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Effect of including different levels of moringa (*Moringa oleifera*) leaf meal in the diet of finishing pigs: Performance, pork quality, fatty acid composition, and amino acid profile

*Tingting Zhang [1,2], Bingwen Si [1], Yan Tu [1], Kai Cui [1], Chaolong Zhou [3], Qiyu Diao [1]**

[1]*Feed Research Institute, Chinese Academy of Agricultural Sciences, Key Laboratory of Feed Biotechnology of the Ministry of Agriculture, Beijing, P.R. China*

[2]*Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing, P.R. China*

[3]*Century Love International Investment Group Co. Ltd., Beijing, P.R. China*

**Corresponding author: diaoqiyu@caas.cn*

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Abstract: A total of 144 cross-bred (Duroc × Landrace × Yorkshire) finishing pigs with a similar initial weight (65.4 ± 1.03 kg) were used to investigate the effect of moringa leaf meal on growth performance, meat quality, fatty acid composition, and amino acid profile. The moringa leaf meal-inclusion rates were 0% (M0 or control), 3% (M3), 6% (M6) and 9% (M9). The results showed that supplementing moringa leaf meal significantly increased the daily weight gain of finishing pigs, but had a minor impact on pork quality indicators and the amino acid profile in the *Longissimus dorsi*. The fatty acid profile in the *Longissimus dorsi* was significantly modified when pigs were fed moringa leaf meal diets. The relative percentage of total unsaturated fatty acid and monounsaturated fatty acid was higher in the meat of pigs fed a 6% moringa leaf meal diet than in the meat of those receiving the control diet. In contrast, the percentage of total saturated fatty acids was lower in the meat of pigs fed the moringa leaf meal diets. Moreover, the omega-6/omega-3 ratio decreased with moringa leaf meal supplementation. Addition of the moringa supplement into the diet of pigs improved growth performance and modified pork fatty acid profile positively. The results suggest that moringa leaf meal could be used as a diet supplement for producing healthier pork.

Keywords: pig; *Moringa oleifera*; growth performance; pork quality

Meat is an essential component of a healthy and well balanced diet owing to its properties as a source of high-quality protein, essential fatty acids, high-available iron and B-group vitamins (Biesalski 2005). However, recent studies have established a likely relationship between meat consumption and an increased risk of suffering serious health disorders such as colorectal cancer and coronary-heart diseases (Ferguson 2010). Animal fat and particularly saturated fatty acids (SFA) have been recognized as influential factors in the pathogenesis of heart failure and cancer associated to meat consumption. Besides, a very high omega-6/omega-3 ratio promotes the pathogenesis of many diseases, including cardiovascular disease, cancer, and inflammatory and autoimmune diseases,

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whereas increased levels of omega-3 fatty acids (a lower omega-6/omega-3 ratio) exert suppressive effects (Simopoulos and Cleland 2003). So meat with a lower omega-6/omega-3 ratio is beneficial for human health (Flock and Kris-Etherton 2013). Accordingly, producing high quality meat with a more proper fatty acid composition is important for human health.

Moringa oleifera Lam, commonly referred to as horseradish tree (describing the flavour of its roots) or drumstick tree (describing the shape of its pods), is a member of the Moringaceae family, which is native to the sub-Himalayan tracts of Northwest India, Afghanistan, Bangladesh, and Pakistan. At present, it grows throughout most of the tropics (Makkar and Becker 1996; Soliva et al. 2005). Most reports have indicated that moringa leaves are rich in protein, varying from 179 to 268 g/kg of dry matter (DM) (Reyes-Sanchez et al. 2006; Mendieta-Araica et al. 2009), and have an amino acid composition that is suitable for human and animal nutrition (Makkar and Becker 1996). Furthermore, moringa leaves contain negligible amounts of anti-nutritional factors and substantial amounts of Fe and vitamins A, B and C (Makkar and Becker 1996). In addition, in the last decade, large-scale cultivation of moringa has been initiated, and over 100 t of DM/ha can be achieved under intensive farming conditions (Makkar and Becker 1996). Therefore, there is a need for effective use of the large amount of protein-rich moringa produced.

In recent years, the interest in moringa as a diet component for animal production has received attention. Experiments assessing the effect of the inclusion of moringa leaf meal in the diets of pigs have focused primarily on growth performance while research regarding the effect of moringa leaf meal on pork quality and nutrient composition has been limited (Oduro-Owusu et al. 2015; Serem et al. 2017). The purpose of the present study was to investigate the effects of dietary moringa leaf meal supplementation on growth performance, pork quality, fatty acid composition, and amino acid profiles in finishing pigs.

MATERIAL AND METHODS

Materials. Leaves of *M. oleifera* plants established at Guangdong, southern China (23°8'N, 113°17'E) were harvested at 56 days of growth (8 weeks of age). The leaves were chopped and sun-dried on thick plastic sheets for 3 days, then bagged and stored until used for supplementation. Representative dry samples were ground using a Wiley mill to pass through a 1-mm screen for chemical analysis. The chemical composition, fatty acid and amino acid profiles of moringa leaves are shown in Table 1.

Table 1. Chemical composition, fatty acid and amino acid profiles of moringa leaf meal

Chemical composition		Fatty acids (g/kg DM)	
DM (g/kg air DM)	867	C6:0	0.03
CP (g/kg DM)	253	C10:0	0.02
EE (g/kg DM)	109	C12:0	0.05
NDF (g/kg DM)	484	C14:0	0.52
ADF (g/kg DM)	280	C15:0	0.07
Ash (g/kg DM)	158	C16:0	6.11
GE (MJ/kg)	17.27	C16:1	0.50
		C17:0	0.14
		C18:0	1.30
		C18:1n9c	1.67
		C18:2n6c	2.16
		C18:3n3	6.53
		C20:0	0.36
		C20:1	0.58
		C21:0	0.05
		C20:2	0.05
		C22:0	0.65
		C23:0	0.17
		C24:0	1.20

DM = dry matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fibre, ADF = acid detergent fibre, GE = gross energy

Experimental design, animals and management. All procedures were reviewed and approved by the Laboratory Animal Welfare and Animal Experimental Ethics Committee of the Institute of Feed Research in the Chinese Academy of Agricultural Sciences, Beijing. We used 144 crossbred (Duroc × Landrace × Yorkshire) female finishing pigs with a similar initial weight (65.4 ± 1.03 kg). Pigs were allocated to 24 pens based on their body weight with 6 pigs per pen, and pens were assigned randomly to 4 dietary treatments. Treatments were (1) control diet, (2) diet containing 3% moringa leaf meal, (3) diet containing 6% moringa leaf

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Table 2. Composition of the experimental diets (% air dry matter)

Ingredients	Control	M3	M6	M9
Corn	62.60	62.53	61.50	60.83
Soybean meal	16.72	15.85	14.73	13.80
Wheat bran	15.00	13.50	13.00	12.00
Soybean oil	1.68	1.12	0.77	0.37
Moringa leaf meal	0.00	3.00	6.00	9.00
Vitamin-trace mineral premix [1]	4.00	4.00	4.00	4.00
Chemical composition[2]				
DM	87.63	87.54	87.47	87.39
CP	15.00	15.00	15.00	15.01
EE	4.57	4.22	4.09	3.89
NDF	11.24	11.91	12.79	13.57
ADF	3.67	4.01	4.42	4.79
DE (kcal/kg)	3200	3200	3200	3202

DM = dry matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fibre, ADF = acid detergent fibre, DE = digestible energy, M3 = diet containing 3% moringa leaf meal, M6 = diet containing 6% moringa leaf meal, M9 = diet containing 9% moringa leaf meal

[1]provided the following (unit per kg of diet): Fe 100 mg, Cu 20 mg, Mn 30 mg, Zn 90 mg, Se 0.3 mg, I 0.4 mg, vitamin A 6400 IU, vitamin D_3 2000 IU, vitamin E 30 IU, vitamin K_3 3 mg, vitamin B_1 0.8 mg, riboflavin 5.5 mg, D-pantothenic acid (D-Ca pantothenate) 14 mg, niacin 27 mg, pyridoxine 0.8 mg, D-biotin 0.05 mg, folic acid 0.68 mg, vitamin B_{12} 0.03 mg

[2]chemical composition was calculated based on tabulated composition of individual feedstuffs (based on the database of bestmix formula software); the chemical composition of moringa leaf meal was determined by analysis, and DE was calculated according to the formulas by Noblet and Perez (1993) and Noblet and Shi (1993)

meal, and (4) diet containing 9% moringa leaf meal. All experimental diets were formulated to meet the nutritional requirements of finishing pigs and to be isoenergetic and isonitrogenous. Diet compositions and fatty acid profile are shown in Tables 2 and 3. Pigs were acclimated for 7 days in a temperature-controlled room at the Nanxiaoying Farm (Beijing, China), fed *ad libitum* with the experimental diets, and had unlimited access to clean drinking water. The experiment lasted for 45 days. Individual body weight (BW) of each pig was recorded at the beginning of the experiment and at the end of the study. Feed allotments were recorded daily. The average daily feed intake (ADFI) and average daily gain (ADG) were calculated for the entire experimental period at the conclusion of the experiment. The feed conversion ratio (FCR) was computed as the feed consumed per unit weight gain (F : G).

Slaughter and sampling procedures. At the end of the growth trial, the final pig BW and residue in the feeders were recorded. Then one pig from each pen was randomly selected, fasted overnight, weighed and slaughtered using standard procedures for pig slaughtering in China (GB/T 17236-2008). Just after slaughter, the hot carcasses were weighed and hung in the cooler room (4°C) for 24 h. The pH measurements were performed on the *Longissimus thoracis* (LT) muscle at the 10^{th} rib interface at both 45 min and 24 h postmortem using a portable pH meter (Model 206-pH2, Testo Co., Germany). The LT muscles were then excised from each carcass, and three consecutive chops were taken for subsequent analyses. The first chop was taken to assess water-holding capacity and meat colour. The second chops were wrapped in plastic bags and frozen at –20°C for subsequent meat quality analyses. The remaining chops were placed in liquid N_2 and stored at

Table 3. Fatty acid profile of the experimental diets (% of total fatty acids)

Fatty acid	Control	M3	M6	M9
C10:0	0.43	0.57	0.60	0.60
C12:0	0.16	0.18	0.18	0.19
C14:0	0.08	0.10	0.13	0.16
C15:0	0.04	0.04	0.04	0.05
C16:0	14.43	15.07	15.30	16.11
C16:1	0.13	0.16	0.19	0.23
C17:0	0.10	0.11	0.11	0.12
C18:0	2.70	2.54	2.47	2.33
C18:1n9c	24.51	24.50	24.47	24.43
C18:2n6c	52.42	51.75	51.38	50.63
C18:3n3	3.69	3.58	3.51	3.42
C20:0	0.39	0.41	0.44	0.45
C20:1	0.31	0.31	0.31	0.31
C21:0	0.06	0.05	0.05	0.05
C22:0	0.29	0.31	0.37	0.37
C24:0	0.26	0.32	0.45	0.55

M3 = diet containing 3% moringa leaf meal, M6 = diet containing 6% moringa leaf meal, M9 = diet containing 9% moringa leaf meal

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–80°C for chemical composition, fatty acid and amino acid analysis.

Chemical analyses. The moringa leaf meal was oven-dried at 65°C for 72 h, milled through a 1-mm screen, and analysed for DM, crude protein (CP), ether extract (EE), and ash content according to AOAC methods 930.15, 990.03, 920.39, and 924.05, respectively (AOAC 1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) values were determined using a Model 200 Fiber Analyzer (ANKOM Technology Corp., USA) as described by Van Soest et al. (1991). Gross energy (GE) content was determined using a bomb calorimeter (C200; IKA Works Inc., Germany). Compositional analysis was determined according to AOAC (1996) methods on meat with connective tissue and subcutaneous fat removed. Moisture contents were determined gravimetrically by oven drying (100°C for 24 h). Protein and fat contents of LT were determined by Kjeldahl and ether extraction methods, respectively.

Meat quality. Meat colour was evaluated with a Chroma Meter (Model WSCS, Shanghai Shenguang Ltd., China) previously calibrated against a white tile according to the manufacturer's recommendations. Colour was measured using a Colortec PCM (Clinton, USA), which had a D-65 light font and an observation angle of 10°. The corresponding values were calculated according to the CIE colour scale of lightness (L*), redness (a*), and yellowness (b*) established by the Commission International de l'Eclairage (1976). Measurements were determined in triplicate at three separate locations in the chop. The average of triplicate measurements was the meat colour. Water-holding capacity (WHC) was measured using the modified filter paper press method (Sanudo et al. 1986). Cooking loss was determined using methods described by AOAC (1995). Samples were, then, cut parallel to the muscle fibres into rectangular cross-section slices of 1.0 cm (width) × 1.0 cm (thickness) × 5.0 cm (length). Each sample was then sheared vertically at right angles using a TA.XT Plus/50 texture analyzer (Stable Micro Systems, UK). A crosshead speed of 200 mm/min and a 5-kN load cell calibrated to read over a range of 0 to 100 N were applied. Six replicates of each sample were measured to calculate the average value. The shear forces are expressed in newtons (N).

Fatty acid and amino acid analyses. Moringa leaves and meat samples were analyzed for fatty acid and amino acid profiles. Meat samples were lyophilized (–56°C, 0.145 to 0.133 mbar) to a constant weight using a Modulyo lyophilizer (Edwards High Vacuum International, UK). Total lipid extracts of samples were transmethylated into fatty acid methyl esters (Sukhija and Palmquist 1988), which were analyzed using a Model 6890N gas chromatograph equipped with a flame-ionization detector (Agilent Technologies, USA). The column used for separation of fatty acid methyl esters was a CP-Sil 88 column (100 m × 0.25 nm; Chrompack). Helium was used as the carrier gas (1 ml/min). The injector and detector temperatures were 250°C. The following oven temperature program was used: hold at 45°C for 4 min, and then an increase to 175°C at 13°C/min, hold at 175°C for 27 min, and then an increase to 215°C at 4°C/min, and then hold at 215°C for 35 min. The standard was FAME Mix C4-C24 (Sigma-Aldrich, USA). Individual fatty acid methyl esters were identified by comparing retention times with those of an authentic standard. The concentration of individual fatty acids was quantified according to the peak area and presented as g per 100 g fatty acids (% by weight) for meat samples. The atherogenic index (AI) and thrombogenicity index (TI) were calculated according to Ulbricht and Southgate (1991).

The amino acid composition of meat samples was determined using an automated amino acid analyzer (Hitachi L-8900, Japan) according to AOAC (1995). Each meat sample (100 mg) was hydrolyzed with 10 ml of HCl (6 mol/l) and frozen at –20°C for later analysis. The various amino acids were separated by ion-exchange chromatography using lithium citrate buffers. After post-column derivatization with ninhydrin, the derivatives were detected at 570 and 440 nm. During acid hydrolysis, the tryptophan and sulfur amino acids were disturbed; therefore, tryptophan was determined using an alkaline hydrolysis method and the sulfur-containing amino acids were determined using an oxidation hydrolysis method.

Statistical analysis. Data were analyzed using PROC GLM of SAS software (Statistical Analysis System, Version 9.2) as a randomized complete block design with the pen considered the experimental unit. Treatment differences were tested using LSMeans with the PDIFF option in SAS. Results are reported as Least Squares Means. Orthogonal polynomial contrasts were then used to determine linear and quadratic responses to moringa leaf meal levels. The fatty acid compo-

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Table 4. Effect of the level of moringa leaf meal in the diet offered finishing pigs on growth performance and carcass characteristics

Item	Treatment				SEM	Effect (*P*-value)	
	Control	M3	M6	M9		linear	quadratic
Initial BW (kg)	64.3	65.0	66.6	65.7	1.03	0.20	0.33
Final BW (kg)	108.7^{b}	111.8^{b}	117.4^{a}	111.9^{b}	1.56	0.03	< 0.01
ADG (kg)	0.99^{b}	1.04^{b}	1.13^{a}	1.03^{b}	0.020	0.03	< 0.01
ADFI (kg)	3.19	3.16	3.37	3.52	0.125	0.03	0.08
F : G	3.22^{b}	3.04^{c}	2.98^{c}	3.42^{a}	0.036	0.40	0.03

BW = body weight, ADG = average daily gain, ADFI = average daily feed intake, F : G = ADFI : ADG, M3 = diet containing 3% moringa leaf meal, M6 = diet containing 6% moringa leaf meal, M9 = diet containing 9% moringa leaf meal
^{a,b}means in the same row with different superscripts differ significantly at $P < 0.05$

sition and amino acid profile of LT between the control group and 6% moringa leaf meal-treatment group were compared using the *t*-test. A level of $P < 0.05$ was used as the criterion for statistical significance.

RESULTS

Growth performance. Feed intake and growth performance results are listed in Table 4. ADFI increased linearly ($P = 0.03$) as the content of moringa leaf meal in the diet increased. Final BW and ADG ($P < 0.01$) showed a quadratic response in the pigs receiving moringa leaf meal, which was the highest for the pigs fed 6% moringa leaf meal. The F : G showed a quadratic response with increasing doses of moringa leaf meal ($P = 0.03$), with the lowest F : G observed in the pigs fed 6% moringa leaf meal.

Meat quality. The a* value of meat increased as moringa leaf meal was included in the diet (linear and quadratic, $P < 0.01$), but no difference was observed in the L* or b* value (Table 5). The pH, water loss rate, cooking loss, shear force and chemical composition were unchanged by the addition of moringa leaf to the diet.

Table 5. Effect of the level of moringa leaf meal in the diet offered finishing pigs on meat quality assessed in the *Longissimus thoracis* muscle

Item	Treatment				SEM	Effect (*P*-value)	
	Control	M3	M6	M9		linear	quadratic
pH 45min	6.10	6.12	6.12	6.12	0.036	0.64	0.87
pH 24h	5.66	5.64	5.65	5.64	0.016	0.63	0.87
Water-holding capacity (% of drip loss)	16.2	16.0	16.1	16.2	0.95	0.99	0.99
Cooking loss (%)	32.9	32.8	33.4	33.1	0.68	0.71	0.93
Shear force (N/cm^2)	33.5	33.9	34.6	33.7	1.23	0.81	0.86
Meat colour							
L*	41.9	40.3	42.4	41.3	0.73	0.92	0.95
a*	2.94^{b}	4.17^{a}	4.20^{a}	4.26^{a}	0.269	< 0.01	< 0.01
b*	6.98	7.08	7.30	7.16	0.220	0.45	0.65
Chemical composition							
Moisture (%)	71.3	71.1	71.5	71.4	0.67	0.83	0.90
Fat (%)	2.08	2.02	2.06	2.12	0.10	0.91	0.86
Protein (%)	22.7	23.1	22.7	23.0	0.44	0.87	0.92

M3 = diet containing 3% moringa leaf meal, M6 = diet containing 6% moringa leaf meal, M9 = diet containing 9% moringa leaf meal
^{a,b}means in the same row with different superscripts differ significantly at $P < 0.05$

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Table 6. Effect of including 6% moringa leaf meal (M6) in the diet offered finishing pigs on the fatty acid profile of the *Longissimus thoracis* muscle (% of total fatty acids)

Item	Treatment		SEM	*P*-value
	Control	M6		
C8:0	0.018	0.021	0.0030	0.46
C10:0	0.120	0.099	0.0050	0.03
C12:0	0.097	0.070	0.0045	< 0.01
C14:0	1.62	1.05	0.041	< 0.01
C14:1	0.020	0.014	0.0018	0.07
C15:0	0.056	0.071	0.0075	0.23
C16:0	25.05	22.78	0.229	< 0.01
C16:1	2.67	2.51	0.115	0.36
C17:0	0.527	0.402	0.0340	0.045
C18:0	12.62	12.35	0.207	0.40
C18:1n9c	37.44	40.76	0.779	0.03
C18:2n6c	14.53	13.90	0.653	0.54
C18:3n6	0.126	0.143	0.0130	0.39
C18:3n3	0.618	0.690	0.0215	0.06
C20:0	0.215	0.214	0.0150	0.99
C20:1	0.679	0.727	0.0330	0.35
C21:0	0.606	0.627	0.0235	0.57
C20:3n6	0.294	0.352	0.0460	0.42
C20:4n6	1.95	2.34	0.389	0.52
C20:3n3	0.115	0.128	0.0020	0.04
C20:5n3	0.066	0.083	0.0065	0.03
C22:0	0.043	0.049	0.0075	0.58
C22:1n9	0.029	0.035	0.0023	0.13
C23:0	0.024	0.029	0.0035	0.40
C24:0	0.279	0.345	0.0445	0.35
C22:6n3	0.111	0.106	0.0185	0.87
C24:1	0.070	0.123	0.0345	0.34
TUFA	58.73	61.91	0.354	< 0.01
TSFA	41.27	38.09	0.354	< 0.01
PUFA	17.81	17.75	1.010	0.97
MUFA	40.91	44.16	0.815	0.03
Total n-3 PUFA[1]	0.911	1.008	0.030	0.03
Total n-6 PUFA[2]	16.90	16.74	0.965	0.91
n-6/n-3[3]	18.60	16.58	0.010	0.02
AI	0.539	0.437	0.008	< 0.01
TI	1.241	1.079	0.019	< 0.01

M6 = diet containing 6% moringa leaf meal, TUFA = total unsaturated fatty acids, TSFA = total saturated fatty acids, PUFA = polyunsaturated fatty acids, MUFA = monounsaturated fatty acids, AI = atherogenic index, TI = thrombogenicity index

[1]∑C18:3n3 + C20:3n3 + C20:5n3 + C22:6n3

[2]∑C18:2n6c + C18:3n6 + C20:3n6 + C20:4n6

[3]n-6/n-3 = ∑n-6/∑n-3

AI and TI were calculated according to the formulas in Ulbricht and Southgate (1991)

Fatty acid composition and amino acid profile. The fatty acid composition of LT was significantly affected by the inclusion of 6% moringa leaf meal in the diet of pigs (Table 6). The relative percentages of C18:1n9c, C20:3n3, C20:5n3, and the total n-3 polyunsaturated fatty acids (PUFA) increased ($P < 0.05$); those of C14:1 ($P = 0.07$) and C18:3n3 ($P = 0.06$) tended to increase; and the concentrations of C10:0, C12:0, C14:0, and C16:0 decreased in the meat of pigs fed the 6% moringa leaf meal diet. Consequently, the relative percentage of total unsaturated fatty acid (TUFA) and monounsaturated fatty acid (MUFA) was higher ($P < 0.05$) in the meat of pigs fed the 6% moringa leaf meal diet than in the meat of those fed the control diet. In contrast, the percentage of total saturated fatty acid (TSFA) decreased ($P < 0.05$) in the meat of pigs fed 6% moringa leaf meal. In addition, the total n-3 PUFA increased and the n-6/n-3 ratio decreased when 6% moringa leaf meal was added to the diet. Besides, the AI and TI both decreased ($P < 0.05$) in the meat of pigs fed the 6%

Table 7. Effect of including 6% moringa leaf meal (M6) in the diet offered finishing pigs on the amino acid profile of the *Longissimus thoracis* muscle (g/kg dried meat)

Item	Treatment		SEM	*P*-value
	Control	M6		
Essential amino acids				
Arg	48.7	48.4	1.18	0.89
His	35.4	35.1	0.76	0.76
Met	24.2	26.1	0.89	0.20
Ile	32.7	32.5	0.90	0.87
Leu	63.4	62.8	1.74	0.84
Lys	72.8	72.4	1.92	0.88
Phe	31.4	31.3	0.80	0.94
Thr	37.7	37.2	1.02	0.72
Trp	10.1	9.90	0.25	0.66
Val	36.1	35.9	0.94	0.88
Non-essential amino acids				
Ala	46.2	46.2	1.04	0.99
Asp	74.8	74.5	1.96	0.90
Glu	114.6	112.0	3.26	0.61
Gly	34.5	34.7	0.56	0.76
Pro	32.2	31.8	0.69	0.72
Ser	32.4	32.0	0.85	0.72
Tyr	28.2	27.9	0.78	0.84
Cys	8.3	8.4	0.22	0.78

M6 = diet containing 6% moringa leaf meal

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moringa leaf meal diet. The amino acid profile of the LT muscle is presented in Table 7. None of the amino acids were significantly affected by the addition of 6% moringa leaf meal ($P > 0.05$).

DISCUSSION

Growth performance. In the present study, the ADFI increased in the pigs receiving moringa leaf meal, suggesting that diets containing moringa leaf meal may be more palatable than the control diet. It is consistent with the report of Mukumbo et al. (2014) who observed increased feed intake in pigs supplemented with moringa leaf meal in diets. However, different results were observed by Serem et al. (2017) and Oduro-Owusu et al. (2015), in which the ADFI unchanged and decreased, respectively. Differences in the response of feed intake to moringa leaf meal supplementation among these studies might have been related to the differences in levels of moringa leaf meal. In the present study, the final BW and ADG increased in the pigs receiving moringa leaf meal, and were the highest for the pigs fed 6% moringa leaf meal. Similar results were observed by Oduro-Owusu et al. (2015) and Serem et al. (2017), and in these studies, the ADG was also increased by the inclusion of moringa leaf meal in the diets of pigs. However, limited information is available about the mechanisms underlying the increased growth rate in finishing pigs. Future studies are necessary to study the mechanisms underlying the effect of moringa leaf meal on the growth performance of finishing pigs. Besides, supplementing moringa leaf meal in the diet significantly decreased the F : G ratio, with the lowest value observed in the 6% group. This observation demonstrates that moringa leaf meal is an excellent feed ingredient for pigs and an inclusion rate of 6% moringa leaf meal in the diet was the most suitable level for the finishing pigs under the current experimental conditions.

Meat quality. Table 3 shows that animals in all experimental groups produced meat classified as normal, with initial pH above 5.8, final pH below 6.0, and L* value between 40 and 49 (Warner et al. 1997). In this study, the moringa leaf meal had only a minor impact on meat-quality indicators. One exception was the a* value of meat. The meat from the pigs fed moringa leaf meal appeared to be more red in colour. The other parameters analyzed such as pH, water loss, cooking loss, and shear force were similar between the experimental groups. The lack of difference in shear force following different dietary treatments indicated that all animals were in good condition prior to slaughter and that this resulted in the normal development of pH and water-holding characteristics. The influence of dietary moringa leaf meal on meat quality has not been previously studied, but the results of this study indicate that it has a limited influence on meat quality. Similarly, in the present study, no differences were observed in the meat chemical composition of pigs fed diets containing different levels of moringa leaf meal. This could be chiefly attributed to the isonitrogenous and isoenergetic diets that were used in our study.

Fatty acid composition and amino acid profile. The meat fatty acid profile was significantly affected by the inclusion of moringa leaf meal in the diets of pigs. The relative percentage of TUFA and MUFA was higher in the meat of pigs fed the 6% moringa leaf meal diet than in the meat of those fed the control diet. In contrast, the percentage of TSFA decreased in the meat of pigs fed the diet containing 6% moringa leaf meal. An increased content of TUFA in pig meat due to the supplementation of feed with plant extracts was also found in the previous studies (Habeanu et al. 2009; Hanczakowska et al. 2015). According to Wood and Enser (1997), antioxidant supplements in fatteners' feed can improve the fatty acid pattern of meat. Phenolic compounds are the main active components of moringa leaves (Makkar and Becker 1997) and are mainly responsible for their antioxidant activity (Wei and Shibamoto 2007). The increased TUFA content in total meat fatty acids observed in pigs fed diets containing 6% moringa leaf meal is important for both human and animal health. Schwingshackl and Hoffmann (2014) suggested that dietary advice should focus on promoting a higher intake of omega-3 PUFAs, rather than UFAs in general, as a substitute for SFAs. Excessive amounts of omega-6 PUFAs and an imbalanced n-6/n-3 ratio promote the pathogenesis of many chronic diseases, including cardiovascular disease, inflammation, autoimmune diseases and cancer (Simopoulos 2008). Therefore, omega-6 and omega-3 PUFAs must be consumed in an appropriate ratio to promote good health and normal body development. In the present

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study, the moringa leaf meal decreased the n-6/n-3 ratio in pork, which is considered beneficial for consumers.

The amino acid composition of pork from pigs fed a diet containing moringa leaf meal has not been previously reported. In this study, 6% moringa leaf meal did not change the amino acid profile of the LT muscle tissue of pigs, indicating that the two groups tested had similar amino acid profiles in this tissue. Feeding pigs the moringa leaf meal, therefore, did not adversely affect the amino acid profile of pork.

The data generated in the present study indicate that pork from pigs fed moringa leaf meal is a good meat product for human consumption when considering the increased UFA content and the reduced n-6/n-3 fatty acids ratio. Pork does not rival the n-3 fatty acids content of fish meat. However, it is possible that an ideal feed mixture may enable the production of healthier pork containing higher levels of n-3 fatty acids.

CONCLUSION

The results obtained in this investigation suggest that including moringa leaf meal in the diet of finishing pigs could be an efficient feeding strategy to promote the use of the large supply of moringa leaf meal. Our findings reveal that the inclusion of 6% moringa leaf meal improves growth performance parameters, with limited effects on meat characteristics. Meat fatty acid profiles were positively modified in pigs fed 6% moringa leaf meal, as the relative percentage of TUFA increased and that of TSFA decreased. In addition, feeding pigs a diet containing 6% moringa leaf meal reduced the n-6/n-3 ratio in the LT tissue, which is critical for optimizing the dietary balance between n-6 and n-3 fatty acids. Healthier meat is a broader strategy for increasing the n-3 intake of humans rather than relying only on fish resources, which are already overexploited.

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