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The effect of supplemental manganese in broiler diets on abdominal fat deposition and meat quality☆

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Abstract

An experiment was conducted using a total of 288 day-old Arbor Acres male broilers to study the effect of supplemental manganese (Mn) levels on carcass traits, meat quality and relative enzyme activities in the abdominal fat and meat. Birds were randomly allotted by body weight to one of six treatments (eight replicate cages of six chicks per cage) in a completely randomized design. Broilers were fed on Mn-unsupplemented maize–soybean meal basal diets containing 9.5 g Ca/kg and 22.74 mg Mn/kg for the first phase of 21days and adjusted to 8.8 g Ca/kg and 18.86 mg Mn/kg for a second phase of 21days (42days total), or fed basal diets supplemented with 100, 200, 300, 400 or 500 mg/kg Mn as Mn sulphate ($MnSO_4 \cdot H_2O$) for the duration of the 42 days. The supplemental Mn level had no effect (P>0.05) on the dressing percentage, the percentage of breast or leg muscles, water-holding capacity, L^* value, a^* value, shear force, and intramuscular fat in breast and leg muscles. Additionally, the supplemental Mn level did not influence (P>0.05) pH values in leg muscles, b^*

Abbreviations: FFA, free fatty acids; HSL, hormone sensitive lipase; LM, longissimus muscle; LPL, lipoprotein lipase; MDA, malondialdehyde; MDH, malate dehydrogenase; MnSOD, manganese-containing superoxide dismutase; PSE, pale, soft, exudative; TBARS, thiobarbituric-acid reactive substances

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value, malondialdehyde (MDA) content and Mn-containing superoxide dismutase (MnSOD) activity in breast muscle, or malate dehydrogenase (MDH) activity and hormone sensitive lipase (HSL) activity in abdominal fat. However, Mn did influence the content of abdominal fat ($P<0.01$), pH in breast muscle ($P<0.05$), b^* value and MDA content in leg muscle ($P<0.05$). Furthermore, Mn affected lipoprotein lipase (LPL) activities in abdominal fat ($P<0.001$) and MnSOD activities in leg muscles ($P<0.05$). Abdominal fat content and LPL activities in the abdominal fat decreased quadraticly ($P<0.01$) as dietary Mn level increased. The pH in breast muscle decreased linearly ($P<0.01$) with increasing Mn levels. As dietary Mn level increased, MDA content and MnSOD activities in leg muscle decreased and increased quadraticly ($P<0.05$), respectively. The results from the study indicate that the addition of 100 mg Mn/kg to broiler diets might decrease the abdominal fat content by reducing LPL activity in abdominal fat, and decrease MDA content in leg muscle by increasing MnSOD activity in leg muscle.

Keywords: Broilers; Manganese; Carcass traits; Meat quality; Enzyme activities

1. Introduction

Manganese (Mn) is an essential trace element in animals, with particular importance for fast growing poultry. In pigs, supplementing diets of weaned gilts with Mn has been shown to decrease backfat thicknesses. Sands and Smith (1999) have also shown that the addition of 240 mg Mn as Mn proteinate/kg decreased abdominal fat deposition as compared with an unsupplemented control (containing 19 mg Mn/kg in the starter diet and 28 mg Mn/kg in the grower diet) in a thermoneutral environment. However, the mechanism for decreasing carcass fat deposition is unknown. Lipoprotein lipase (LPL) is an adipocyte enzyme that cleaves fatty acids from circulating lipoproteins, and fatty acids enter the cell to be oxidized or esterified into triacylglycerol (Mersmann, 1998). Hormone sensitive lipase (HSL) is an adipocyte enzyme that cleaves fatty acids from intracellular triacylglycerol (Mersmann, 1998). Malate dehydrogenase (MDH) is involved in the synthesis of reduced nicotinamide adenine dinucleotide phosphate (NADPH) and NADPH is an important factor in lipid synthesis (Shen et al., 1991). Therefore, LPL, HSL, and MDH are three important enzymes in the metabolism of lipid of animals. Manganese may affect fat deposition in broilers by influencing activities of these enzymes in abdominal adipose tissues. Manganese is a component of Mn-containing superoxide dismutase (MnSOD), which functions as an antioxidant in animal bodies. Therefore, manganese may influence meat quality through MnSOD. Roberts et al. (2002) found that the color of pork from pigs fed on a diet supplemented with 350 mg Mn as Availa-Mn/kg was darker than that from pigs fed on a control diet, a diet supplemented with 700 mg Mn as Availa-Mn/kg or 350 mg Mn as Mn sulphate ($MnSO_4 \cdot H_2O$)/kg. In addition, they noted that the longissimus muscle (LM) from weaned pigs fed on 350 mg Mn as $MnSO_4$/kg had lower thiobarbituric-acid reactive substances (TBARS) values than the LM from pigs consuming the control diets. In the study of Roberts et al. (2002), Malondialdehyde (MDA) concentration in meat was determined by analyzing the content of pink substances in meat, and these pink substances were produced from a chemical reaction of MDA with thiobarbituric-acid, thus a lower TBARS value means a lower MDA content in meat; MnSOD activity in pork was however not determined. Furthermore, no information is available regarding the effect of Mn levels on the meat quality of broilers. Mn sulphate is an inorganic Mn source widely used in

current commercial diets of broilers, and the objective of the current study was to investigate the effect of supplemental Mn (as Mn sulphate) levels on the growth performance, carcass traits, meat quality, and relative enzyme activities in the abdominal fat and meat of broilers.

2. Materials and methods

2.1. Animals and diets

The experiment was conducted using a total of 288 commercial Arbor Acres male broilers of day-old. Birds were randomly allotted by body weight to one of six treatments (eight replicate cages of six chicks per cage) in a completely randomized design. Broilers were housed in electrically heated, thermostatically controlled cages (length 100 cm × width 50 cm × height 45 cm) with fibre-glass feeders and waterers. Chicks were maintained on a 24 h constant-light schedule and allowed *ad libitum* access to experimental diets and tap water (containing 106 μg Ca/ml, 42 μg magnesium/ml, 0 μg copper/ml, 0 μg iron/ml, 0.01 μg Mn/ml and 3.3 μg zinc/ml). Birds were managed according to guidelines approved by Arbor Acres Farm in Beijing. Body weight, feed consumption and incidence of leg abnormalities of each replicate cage were recorded at the end of each week. Incidence of leg abnormalities was calculated as a percentage of chicks within each cage with visual swelling at the tibiotarsus joint (Luo et al., 1991).

The basal diets (Tables 1 and 2) were formulated to meet or exceed NRC (1994) requirements for broilers except for Mn. Broilers were fed on Mn-unsupplemented maize–soybean

Table 1
Composition of the basal diet for 1–21 day-old broilers

Ingredient[a]	Composition (g/kg)	Composition (g/kg)	Amount
Ground yellow maize	502.4	AME (MJ/kg)	12.26
Maize starch	10.0	Crude protein[b]	236.3
Soybean meal	370.0	Lysine	13.7
Fish meal	52.0	Methionine	5.4
Soybean oil	35.0	Methionine + cystine	9.0
Dicalcium phosphate	13.0	Calcium[b]	9.5
Ground limestone	10.0	Non-phytate phosphorus	5.0
Iodized salt	3.0	Magnesium[b]	0.18
D,L-Methionine	1.5	Manganese[b] (mg/kg)	22.74
Micronutrients[c]	3.1	Iron[b] (mg/kg)	206.80
		Copper[b] (mg/kg)	16.26
		Zinc[b] (mg/kg)	60.79

[a] Ingredient and nutrient composition reported on an as-fed basis.

[b] Determined by analysis. Each value based on triplicate determinations. See Table 3 for analyzed Mn composition of each diet.

[c] Provided per kg of diet: Vitamin A (as all-*trans* retinol acetate), 15,000 IU; cholecalciferol, 3,900 IU; Vitamin E (as all-rac-α-tocopherol acetate), 30 IU; Vitamin K (as menadione sodium bisulfate), 3.0 mg; thiamin (as thiamin mononitrate), 2.4 mg; riboflavin, 9.0 mg; Vitamin B_6, 4.5 mg; Vitamin B_{12}, 0.021 mg; calcium pantothenate, 30 mg; niacin, 45 mg; folic acid, 1.2 mg; biotin, 0.18 mg; choline (as choline chloride), 700 mg; copper (from copper sulphate), 8 mg; zinc (from zinc sulphate), 40 mg; iron (from iron sulphate), 80 mg; iodine (from potassium iodide), 0.35 mg; selenium (from sodium selenite), 0.15 mg.

Table 2
Composition of the basal diet for 22–42 day-old broilers[a]

Ingredient[a]	Composition (g/kg)	Composition (g/kg)	Amount
Ground yellow maize	567.6	AME (MJ/kg)	12.46
Maize starch	10.0	Crude protein[b]	206.7
Soybean meal	330.0	Lysine	11.6
Fish meal	30.0	Methionine	4.4
Soybean oil	35.0	Methionine + cystine	7.7
Dicalcium phosphate	11.0	Calcium[b]	8.8
Ground limestone	10.5	Non-phytate phosphorus	3.8
Iodized salt	3.0	Magnesium[b]	0.17
D,L-Methionine	1.0	Manganese[b] (mg/kg)	18.86
Micronutrients[c]	1.9	Iron[b] (mg/kg)	206.20
		Copper[b] (mg/kg)	18.02
		Zinc[b] (mg/kg)	61.56

[a] Ingredient and nutrient composition reported on an as-fed basis.
[b] Determined by analysis. Each value based on triplicate determinations. See Table 3 for analyzed Mn composition of each diet.
[c] Provided per kg of diet: Vitamin A (as all-*trans* retinol acetate), 10,000 IU; cholecalciferol, 2600 IU; Vitamin E (as all-rac-α-tocopherol acetate), 20 IU; Vitamin K (as menadione sodium bisulfate), 2.0 mg; thiamin (as thiamin mononitrate), 1.6 mg; riboflavin, 6.0 mg; Vitamin B_6, 3.0 mg; Vitamin B_{12}, 0.014 mg; calcium pantothenate, 20 mg; niacin, 30 mg; folic acid, 0.8 mg; biotin, 0.12 mg; choline (as choline chloride), 500 mg; copper (from copper sulphate), 8 mg; zinc (from zinc sulphate), 40 mg; iron (from iron sulphate), 80 mg; iodine (from potassium iodide), 0.35 mg; selenium (from sodium selenite), 0.15 mg.

meal basal diets (Tables 1 and 2) containing 9.5 g Ca/kg and 22.74 mg Mn/kg for the first phase of 21d and adjusted to 8.8 g Ca/kg and 18.86 mg Mn/kg for a second phase of 21d (42d total), or fed basal diets supplemented with 100, 200, 300, 400 or 500 mg Mn as Mn sulphate/kg for the duration of the 42 days. A single batch of basal diet was mixed at first, and then divided into six aliquots according to the experimental treatment arrangement. Each of the Mn supplements was mixed with maize starch to the same weight at first, and then mixed with each aliquot of the basal diet. Dietary analyzed Mn concentrations are shown in Table 3.

2.2. Sample collection

On day 42 of the trial, two broilers from each cage were selected according to average body weight within the cage following a 12-h fasting, weighed individually, and

Table 3
Added and analyzed manganese concentrations (mg/kg) of diets for broilers

Mn sources	Added Mn	Dietary Mn (D1–21)	Dietary Mn (D22–42)
Control	0	22.7	18.9
$MnSO_4 \cdot H_2O$	100	106.2	106.0
	200	193.0	185.2
	300	270.4	284.7
	400	357.4	364.2
	500	432.7	440.8

killed by cervical dislocation, and then were immediately bled. The abdominal fat, breast and leg muscle were removed, and weighed to determine the content of abdominal fat, breast and leg muscle. Some muscles from the breast and leg were immediately stored at −80 °C for assessing crude fat content and enzyme activities, and others were stored individually in plastic bags at 4 °C for analysis of meat quality and MDA content. Some abdominal fat was also immediately stored at −80 °C for analysis of enzyme activities. Birds were handled in accordance with practices approved by the Office of the Beijing Veterinarian.

2.3. Manganese concentration in diets

Manganese concentrations in diets were determined by inductively coupled argon plasma spectroscopy (Model 9000, Thermal Jarrell Ash, Waltham, Massachusetts). Approximately 0.2 g of each sample was weighed in triplicate and digested with 8 ml HNO_3 and 0.5 ml $HClO_4$ at 200 °C in 50 ml calibrated flask until the solution cleared then condensed to approximately 0.2 ml and diluted 1:20 with deionized water before analysis. Validation of the Mn analysis was conducted using bovine liver powder as a standard reference material (National Institute of Standards and Technology, Beijing, China).

2.4. Meat quality measurements

2.4.1. Muscle pH

At 12 h after slaughter the breast and leg muscle pH was tested at a depth of 2.5 cm below the surface using a Model PH-211 m equipped with a spear electrode.

2.4.2. Color measurements

The commission International de 1'Eclairage color values L^*, a^*, and b^* (Commission Internationale de 1'Eclairage (CIE), 1976) corresponding to lightness, redness, and yellowness, respectively, were determined for the raw breast and leg muscles using a TC-PG chroma meter 5 min after slaughter.

2.4.3. Water-holding capacity

The water-holding capacity of the breast and leg meat was measured immediately after slaughter according to a press method described by Sun and Luo (1993). A 0.3-g breast muscle (pectoralis major) or leg muscle (gastrocnemius and peroneous longus) sample was pressed onto an oven-dried Whatman 125-mm filter paper at 3000 psi. The water-holding capacity values were calculated as the ratio of the area of expressed water to the area of the pressed meat sample as measured with a planimeter (Model 4236; Keuffel and Esser, Hoboken, NJ). Therefore, a lower ratio indicates a greater water-holding capacity.

2.4.4. Shear force measurements

At 24 h after slaughter, the breast muscles (pectoralis major) and leg muscles (gastrocnemius and peroneous longus) were heated in plastic bags in a water bath at 96 °C for 10 min.

After cooling at room temperature, shear force was measured in triplicate as described by Gwartney et al. (1992).

2.4.5. Intramuscular fat determination

Crude fat content was determined on duplicate 1.5 g samples of breast and leg muscle according to the Association of Official Analytical Chemists method 960.39 (AOAC), 1990 (Soxhlet procedure).

2.4.6. Measurement of MDA

Malondialdehyde content in breast or leg muscle was determined as described by Mak et al. (1983).

2.5. Measurement of enzyme activities

The MDH activity in abdominal fat was determined as described by Rogdakis (1974), and the activity of HSL in abdominal fat measured as described by Jin (1995). The LPL activity in the abdominal fat was determined according to methods described in Taskinen (1980). The activity of MnSOD in breast and leg muscle was tested according to the method of Oyanagui (1984).

2.6. Statistical analysis

All data from the study were analyzed as a completely randomized design using least squares analysis of variance and general linear model procedures (GLM) in Statistical Analysis Systems Institute (SAS, 1989). The model only included the level of Mn. Orthogonal comparisons were used to determine the linear and quadratic effects of the increasing levels of Mn. The probability level of 0.10 was used to test significance (Luo and Dove, 1996).

3. Results

Supplemental manganese level had no effect ($P>0.05$) on ADG, ADFI, F/G or the incidence of leg abnormality (data not shown).

The dressing percentage and the percentage of breast or leg muscle were not affected ($P>0.05$) by Mn supplementation (data not shown). However, Mn did influence ($P<0.01$) the content of abdominal fat (Table 4). Abdominal fat content decreased quadratically ($P<0.01$) as dietary Mn level increased.

Dietary Mn level had no effect ($P>0.05$) on pH in leg muscle, water loss percentage in breast and leg muscle, the shear force and intramuscular fat in breast and leg muscle, L^* value, a^* value, b^* value and MDA content in breast muscle, or L^* value and a^* value in leg muscle (data not shown), but influenced ($P<0.05$) pH in breast muscle, b^* value and MDA content in leg muscle (Table 4).

The pH in breast muscle decreased linearly ($P<0.01$) as dietary Mn level increased. Furthermore, MDA content in leg muscle decreased quadratically ($P<0.05$) as dietary Mn level increased.

Table 4
The effect of dietary manganese on abdominal fat percentage and meat quality of broilers[a]

Mn source	Added Mn level (mg/kg)	Abdominal fat[b] (g/kg)	pH in breast muscle[c]	b^* Value in leg muscle	MDA content in leg muscle[d,e]
Control	0	20.3	5.84	6.0	0.58
$MnSO_4 \cdot H_2O$	100	13.6	5.94	5.4	0.44
	200	14.3	5.81	3.0	0.45
	300	16.1	5.75	4.1	0.45
	400	14.1	5.77	4.2	0.51
	500	17.2	5.74	3.0	0.47
Pooled SE		1.30	0.04	0.73	0.03
P-value[f]		0.009	0.019	0.024	0.013

[a] Each value represents the mean of eight cages with two chicks per cage.
[b] Quadratic effect (P<0.01).
[c] Linear effect (P<0.01).
[d] Fresh basis.
[e] Quadratic effect (P<0.05).
[f] Probability values for main effects of ANOVA.

Dietary Mn level had no effect (P>0.05) on MDH and HSL activities in abdominal fat (data not shown), but influenced (P<0.001) LPL activities in abdominal fat (Table 5). Lipoprotein lipase activities in the abdominal fat decreased quadratically (P<0.01) as dietary Mn increased.

Dietary Mn level had no effect (P>0.05) on MnSOD activities in breast muscles (data not shown), but affected (P<0.05) MnSOD activities in leg muscles (Table 5). As dietary Mn level increased, MnSOD activities increased quadratically (P<0.05).

Table 5
The effect of dietary Manganese (Mn) on lipoprotein lipase (LPL) activity in abdominal fat and Mn-containing superoxide dismutase (MnSOD) activity in leg muscle of broilers[a]

Mn source	Added Mn level (mg/kg)	LPL activity in abdominal fat[b] (U/mg protein)	MnSOD activity in leg muscle [c,d] (NU/g tissue)
Control	0	1.42	102
$MnSO_4 \cdot H_2O$	100	1.25	114
	200	1.35	111
	300	1.30	111
	400	1.29	105
	500	1.37	109
Pooled SE		0.02	2.7
P-value[e]		0.0001	0.040

[a] Each value represents the mean of eight cages with two chicks per cage.
[b] Quadratic effect (P<0.01).
[c] MnSOD activity in breast or leg muscle was expressed as nitrite units per gram of fresh weight (NU/g of fresh weight), and one NU was defined as the amount of enzyme needed to obtain 50% inhibition of nitrite formation.
[d] Quadratic effect (P<0.05).
[e] Probability values for main effects of ANOVA.

4. Discussion

The Mn requirement for broilers during the first 3 weeks of life is 60 mg/kg (NRC, 1994). Luo et al. (1991) reevaluated dietary Mn requirement for broilers based on heart MnSOD activity, tissue Mn concentrations as well as growth performance and incidence of leg abnormality, and reported that 120 mg Mn/kg would be an optimal Mn level for broilers fed a practical maize–soybean meal diet during 1–28 days. The Mn requirement of 120 mg/kg is being widely used in the broiler industry in China and some other countries. Furthermore, previous researches have indicated that high Mn supplementation can decrease the abdominal fat deposition of broilers (240 mg Mn as Mn proteinate/kg) (Sands and Smith, 1999) and improve the color of pork (350 mg Mn as Availa-Mn/kg) (Roberts et al., 2002). Based on these previous findings, the six supplemental Mn levels of 100, 200, 300, 400, and 500 mg/kg in the current study were chosen.

The results from growth performance in the current study are consistent with previous results from the same laboratory, in which ADG, ADFI, and F/G were not affected in broilers fed on maize–soybean basal diets supplemented with Mn (Luo et al., 1991). Furthermore, in the current study the incidence of leg abnormality on the $MnSO_4$ treatments tended to decrease but did not reduce to zero. Luo et al. (1991) reported that cage-feeding condition played a functional role in leg abnormality development. This result indicate that factors other than Mn, such as cage feeding condition, might be involved in leg abnormality development.

The results from the current study indicate that the addition of Mn to broiler diets decreased the content of abdominal fat and improved carcass quality. Sands and Smith (1999) reported a similar response in broilers. Plumlee et al. (1954) conducted a study where weaned piglets were fed a semi-purified ration containing either 0.5 or 40 mg Mn as $MnSO_4$ /kg. The average backfat thicknesses were higher for pigs fed on diets containing 0.5 mg Mn/kg than for those fed on diets containing 40 mg Mn/kg, which is in agreement with the results from the current study. However, Plumlee et al. (1954) did not analyze relative enzyme activities in adipose tissue and other tissues of broilers and pigs, and thus they were unable to explain why Mn resulted in the above changes. In the current study, the quadratic response curve of abdominal fat content with supplemental Mn levels might be due to relative changes of LPL activities in abdominal adipose tissue, as discussed below, because LPL plays an important role in the synthesis of triacylglycerol in adipose tissue. Therefore, when LPL activity in abdominal fat was the lowest at 100 mg Mn/kg, the lowest content of abdominal fat was observed.

Generally, pH value is a direct reflection of muscle acid content, and affects shear force, drip loss and color in meat. Muscle pH variation is also related to glycogenolysis, and increased catecholamine secretion in response to an acute stressor just prior to slaughter increases glycogen breakdown and the rate of pH decline post-slaughter while the carcass temperature is still high, resulting in pale, soft, exudative (PSE) pork (Briskey and Wismer-Pedersen, 1961). The data from the current study indicate that the addition of high levels of Mn to broiler diets might have a negative effect on breast muscle pH.

Drip loss or water loss percentage is a widely investigated approach for measuring water-holding capacity, by which savor, tenderness, colour, fragrance, and nutrient content in muscle can be influenced (Tian and Yu, 2001). Lower water-holding capacity in muscles

can induce liquid outflow, loss of soluble nutrients and flavor. Therefore, the muscle becomes dry, hard and tasteless, and meat quality is decreased. Roberts et al. (2001) reported that the addition of 350 or 700 mg Mn as $MnSO_4$/kg to diets of weaned piglets did not influence drip loss percentages in loins, which was similar to the results from the current study.

Color is a major criterion that can be used by consumers to judge meat quality. L^* value is important in white muscles and correlates with drip loss and pH (Barbut, 1997). Roberts et al. (2001) reported that the addition of 350 or 700 mg Mn ($MnSO_4$)/kg to the diet had no significant effect on L^* and a^* value in loins of weaned piglets, which agreed with the results from the current study. Roberts et al. (2002) found that LM from weaned piglets fed on 350 mg Mn as availa-Mn/kg tended to be less yellow than the LM from pigs fed on the control diets during retail display. The results from the current study are in agreement with the previous report.

Lipid oxidation is a factor that reduces meat quality. Malondialdehyde is a soluble degraded product of lipids and an indicater that can be widely used to reflect the extent of lipid oxidation in meat (Raharjo and Sofos, 1993). Roberts et al. (2002) reported that the addition of 350 mg Mn as $MnSO_4$/kg decreased TBARS values (a lower TBARS value means a lower MDA content) in pork, which agreed with the results from this study. In this study, the quadratic response curve of MDA content in leg muscle with supplemental Mn levels might be due to the changes of MnSOD activities in leg muscle in mitochondria of muscle cells, since MnSOD plays an important role in retarding lipid peroxidation of cellular membrane.

Lin et al. (1997) observed that hepatic activities of MDH was correlated with abdominal fat pad weight in broilers. Hormone sensitive lipase is considered to be the rate-limiting enzyme of lipolysis in adipose tissue of animals (Fredrikson et al., 1981; Belfrage et al., 1984). However, no information is available regarding the effect of dietary Mn levels on the activities of MDH and HSL in abdominal fat of broilers. Lipoprotein lipase is synthesized mostly in adipose tissues and skeletal muscles. Lipoprotein lipase can hydrolyze triglycerides of chylomicrons and low-density lipoproteins to free fatty acids (FFA) and glycerols, which go into adipose tissue and are esterified into triglycerides. Researches in animal science has shown that LPL activity did not increase before the size and weight of adiposity cells increased (Dugail et al., 1988). Therefore, the key factor in maintaining adiposity was the increase of LPL activity in adipose tissues. Furthermore, Baziz et al. (1996) demonstrated that in broilers, the lipids deposited in the adipose tissues are almost exclusively synthesized in the liver, and taken up through the LPL activity. However, the effect of dietary Mn level on LPL activity in abdominal fat has not been investigated before. The data from the current study suggested that supplementation of Mn could reduce abdominal fat percentage by decreasing LPL activity in abdominal fat. The quadratic response curve of LPL activity in abdominal fat with supplemental Mn levels might be related to changes in interactions between Mn and other trace elements in inhibiting the LPL activity. When supplemental Mn levels in the basal diet was 100 mg/kg, the proportion of Mn to other trace elements in the body might be optimal for decreasing LPL activity in abdominal fat, and thus the lowest LPL activity was observed on the 100 mg/kg diet. When supplemental Mn levels in the basal diet were 200, 300, 400, or 500 mg/kg, the function of other trace elements in inhibiting LPL activity in abdominal fat might be affected to different extents by Mn, and thus the LPL activities in abdominal fat of broilers on these treatments were higher than

that in abdominal fat of the broilers on the 100 mg/kg Mn treatment. However, whether Mn inhibited the activity of LPL directly or indirectly is still unknown, and further experiments should be carried out to elucidate how Mn affects LPL activity in abdominal fat.

Previous studies have shown that heart MnSOD activity is very sensitive to the supplemental Mn level in the maize–soybean meal basal diet (Luo et al., 1992). However, the effect of dietary Mn supplementation on MnSOD activities in leg or breast muscle is largely unknown. Compared with breast muscle, leg muscle in broilers has more red muscle, and red muscle is rich of mitochondrias. The energy produced through metabolism thrives in mitochondrias and consumes much oxygen in addition to producing a lot of superoxide free radicals. Excessive superoxide free radicals then activate the synthesis of MnSOD in leg muscle cells, which can clear away the excessive superoxide free radicals. Thus relative balance between oxidation and antioxidation systems in leg muscle cells is maintained and the integral structure and normal function of leg muscle cells preserved. In the current study, the quadratic response curve of MnSOD activity in leg muscle with supplemental Mn levels might be related to the saturated degree of Mn in the active center of MnSOD with increasing Mn levels. When supplemental Mn level in the basal diet was 100 mg/kg, Mn in the active center of MnSOD just reached its saturated state, and thus the highest MnSOD activity in leg muscle was observed. However, when supplemental Mn levels in the basal diet were 200, 300, 400 or 500 mg/kg, MnSOD activities in leg muscle tended to decrease gradually, and exact reasons are unclear. The results from the current study suggested that Mn supplementation could reduce MDA content in leg muscle by increasing MnSOD activity in the mitochondria of leg muscle cells, and thus might prolong the shelf life of leg muscle.

5. Conclusion

The addition of Mn from $MnSO_4$ to broiler diets decreased LPL activities and increased MnSOD activities, leading to an improvement in carcass traits and meat quality. The data also indicate that the addition of 100 mg Mn from $MnSO_4$/kg to the broiler diet was adequate for improving carcass traits and meat quality.

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