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Effects of Mineral Methionine Hydroxy Analog Chelate in Diets on Meat Quality, Muscular Amino Acids and Fatty Acids in Pigs

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ABSTRACT

Background: Organic trace minerals can improve the improve the bioavailability and reduce the environmental pollution, but the effect of organic trace minerals on meat quality of pigs are still unclear.

Methods: Adult healthy 33.68 kg pigs (n=253) were randomly allotted to six dietary treatments, with 6 pens per treatment and 7-8 pigs per pen in a completely randomized design: 1) ITM: inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, Fe, Mn and Zn in sulfate form; 2) T1: ITM was replaced with 20% mineral methionine hydroxy analog chelate (MMHAC); 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

Result: In the present study, shoulder fat thickness, the 6th to 7th rib fat thickness (P<0.05), the 10th rib fat thickness, the last rib fat thickness and lumbosacral fat thickness tended to decrease with the increase of the MMHAC. In addition, MMHAC increased pH by 1.05~3.68% and reduced drip loss by 5.08~19.77% and cooking loss by 2.67~7.67% compared with the ITM group. Furthermore, MMHAC reduced methionine by 3.51~7.02%, phenylalanine by 1.14~3.41%, arginine by 1.52~3.79% compared with ITM group. Our results showed that MMHAC improved carcass traits, meat quality and meat flavor partly compared with the ITM group.

Key words: Amino acid, Chelated minerals, Fatty acid, Meat quality, Pigs.

INTRODUCTION

Trace minerals participate in biological metabolism processes in animals as cofactors of enzymes or catalyzers, which are vital for maintaining normal physiological function and health (Liu *et al*., 2014). Higher trace minerals supplementation can affect feed intake and improve growth performance by regulation of growth factors or nutrient digestibility (Mondal *et al*., 2010). However, evidence showed excessive intake of trace minerals in animals will lead to increase in fecal trace minerals, which not only causes environmental pollution but also affects human health through ecological cycles (Ohki, 1984). The use of organic trace minerals increases the bioavailability of microminerals, improves health of animals and reduces environmental pollution (Zhang *et al*., 2021). Min *et al*. (2018) showed zinc-methionine hydroxy analog chelate (Zn-MHAC) could improve eggshell quality and promoting Zn and calcium (Ca) deposition in eggshells in laying hens. Ren *et al*. (2021) founded that Cu-MHAC led to greater growth rate in nursery pigs than $CuSO_4$ in the presence of phytase supplementation. In addition to consideration in animal health, it is important to consider the effects of trace minerals on meat quality as consumers are increasingly concerned about the nutritional value and sensory value of pork. The composition of amino acids and fatty acids are critical factors that affect meat quality, such as firmness, flavor and muscle color (Yin *et al*., 2017), but less is known about the effects of organic trace minerals on meat quality. Therefore, this study aimed to evaluate the effects of mineral methionine hydroxyl analogue chelate (MMHAC) on carcass trait and meat quality in pigs.

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MATERIALS AND METHODS

The present experiment was conducted at the FengNing Swine Research Unit of China Agricultural University (Fengning, Hebei, China). This study was performed in line with the Laboratory Animal Welfare and Use Committee of China Agricultural University (Beijing, China; No. AW40801202-1-1). A total of 253 Duroc × Landrace × Yorkshire pigs (initial body weight (BW) 33.68 kg) were used in this study. Pigs were housed in pens with slatted floors and had free access to drinking water and feed during the entire experimental period. A three-phase feeding program (days 0-35, 36-70, 71-91) was used in the present study. The MMHAC is purchased from the Changsha Xinjia Bio-Engineeriong Co.,Ltd and the relevant information is shown in Table 1.

Pigs were allotted to six dietary treatments according to a randomized complete block design, with 6 pens per treatment and 7-8 pigs per pen. A basal diet for each phase was formulated to meet the nutrient requirements based on the nutrient recommendations from the National Research Council (NRC, 2012), with the exception of trace minerals (Table 2). In addition, the supplemental levels and measured levels of microminerals are shown in Table 3. The protocol of treatments was as follows: 1) ITM: inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, Fe, Mn and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

After fasting for 12 h, one pig per pen closing to average body weight was selected to slaughter. The carcass weight was recorded immediately after slaughter to calculate the dressing percentage:

$$\text{Dressing percentage} = \frac{\text{Carcass weight}}{\text{Live weight}} \times 100$$

The left longissimus thoracis (LT) between the 10th and 12th were taken, frozen in liquid nitrogen and stored at -80°C refrigerator until analysis.

Backfat thickness was measured at the 6th to 7th rib, shoulder, lumbar, 10th rib and the last rib. The formula is as follows:

Loin eye area (cm^2) =

The length of loin eye (cm) × The width of loin eye (cm) × 0.7

The meat color of the LT was measured using the color meter (CR410, Minolta, Japan), 45 min after slaughter. The pH was measured using the pH meter (DK-2730, SFK-Technology, Denmark), 24 h after slaughter. Approximately 100 g LT was put into sealed plastic bags and suspended for 24 h at 4°C to calculate the drip loss based on the meat weight difference before and after suspension. Approximately 1 cm thick 100 g of LT was placed in a sealed bag in a 70°C water bath for 20 min and then the cooking loss was calculated based on the weight of LT before and after cooking. Moreover, the Instron machine (C-LM3B, Tenovo, Haerbing) was used to determine the shear force following the instruction. Approximately 20 g of LT was processed in a vacuum freeze dryer (Model 4.5, Labconco Corp, SA), lyophilized and then pulverized. Intramuscular fat (IMF) content was determined by the Soxhlet extraction.

Free amino acids (FAA) were analyzed following the method of Yin *et al.* (2016) and as follows: the LT samples (0.3 g) were mixed with 8 μL internal standard (2.5 mM D-Phe) and 5 mL methyl alcohol/water (8/2). The above-mixed liquor was treated with ultrasound for 5 min and left for 1 min at room temperature, repeat 6 times. Then, the

Table 1: Relevant information of methionine hydroxyl analogu chelated microminerals.

Microminerals	Micromineral content (%)	Hydroxy methionine (%)	Chelation rate (%)	Stability constant (lgK)	Carrier (%)
Cu-MHAC	12	28	99.4	5.2	60
Fe-MHAC	12	33	94.0	4.8	55
Mn-MHAC	12	28	94.3	5.8	60
Zn-MHAC	12	33	95.5	5.0	55

Cu-, Fe-, Mn-, Zn-MHAC are methionine hydroxyl analogue chelated-Cu, -Fe, -Mn and -Zn.

Table 2: Composition of basal experimental diets (as-fed basis).

Items	Phase 1 (day 0-35)	Phase 1 (day 36-70)	Phase 1 (day 71-91)
Ingredients, %			
Corn	71.12	76.06	79.96
Soybean meal	22.05	16.25	11.68
Wheat bran	2.00	3.00	4.00
Soybean oil	1.07	1.13	1.12
Dicalcium phosphate	1.30	0.90	0.70
Limestone	0.67	0.82	0.80
Salt	0.30	0.30	0.30
L-Lysine-HCl	0.59	0.60	0.55
DL-Methionine	0.10	0.09	0.07
L-Threonine	0.26	0.29	0.26
L-Tryptophan	0.04	0.06	0.06
Vitamin premix[a]	0.10	0.10	0.10
Mineral premix[b]	0.40	0.40	0.40
Total	100.00	100.00	100.00
Calculated nutrient composition			
ME, Kcal/kg	3300.24	3300.23	3300.38
Crude protein, %	16.69	14.75	13.13
Ca, %	0.66	0.59	0.52
Available P	0.31	0.27	0.24
SID[c] Lysine	1.12	0.97	0.84
SID Methionine	0.32	0.28	0.25
SID Threonine	0.72	0.64	0.56
SID Tryptophan	0.19	0.17	0.15

[a]Supplied the following nutrients per kilogram of diets: vitamin A, 6000 IU; vitamin D_3, 2400 IU; vitamin E, 21.6 IU; vitamin K_3, 2 mg; vitamin B_{12}, 12 μg; riboflavin, 5.2 mg; pantothenic acid, 11.2 mg; niacin, 22 mg; choline chloride, 400 mg; folacin, 0.4 mg; vitamin B_1, 0.96 mg; vitamin B_6, 2 mg; biotin, 0.04 mg. [b] The trace mineral premix supplied the following nutrients per kilogram of diets: Cu, Fe, Mn and Zn according to the protocol of treatments; I, 0.5 mg as ethylenediamine dihydriodide; Se, 0.3 mg as sodium selenite; phytase, 100 mg. [c] SID standardized ileal digestible. The protocol of treatments: 1) ITM: inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, iron (Fe), manganese (Mn) and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC. MMHAC: mineral methionine hydroxy analog chelate.

samples were placed on ice for 2 h, centrifuged at 9,000 g for 10 min at 4°C and collected the supernatant. The supernatant (400 μL) was dried in a vacuum compressor and then redissolved with 100 μL of borate buffer. The redissolved samples (10 μL) were added with 50 μL borate buffer and 20 μL derivative reagent, mixed immediately and heated at 55°C for 10 min. After cooling, the solution was transferred to the high performance liquid chromatograph (Waters ACQUITY UPLC I-Class, Waters Co., Ltd, USA) and high-resolution mass spectrometer (Q-Exactive, Thermo Fisher Co., Ltd, USA) to analyze the amino acids.

The LT samples (150 mg) were mixed with 4 mL chloroacetyl/methanol (1/10), 1 mL normal hexane and 1 mL internal standard (1 mg/mL 11 carbon-fatty acid methyl ester) in the glass tube, then heated for 2.5 h at 75°C. After cooling, the solution was mixed with 5 mL 7% K_2CO_3, centrifuged for 3 min at 900 g. The supernatant was transferred to the gas chromatograph (Agilent Technologies Inc, Santa Clara, Canada) for analysis.

Individual pig was the experimental unit and was analyzed as a randomized complete block design by the GLM model of SAS 9.4 (SAS Institute, Cary, NC). Statistical differences were determined using the Tukey's multiple range test. Significant differences were identified at $p<0.05$.

RESULTS AND DISCUSSION

Carcass traits

The effects of MMHAC on carcass traits of pigs were shown in (Table 4). There were no differences among the six different treatments on carcass weight, dressing percentage and loin eye area. However, shoulder fat thickness, the 6th to 7th rib fat thickness ($P<0.05$), the 10th rib fat thickness, the last rib fat thickness, lumbosacral fat thickness decreased with the increase of MMHAC.

As the cofactors for antioxidative enzymes, dietary trace minerals are very important for the carcass traits and meat quality. Wen *et al*. (2019) reported that the weight of slaughtered, carcass, eviscerated and the yield of breast or leg muscle were increased with the dietary zinc supplementation in Pekin ducks, this is mostly because Zn activates skeletal muscle protein synthesis and promotes myogenic cell proliferation through the mechanistic target of rapamycin (mTOR) pathway (Ohashi *et al*., 2015). However, our results showed that carcass weight, dressing percentage and loin eye area were not affected by the source or level of trace mineral, we speculate that the protein anabolism is not affected under dietary Zn is sufficient. Sirri *et al*. (2016) reported that different levels of dietary Zn, Cu and Mn did not affect carcass yield and meat quality for

Table 3: The supplemental levels and measured levels of trace minerals.

Micromineral		ITM	T1	T2	T3	T4	MHA-M
Cu (mg/kg)	Adding level	20	4	8	12	16	20
	Analyzed level	29.14	8.87	14.02	19.34	27.02	30.1
Fe (mg/kg)	Adding level	100	20	40	60	80	100
	Analyzed level	263.6	179.9	199	211.4	220.3	246.7
Mn (mg/kg)	Adding level	40	8	16	24	32	40
	Analyzed level	66.5	33.14	40.47	54.39	59.14	68.65
Zn (mg/kg)	Adding level	60	12	24	36	48	60
	Analyzed level	102.89	43.31	58.32	73.95	93.07	115.05

MMHAC: Mineral methionine hydroxy analog chelate. ITM: Inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, iron (Fe), manganese (Mn) and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

Table 4: Effect of MMHAC on carcass traits of longissimus thoracis in pigs.

Item	ITM	T1	T2	T3	T4	T5	SEM	*P*-value
Carcass weight, kg	76.65	76.17	79.12	77.92	75.25	77.28	1.258	0.972
Dressing percentage, %	71.27	69.53	72.65	71.54	71.45	71.57	0.329	0.195
Back fat depth, mm								
Shoulder fat thickness	25.17	25.82	25.58	25.77	23.99	23.02	0.883	0.934
The 6th to 7th rib fat thickness	19.90^{a}	20.34^{a}	20.33^{a}	19.47^{ab}	15.85^{c}	15.87^{bc}	0.488	<0.001
The 10th rib fat thickness	15.54	13.92	15.50	15.17	15.18	13.56	0.512	0.829
The last rib fat thickness	14.21	14.08	15.91	15.44	14.10	12.51	0.631	0.731
Lumbosacral fat thickness	8.39	7.25	8.12	8.31	7.37	7.63	0.319	0.862
Loin eye area, cm^2	35.95	35.67	35.53	34.40	35.59	35.72	1.468	1.000

$^{a-c}$ Values within a row with different superscripts differ significantly at $p<0.05$. MMHAC: Mineral methionine hydroxy analog chelate. ITM: Inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, iron (Fe), manganese (Mn) and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

broilers, which is in agreement with our results. However, as the level of organic trace mineral in the diet increases, back fat depth in pigs decreases in the present study, which may be due to the effect of trace minerals on lipid deposition. Furthermore, T5 group could reduce the back fat depth compared with the ITM group in various degree. Chen *et al.* (2018) reported that dietary Cu could reduce the triacylglycerol storage by suppressing lipogenesis and lipid absorption and accelerating lipid transport, which explained our results.

Meat quality

The effects of MMHAC on meat quality of pigs were shown in (Table 5). There were no differences among the six different treatments on lightness, redness and yellowness, flesh color score, shear force and IMF in the LT, while MMHAC increased pH by 1.05~3.68% and reduced drip loss by 5.08~19.77% and cooking loss by 2.67~7.67% compared with the ITM group.

The sensory qualities of the meat include meat color, flavor, tenderness, multiplicity and water-holding capacity (WHC). Meat color is generally used as an indicator of pork freshness and to estimate the incidence of pale, soft and exudative state of meat (PSE) and is related to deoxymyoglobin content (Phung, 2012). In our current study, there were no differences among different treatments on lightness, redness and yellowness. Shear force is a reliable indicator for meat tenderness (Destefanis *et al.*, 2008). Yang *et al.* (2011) showed that the shear force decreases with the decrease of Cu and Fe concentration, but increased with the decrease of Zn concentration in the diet, but sources

Table 5: Effect of MMHAC on quality traits of longissimus thoracis in pigs.

Item	ITM	T1	T2	T3	T4	T5	SEM	*P*-value
Lightness, ΔL*	50.00	49.61	51.01	51.36	49.44	50.92	0.443	0.759
Redness, Δa*	18.25	18.35	17.62	17.71	18.39	17.93	0.187	0.727
Yellowness, Δb*	-0.10	0.45	1.06	0.29	-0.05	0.90	0.151	0.163
pH	5.70	5.76	5.82	5.80	5.91	5.88	0.030	0.388
Flesh color score	1.48	1.46	1.50	1.60	1.45	1.46	0.036	0.955
Drip loss, %	1.77	1.42	1.67	1.68	1.43	1.49	0.108	0.938
Cooking loss, %	31.83	30.98	30.53	30.87	29.44	29.39	0.343	0.428
Shear force, N	60.76	60.82	62.59	61.61	65.82	61.25	1.831	0.961
Intramuscular fat, %	2.35	2.42	2.26	2.34	2.37	2.43	0.086	0.996

MMHAC: Mineral methionine hydroxy analog chelate. ITM: Inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, iron (Fe), manganese (Mn) and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

Table 6: Effect of MMHAC on free amino acids following hydrolysis of longissimus thoracis in pigs (g/100 g muscle based on wet weight).

Item	ITM	T1	T2	T3	T4	T5	SEM	*P*-value
Aspartic acid	1.94	1.92	1.86	1.87	1.87	1.91	0.011	0.269
Threonine	0.98	0.98	0.95	0.95	0.95	0.97	0.005	0.429
Serine	0.79	0.79	0.77	0.77	0.77	0.78	0.004	0.497
Glutamic acid	3.00	2.99	2.90	2.93	2.91	2.97	0.018	0.481
Proline	0.89	0.89	0.85	0.85	0.88	0.88	0.007	0.500
Glycine	0.86	0.87	0.82	0.84	0.85	0.86	0.010	0.200
Alanine	1.14	1.13	1.09	1.10	1.12	1.13	0.007	0.295
Cystine	0.25	0.25	0.23	0.24	0.24	0.24	0.002	0.208
Valine	1.01	1.01	0.97	0.97	0.97	1.00	0.007	0.255
Methionine	0.57	0.55	0.53	0.54	0.56	0.56	0.003	0.046
Isoleucine	1.00	0.99	0.95	0.96	0.95	0.99	0.007	0.126
Leucine	1.73	1.71	1.67	1.67	1.67	1.71	0.011	0.382
Tyrosine	0.68	0.68	0.66	0.65	0.66	0.66	0.004	0.381
Phenylalanine	0.88	0.87	0.85	0.85	0.85	0.87	0.005	0.277
Histidine	1.03	1.03	0.99	1.00	0.96	1.01	0.010	0.364
Lysine	1.90	1.88	1.83	1.84	1.84	1.88	0.012	0.439
Arginine	1.32	1.30	1.27	1.27	1.29	1.30	0.008	0.284
Tryptophan	0.27	0.26	0.25	0.26	0.26	0.26	0.002	0.043

MMHAC: Mineral methionine hydroxy analog chelate. ITM: Inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, iron (Fe), manganese (Mn) and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

and supplemental levels of trace elements did not affect the shear force in the present study, this may be due to the interaction of Cu, Fe and Zn. WHC refers to the ability of muscle tissue to maintain water, which is closely related to the flavor and taste of pork but also related to the shelf life and processing performance of fresh meat. A rapid drop in pH due to the accumulation of lactic acid by glycogenolysis in muscle tissue after slaughter reduces protein solubility and reduces the ability to absorb water (Lesiów and Xiong, 2013). Compared with the ITM group, organic trace minerals decreased the drip loss and cooking loss, increased the pH value in the present study. Wen *et al*. (2019) reported that the 24-h postmortem pH values in duck breast meat were increased with zinc supplementation, these results showed Zn could improve WHC by increasing the pH value, which is in agreement with our results.

Free amino acids of longissimus thoracis

The effects of MMHAC on free amino acids in pigs were shown in (Table 6). There were no significantly differences among the six different treatments were observed in the concentrations of amino acids in LT. However, MMHAC reduced methionine by 3.51~7.02%, phenylalanine by 1.14~3.41%, arginine by 1.52~3.79% compared with ITM group.

The intramuscular content of free amino acids is regarded as being a crucial indicator of meat flavor. Lorenzo and Franco have reported the sensory properties of free amino acids (Lorenzo and Franco, 2012): glutamic acid and aspartic acid as flavor amino acids; glycine, alanine and serine as sweet amino acids; methionine, valine, histidine, phenylalanine, arginine, leucine and isoleucine as bitter amino acids; proline and lysine showing sweet or bitter; other amino acids showing sour or salty taste. In the present study, MMHAC reduced methionine by 3.51~7.02%, phenylalanine by 1.14~3.41%, arginine by 1.52~3.79% compared with ITM group, which showed MMHAC could improve meat flavor by reducing the content of bitter amino acids. However, the effect of trace elements on muscle amino acids has not been reported before, the mechanism needs to be further research.

Table 7: Effect of MMHAC on long-chain fatty acids profile of longissimus thoracis in pigs (% total fatty acids).

Item	ITM	T1	T2	T3	T4	T5	SEM	*P*-value
C10:0	0.10	0.10	0.10	0.09	0.09	0.11	0.004	0.987
C12:0	0.08	0.09	0.08	0.07	0.09	0.10	0.005	0.588
C14:0	1.12	1.13	1.08	1.12	1.06	1.16	0.077	0.995
C14:1	0.02	0.02	0.02	0.02	0.02	0.02	0.004	0.431
C15:0	0.03	0.03	0.03	0.03	0.04	0.03	0.001	0.559
C16:0	21.20	20.78	20.78	20.32	20.14	21.55	1.279	0.878
C16:1	2.26	2.38	2.22	2.23	2.30	2.31	0.159	0.999
C17:0	0.18	0.19	0.18	0.17	0.19	0.18	0.007	0.983
C18:0	12.45	12.04	12.05	12.25	12.84	12.57	0.751	0.999
C18:1n9c	32.70	32.11	31.99	31.80	31.54	31.25	2.151	0.999
C18:2n6c	8.50	10.13	8.37	8.58	10.16	9.07	0.324	0.342
C18:3n3	0.32	0.37	0.32	0.33	0.34	0.33	0.022	0.960
C20:0	0.21	0.21	0.20	0.20	0.20	0.23	0.013	0.943
C21:0	0.34	0.37	0.34	0.32	0.31	0.36	0.018	0.821
C20:3n6	0.20	0.23	0.20	0.22	0.22	0.21	0.004	0.254
C20:4n6	1.61	1.63	1.60	1.57	1.65	1.59	0.033	0.909
C20:3n3	0.08	0.09	0.08	0.06	0.09	0.09	0.004	0.081
C22:0	0.06	0.06	0.06	0.06	0.06	0.06	0.001	0.264
C20:5n3	0.06	0.07	0.06	0.06	0.06	0.06	0.001	0.183
C24:0	0.05	0.05	0.05	0.05	0.05	0.05	0.001	0.788
C24:1	0.09	0.10	0.09	0.09	0.10	0.10	0.003	0.793
C22:6n3	0.11	0.12	0.09	0.09	0.10	0.10	0.003	0.265
SFA	35.59	35.06	34.92	34.80	34.13	36.32	1.612	0.999
MUFA	32.04	32.99	31.70	30.91	30.49	33.64	1.716	0.745
PUFA	10.81	12.56	10.58	10.24	11.82	10.03	0.275	0.043
n-6 pUFA	10.25	12.08	10.04	10.37	12.03	10.74	0.281	0.274
n-3 pUFA	0.60	0.64	0.57	0.49	0.57	0.60	0.026	0.597
n-6/n-3	18.47	18.16	18.71	19.78	18.10	18.09	0.308	0.830

MMHAC: Mineral methionine hydroxy analog chelate. ITM: Inorganic trace minerals with 20, 100, 40 and 60 mg/kg of Cu, iron (Fe), manganese (Mn) and Zn in sulfate form; 2) T1: ITM was replaced with 20% MMHAC; 3) T2: ITM was replaced with 40% MMHAC; 4) T3: ITM was replaced with 60% MMHAC; 5) T4: ITM was replaced with 80% MMHAC; 6) T5: ITM was replaced with 100% MMHAC.

Fatty acid profiles of longissimus thoracis

The effects of MMHAC on long-chain fatty acids profile in pigs were in (Table 7). There were no differences among the six different treatments in the long-chain fatty acids profile. The previous study demonstrated that IMF and fatty acid composition are influenced by environmental or genetic factors, such as dietary composition, age, genotype, gender (Jeong *et al*., 2010). In our study, IMF and fatty acid composition in the pigs were not affected by the dietary trace minerals.

CONCLUSION

In conclusion, our results show that MMHAC could improve the carcass traits by reducing the back fat depth. Additionally, MMHAC could improve the meat quality through increasing the pH value, reducing the drip loss and cooking loss, improve meat flavor by decreasing the content of methionine, phenylalanine and arginine compared with inorganic trace minerals in various degree.

Conflict of interest: None.

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