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The influence of dietary inclusion of wood vinegar supplementation on growth performance, nutrient digestibility, and meat quality in grower-finisher pigs

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The current research aimed to evaluate the effects of dietary inclusion of wood vinegar on growth performance, nutrient digestibility, and meat quality of grower-finisher pigs. In total, 132 crossbred ({Landrace × Yorkshire × Duroc}) grower-finisher pigs with an initial average body weight 30.48±4.23 kg (11 replications/treatment; 4 pigs/pen) were used in a 16-week trial. Based on the body weight and sex the pigs were randomly assigned to three treatments. Dietary treatments consisted of the basal diet (CON) or the basal diet supplemented with 0.05% and 0.1% wood vinegar. The inclusion of dietary wood vinegar supplementation significantly improved the body weight gain (BWG) and average daily gain (ADG) (*P*=0.0521; 0.043) of pigs at week 16. The total track nutrient digestibility of dry matter and nitrogen was linearly increased in pigs fed with an increased amount of wood vinegar. In addition, dietary supplementation of wood vinegar linearly improved longissimus muscle area, yellowness (b*) of the meat color, and carcass weight (*P*<0.05) and a tendency in linear reduction was observed for water holding capacity (*P*=0.068), and drip loss at d5 and d7 (*P*=0.091, 0.069). However, there was no significant difference found for lean meat percentage and backfat thickness in this experiment. In summary, dietary inclusion of wood vinegar supplementation enhanced growth performance and total track digestibility of nutrients and had no effects on lean meat percentage and backfat thickness of grower-finisher pigs.

Keywords: wood vinegar, grower-finisher pigs, nutrient digestibility, meat quality, growth performance

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Abbreviations: BW, body weight; ADG, average daily gain; ADFI, average daily feed intake, G; F, gain to feed ratio; DM, dry matter; N, nitrogen; BFT, backfat thickness; LMP, lean meat percentage; AGP, antibiotic growth promoters; WHC, water-holding capacity

INTRODUCTION

Antibiotics, as growth promoters and therapeutic compounds, are widely used to decrease the susceptibility to infectious diseases, and have been employed in animal production for several years (Barton, 2000). Nevertheless, widespread concern about the use of antibiotics in animals has risen in recent years owing to the appearance of antibiotic-resistant bacteria that could pose a danger to human health (Huang *et al.,* 2010). The use of antibiotics as growth promoters in animal feed has been prohibited in South Korea since 2011 (Global Agricultural Information Network, 2011). Therefore, it has become mandatory to develop antibiotic-free diets for domestic animals including swine (Bae *et al.,* 1999) and thus, an immense effort has been made towards the identification of the alternatives to antibiotics as growth promoters in the livestock industry (Hong *et al.,* 2004; Cho *et al.,* 2006). Consequently, several alternatives such as probiotics, prebiotics, organic acids, phytogenics and so on are used as a substitute for antibiotic growth promoters (AGP). Wood vinegar is obtained from the distillation of smoke from burning wood and is a complex mixture of water and organic compounds. Moreover, wood vinegar contains phenolic compounds similar to catechols, guaiacols, and organic acids such as acetic, propionic, and formic acid (Mohan *et al.,* 2006; Cai *et al.,* 2012). Previously, Wang *et al.* (2012) stated that the presence of acetic acid and phenolic compounds in wood vinegar could have an anti-germination effect. Moreover, Samanya and Yamauchi (2001) stated that dietary supplementation of wood vinegar enhanced the feed efficiency and intestinal morphology of villus height and crypt depth in chickens. Similarly, Mekbungwan and others (Mekbungwan *et al.,* 2004) and Choi and others (Choi *et al.,* 2009) stated that 0.3% wood vinegar supplementation improved growth performance and apparent total digestibility of weaning pigs during the overall experiment. However, to date, the literature on the application of wood vinegar in grower-finisher pigs is still limited. Therefore, the aim of this research was to evaluate the efficacy of wood vinegar on growth performance, nutrient digestibility, and meat quality of grower-finisher pigs.

MATERIALS AND METHODS

The described protocol (Approval No: DK-2-2204) was permitted and pigs were maintained according to the guidelines of the Animal Care and Use Committee of Dankook University, Republic of Korea.

Sources of wood vinegar

Wood vinegar used in the present study was obtained from Chumdan Environment Co. Ltd, Republic of Korea. The *Quercus acutissima* plants were burned at 550–650°C then the smoke was cooled by a water-cooling system and distilled. It was stored for 6 months. Then the filtrate solution was distilled to remove harmful substances, the supernatant was collected and purified to use for the experiment. Wood vinegar composition contained 10.97% propionic compound and 3.89% acetic acid as analyzed by Korea Chemistry Association.

Trial design and diet

A total of 132 mixed-sex {Landrace × Yorkshire × Duroc} grower-finisher pigs with an initial average body weight of 30.48±4.23 kg (Mean ± S.E.) were used in a 16-week experimental trial. At first, grower-finisher pigs were randomly divided according to their initial body weight and sex (4 pigs (2 gilts and 2 barrows) per pen). Thirty-three pens were randomly allotted to 3 treatments, where each pen was counted as one replication and each treatment had 11 replications. The treatments were as follows: basal diet (Control), the basal diet with 0.05% and 0.1% wood vinegar. The dietary treatments were based on a corn-wheat-soybean meal diet formulated as per the recommendation of the National Research Council (2012) (Table 1). The pigs were housed at a thermostatically controlled ambient environmental temperature (25°C) on a slatted plastic floor, and every pig was individually identified using tags. The pigs had access to feed and water *ad libitum*, through a self-feeder and nipple drinker, respectively.

Sampling and laboratory analysis

Individual pigs body weight (BW) was measured at the start of the experiment, in week 4 and week 16 to determine the daily gain (ADG). In addition, the consumption of feed and leftovers was calculated on pen basis during the whole experimental period to determine the average daily feed intake (ADFI) and gain to feed ratio (G: F). In order to measure the total tract digestibility of dry matter (DM), nitrogen (N), and energy, 0.20% chromium oxide was added to the diet as an indigestible marker 7 days prior to fecal collection at end of the experiment. Feed and fecal samples were collected randomly from at least 2 pigs (1 barrow and 1gilt) per pen then homogenized well and stored in a freezer at –20°C. All feed and fecal samples were freeze-dried and finely ground to pass through a 1 mm screen. DM and N digestibility was determined using methods established by the Association of Official Analytical Chemists (AOAC, 2000). Chromium absorption was determined by UV absorption spectrophotometry (UV-1201, Shimadzu, Kyoto, Japan). The energy was measured by the heat combustion of the samples using Parr 6100 oxygen bomb calorimeter (Parr Instrument Co., Moline, IL, USA). The apparent total tract digestibility was calculated using the following formula: digestibility (%)={1−[(Nf×Cd)/(Nd × Cf)]}×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).

Backfat thickness and lean meat percentage were assessed at the beginning and at the end of the experiment. Backfat thickness was measured using Pig-log 105 (Carometec Food Technology, Denmark) at the P2 position (6.5 cm area on the right and left end frames). To determine the quality of pork meat 2 pigs (per pen) were slaughtered by exsanguinations and evisceration at a local commercial slaughterhouse. 30 min after death pork muscle was collected and stored at –4°C for further analysis. Lean meat samples were thawed at room temperature prior to evaluation. According to the protocols of the National Pork Producers Council (NPPC) the meat color, marbling and firmness scores were determined. To detect lightness, redness, and yellowness values each sample (surface) was measured at 3 locations using CR-410 Chromameter (Konica Minolta Sensing Inc., Osaka, Japan). The pH of muscle was measured 24 h after postmortem using a pH meter (Testo 205, Testo, Germany). The water-holding capacity (WHC) was determined following the method of Kauffman and others (Kauffman *et al.*, 1986). In brief, a 0.3 g pork meat sample was kept

Table 1. Ingredients and chemical composition of the complete diet (g/kg, as fed basis).

Ingredient	Grower	Finisher
Corn	474	566.3
Wheat	30	20
Molasses	40	40
Wheat bran	30	-
Corn gluten feed	19	20
Soybean meal	306	249
Rapeseed meal	20	20
Corn germ meal	-	10
Lysine (80%)	1	0.6
Methionine (99%)	0.4	-
Tallow (liquid)	50	46
Limestone	9.3	12.3
Di-calcium Phosphate	15.6	11.3
Salt	2	2
Vitamin premix[1]	1.5	1.5
Mineral premix[2]	1	1
Calculated composition		
Crude protein	194.1	171.2
Crude fat	76.3	74.1
Crude fiber	31.0	27.6
Crude ash	58.1	53.2
Calcium	8.0	8.0
Total phosphorus	6.0	5.0
Available phosphorus	3.5	2.7
Total lysine	11.3	9.5
Methionine	3.5	2.8
Available methionine	3.1	2.5
Analyzed composition		
Metabolize energy, MJ/kg	13.21	13.80
Crude protein	195.6	170.5
Crude fat	76	73.2
Crude fiber	32.3	27.9
Crude ash	58.5	53.1
Calcium	8.1	8.0
Total phosphorus	5.9	5.1
Total lysine	11.8	9.8
Methionine	3.7	2.9

[1]Provided per kilogram of complete diet: 1.3 mg of Vitamin A (Retinol); 0.022 mg of Vitamin D_3 (Cholecalciferol); 45 mg Vitamin E (Tocotrienol); 4.2 mg Vitamin K_3 (Menodione); 24.6 mg Vitamin B_5 (d-Ca-pantothenate); 8.6 mg Vitamin B2 (Riboflavin); and 0.04 mg Vitamin B_{12} (Cobalamins).
[2]Provided per kilogram of complete diet: 15 mg Cu; 80 mg Fe; 56 mg Zn; 73 mg Mn; 0.3 mg I; 0.5 mg Co; 0.4 mg Se.

Table 2. Effects of dietary inclusion of wood vinegar on growth performance of grower-finisher pigs.

Item	Wood vinegar (%)			S.E.M.[1]	*P*-value[2]	
	0	0.05	0.1		Linear	Quadratic
Bodyweight (kg)						
Initial	20.94	20.83	20.82	0.10	0.667	0.748
Week 4	44.07	44.18	44.19	0.25	0.092	0.364
Week 16	111.59	111.78	112.2	0.87	0.052	0.741
Week 4						
ADG, g	687	711	738	12	0.009	0.960
ADFI, g	1611	1619	1636	20	0.372	0.853
G:F	0.427	0.439	0.451	0.010	0.093	0.997
Week 12						
ADG, g	756	748	812	33	0.054	0.379
ADFI, g	1944	1973	1980	12	0.248	0.481
G:F	0.389	0.378	0.41	0.016	0.374	0.300
Week 16						
ADG, g	794	827	856	22	0.063	0.941
ADFI, g	2406	2435	2411	27	0.094	0.428
G:F	0.33	0.341	0.355	0.011	0.119	0.886
Overall						
ADG, g	750	761	806	22	0.043	0.531
ADFI, g	2016	2039	2041	12	0.152	0.456
G:F	0.372	0.373	0.395	0.011	0.168	0.467

[1]Standard error of means. Values are represented by 44 pigs per treatment; 4 pigs (2 gilts and 2 barrows) per pen; 11 pens per treatment.

in 125 mm diameter filter paper and pressed for 3 min at 26°C. The moisture exposure of the compressed areas was determined using a digitalized area-line sensor (MT-10S, M.T. Precision Co. Ltd., Tokyo, Japan). The ratio of water: meat area was then calculated (a smaller ratio indicates increased WHC). Meat sample, 4 g, was sliced and weighed, then the samples were placed in a zipper bag and stored at 4°C. The samples were weighed on days 1, 3, 5, and 7 from the date of sample collection. The initial and the final weight of each sample was used to calculate the drip loss level. Cooking loss was calculated according to the methods of Albercht and others (Albercht *et al.,* 2019).

Statistical analysis

All data were statistically analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA) in a randomized complete block design. The experimental unit was the pen and the blocks were the sexes. The statistical model for growth performance, nutrient digestibility, and meat quality included effects of dietary treatment as a fixed effect and sex as a random effect. Orthogonal comparisons were conducted using polynomial regression to determine linear and quadratic effects of wood vinegar level on all measurements. Results were considered significant at $P<0.05$ level and $P<0.10$ was considered a trend.

RESULT AND DISCUSSION

Effects of dietary wood vinegar supplementation on growth performance of grower-finisher pigs were presented in Table 2. The inclusion of dietary wood vinegar supplementation resulted in a trend of linear increase

Table 3. Effects of dietary inclusion of wood vinegar on nutrient digestibility of grower-finisher pigs.

Item	Wood vinegar (%)			S.E.M.[1]	*P*-value[2]	
	0	0.05	0.1		Linear	Quadratic
Dry matter	694.2	712.7	724.7	0.62	0.004	0.397
Nitrogen	687.5	711.3	723.1	0.97	0.052	0.742
Energy	705.6	717.2	725.8	0.87	0.083	0.522

[1]Standard error of means. Values are represented by 44 pigs per treatment; 4 pigs (2 gilts and 2 barrows) per pen; 11 pens per treatments.

Table 4. Effects of dietary inclusion of wood vinegar on the backfat thickness and lean meat percentage of grower-finisher pigs.

Variable	Wood vinegar (%)			S.E.M.[1]	*P*-value[2]	
	0	0.05	0.1		Linear	Quadratic
Back-fat thickness, mm						
Initial	10.0	9.9	9.9	0.1	0.626	0.574
Final	20.7	20.8	21.3	0.4	0.327	0.717
Lean meat, %						
Initial	63.9	63.8	64.0	0.1	0.521	0.328
Final	49.5	50.0	49.6	0.4	0.864	0.396

[1]S.E.M. – standard error of the mean. Values are represented by 44 pigs per treatment; 4 pigs (2 gilts and 2 barrows) per pen; 11 pens per treatments.

of the BW of pigs at week 4 (P=0.092) and at week 16 (P=0.052). In addition, in pigs fed a diet containing wood vinegar supplementation ADG increased linearly during week 4, 12, and during the whole experiment (P=0.009, 0.054, and 0.043 respectively) and tended to increase (P=0.063) in week 16. Our finding was consistent with the study of Choi and others (Choi *et al.,* 2009) who observed a higher daily gain in pigs fed graded levels of wood vinegar supplement. Similarly, Wang and others (Wang *et al.,* 2012) stated that feeding weaner pigs with 0.8% bamboo vinegar had a beneficial effect on growth performance. The dietary inclusion of wood vinegar supplementation failed to affect the ADFI of grower-finisher pigs which was inconsistent with the study of Choi and others (Choi *et al.,* 2009) who observed an increased feed intake in pigs fed a diet containing an increased level of wood vinegar. Similarly, Kook and Kim (Kook & Kim, 2003) reported that dietary inclusion of bamboo vinegar increased the feed intake of ducks. Our study revealed that dietary wood vinegar supplementation tended to increase the gain to ratio (P=0.093) in week 4, which was opposite to the research of Choi and others (Choi *et al.,* 2009) who observed no difference in the feed efficacy in pigs fed a diet containing wood vinegar supplement. We assume that the discrepancies between the findings might be due to the difference in dosage or in animals age. To our knowledge, limited research was presented on the application of wood vinegar in the diet of grower-finisher pigs, thus sufficient comparisons could not be made.

Effects of dietary wood vinegar supplementation on total tract nutrient digestibility of grower-finisher pigs are presented in Table 3. In pigs fed a diet containing 0.1% wood vinegar supplementation we observed linearly in-

Table 5. Effects of dietary inclusion of wood vinegar on meat quality traits of grower-finisher pigs.

Item	Wood vinegar (%)			S.E.M.[1]	*P*-value[2]	
	0	0.05	0.1		Linear	Quadratic
pH	5.32	5.40	5.27	0.06	0.567	0.171
Longinus muscle area, cm^2	46.47	48.52	48.90	0.55	0.005	0.231
Sensory evaluation						
Color	1.70	1.98	1.78	0.10	0.618	0.080
Marbling	1.58	1.60	1.51	0.11	0.706	0.687
Firmness	1.74	1.91	1.81	0.09	0.574	0.241
Drip loss, %						
Day 1	6.29	10.93	6.95	1.08	0.669	0.004
Day 3	9.99	13.30	12.98	1.32	0.127	0.276
Day 5	13.90	14.14	16.67	1.10	0.091	0.407
Day 7	15.12	17.23	19.68	0.94	0.069	0.013
Water holding capacity, %	41.18	39.44	37.53	1.32	0.068	0.113
Meat color						
L	57.96	54.73	57.69	1.06	0.858	0.027
a	16.41	17.13	16.80	0.37	0.466	0.265
b	8.79	9.61	9.88	0.28	0.145	0.012
Cook loss %	25.31	25.13	24.86	0.73	0.670	0.961
Carcass weight (kg)	87.9	89.6	92.4	1.7	0.043	0.875

[1]Standard error of means. Values are represented by 44 pigs per treatment; 4 pigs (2 gilts and 2 barrows) per pen; 11 pens per treatments.

creased apparent total digestibility of DM (P=0.004), N (P=0.052), and a tendency of increased energy (P=0.083) at the end of the experiment, which was not consistent with Rodjan *et al.* (2018) who observed a reduced DM, N and E in grower-finisher pigs fed diet containing mangosteen wood vinegar supplement. However, in 2009, Choi and others reported that graded levels (0, 0.1, 0.2, and 0.3%) of wood vinegar in the diet of pigs significantly increased the nutrient digestibility of dry matter, crude protein, and gross energy. Similarly, Yan and others (Yan *et al.,* 2012) pointed out that the use of 0.1 and 0.2% of bamboo vinegar led to a greater apparent total tract digestibility of dry matter and nitrogen in pigs. Previously, Burnell and others (Burnell *et al.,* 1988) stated that dietary inclusion of wood vinegar enhanced pH level in gastrointestinal tract thereby reducing the harmful intestinal microflora. From this view, we assume that the increased digestibility might be due to the effect of wood vinegar which balanced the pH level of the intestinal tract thereby reducing the intestinal microbiota.

Effects of dietary wood vinegar on the backfat thickness and lean meat percentage of grower-finisher pigs are shown in Table 4. Dietary inclusion of wood vinegar supplementation failed to affect the BFT and LMP of grower-finisher pigs. To the best of our knowledge, still, now no experiments have been carried out on the effect of wood vinegar supplementation on the backfat thickness and lean meat percentage, especially in grower-finisher pigs. Thus, adequate comparisons could not be made. Generally, meat pH is a direct reflection of muscle acid content and it affects sheer force, drip loss and the colour of the meat (Hossain *et al.*, 2015). In 2017, Balasubramanian and others (Balasubramanian *et al.,* 2017)stated that drip loss was used as the main indicator of higher meat quality. However, in this experiment, pigs fed a diet containing 0.1% wood vinegar supplementation tended to have reduced WHC (P=0.068) and drip loss (P=0.091 and 0.069) on d5 and d7, respectively. Also, the longissimus muscle area was linearly increased (P=0.005) in the wood vinegar supplementation group compared to the control group. In contrast, Yan and others (Yan *et al.,* 2012) stated that dietary inclusion of bamboo vinegar supplementation had no significant effect on longissimus water holding capacity and TBARS values during the whole experiment. Increased carcass weight is one of the methods of increasing the output and efficiency of meat at the stage of production and processing. Most of the consumers demand leaner meat, but nutritional value increasing carcass weight was associated with an increase in carcass fatness. In this trial, the inclusion of dietary wood vinegar supplementation linearly increased the carcass weight (P=0.04). As observed by Stupka and others (Stupka *et al.,* 2008) increased carcass weight may decrease the lean content and from those findings, we assume that the lack of effects on lean meat percentage may be due to the increased carcass weight. However, apart from WHC, drip loss, longissimus muscle and carcass weight no significant (P>0.05) effects were observed in meat color, sensory evaluation, pH, and cooking loss (Table 5) thus future investigation is needed to optimize the level of wood vinegar in the diet of grower-finisher pigs.

CONCLUSION

The dietary supplementation of wood vinegar showed a positive impact on the growth performance and apparent total digestibility of grower-finisher pigs. However, the meat quality traits were partially enhanced thus, further research is needed to determine the optimal level of dietary wood vinegar in the diet of grower-finisher pigs that could improve the meat quality for human consumption as well as to optimize the swine production.

Competing interests

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

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