

**On-farm application of magnesium supplementation through water to  
improve pork quality under various slaughter conditions<sup>1</sup>**

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**ABSTRACT:** The objective of this project was to determine the effects of water supplementation with magnesium under commercial production conditions on the quality of pork (both ham and loin) obtained from slaughter plants of different sizes and with distinctly different stunning and slaughter methods. Research was conducted in an independent commercial swine facility and two packing plants with distinctly different slaughter methods. Magnesium was supplemented two days before slaughter via a water medicator at 300 ppm. Following Mg supplementation, 18 barrows and 18 gilts from each of the two treatment groups (72 pigs total) were randomly selected. Eight barrows and 8 gilts from each of the control and Mg supplemented groups were transported to a packing plant that used electrical stunning to immobilize the pigs and 10 barrows and 10 gilts from each of the control and Mg supplemented groups were transported to a packing plant that used CO<sub>2</sub> stunning to immobilize the pigs. Shipment of each group was conducted at approximately the same time, while the duration of shipping and lairage period was kept as similar as possible. Plasma magnesium, hot carcass weights, ultimate pH and pork quality of the longissimus dorsi and semimembranosus (drip loss, color, and display characteristics) were determined. Results indicate that pork quality of LM and SM was markedly better in the plant that employed CO<sub>2</sub> stunning compared to the plant using electrical stunning. However, in spite of large differences in pork quality between packing plants, supplementation of pigs with Mg did not improve pork quality in either plant. Thus, the results indicate that there was no value of Mg supplementation on-farm under the commercial conditions of this study.

Keywords: Age, Growth Rate, Magnesium, Pork, Quality, Water

## Introduction

Consumer perception of pork quality, as well as the manner in which the pig was reared, has become increasingly important. Consumers demand a fresh, eye-appealing cut with little purge. Therefore, excess exudative water loss or poor color are unacceptable from a consumer perspective. Furthermore, excess water loss accounts for a loss of profit for the pork industry. Short term supplemental dietary Mg decreases water loss (D'Souza et al. 1998 1999, 2000) and improves color (D'Souza et al., 1998, 2000). Magnesium potentially decreases lipid oxidation of stored pork (Apple et al., 2001). A comprehensive review of the effects of Mg on pork quality is available (van Heugten and Frederick, 2004).

Although many studies have concentrated on supplemental Mg in feed, supplementation through drinking water has not been extensively investigated. Our previous work demonstrated that supplementation of 300 ppm of Mg through the water for as brief as two days improved several aspects of pork quality (Frederick et al., 2004). Interestingly, we observed greater effects of Mg in the ham (semimembranosus) than in the loin. Most studies have focused on effects in the loin (van Heugten and Frederick, 2004). In our subsequent studies, Mg supplementation did not improve pork quality in different genotypes or in slow-growing and fast-growing pigs (Frederick et al., 2006). This experiment focused on supplementation of Mg through the water under commercial conditions and its effect was determined at multiple packing plants with known differences in slaughter method (electrical stunning and CO<sub>2</sub> stunning). Electrical stunning causes pigs to enter into immediate muscle contractions upon stunning and energy depletion. However, when CO<sub>2</sub> is administered, pigs begin to enter the anaerobic state with much less muscle contraction and, thus, energy is conserved. Therefore, an interaction between Mg and stunning method is expected, but this has never been tested (van Heugten and Frederick, 2004). Delivering feed containing supplemental Mg for as brief as 2 to 5 days, as has been done in other studies, may not be very practical for many commercial producers. Feed is commonly withdrawn prior to slaughter and, if Mg supplementation is required for positive effects on pork quality within 24 h of slaughter, water delivery is a much more viable option.

The objective of this study was to determine the effects of water supplementation with Mg under commercial production conditions on the quality of pork (both ham and loin) obtained from slaughter plants with distinctly different stunning and slaughter methods. We hypothesize

that the supplementation of Mg is an easy cost-effective method to improve pork quality and that the effects are dependent on slaughter plant conditions.

## **Materials and Methods**

### *Animals and Treatments*

All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University. A commercial swine barn with approximately 800 pigs that were market weight was used. Pigs had been placed into the unit from off-site nurseries and, therefore, were randomly distributed throughout the barn with regard to ancestry, sex, and BW. The water line from the right side of the barn was fitted with a water medication device and the water line on the left side of the barn remained unaltered. Two days before slaughter (1900 h), pigs on the right side of the barn were supplemented via the water medicator with 300 ppm of Mg, whereas the water on the other side of the barn was not supplemented and served as a control. Thus, we were able to determine pork quality in gilts and barrows, either supplemented with Mg or not. Water samples were obtained from at least six randomly selected pens on each side of the barn to verify water treatments.

Two days after the study was started, 18 barrows and 18 gilts from each of the two treatment groups (72 pigs total) were randomly selected. Eight barrows and 8 gilts from each of the control and Mg supplemented groups were weighed and tattooed individually and loaded (2240 h) onto a livestock trailer and transported to a packing plant that used electrical stunning to immobilize the pigs. Subsequently, 10 barrows and 10 gilts from each of the control and Mg supplemented groups were weighed and tattooed, loaded (0010) and transported to a packing plant that used CO<sub>2</sub> stunning to immobilize the pigs.

### *Slaughter Data Collection*

The packing plant using electrical stunning was located 293 km from the swine production facility and pigs arrived at the plant at 0235 h. They remained in lairage for 3.5 h and were then slaughtered by electrical stunning. The packing plant using CO<sub>2</sub> stunning was located 202 km from the swine facility and pigs arrived at the plant at 0350 h. Lairage time was 2 h after which pigs were killed by CO<sub>2</sub> stunning. At both plants, blood was collected during

exsanguination for plasma Mg determination. Hot carcass weights were collected prior to refrigeration to determine dressing percent.

After a 24-h chilling period at 2°C, entire, bone-in loins and hams from the right sides were removed at each of the plants. Longissimus (LM) and semimembranosus (SM) muscle were collected from the loins and hams, respectively by abattoir personnel in the plant using electrical stunning, while maintaining individual identification. In the plant with CO<sub>2</sub> stunning, LM was obtained from bone-in loins by abattoir personnel and whole hams were obtained with individual identification. Product from both plants was transported by refrigerated truck to the North Carolina State University Meat Processing Laboratory for further analysis. The SM was removed from the hams from the plant using CO<sub>2</sub> stunning. Subsequently, all procedures were identical for samples obtained from each plant.

#### *Pork Quality Measurements*

A total of two 2.54-cm thick chops from the LM was obtained posterior to approximately the 7th and 8th rib interface and two 2.54-cm thick chops were obtained from the center of the SM. The first SM and LM chops were used to determine drip loss using the filter paper method (Kaufman et al., 1986) and ultimate pH with a pH probe and then placed in a plastic bag and stored at 2°C to determine ultimate pH on the ground and homogenized sample. The second chops were used for color determination on the same day of collection. The second chops were then placed on a Dri-Lock AC-25 absorbent pad (Cryovac Sealed Air Corp., Duncan, SC) within a foam tray, and wrapped with a polyvinyl chloride film (Prime Source Meat Film, Bunzl-Koch Supply, Kansas City, MO). Packages were stored at 2°C on a tabletop to simulate retail display for 2, 4, 6, and 8 days. Fluorescent lights (GE fluorescent gas tube luminaire 32 W) were hung 1 m from the table top and left on continuously for the duration of the study.

Ultimate pH was measured using two methods. First, pH was determined using a pH probe inserted into the chop. For the second measurement, between 5 and 6 g of the first chop collected from the LM and SM was placed into a variable speed laboratory blender (Waring, New Hartford, CT) and deionized water was added to a final dilution of 1:10. Samples were blended for 20 s and pH was determined using an Accumet Excel XL15 pH meter with glass tip probe (Thermo Fisher Scientific, Waltham, MA).

Surface exudate was determined by the filter paper method developed by Kauffman et al. (1986). Briefly, a filter paper, 4.5 cm (#589, Schleicher and Schuell, Inc., Keene, NH) was weighed and then placed on the surface of each muscle for 2 s, 20 min after the initial cut. The filter paper was reweighed to determine weight gain of the filter paper which was an indicator of the extent of surface exudate accumulation.

Display fluid loss was determined on chops in a simulated retail display. The chops from each muscle were removed from the tray on d 2, 4, 6, and 8, gently blotted with a paper towel, and weighed to determine display fluid loss, expressed as a percent of initial chop weight.

Color of the LM and SM was objectively evaluated by Minolta L\*, a\*, and b\* measurements using a Minolta Chroma Meter (CR-200, Ramsey, New Jersey) using D65 illuminant and calibrated with a standard white plate. Minolta values were reported as the average color values from measurements conducted at three positions on the surface of each chop. The initial measurement of color was performed after a minimum of 20 min of the initial cut. Additionally, color was determined every 2 d for 8 d of display storage. Plasma Mg concentration was determined in duplicate by atomic absorption as described previously (Frederick et al., 2004).

### *Statistical Analyses*

Data were analyzed using the General Linear Model procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the effects of packing plant, Mg supplementation, sex and all appropriate interactions.

## **Results and Discussion**

The aim of the current study was to determine the effects of supplementation of Mg through the water under commercial conditions on pork quality and whether this effect was different between packing plants with known differences in slaughter method. We chose two commercial packing plants with distinctly different slaughter methods. One plant used electrical stunning and the other plant used CO<sub>2</sub> stunning to incapacitate the pigs. Electrical stunning causes pigs to enter into immediate muscle contractions upon stunning and energy depletion. When CO<sub>2</sub> is administered, pigs begin to enter the anaerobic state with much less muscle

contraction and, thus, energy is conserved. Considering the role of Mg in the control of intracellular Ca (Laver et al., 1997), and the delay in the initiation of glycolysis by maintaining high-energy phosphates postmortem (Moesgaard et al., 1993), we hypothesize that a Mg interaction with stunning method may be expected (van Heugten and Frederick, 2004).

Analyzed concentration of Mg in the control water (not supplemented) was 23 mg/L and the concentration of Mg in supplemented water was 383 mg/L. Thus, we achieved a level of Mg supplementation of 360 mg/L rather than the targeted 300 mg/L. Supplementation of Mg had no effect ( $P = 0.62$ ) on serum Mg concentration (Table 1). This is in contrast to our previous results in which we demonstrated an increase in serum Mg with increasing levels of supplemental Mg (Frederick et al., 2006) and with increasing duration of supplementation (Frederick et al., 2004). In these studies, total time of shipping and lairage was 2.5 and 6.75 h, compared to 6 to 7.5 h in the present study. Serum Mg concentrations were much greater ( $P < 0.001$ ) in pigs subjected to CO<sub>2</sub> stunning compared to pigs that were stunned electrically. Blood samples collected from pigs at the plant using CO<sub>2</sub> stunning had much more lysis of red blood cells, which may partly explain the greater levels of Mg in serum.

Although pigs were randomly assigned to treatments, pigs drinking control water and slaughtered using electrical stunning were heavier prior to slaughter than pigs in the other treatments (interaction,  $P = 0.06$ ; Table 1). Differences in BW of this magnitude were not expected to impact pork quality measurements. Supplementation with Mg tended ( $P = 0.08$ ) to increase yield, particularly when pigs were immobilized by electrical stunning (Table 3). This effect appeared to be due mainly to the lower yield of electrically stunned pigs that were not fed Mg compared to all other treatments.

Ultimate pH was measured by inserting a pH probe in the chops and in a chop sample that was homogenized prior to pH measurement. Ultimate pH of the LM was lower ( $P < 0.001$ ) in pigs that were electrically stunned when measured directly using a probe, and tended to be lower ( $P = 0.13$ ) when pH was measured in the homogenized sample (Table 2). In the SM, we observed the opposite effect; pH was higher in samples from pigs slaughtered at the plant using electrical stunning when measured using the probe directly ( $P = 0.01$ ) and in the homogenized sample ( $P < 0.001$ ). Ultimate pH is often used as a predictor of pork quality (NPPC, 2001) with an ultimate pH of 5.7 to 6.1 being considered optimal. The probe pH values in the present study are within this normal range.

Drip loss measured using the filter paper method for both the LM and SM was dramatically lower in pigs stunned using CO<sub>2</sub> compared to those stunned electrically (Table 2). Display fluid loss of the LM tended to be lower on d 2 (P = 0.13), d 4 (P = 0.14), d 6 (P = 0.08), and was lower (P = 0.04) on d 8 of display for pigs slaughtered at the packing plant using CO<sub>2</sub> stunning. The effect of packing plant on display fluid loss was greater in the SM, with pigs that were stunned using CO<sub>2</sub> had lower fluid loss (P ≤ 0.02) at all time point compared to pigs with electrical stunning. Supplementation of Mg did not impact drip loss as measured using filter paper or display fluid loss in either muscle (Tables 2 and 3).

Longissimus muscle chops from pigs slaughtered with CO<sub>2</sub> stunning were darker (lower L\* value) on d 0 (P = 0.05), d 2 (P < 0.002), and d 6 (P = 0.03), less red (lower a\* value) on d 0, 2, 4, 6, and 8 (P < 0.01), and less yellow (lower b\* value) on d 0 (P = 0.005), 2 (P < 0.001), d 4 (P = 0.003) and d 8 (0.09) than LM from pigs immobilized with electrical stunning (Table 4). Interactive effects (P = 0.05) between packing plant and Mg supplementation were observed for LM displayed for 6 d, indicating that Mg supplementation increased the lightness of the LM when the electrical stunning was employed. In addition, redness of the LM appeared to increase with Mg supplementation within CO<sub>2</sub> stunning, but was decreased with Mg within electrical stunning (interaction, P = 0.05).

When evaluating SM, initial lightness (on d 0) tended to be greater (P = 0.08) in chops from pigs slaughtered at the plant using CO<sub>2</sub> stunning and Mg supplementation tended to increase (P = 0.07) lightness, regardless of packing plant (Table 5). On d 2 (P = 0.09), 4 (P = 0.02), 6 (P = 0.02), and 8 (P < 0.001), SM chops from pigs from the plant using CO<sub>2</sub> stunning were darker (lower L\*) than those from pigs from the plant using electrical stunning. Supplementation of Mg increased the lightness of SM chops on d 8 (P = 0.003) of display. Similar to LM, SM chops from pigs slaughtered at the plant using CO<sub>2</sub> were less red on d 2 (P < 0.001), 6 (P = 0.07), and 8 (P = 0.01) and less yellow on d 0 (P = 0.09), 2 (P < 0.001), 4 (P < 0.001), and 8 (P < 0.001) than those from pigs slaughtered at the plant using electrical stunning. Supplementation with Mg tended (P = 0.08) to increase yellowness on d 0 of display, but no other effects of Mg were observed.

This study demonstrates that pork quality of LM and SM was markedly better in the plant that employed CO<sub>2</sub> stunning compared to the plant using electrical stunning. Differences in pork quality can not be solely attributed to the stunning method, although this was the main relevant

difference between the two plants that were evaluated. In addition, this study was planned such that pigs were killed on the same day at approximately the same time at both plants to minimize variation due to timing. In spite of large differences in pork quality between packing plants, supplementation of pigs with Mg did not improve pork quality in either plant. Thus, the results indicate that there was no value of Mg supplementation on-farm under the commercial conditions of this study.

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**Table 1.** Effects of packing plant (CO<sub>2</sub> stunning or electrical stunning) and Mg supplementation in the drinking water (0 or 300 ppm) on body weight, carcass weight, yield, and serum Mg concentration<sup>a</sup>

Variable	CO <sub>2</sub>		Electrical		SEM	P value <sup>b</sup>		
	0	300	0	300		Plant	Mg	P x Mg
Body Weight, kg	121.0	121.3	124.4	121.1	0.92	0.09	0.11	0.06
Hot Carcass Wt, kg	88.4	88.6	89.8	88.9	0.77	0.30	0.69	0.46
Yield, %	73.0	73.1	72.2	73.6	0.40	0.71	0.08	0.09
Serum Mg, mg/L	42.5	42.8	23.2	24.3	1.34	< 0.001	0.62	0.76

<sup>a</sup>Each value represents the mean of eight pigs within the electrical stunning group and 10 pigs within the CO<sub>2</sub> stunning group.

<sup>b</sup>Probability values for main effects of packing plant, Mg supplementation, and the plant x Mg supplementation interaction (P x Mg).

**Table 2.** Effects of packing plant (CO<sub>2</sub> stunning or electrical stunning) and Mg supplementation in the drinking water (0 or 300 ppm) on pH and drip loss in longissimus and semimembranosus muscle<sup>a</sup>

Variable	CO <sub>2</sub>		Electrical		SEM	P value <sup>b</sup>		
	0	300	0	300		Plant	Mg	P x Mg
<b>longissimus</b>								
Ultimate pH								
Probe	5.86	5.85	5.70	5.72	0.03	< 0.001	0.87	0.64
Homogenized	5.52	5.51	5.49	5.46	0.03	0.13	0.42	0.71
Drip loss, mg	43.1	45.6	62.1	62.7	4.45	< 0.001	0.72	0.84
<b>semimembranosus</b>								
Ultimate pH								
Probe	5.80	5.78	5.89	5.88	0.04	0.01	0.70	0.97
Homogenized	5.42	5.46	5.74	5.60	0.08	0.005	0.54	0.25
Drip loss, mg	30.7	26.9	72.7	61.4	5.48	< 0.001	0.17	0.50

<sup>a</sup>Each value represents the mean of eight pigs within the electrical stunning group and 10 pigs within the CO<sub>2</sub> stunning group.

<sup>b</sup>Probability values for main effects of packing plant, Mg supplementation, and the plant x Mg supplementation interaction (P x Mg).

**Table 3.** Effects of packing plant (CO<sub>2</sub> stunning or electrical stunning) and Mg supplementation in the drinking water (0 or 300 ppm) on display fluid loss in longissimus and semimembranosus muscle<sup>a</sup>

Variable	CO <sub>2</sub>		Electrical		SEM	P value <sup>b</sup>		
	0	300	0	300		Plant	Mg	P x Mg
<b>longissimus</b>								
Display fluid loss, %								
Day 2	1.22	1.33	1.46	1.56	0.15	0.13	0.51	0.99
Day 4	2.56	2.57	2.75	3.00	0.21	0.14	0.53	0.57
Day 6	3.64	3.59	3.98	4.23	0.28	0.08	0.72	0.61
Day 8	4.38	4.15	4.75	5.13	0.32	0.04	0.82	0.35
<b>semimembranosus</b>								
Display fluid loss, %								
Day 2	0.69	0.73	1.96	1.57	0.25	< 0.001	0.47	0.39
Day 4	1.64	1.42	3.06	2.73	0.35	< 0.001	0.43	0.87
Day 6	2.22	1.99	3.71	3.53	0.39	< 0.001	0.60	0.95
Day 8	4.09	2.95	4.63	4.73	0.48	0.02	0.30	0.21

<sup>a</sup>Each value represents the mean of eight pigs within the electrical stunning group and 10 pigs within the CO<sub>2</sub> stunning group.

<sup>b</sup>Probability values for main effects of packing plant, Mg supplementation, and the plant x Mg supplementation interaction (P x Mg).

**Table 4.** Effects of packing plant (CO<sub>2</sub> stunning or electrical stunning) and Mg supplementation in the drinking water (0 or 300 ppm) on color of longissimus muscle<sup>a</sup>

Variable	CO <sub>2</sub>		Electrical		SEM	P value <sup>b</sup>		
	0	300	0	300		Plant	Mg	P x Mg
L* (Lightness) <sup>c</sup>								
Day 0	46.0	45.0	46.5	47.1	0.63	0.05	0.73	0.22
Day 2	54.4	54.1	56.6	57.2	0.63	< 0.001	0.81	0.49
Day 4	54.3	54.1	53.2	54.2	0.47	0.32	0.39	0.23
Day 6	53.7	53.3	51.7	53.2	0.47	0.03	0.27	0.05
Day 8	55.5	54.9	54.4	55.1	0.47	0.36	0.87	0.15
a* (Redness) <sup>c</sup>								
Day 0	8.37	8.86	9.50	9.31	0.28	0.006	0.60	0.23
Day 2	9.08	9.42	11.65	11.27	0.26	< 0.001	0.95	0.18
Day 4	5.67	6.23	7.63	7.17	0.25	< 0.001	0.84	0.05
Day 6	6.43	6.98	8.10	8.08	0.23	< 0.001	0.26	0.23
Day 8	6.65	6.84	8.13	7.76	0.25	< 0.001	0.72	0.26
b* (Yellowness) <sup>c</sup>								
Day 0	1.09	1.71	2.03	2.00	0.21	0.005	0.16	0.13
Day 2	4.64	4.77	5.47	5.41	0.20	< 0.001	0.85	0.63
Day 4	5.48	5.88	6.26	6.36	0.20	0.003	0.22	0.48
Day 6	5.09	5.39	5.06	5.20	0.19	0.56	0.24	0.68
Day 8	5.53	5.59	5.84	5.91	0.18	0.09	0.75	0.98

<sup>a</sup>Each value represents the mean of eight pigs within the electrical stunning group and 10 pigs within the CO<sub>2</sub> stunning group.

<sup>b</sup>Probability values for main effects of packing plant, Mg supplementation, and the plant x Mg supplementation interaction (P x Mg).

<sup>c</sup>L\* is a measure of darkness to lightness (larger L\* value indicates a lighter color), a\* is a measure of redness (larger a\* value indicates a redder color), and b\* is a measure of yellowness (larger b\* value indicates a more yellow color).

**Table 5.** Effects of packing plant (CO<sub>2</sub> stunning or electrical stunning) and Mg supplementation in the drinking water (0 or 300 ppm) on color of semimembranosus muscle<sup>a</sup>

Variable	CO <sub>2</sub>		Electrical		SEM	P value <sup>b</sup>		
	0	300	0	300		Plant	Mg	P x Mg
L* (Lightness) <sup>c</sup>								
Day 0	48.7	49.8	46.7	48.8	0.84	0.08	0.07	0.60
Day 2	53.5	55.2	55.4	55.8	0.69	0.09	0.12	0.38
Day 4	51.4	52.3	53.3	53.6	0.71	0.02	0.39	0.68
Day 6	51.3	52.3	53.0	53.9	0.71	0.02	0.17	0.89
Day 8	52.2	53.6	54.5	57.0	0.62	< 0.001	0.003	0.39
a* (Redness) <sup>c</sup>								
Day 0	15.34	15.55	15.87	15.22	0.45	0.82	0.63	0.35
Day 2	15.39	15.63	17.25	17.11	0.38	< 0.001	0.90	0.62
Day 4	12.58	12.68	12.93	12.75	0.38	0.58	0.92	0.71
Day 6	12.59	12.76	13.73	12.89	0.34	0.07	0.33	0.15
Day 8	10.88	11.25	12.07	11.56	0.29	0.01	0.80	0.13
b* (Yellowness) <sup>c</sup>								
Day 0	4.98	5.86	5.82	6.22	0.35	0.09	0.08	0.50
Day 2	8.73	8.85	9.87	9.73	0.24	< 0.001	0.98	0.61
Day 4	9.69	9.62	10.62	10.28	0.21	< 0.001	0.35	0.53
Day 6	9.54	9.61	10.11	9.62	0.20	0.14	0.29	0.16
Day 8	7.96	8.36	10.07	9.85	0.21	< 0.001	0.67	0.14

<sup>a</sup>Each value represents the mean of eight pigs within the electrical stunning group and 10 pigs within the CO<sub>2</sub> stunning group.

<sup>b</sup>Probability values for main effects of packing plant, Mg supplementation, and the plant x Mg supplementation interaction (P x Mg).

<sup>c</sup>L\* is a measure of darkness to lightness (larger L\* value indicates a lighter color), a\* is a measure of redness (larger a\* value indicates a redder color), and b\* is a measure of yellowness (larger b\* value indicates a more yellow color).