteristics in the finishing period of gilts. Food Sci Anim Res. 2009 Apr 30;29(2):188-93. Korean.

Kim MJ, Park M, Jeong MK, Yeo J, Cho WI, Chang PS, Chung JH, Lee J. Radical scavenging activity and antiobesity effects in 3T3-L1 preadipocyte differentiation of

https://doi.org/10.17221/110/2022-CJAS

Ssuk (Artemisia princeps Pamp.) extract. Food Sci Biotechnol. 2010 Apr;19(2):535-40.

Kwon OS, Cho JH, Min BJ, Kim HJ, Chen YG, Yoo JS, Kim IH, La JC, Park HK. Effect of supplemental medicinal plants (Artemisia, Acanthopanax and Garlic) on growth performance, IGF-1 and meat quality characteristics in growing-finishing pigs. Food Sci Anim Res. 2005 Sep 1; 25(3):316-21. Korean.

Lee CH, Kim M, Han KH, Jo HY. The effect of mugwort and ginseng supplementation on the fatty acid composition and TBA value in korean native goat meat. animal resources research center. Kon-Kuk Universtiy. 1998;19:31-6.

Lee CH, Han KH, Choi IS, Kim CY, Cho JK. Effects of mugwort-water extracts on cadmium toxicity in rats. Korean J Food Sci Anim Res. 1999 Feb;19(2):188-97. Korean.

Li J. Current status and prospects for in-feed antibiotics in the different stages of pork production – A review. Asian-Australas J Anim Sci. 2017 Dec 1;30(12):1667-73.

MAFRA – Ministry of Agriculture, Food and Rural Affairs. Grade rule for pig carcass in Korea. Sejong, Korea: Korea Ministry of Government Legislation [cited 2017 Nov 30]. Available from: http://www.law.go.kr/main.html

Mattson FH, Grundy SM. Comparison of effects of dietary saturated, monounsaturated, and polyunsaturated fatty acids on plasma lipids and lipoproteins in man. J Lipid Res. 1985 Feb;26(2):194-202.

Paiva-Martins F, Barbosa S, Pinheiro V, Mourao JL, Outor-Monteiro D. The effect of olive leaves supplementation on the feed digestibility, growth performances of pigs and quality of pork meat. Meat Sci. 2009 Aug;82(4):438-43.

Park CI, Kim YJ. Effects of dietary mugwort powder on the VBN, TBARS, and fatty acid composition of chicken meat during refrigerated storage. Food Sci Anim Res. 2008 Oct 31;28(4):505-11. Korean.

Pascual JV, Rafecas M, Canela MA, Boatella J, Bou R, Barroeta AC, Codony R. Effect of increasing amounts of a linoleic-rich dietary fat on the fat composition of four pig breeds. part II: Fatty acid composition in muscle and fat tissues. Food Chem. 2007;100(4):1639-48.

Salminen S, Ouwehand A, Benno Y, Lee YK. Probiotics: How should they be defined? Trends Food Sci Technol. 1999 Mar;10(3):107-10.

Wood JD, Enser M, Fisher AV, Nute GR, Sheard PR, Richardson RI, Hughes SI, Whittington FM. Fat deposition, fatty acid composition and meat quality: A review. Meat Sci. 2008 Apr;78(4):343-58.

Yan L, Meng QW, Kim IH. The effects of dietary houttuynia cordata and taraxacum officinale extract powder on growth performance, nutrient digestibility, blood characteristics and meat quality in finishing pigs. Livest Sci. 2011 Nov;141(2-3):188-93.

Ziemer CJ, Gibson GR. An overview of probiotics, prebiotics and synbiotics in the functional food concept: Perspectives and future strategies. Int Dairy J. 1998 May; 8(5-6):473-9.

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