

Effect of Dietary Manganese Inclusion Level on Performance and Carcass Characteristics of Growing-Finishing Swine

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Story in Brief

Crossbred pigs (n = 216) were blocked by BW, assigned to pens (six pigs/pen) within blocks, and pens (six pens/block) were allotted randomly to either a corn-SBM starter (52.0 to 80.0 lb), grower I (80.0 to 150.0 lb), grower II (150.0 to 200.0 lb), and finisher (200.0 to 235.0 lb) diet with no supplemental manganese (Mn) or diets supplemented with 20, 40, 80, 160, or 320 ppm Mn from Availa-Mn. When the lightest block averaged 235.0 lb, pigs were harvested, and boneless pork loins were captured during fabrication. Loin chops fabricated from each loin, and subjective and instrumental measures of color were collected. Pigs fed 40, 80, and 320 ppm Mn consumed less ($P < 0.02$) feed than pigs fed unsupplemented diets or 20 ppm Mn during the starter phase. Although dietary Mn had no ($P \geq 0.71$) effect on performance during the early grower phase, pigs fed 40 and 320 ppm Mn had higher ADG, and lower F/G, than pigs fed the control diet or diets fortified with 20, 80, and 160 ppm Mn (cubic effect; $P < 0.02$ and $P < 0.05$, respectively) during the late grower phase. Across the entire trial, there was a trend (cubic effect; $P = 0.08$) for F/G to be less in pigs fed diets containing 320 ppm than those fed the control diets or diets containing 20, 80, and 160 ppm Mn. Dietary Mn did not affect ($P \geq 0.18$) pork carcass composition or loin muscle quality characteristics. Even though Mn supplementation had no appreciable effects on pork quality during display in the present study, results indicate that supplementing diets with 40 or 320 ppm Mn from Availa-Mn may enhance pig performance, especially feed efficiency.

Introduction

The dietary requirements for manganese (Mn) in swine diets are quite low and not well established, and are largely based on research conducted 30 years ago with inorganic sources of Mn. Grummer et al. (1950) observed improvements in growth rate and feed efficiency in pigs fed supplemental manganese. Conversely, neither Plumlee et al. (1956), Leibholz et al. (1962), nor Roberts et al. (2001) reported differences in daily gain and efficiency between pigs fed diets supplemented with, or without, Mn. Although not statistically significant, Svajgr et al. (1969) noted that feed efficiency was improved by inclusion of 100 ppm Mn in swine finishing diets.

In the only trial to measure pork carcass composition and quality, Roberts et al. (2002) reported that loin chops from pigs supplemented with 350 ppm of Mn from Availa-Mn received higher Japanese and American color scores than pigs fed unsupplemented diets or diets supplemented with 700 ppm from Availa-Mn, 350 and 700 ppm Mn sulfate. Furthermore, these authors demonstrated that loin chops from pigs fed 350 ppm Mn from Availa-Mn tended to be darker and less yellow than chops from pigs fed the control diets or diets supplemented with 700 ppm Availa-Mn (Roberts et al., 2001). They concluded that supplementing diets with 350 ppm Mn could enhance pork quality, but inclusion of 700 ppm Mn, regardless of source, had no beneficial effects on pork quality or composition. There is no available information concerning the effects of supplementing Mn at inclusion levels less than 350 ppm; therefore, the objectives of this research were to assess the effects of dietary inclusion level of Availa-Mn on performance, carcass composition, and pork quality of growing-finishing swine.

Experimental Procedures

Two hundred and sixteen crossbred barrows and gilts (EB-348 line; DeKalb Choice Genetics, St. Louis, MO) with an initial BW of 52.4 ± 7.5 lb were sorted into six weight blocks of 36 pigs/block.

Pigs within each block were allotted randomly to pens (six pigs/pen) and stratified across pens according to gender and litter origin. A total of 36 pens were assigned randomly to one of six dietary treatments consisting of control corn-wheat middlings-soybean meal starter, grower and finisher diets with no supplemental Mn, and the control diets supplemented with either 20, 40, 80, 160, or 320 ppm Mn from Availa-Mn (a manganese-amino acid complex produced by Zinpro Corporation, Eden Prairie, MN). Pigs were fed a four-phase dietary program with transition from starter to grower-I, grower-I to grower-II, and grower-II to finisher phases occurring when average block weight reached 80, 150, and 200 lb, respectively. Additionally, diets were formulated to be isolysininc and isocaloric (Table 1). Although the mineral premix incorporated in all diets was devoid of Mn, feedstuffs supplied between 44 and 50 ppm of Mn, and Availa-Mn was added at the expense of corn starch. All diets were formulated to meet, or exceed, NRC (1998) amino acid, energy, and other nutrient requirements for growing-finishing swine. Individual pigs weights were measured weekly, and feed disappearance was recorded at 7-d intervals during each phase to calculate ADG, ADFI, and feed:gain (F/G).

When the mean weight of pigs was 235 lb, all pigs were transported approximately 472 miles to a commercial pork harvest/fabrication plant (Bryan Foods, Inc., West Point, MS). Pigs were harvested after a 12-h rest period at the plant, and 10th rib fat and loin eye depths were measured online with a Fat-O-Meater automated probe (SFK Technology A/S, Cedar Rapids, IA), and hot carcass weight was recorded. Carcasses were subsequently subjected to a conventional spray-chilling system for 24 h. Prior to carcass fabrication, midline backfat depths were recorded to calculate average backfat depth. Boneless pork loins were captured during fabrication, vacuum-packaged, boxed, loaded onto a refrigerated truck, and transported to the University of Arkansas for pork quality data collection.

At approximately 48 h postmortem, pork loins were cut between the 10th and 11th ribs, and two 1-in thick loin chops were removed from the posterior portion of the loin. After a 45-min bloom period at 34°F, chops were visually evaluated for marbling (1 =

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devoid [1% intramuscular fat] to 10 = abundant [10% intramuscular fat]; NPPC, 1999) and color based on both the American (1 = pale, pinkish gray to 6 = dark purplish red; NPPC, 1999) and Japanese color standards (Nakai et al., 1975). Also, L* (measure of darkness to lightness; larger number indicates a lighter color), a* (measure of redness; larger number indicates a redder color), and b* (measure of yellowness; larger number indicates a more yellow color) values were determined from a mean of four random readings (two readings for each chop) made with a Hunter MiniScan XE (model 45/0-L; Hunter Associates Laboratory, Reston, VA) using illuminate C. The saturation index, or chroma (C*), was calculated as $C^* = (a^{*2} + b^{*2})^{1/2}$, and is a measure of the total color or vividness of the color of the longissimus muscle (LM).

A 2-g sample of LM was homogenized in 20 mL of distilled, deionized water, and the pH of the homogenate was measured with a temperature-compensating combination electrode (model 300731.1; Denver Instrument Co., Arvada, CO) attached to a pH/ion/FET-meter (model AP25; Denver Instrument Co., Arvada, CO). After color data collection, chops were weighed, placed on foam trays with an absorbent diaper, overwrapped with an oxygen-permeable PVC film, and stored at 34°F for 48 h. After the 48-h storage period, chops were removed from their packages and reweighed. The difference between pre- and post-storage chop weights was divided by the initial chop weight to calculate moisture loss percentage.

Data were analyzed as a randomized complete block design, with blocks based on initial BW. Analysis of variance was generated using the mixed-model procedure (PROC MIXED) of SAS (SAS Inst., Inc., Cary, NC). The experimental unit for all performance data was pen; however, carcass was considered as the experimental unit in the analysis of pork carcass composition and pork quality data. Dietary treatment was included in the model as the lone fixed effect, and block and the block x pen x treatment (performance data) or block x pen x carcass x treatment (carcass data) was included in the models as random effects. Least-squares means were computed for the dietary treatments, and orthogonal comparisons of controls vs Mn-fed pigs and the highest inclusion level (320 ppm) vs all other inclusion levels (20, 40, 80, and 160 ppm) were included in the statistical model. Additionally, linear, quadratic, and cubic polynomials were used to detect the response to dietary inclusion level (20, 40, 80, 160, and 320 ppm) of Mn from Availa-Mn.

Results and Discussion

Pigs fed the control diet consumed more ($P < 0.01$) feed during the starter phase than pigs fed Mn-supplemented diets (Table 2). Additionally, pigs fed diets with 40, 80, and 320 ppm Mn consumed less ($P < 0.02$) feed than pigs fed 20 ppm Mn during the starter phase (cubic effect; $P < 0.10$); however, dietary Mn did not ($P > 0.10$) affect either ADG or F/G (Table 2). Even though dietary Mn level had no ($P > 0.10$) effect on performance during the grower-I phase or finisher phase, pigs fed 40 and 320 ppm Mn had higher ADG, and lower F/G, than pigs fed diets fortified with 20, 80, and 160 ppm Mn (cubic effect; $P < 0.02$ and $P < 0.05$, respectively) during the grower-II phase. Over the entire study (52.0 to 235.0 lb), neither ADG nor ADFI were affected ($P > 0.10$) by dietary Mn, but there was a trend (cubic effect; $P < 0.08$) for F/G to be less in pigs fed diets containing 320 ppm than those fed the control diets or diets containing 20, 80, and 160 ppm Mn. Unlike different Mn sources, our results concur with those of Grummer et al. (1950), who reported improvements in ADG and F/G in pigs fed supplemental Mn. On the other hand, previous results from our laboratory failed to note differences

in pig performance among pigs supplemented with 350 or 700 ppm from either Mn-sulfate or Availa-Mn (Roberts et al., 2001).

The effects of dietary inclusion level of Mn on pork carcass composition are presented in Table 3. In agreement with previous results from our laboratory (Roberts et al., 2001), dietary Mn did not ($P > 0.10$) affect hot carcass weight, average backfat thickness, loin eye and 10th rib fat depths, and fat-free lean yield. However, carcasses from pigs fed 80 ppm Mn were trimmer at the last lumbar vertebrae than carcasses from pigs fed 20 or 320 ppm Mn (quadratic effect; $P < 0.03$).

Ultimate (48-h) pH of the LM decreased linearly ($P < 0.01$) as dietary Mn inclusion level increased from 20 to 320 ppm (Table 4). Reductions in muscle pH are typically associated with lower water-holding capacity and a lighter, paler lean color; however, dietary Mn did not ($P > 0.10$) affect moisture loss percentage, American and Japanese color scores, or L* and b* values. Roberts et al. (2001) reported that muscle pH, subjective color scores, and drip loss percentage was not affected by dietary Mn inclusion level or source; however, when chops (from randomly selected loins) from these pigs were subjected to 7 d of retail display, loin chops from pigs 350 ppm of Mn from Availa-Mn received higher Japanese and American color scores than pigs fed unsupplemented diets or diets supplemented with 700 ppm from Availa-Mn, 350 and 700 ppm Mn sulfate (Roberts et al., 2002).

There was a trend for loin chops to become redder (linear effect; $P < 0.10$) as the dietary Mn inclusion level increased from 20 to 320 ppm (Table 4). Finally, the color of chops from pigs fed diets containing 40 and 320 ppm Mn from Availa-Mn was more vivid than chops from pigs fed the control, 20 ppm, 80 ppm or 160 ppm Mn (cubic effect; $P < 0.03$). Roberts et al. (2001) demonstrated that pork from pigs fed 350 ppm Mn from Availa-Mn was darker (lower L* values) than pork from pigs fed diets supplemented with 700 ppm Mn from Availa-Mn, and tended to be less yellow than chops from pigs fed the control diets or diets supplemented with 700 ppm Availa-Mn (Roberts et al., 2002).

Implications

Results from the present study indicate that supplementing swine diets with 40 or 320 ppm manganese from Availa-Mn may enhance pig performance, in particular feed efficiency. Even though pork loin chops tended to become redder as the level of dietary manganese increased from 20 to 320 ppm, the lower dietary manganese inclusion levels (less than 350 ppm) used in the present study may have contributed to the lack of any appreciable effects on pork quality during retail display.

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Table 1. Composition of control starter, grower I, grower II, and finisher diets.

Ingredient, % ^a	Starter phase	Grower I phase	Grower II phase	Finisher phase
Corn (Exp. 2)	65.27	68.48	77.84	76.945
Soybean meal, 48% (Exp. 2)	28.86	20.30	11.85	5.55
Wheat middlings	---	7.50	7.50	15.00
Fat	2.30	0.65	---	---
Calcium carbonate	0.92	1.00	0.88	0.90
Corn Starch ^b	0.40	0.40	0.40	0.40
Salt	0.50	0.50	0.50	0.50
Monocalcium phosphate	0.75	0.68	0.55	0.25
Lysine	0.15	0.15	0.15	0.15
Vitamin premix ^c	0.15	0.15	0.15	0.125
Mineral premix ^d	0.10	0.10	0.10	0.10
Tylan 40	0.05	0.05	0.05	0.05
Ethoxyquin	0.03	0.03	0.03	0.03
Theronine	0.02	0.01	---	---
Methionine	0.02	---	---	---
CP, %	19.28	16.61	13.36	11.49
Lysine, %	1.16	0.95	0.72	0.57
Methionine + cysteine, %	0.66	0.57	0.49	0.44
Threonine, %	0.74	0.62	0.48	0.40
Tryptophan, %	0.23	0.19	0.14	0.11
Calcium, %	0.60	0.60	0.51	0.45
Phosphorus, %	0.54	0.54	0.48	0.44
Basal manganese, ppm	44.0	48.0	45.0	50.0
ME, Mcal/kg	3.41	3.32	3.31	3.30

^a Ingredients reported on an as-fed basis.

^b Corn starch was replaced by 0.025, 0.05, 0.10, 0.20, and 0.40% Availa-Mn for the 20, 40, 80, 160, and 320 ppm Mn treatments, respectively.

^c Premix contained 909,091 IU of vitamin A, 136,364 IU of vitamin D, 3,636 IU of vitamin E, 3.6 mg of vitamin B12, 364 mg of vitamin K, 818 mg of riboflavin, 2,727 mg of D-pantothenic acid, and 4,546 mg of niacin per kilogram (Nutra Blend Corp., Neosho, MO).

^d Premix contained 11.0% Iron, 11.0% Zinc, 1.1% Copper, 0.02% Iodine, and 0.02% Selenium (Nutra Blend Corp., Neosho, MO).

Table 2. Effect of dietary supplementation level of manganese on growth performance of growing-finishing swine.

Item	Control	Manganese, ppm					SEM
		20	40	80	160	320	
Starter phase (52.0 to 80 lb)							
ADG, lb	1.41	1.41	1.34	1.34	1.36	1.36	0.066
ADFI, lb ^{1,2}	2.73	2.71	2.53	2.55	2.57	2.55	0.090
F/G	1.93	1.91	1.93	1.89	1.94	1.89	0.061
Grower I phase (80.0 to 150.0 lb)							
ADG, lb	1.91	1.89	1.91	1.87	1.94	1.96	0.084
ADFI, lb	4.99	5.04	4.97	4.95	4.93	5.04	0.165
F/G	2.57	2.65	2.60	2.67	2.55	2.57	0.073
Grower II phase (150.0 to 200.0 lb)							
ADG, lb ³	1.74	1.85	1.98	1.83	1.72	1.87	0.073
ADFI, lb ⁴	6.25	6.36	6.31	6.18	5.90	6.09	0.209
F/G ^{5,6}	3.60	3.46	3.18	3.39	3.47	3.24	0.118
Finisher phase (200.0 to 235.0 lb)							
ADG, lb	1.21	1.28	1.28	1.21	1.25	1.32	0.099
ADFI, lb	6.25	6.23	6.31	6.47	6.60	6.07	0.279
F/G	5.24	5.31	5.01	5.38	5.41	4.72	0.325
Overall (52.0 to 235.0 lb)							
ADG, lb	1.61	1.63	1.67	1.58	1.61	1.67	0.048
ADFI, lb	5.19	5.21	5.15	5.17	5.15	5.08	0.198
F/G ⁷	3.23	3.21	3.11	3.25	3.20	3.05	0.059

¹ Pigs fed control diets differ from pigs fed manganese-supplemented diets ($P < 0.01$).

² Cubic effect of manganese-supplementation level ($P < 0.10$).

³ Cubic effect of manganese-supplementation level ($P < 0.02$).

⁴ Linear effect of manganese-supplementation level ($P = 0.11$).

⁵ Pigs fed control diets differ from pigs fed manganese-supplemented diets ($P < 0.06$).

⁶ Cubic effect of manganese-supplementation level ($P < 0.05$).

⁷ Cubic effect of manganese-supplementation level ($P < 0.08$).

Table 3. Effect of dietary supplementation level of manganese on pork carcass cutability characteristics.

Item	Control	Manganese, ppm					SEM
		20	40	80	160	320	
Hot carcass wt, lb	175.8	178.2	178.6	174.2	176.2	178.2	5.39
Backfat depth, in							
First rib	1.48	1.54	1.39	1.45	1.43	1.42	0.050
Last rib	0.82	0.83	0.78	0.81	0.83	0.80	0.046
Last lumbar vertebrae ¹	0.77	0.83	0.73	0.70	0.75	0.77	0.070
Average	1.03	1.07	0.97	0.99	1.00	1.00	0.042
Loin eye depth, in	1.7	1.7	1.8	1.8	1.8	1.7	0.05
10th rib fat depth, in	0.9	0.9	0.9	0.9	0.8	0.9	0.04
Fat-free lean yield, % ^a	50.13	48.95	49.00	49.87	50.55	49.84	0.720

^a Fat-O-Meater equation: $((15.3098 - (31.2796 \times 10\text{th rib fat depth, in.}) + (3.8132 \times \text{loin eye depth, in.}) + (0.5096 \times \text{hot carcass wt, lb.})) \div \text{hot carcass wt, lb}) \times 100$.

¹ Quadratic effect of manganese-supplementation level ($P < 0.03$).

Table 4. Effect of dietary supplementation level of manganese on pork quality characteristics.

Item	Control	Manganese, ppm					SEM
		20	40	80	160	320	
48-h muscle pH ¹	5.94	5.91	5.92	5.89	5.84	5.73	0.090
Moisture loss, %	3.31	2.82	2.90	2.96	3.64	3.38	0.417
American color score ^a	3.7	3.8	3.7	3.8	3.7	3.7	0.09
Japanese color score ^b	3.4	3.7	3.5	3.5	3.4	3.5	0.10
Lightness (L*) ^c	51.38	51.53	53.20	51.18	51.64	51.70	0.586
Redness (a*) ^{c,2}	6.43	6.27	6.54	6.58	6.60	6.70	0.202
Yellowness (b*) ^c	13.90	14.17	14.69	14.00	13.89	14.08	0.187
Chroma ^{d,3}	15.34	15.52	16.12	15.48	15.40	15.61	0.217
Marbling score ^e	2.1	1.9	2.0	2.0	2.0	1.9	0.10

^a American color: 1 = pale, pinkish gray and 6 = dark purplish-red (NPPC, 1999).

^b Japanese color: 1 = pale gray and 6 = dark purple (Nakai et al., 1975).

^c L* = measure of lightness to darkness (larger number indicates a lighter color); a* = measure of redness (larger number indicates a more intense red color); and b* = measure of yellowness (larger number indicates a more yellow color).

^d Chroma is a measure of total color (larger number indicates a more vivid color).

^e Marbling: 1 = 1% intramuscular fat (devoid) to 10 = 10% intramuscular fat (abundant; NPPC, 1999).

¹ Linear effect of manganese-supplementation level (P < 0.01).

² Linear effect of manganese-supplementation level (P < 0.10).

³ Cubic effect of manganese-supplementation level (P < 0.03).