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Dietary supplementation of magnesium sulfate and sodium bicarbonate and its effect on pork quality during environmental stress

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ABSTRACT

Market hogs ($n = 160$) were allotted to four dietary treatments to evaluate the effectiveness of magnesium sulfate ($MgSO_4$) and sodium bicarbonate ($NaHCO_3$) on improving pork quality during times of environmental stress. The experiment was conducted in four different months (Trial) to evaluate temperature as an environmental stressor. The dietary treatments were: 1) control 2) control + 3.2 g*pig-1*d-1 of $MgSO_4$ for a minimum of 14 days prior to slaughter, 3) control + 1.5% $NaHCO_3$ fed for 48 h prior to slaughter, and 4) control + 3.2 g*pig-1*d-1 $MgSO_4$ + 1.5% $NaHCO_3$. No differences ($P>0.05$) in pork quality were found between dietary treatments. Live weight, carcass weight and dressing percentage did not differ ($P>0.05$) by Trial whereas measures of pork quality (24 h pH, *L*, *a*, and *b* values, NPPC color scores, drip loss, and Warner Bratzler shear force [WBSF]) values were affected ($P<0.05$) by Trial. Time in lairage increased ($P<0.05$) dressing percentage and impacted ($P<0.05$) initial loin pH, 24 h ham pH, ham *a* values, and WBSF. Although dietary treatment had no effect on pork quality, the month of the year when pigs were slaughtered played a relevant role in pork quality.

1. Introduction

Monogastric animals, such as pigs, are able to transfer nutrients and feed additives directly to muscle and tissue, which can positively or negatively affect pork quality (Rosenvold and Andersen, 2003). Numerous dietary supplements have been researched to determine their effectiveness in improving pork quality.

Magnesium (Mg) helps maintain osmotic pressure, acid–base balance, membrane potential, substrate transport, and enzymatic cofactors (Crenshaw, 1991). More recently, however, dietary supplementation of Mg has been shown to improve pork quality (D'Souza et al., 1999, 2000). The most common Mg source for supplementation is magnesium sulfate ($MgSO_4$), and D'Souza et al. (2000) reported that pigs fed $MgSO_4$ for 5 days prior to slaughter decreased the incidence of pale, soft, and exudative (PSE) carcasses. Other research has been less supportive of supplementing diets with Mg, showing little or no improvement in pork quality (Apple et al., 2000, 2002; Hamilton et al., 2002).

Pigs can experience many different stressors prior to slaughter, including transportation and environmental conditions. The animal's ability to appropriately handle this stress will have an effect on meat quality (Hambrecht et al., 2005; Küchenmeister et al., 2005). Heat stress, in particular, can upset the acid–base balance of an animal, whereas adding electrolytes to finishing diets can help increase feed intake and, in turn, keep rate of gain consistent through hot periods of the year (Haydon et al., 1990). Researchers (Ahn et al., 1992; Boles et al., 1993, 1994) have shown that 1 to 2% electrolytes fed prior to slaughter increased the initial muscle pH by slowing glycogen metabolism and improving pork color (Minolta *b**). Thus, the objectives of the research were to determine if dietary supplementation of $MgSO_4$ and $NaHCO_3$ improves pork quality

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Table 1
Composition of basal diet.

Ingredient	% of Diet
Corn	80
Soybean meal-48%	15.7
Dicalcium phosphate	2.5
Limestone	0.75
Salt	0.4
Vitamin premix [a]	0.25
Trace mineral premix [b]	0.15
L-lysine	0.15

CP, 13.5%, Lys., 0.8%.

[a] Supplied per kilogram of diet:retinyl acetate, 11,000 IU; cholecalciferol, 1100 IU; DL-α-tocopheryl acetate, 44.1 IU; menadione Na dimethylpyrimidinol bisulfate, 4.0 mg; vitamin B12, 30.3 μg; riboflavin, 8.3 mg; D-Ca-pantothenate, 28.1 mg; nicotinamide, 33.1 mg; choline chloride, 551.3 mg; D-biotin, 0.22 mg; folic acid, 1.65 mg.

[b] Supplied per kilogram of diet: Zn, 165 mg ($ZnSO_4$); Fe, 165 mg ($FeSO_4H_2O$); Cu, 16.5 mg ($CuSO_45H_2O$); Mn, 33 mg ($MnSO_4$); I, 0.3 mg $Ca(IO_3)_2$; Se, 0.3 mg (Na_2SeO_3).

and to determine time of year to supplement with $MgSO_4$ and/or $NaHCO_3$ to overcome environmental stress.

2. Materials and methods

2.1. Dietary treatment and environmental stressor

One hundred sixty Duroc and Berkshire × Duroc market weight pigs (114 kg ± 7.5 kg) were grouped by gender, beginning weight and breed type, and allotted into one of four dietary treatments: 1) control, 2) control and $NaHCO_3$, 3) control and $MgSO_4$, and 4) control, $MgSO_4$, and $NaHCO_3$. Basal diets were formulated using corn and soybean meal to contain 13.5% crude protein and 0.8% total lysine on an as fed basis (Table 1).

Magnesium sulfate was added to the diet and fed at a rate of 3.2 g*pig-1*d-1, for a minimum of 14 days prior to loading for slaughter. Sodium bicarbonate was supplemented 48 h prior to loading and fed at 1.5% of the diet. Environmental temperature was used as a stressor, and the experiment was replicated in 4 months of the year. Temperatures in the finishing barn (Table 2) were recorded every hour for the 14-day feeding period using two Nomad™ data loggers (Omega Engineering, Inc., Stamford, CT, USA).

Pigs were transported approximately 320 km from a southwest Missouri pork producer to central Missouri for the 2-week feeding trial, where animals were housed in a 14.63 m × 9.75 m confinement building with adjustable side wall curtains to regulate indoor temperature and maximize temperature stress. Five pigs were allotted to each pen (allowing 2.08 m^2/pig) and sorted into dietary treatments as to balance treatments by breed, gender, and initial body weight. Pigs were fed *ad libitum* for the 2-week feeding trial and water was provided through two nipple waterers in each pen. In each replicate, 20 pigs ($n = 5$/dietary treatment) were weighed and loaded on a livestock trailer (0.89 m^2/pig) approximately 12 h prior to slaughter, and housed on the livestock trailer overnight. Then, pigs were transported 48 km to the University of Missouri-Columbia abattoir, and allowed from 0.5 to 5 h of lairage time and killed in random order. Two days later, the remaining 20 pigs were transported to slaughter according to the same protocols.

2.2. Meat quality

Pigs were rendered unconscious with electrical stunning following standards set forth by the Humane Methods of Slaughter Act with a two prong head only stunner calibrated to the weight of the pig for a minimum of 15 s (Best and Donovan, Hog Stunner Model "ES", 100 V, 5 A, Cincinnati, OH, USA.) Exsanguination occurred immediately after shackling. Temperature and pH of the carcass were obtained from the side of the carcass that was shackled using a HH-21 calibrated thermometer (Omega Engineering, Inc., Stamford, CT) for recording the temperature and a SevenGo™ SG2 pH meter (Mettler Toledo, Columbus, OH) for recording the pH. Temperature and pH were recorded at 0, 15, 30, 60 min, and 24 h postmortem, and taken at the 10th rib of the *Longissimus thoracis* (LT) and the *Semimembranosus* (SM). Hot carcass weight was taken before carcasses were chilled at ~2 °C for 24 h prior to fabrication.

Pork carcasses were fabricated according to the National Association of Meat Processors (NAMP) guidelines (NAMP, 1997). The SM was removed from the primal ham (NAMP #401), whereas the primal loin (NAMP #410) was further processed into a boneless, center-cut loin (NAMP #413). The boneless loins were cut in half at approximately the 10th rib. The SM and LT were both allowed 10 min to bloom period before visual color and marbling scores (NPPC, 1999) were recorded. Instrumental color (*L*, *a*, and *b*) values were recorded using a Minolta Chroma Meter CR-400/410 (Konica Minolta, Japan). The 24 h pH was taken again on the LT at the 10th rib interface and the SM. Three 2.54 cm chops were then removed at the 10th rib, two chops were vacuum packaged and frozen for Warner Bratzler shear force (WBSF) measurement while one chop was used to determine drip loss.

Drip loss was measured using the NPPC (2000) 48 h drip loss test. The LT chops were thawed at ~4 °C for 24 h prior to cooking and determination of WBSF according to AMSA (1995) guidelines. A copper constantan thermocouple

Table 2
Average, low, and high barn and air temperatures of the four trials and high temperatures for each slaughter day (°C).

Trial (month)	Avg. barn temp	Avg. air temp [a]	Low barn temp	Low air temp [a]	High barn temp	High air temp [a]	Slaughter day 1 air temp [a]	Slaughter day 2 air temp [a]
1 (Dec)	9.4	−3.8	3.1	−15.5	17.6	6.4	4.0	0.5
2 (Feb)	11.9	0.8	3.9	−9.5	27.9	15.5	1.4	7.0
3 (May)	21.0	23.1	11.7	11.6	31.5	33.6	23.8	20.2
4 (July)	23.8	24.8	14.6	14.5	34.2	35.2	30.3	31.2

[a] Air temperatures were recorded at Sanborn Field at the University of Missouri-Columbia Experiment Station.

(Omega Engineering, Inc., Stamford, CT) was placed in the geometric center of each chop and then attached to an HH-21 calibrated thermometer. Chops were cooked on a preheated Hamilton Beach® Indoor/Outdoor grill (Hamilton Beach, Southern Pines, NC), turned when the internal temperature reached 35 °C, and removed from the grill at a final internal temperature of 71 °C. Chops were subsequently wrapped in a PVC film (Glad® ClingWrap, Oakland, CA) and cooled at ~4 °C for 24 h. After cooling, six 1.27-cm cores were removed from the chops parallel to the muscle fibers (AMSA, 1995) and each core was sheared perpendicular to the muscle fibers using a United STM Smart-1 Test System SSTM-500 (United Calibration Corp., Huntington Beach, CA) with a crosshead speed of 250 mm/min. Shear force values (in N) of all cores were averaged for each chop for statistical analysis.

2.3. Statistics

Data was analyzed as a randomized complete block design using the GLM procedure of SAS (SAS Inst., Cary, NC). Pen was used as the experimental unit for all growth performance data and treatment, trial, and day were used as the main effects. Pig was analyzed as the experimental unit for meat quality data and treatment, trial, day, breed, gender, and lairage were used as the main effects. Interactions were observed between treatment, trial, and day. Least squares means were calculated and all main effects and interactions were considered significant at $P<0.05$. No interactions with breed or gender were reported due to current literature explaining differences between these two characteristics.

3. Results

3.1. Growth performance and carcass data

The Berkshire × Duroc pigs had heavier ($P<0.05$) initial and ending body weights than the Duroc sired animals (Table 3). Even though Berkshire × Duroc pigs produced heavier ($P<0.05$) carcasses, dressing percentages were similar ($P>0.05$) between breed-types. Pigs in Trial 2 had heavier ($P<0.05$) initial weights than pigs in Trial 3, pigs in Trial 4 had higher ($P<0.05$) dressing percentages than pigs in Trial 2. The pigs in Trial 3 had heavier ($P<0.05$) total weight gains during the 2-week feeding trial compared to pigs in Trials 2 and 4. Although, there were no differences ($P>0.05$) in initial and final live weights, hot carcass weight, or dressing percentage between the two slaughter days, pigs slaughtered on day 1 had a greater ($P<0.05$) average daily gain than pigs slaughtered on day 2. Pigs that were rested for 1 to 3 h in lairage produced the heaviest ($P<0.05$) carcasses, whereas pigs given 3 to 5 h yielded the lightest ($P<0.05$) carcasses. Pigs given 3 to 5 h of lairage had greater ($P<0.05$) dressing percentages than pigs afforded less than 1 h and those given 1 to 3 h of lairage.

3.2. Loin temperature and pH

Berkshire × Duroc pigs had a higher ($P<0.05$) 24 h LT temperature than Duroc pigs (Table 4), whereas barrows had a higher ($P<0.05$) pH at 24 h than gilts. There were no other differences ($P>0.05$) in LT 0 min pH or temperature between

Table 3
Effects of breed-type, gender, environmental temperature, feed supplementation, slaughter day and lairage on pig growth performance and carcass characteristics (means ± SE).

	Beginning weight (kg)	Ending weight (kg)	Total weight gain (kg)	Carcass weight (kg)	Dressing %
Breed-type[1]					
B × D	$116.8^{a} \pm 2.6$	$124.6^{a} \pm 3.1$	7.78 ± 0.85	$92.1^{a} \pm 2.2$	73.8 ± 0.3
D	$113.0^{b} \pm 1.9$	$118.0^{b} \pm 2.3$	5.85 ± 0.64	$86.9^{b} \pm 1.7$	73.7 ± 0.2
Gender[2]					
Barrow	114.5 ± 2.5	121.5 ± 3.0	6.98 ± 0.83	89.5 ± 2.2	73.9 ± 0.3
Gilt	114.5 ± 1.6	121.1 ± 1.9	6.65 ± 0.52	89.5 ± 1.4	73.6 ± 0.2
Trial					
Dec.(1)	$115.5^{ab} \pm 3.3$	122.4 ± 3.9	$6.95^{ab} \pm 1.08$	89.9 ± 2.8	$73.4^{ab} \pm 0.3$
Feb.(2)	$115.6^{a} \pm 2.7$	121.9 ± 3.2	$6.26^{b} \pm 0.88$	89.7 ± 2.3	$73.3^{b} \pm 0.3$
May(3)	$112.3^{b} \pm 2.6$	121.3 ± 3.1	$8.98^{a} \pm 0.85$	89.5 ± 2.2	$73.8^{ab} \pm 0.3$
July(4)	$114.5^{ab} \pm 2.9$	119.5 ± 3.4	$5.06^{b} \pm 0.95$	88.9 ± 2.5	$74.4^{a} \pm 0.4$
Treatment[3]					
Control	114.9 ± 2.7	120.8 ± 3.2	5.86 ± 0.88	89.2 ± 2.3	73.8 ± 0.3
Control + E	114.4 ± 2.7	121.5 ± 3.2	7.06 ± 0.88	89.4 ± 2.3	73.5 ± 0.3
$MgSO_4$	114.3 ± 2.7	121.1 ± 3.2	6.87 ± 0.89	89.6 ± 2.3	73.9 ± 0.3
$MgSO_4$ + E	114.2 ± 2.7	121.7 ± 3.2	7.48 ± 0.88	89.9 ± 2.3	73.8 ± 0.3
Day					
1	114.5 ± 2.0	121.8 ± 2.4	7.29 ± 0.65	89.7 ± 1.7	73.6 ± 0.2
2	114.4 ± 2.0	120.8 ± 2.4	6.34 ± 0.67	89.3 ± 1.8	73.9 ± 0.2
Lairage[4]					
<1 h	–	–	–	$89.4^{ab} \pm 2.7$	$73.1^{b} \pm 0.3$
1–3 h	–	–	–	$90.9^{a} \pm 1.7$	$73.7^{b} \pm 0.2$
3–5 h	–	–	–	$88.3^{b} \pm 1.9$	$74.5^{a} \pm 0.2$

[1]B × D (Berkshire × Duroc, $n=69$); D (Duroc, $n=91$).
[2]Barrow ($n=49$); Gilt ($n=111$).
[3]$MgSO_4$ = 3.2 g*pig-1*d-1, E = $NaHCO_3$ supplemented 48 h prior to loading.
[4]<1 h ($n=29$), 1–3 h ($n=74$), 3–5 h ($n=57$).
[a,b]Means within a column and subheading that do not have a common superscript differ ($P<0.05$).

Table 4
Effects of breed-type, gender, environmental temperature, feed supplementation, slaughter day and lairage on initial and ultimate loin pH and temperature (means ± SE).

	Loin pH		Loin temperature	
	0 min	24 h	0 min	24 h
Breed-type[1]				
B × D	6.61 ± 0.04	5.74 ± 0.03	39.4 ± 0.2	1.9[a] ± 0.1
D	6.62 ± 0.03	5.74 ± 0.02	39.5 ± 0.1	1.7[b] ± 0.1
Gender[2]				
Barrow	6.64 ± 0.04	5.78[a] ± 0.03	39.5 ± 0.2	1.7 ± 0.1
Gilt	6.60 ± 0.03	5.70[b] ± 0.02	39.3 ± 0.1	1.8 ± 0.1
Trial				
Dec.(1)	6.56 ± 0.06	5.70[b] ± 0.04	39.3[ab] ± 0.2	1.4 ± 0.1
Feb.(2)	6.59 ± 0.05	5.58[c] ± 0.03	39.7[a] ± 0.2	2.1 ± 0.1
May(3)	6.63 ± 0.04	5.78[ab] ± 0.03	39.8[a] ± 0.2	2.3 ± 0.1
July(4)	6.69 ± 0.05	5.88[a] ± 0.04	39.0[b] ± 0.2	1.3 ± 0.1
Treatment[3]				
Control	6.55[b] ± 0.05	5.74 ± 0.03	39.5 ± 0.2	2.0[a] ± 0.1
Control + E	6.68[a] ± 0.05	5.75 ± 0.03	39.5 ± 0.2	1.7[b] ± 0.1
$MgSO_4$	6.65[ab] ± 0.05	5.73 ± 0.03	39.2 ± 0.2	1.8[ab] ± 0.1
$MgSO_4$ + E	6.60[ab] ± 0.05	5.73 ± 0.03	39.5 ± 0.2	1.7[b] ± 0.1
Day				
1	6.56 ± 0.03	5.73 ± 0.03	39.3 ± 0.1	1.6 ± 0.1
2	6.68 ± 0.04	5.75 ± 0.03	39.5 ± 0.1	1.9 ± 0.1
Lairage[4]				
<1 h	6.72[a] ± 0.05	5.70 ± 0.04	39.2 ± 0.2	1.8 ± 0.1
1–3 h	6.56[b] ± 0.03	5.74 ± 0.02	39.5 ± 0.1	1.8 ± 0.1
>3 h	6.57[b] ± 0.04	5.77 ± 0.03	39.5 ± 0.1	1.8 ± 0.1

[1]B × D (Berkshire × Duroc, $n = 69$); D (Duroc, $n = 91$).
[2]Barrow ($n = 49$); Gilt ($n = 111$).
[3]$MgSO_4$ = 3.2 g*pig-1*d-1, E = $NaHCO_3$ supplemented 48 h prior to loading.
[4]<1 h ($n = 29$), 1–3 h ($n = 74$), 3–5 h ($n = 57$).
[a,b]Means within a column and subheading that do not have a common superscript differ ($P < 0.05$).

breed types or genders. Pigs fed the control diet had the highest ($P < 0.05$) 24 h LT temperature, whereas pigs fed diets supplemented with $NaHCO_3$ and $MgSO_4 + NaHCO_3$ had the lowest ($P < 0.05$) 24 h LT temperature.

Initial LT pH was highest ($P < 0.05$) for pigs slaughtered day 2 of Trial 2, and lowest ($P < 0.05$) for day 1 Trial 2 (Table 5). The 24 h LT pH was highest ($P < 0.05$) for day 1 Trial 3 pigs and day 2 Trial 4 pigs, while pigs slaughtered on days 1 and 2 of Trial 2 had the lowest 24 h pH. Temperature of the LT at 24 h was highest ($P < 0.05$) for days 1 and 2 of Trial 3 and day 2 of Trial 2.

Table 5
Effect of environmental temperature and slaughter day on trial by day interactions for loin pH and temperature and ham temperature (means ± SE).

Trial	Day	Loin pH 0 min	Loin pH 24 h	Loin temp 24 h	Ham temp 0 min
1	1	6.53[bc] ± 0.07	5.67[bc] ± 0.05	1.2[d] ± 0.1	40.2[ab] ± 0.2
1	2	6.59[b] ± 0.07	5.74[b] ± 0.05	1.6[c] ± 0.1	40.5[a] ± 0.2
2	1	6.42[c] ± 0.06	5.58[c] ± 0.05	1.9[b] ± 0.1	40.5[a] ± 0.1
2	2	6.77[a] ± 0.06	5.58[c] ± 0.05	2.2[a] ± 0.1	40.2[ab] ± 0.1
3	1	6.58[b] ± 0.06	5.90[a] ± 0.05	2.3[a] ± 0.1	40.4[a] ± 0.1
3	2	6.68[ab] ± 0.06	5.67[bc] ± 0.05	2.2[a] ± 0.1	40.3[a] ± 0.1
4	1	6.71[ab] ± 0.07	5.76[b] ± 0.05	1.0[d] ± 0.1	39.6[c] ± 0.1
4	2	6.67[ab] ± 0.07	6.01[a] ± 0.05	1.7[bc] ± 0.1	39.8[bc] ± 0.1

[a,b,c,d]Means within a heading that do not have a common superscript differ ($P < 0.05$).

3.3. Ham pH and temperature

There were no differences ($P > 0.05$) in SM 0 min pH between the breed-types or genders. Similar to LT temperatures, Berkshire × Duroc pigs had a higher ($P < 0.05$) 24 h SM temperature than Durocs (Table 6), and barrows had a higher ($P < 0.05$) SM pH at 24 h than gilts.

Trial 4 pigs had a higher ($P < 0.05$) pH at 24 h while Trial 1 and Trial 2 pigs had a lower ($P < 0.05$) SM pH at 24 h than Trial 3 and 4. Moreover, 24 h SM pH was greater ($P < 0.05$) in pigs given more than 3 to 5 h of lairage than for pigs provided only 1 h of lairage. Trial 2 and 3 had the highest ($P < 0.05$) 24 h SM temperatures. Pigs slaughtered on day 2 had a higher ($P < 0.05$) 24 h SM temperature. Length of lairage had no effect ($P > 0.05$) on SM pH or temperature measured at any time postmortem.

Initial SM temperature was greatest ($P < 0.05$) for pigs slaughtered on the first day of Trials 2 and 3 as well as the second day of Trial 1 and 3. Initial ham temperature was lowest ($P < 0.05$) for day 1 of trial 4 (Table 5).

3.4. Loin and ham color, marbling, drip loss, and WBSF

The Berkshire × Duroc pigs had a lower ($P < 0.05$) *L* value in the ham than the Duroc pigs (Table 7). Gilts had a higher ($P < 0.05$) ham a values than the barrows. Trial 3 had the highest ($P < 0.05$) *L* values in the loin, while *L* value was lowest ($P < 0.05$) for Trial 4 in the loin. The ham had the lowest

Table 6
Effects of breed-type, gender, environmental temperature, feed supplementation, slaughter day and lairage on initial and ultimate ham pH and temperature (means ± SE).

	Ham pH		Ham temperature	
	0 min	24 h	0 min	24 h
Breed-type[1]				
B × D	6.59 ± 0.06	5.74 ± 0.03	40.2 ± 0.1	3.3[a] ± 0.1
D	6.67 ± 0.04	5.80 ± 0.02	40.1 ± 0.1	2.9[b] ± 0.1
Gender[2]				
Barrow	6.66 ± 0.06	5.82[a] ± 0.03	40.2 ± 0.1	3.1 ± 0.1
Gilt	6.60 ± 0.04	5.71[b] ± 0.02	40.1 ± 0.1	3.2 ± 0.1
Trial				
Dec.(1)	6.54 ± 0.08	5.67[c] ± 0.04	40.4 ± 0.1	2.7[b] ± 0.1
Feb.(2)	6.62 ± 0.06	5.63[c] ± 0.03	40.4 ± 0.1	3.4[a] ± 0.1
May(3)	6.72 ± 0.06	5.78[b] ± 0.03	40.4 ± 0.1	3.4[a] ± 0.1
July(4)	6.65 ± 0.07	5.99[a] ± 0.04	39.8 ± 0.1	2.9[b] ± 0.1
Treatment[3]				
Control	6.63 ± 0.06	5.79 ± 0.27	40.2 ± 0.1	3.0 ± 0.1
Control + E	6.63 ± 0.06	5.79 ± 0.27	40.2 ± 0.1	3.0 ± 0.1
$MgSO_4$	6.56 ± 0.06	5.75 ± 0.27	40.1 ± 0.1	3.2 ± 0.1
$MgSO_4$ + E	6.71 ± 0.06	5.75 ± 0.27	40.2 ± 0.1	3.2 ± 0.1
Day				
1	6.62 ± 0.05	5.75 ± 0.02	40.2 ± 0.1	3.0[b] ± 0.1
2	6.64 ± 0.05	5.79 ± 0.02	40.2 ± 0.1	3.3[a] ± 0.1
Lairage[4]				
<1 h	6.58 ± 0.07	5.71[b] ± 0.04	40.0 ± 0.1	3.0[b] ± 0.1
1–3 h	6.63 ± 0.05	5.78[ab] ± 0.02	40.2 ± 0.1	3.4[a] ± 0.1
>3 h	6.69 ± 0.05	5.83[a] ± 0.03	40.3 ± 0.1	2.9[b] ± 0.1

[1]B × D (Berkshire × Duroc, $n = 69$); D (Duroc, $n = 91$).
[2]Barrow ($n = 49$); Gilt ($n = 111$).
[3]$MgSO_4$ = 3.2 g*pig-1*d-1ay, E = $NaHCO_3$ supplemented 48 h prior to loading.
[4]<1 h ($n = 29$), 1–3 h ($n = 74$), 3–5 h ($n = 57$).
[a,b]Means within a column and subheading that do not have a common superscript differ (P < 0.05).

Table 7
Effects of breed-type, gender, environmental temperature, feed supplementation, slaughter day and lairage on instrumental color scores (means ± SE).

	Loin			Ham		
	L	*a*	*b*	*L*	*a*	*b*
Breed-type[1]						
B × D	44.55 ± 0.47	14.65 ± 0.12	4.34 ± 0.11	43.00^{b} ± 0.59	15.52 ± 0.16	4.41 ± 0.14
D	43.73 ± 0.35	14.37 ± 0.09	4.08 ± 0.09	44.95^{a} ± 0.44	15.22 ± 0.12	4.55 ± 0.10
Gender[2]						
Barrow	44.10 ± 0.47	14.55 ± 0.12	4.23 ± 0.11	44.08 ± 0.58	15.17^{b} ± 0.16	4.43 ± 0.14
Gilt	44.18 ± 0.29	14.47 ± 0.08	4.18 ± 0.07	43.86 ± 0.36	15.57^{a} ± 0.10	4.53 ± 0.09
Trial						
Dec.(1)	44.34^{b} ± 0.60	14.53^{ab} ± 0.16	4.32 ± 0.14	42.23 ± 0.74	15.97 ± 0.21	4.61^{a} ± 0.18
Feb.(2)	44.32^{b} ± 0.49	14.53^{ab} ± 0.13	4.16 ± 0.12	46.51 ± 0.60	14.98 ± 0.17	4.86^{a} ± 0.14
May(3)	45.93^{a} ± 0.48	14.69^{a} ± 0.12	4.58 ± 0.11	44.60 ± 0.59	15.61 ± 0.16	4.63^{a} ± 0.14
July(4)	41.96^{c} ± 0.53	14.29^{b} ± 0.14	3.76 ± 0.13	42.55 ± 0.66	14.92 ± 0.18	3.81^{b} ± 0.16
Treatment[3]						
Control	44.25 ± 0.49	14.67^{a} ± 0.13	4.30 ± 0.12	44.22 ± 0.61	15.50 ± 0.17	4.43 ± 0.15
Control + E	43.72 ± 0.49	14.32^{b} ± 0.13	4.16 ± 0.12	44.15 ± 0.61	15.24 ± 0.17	4.58 ± 0.14
$MgSO_4$	44.23 ± 0.50	14.44^{ab} ± 0.13	4.10 ± 0.12	43.62 ± 0.61	15.23 ± 0.17	4.29 ± 0.15
$MgSO_4$ + E	44.35 ± 0.49	14.60^{ab} ± 0.13	4.27 ± 0.12	43.91 ± 0.61	15.51 ± 0.17	4.61 ± 0.14
Day						
1	44.71^{a} ± 0.36	14.50 ± 0.09	4.38 ± 0.09	43.53 ± 0.45	15.55 ± 0.12	4.57 ± 0.11
2	43.56^{b} ± 0.37	14.52 ± 0.09	4.04 ± 0.09	44.41 ± 0.46	15.19 ± 0.12	4.38 ± 0.11
Lairage[4]						
<1 h	43.99 ± 0.58	14.53 ± 0.15	4.06 ± 0.14	43.84 ± 0.71	15.64^{a} ± 0.19	4.47 ± 0.17
1–3 h	44.44 ± 0.36	14.51 ± 0.09	4.35 ± 0.09	43.75 ± 0.44	15.37^{ab} ± 0.12	4.37 ± 0.10
>3 h	44.55 ± 0.47	14.65 ± 0.12	4.34 ± 0.11	43.00^{b} ± 0.59	15.52 ± 0.16	4.41 ± 0.14

[1]B × D (Berkshire × Duroc, $n = 69$); D (Duroc, $n = 91$).
[2]Barrow ($n = 49$); Gilt ($n = 111$).
[3]$MgSO_4$ = 3.2 g*pig-1*d-1, E = $NaHCO_3$ supplemented 48 h prior to loading.
[4]<1 h ($n = 29$), 1–3 h ($n = 74$), 3–5 h ($n = 57$).
[a,b,c]Means within a column and subheading that do not have a common superscript differ ($P < 0.05$).

($P < 0.05$) b value in Trial 4 while the other trials showed no differences. Pigs slaughtered on day 1 had higher ($P < 0.05$) loin *L* values than those slaughtered on day 2. Pigs held the least amount of lairage time had higher ($P < 0.05$) ham a values than pigs held for more than 3 h.

Trial 3 had the highest ($P < 0.05$) drip loss while no differences ($P > 0.05$) were found between the other three trials (Table 8). Trials 1 and 2 had the toughest ($P < 0.05$) meat while Trials 3 and 4 had lower shear force values. Marbling was higher ($P < 0.05$) for hogs slaughtered on day 2. Pigs given the greatest amount of lairage time had the highest ($P < 0.05$) WBSF values.

Loin *b* was highest ($P < 0.05$) for pigs slaughtered on day 1 of Trials 1 and 2 and days 1 and 2 of Trial 3 (Table 9). Pigs slaughtered on day 2 of Trial 4 had the lowest ($P < 0.05$) loin *b* values. Ham *L* value was highest ($P < 0.05$) for pigs slaughtered on day 2 of Trial 2, while pigs slaughtered on days 1 and 2 of Trial 4 and day 1 of Trial 1 had the lowest *L* values. Pigs slaughtered on days 1 and 2 of Trial 1, day 1 of Trial 2 and day 2 of Trial 3 had a higher ($P < 0.05$) *a* value in the ham while pigs slaughtered on day 2 of Trial 4 had the lowest *a* values. Hogs slaughtered on days 1 and 2 of Trial 1, day 1 of Trial 2 and day 1 of Trial 4 had the highest ($P < 0.05$) NPPC loin color score while day 2 Trial 3 pigs had the lowest ($P < 0.05$) color score.

4. Discussion

4.1. Breed-type and gender

As expected, Berkshire cross pigs had lower *L* values in the ham relating to a darker color meat as well as lower shear force values which agrees with the results of the National Genetic Evaluation Project (NPPC, 1995) and National Barrow Show (NBS) Progeny Tests. From the NBS results, Berkshire pork scored highest in 19 of 22 quality measures (Hasty et al., 2002). Barrows had higher ultimate pH values in the ham and the loin which disagrees with Nold et al. (1999) who reported no differences in pH between genders.

4.2. Dietary treatments

Previous work by Peeters et al. (2006) has shown that supplementing swine diets with Mg produces calmer pigs on arrival at the slaughter facility, which could lead to improvements in pork quality due to less aggressive behavior and stress. In the current study, pigs supplemented with $MgSO_4$ did not seem less aggressive or calmer than pigs fed the control diet according to visual observations by the research team. All pigs were pen mates prior to the feeding trial and no new pigs were introduced which could explain the lack of fighting or aggressive behavior. A tendency towards improved ADG was reported by Utley et al. (1987) when electrolyte balance was maintained at 250 meq/kg while Haydon et al. (1990) stated that 250 meq/kg was the optimal rate of $NaHCO_3$ to be added to the ration to maintain ADG through periods of hot weather. No such increase in ADG was found in the current study during the 14-day feeding period.

In previous studies, initial and ultimate pH was not affected by Mg supplementation (D'Souza et al., 1999, 2000; Hamilton et al., 2002, 2003; Frederick et al., 2006). However, Swigert et al. (2004) reported an increase in ultimate pH for

Table 8
Effects of breed-type, gender, environmental temperature, feed supplementation, slaughter day and lairage on marbling, visual color, drip loss and Warner Bratzler shear force (means ± SE).

	Marb[5]	Color[6]	Drip	WBSF(N/cm^2)
Breed-type[1]				
B × D[1]	2.0 ± 0.1	3.4 ± 0.1	2.4 ± 0.3	33.6^{b} ± 1.1
D[2]	2.2 ± 0.1	3.4 ± 0.1	2.2 ± 0.2	37.4^{a} ± 0.8
Gender[2]				
Barrow	2.2 ± 0.1	3.4 ± 0.1	2.3 ± 0.3	35.3 ± 1.1
Gilt	2.1 ± 0.1	3.4 ± 0.1	2.4 ± 0.2	35.8 ± 0.7
Trial				
Dec.(1)	2.1 ± 0.2	3.9 ± 0.1	1.6^{b} ± 0.3	38.8^{a} ± 1.4
Feb.(2)	2.0 ± 0.1	3.4 ± 0.1	2.3^{b} ± 0.3	38.0^{a} ± 1.1
May(3)	2.0 ± 0.1	2.9 ± 0.1	3.4^{a} ± 0.3	32.6^{b} ± 1.1
July(4)	2.3 ± 0.1	3.5 ± 0.1	1.8^{b} ± 0.3	32.7^{b} ± 1.2
Treatment[3]				
Control	2.0 ± 0.1	3.4 ± 0.1	2.4 ± 0.3	34.8 ± 1.1
Control + E	2.3 ± 0.1	3.6 ± 0.1	1.9 ± 0.3	35.8 ± 1.1
$MgSO_4$	2.1 ± 0.1	3.3 ± 0.1	2.2 ± 0.3	36.1 ± 1.2
$MgSO_4$ + E	2.1 ± 0.1	3.4 ± 0.1	2.6 ± 0.3	35.5 ± 1.1
Day				
1	2.0^{b} ± 0.1	3.5 ± 0.1	2.4 ± 0.2	35.6 ± 0.8
2	2.3^{a} ± 0.1	3.3 ± 0.1	2.1 ± 0.2	35.5 ± 0.9
Lairage[4]				
<1 h	2.0 ± 0.2	3.4 ± 0.1	1.9 ± 0.3	34.4^{b} ± 1.3
1–3 h	2.1 ± 0.1	3.5 ± 0.1	2.5 ± 0.2	34.1^{b} ± 0.8
>3 h	2.2 ± 0.1	3.4 ± 0.1	2.4 ± 0.2	38.0^{a} ± 1.0

[1]B × D (Berkshire × Duroc, $n = 69$); D (Duroc, $n = 91$).
[2]Barrow ($n = 49$); Gilt ($n = 111$).
[3]$MgSO_4$ = 3.2 g*pig-1*d-1, E = $NaHCO_3$ supplemented 48 h prior to loading.
[4]<1 h ($n = 29$), 1–3 h ($n = 74$), 3–5 h ($n = 57$).
[5]NPPC marbling standards (NPPC, 1999).
[6]NPPC color score: 1 = pale pinkish gray and 6 = dark purplish red (NPPC, 1998).
[a,b]Means within a column and subheading that do not have a common superscript differ ($P < 0.05$).

pigs supplemented with Mg. Ahn et al. (1992) observed a decrease in pH decline in the LT when pigs were supplemented with electrolytes immediately prior to slaughter. Boles et al. (1993) found no differences in pH of halothane positive pigs supplemented with electrolytes 4 day prior to slaughter. Pigs supplemented with the $MgSO_4$ + $NaHCO_3$ diet did have a higher pH during Trial 4, suggesting the $MgSO_4$ + $NaHCO_3$ supplementation might improve pH during the hottest times of the year but this did not equate to improved overall pork quality in this study due to the already exceptional meat quality of the experimental pigs. Apple et al. (2005) found that Mg supplementation can increase initial and 45 min pH when a short transportation to slaughter is involved but the current study did not report similar findings. Since the pigs were loaded approximately 12 h prior to slaughter and removed from feed and water the dietary supplements could have been metabolized returning glycogen to basal levels prior to slaughter, therefore were not available for raising initial pH and subsequently improving pork quality.

D'Souza et al. (1998) reported a total elimination in PSE carcasses from pigs supplemented with 3.2 g*pig-1*d-1 of $MgSO_4$ for 5 days prior to slaughter. Swigert et al. (2004) reported that chops from pigs supplemented with Mg at 3.5 g*pig-1*d-1 for 48 h prior to slaughter had lower L^* values or darker colored meat than the other diets supplemented with Vitamin E or D_3. Swigert et al. (2004) concluded that Mg supplemented diets decreased purge but no differences were found in tenderness between supplemented and control animals. Peeters et al. (2006) concluded that pigs supplemented with Mg must be stressed to a greater extent to see improvements in pork quality such as color and drip loss. Geesink et al. (2004) went on to state that under normal processing conditions dietary magnesium showed no improvement on pork quality. Although there were no improvements in pork quality when pigs were supplemented the $MgSO_4$ or $NaHCO_3$ the pigs were all in the acceptable pork quality range of a 3–5 NPPC color score and an ultimate pH of 5.6–5.9 (NPPC, 1998).

4.3. Environment/trial

The warmest temperatures were reported during Trial 4 which, according to Heitman et al. (1958) were high enough to cause heat stress lowering ADG in Trial 4. Lopez et al. (1991) stated that high temperatures cause a decrease in feed intake and gain. Pigs gained the most weight in Trial 3 which was closest to the animals' ambient temperature; however ADG was low in all four trials, mostly likely due to stress from transport to the experimental facility and short feeding period at the end of the finishing phase. Data in the current study agreed with Gosalvez et al. (2006) who stated that time of year had no effect on carcass yield. During Trials 1 and 2 dressing percentage tended ($P = 0.14$) to be lower, which agrees with Lefaucheur et al. (1991) who stated pigs in colder temperatures had reduced dressing percentages. Lefaucheur et al. (1991) stated that a lower environmental temperature increased pH decline, and went on to hypothesize that lower environmental temperatures adversely affects overall pork quality. Lower pH values were observed in the current study during the colder trials as opposed to the warmer trials. Temperatures in Trial 3 showed the greatest fluctuation between hot and cold resulting in pigs having the lowest values for NPPC color and the highest drip loss of the four Trials. Although these animals were not deemed to be PSE, Judge et al. (1959) stated that pigs finished under highly variable temperatures are most likely to have poor pork quality.

4.4. Lairage

Tarrant (1989) concluded that shorter trips to slaughter can be the most detrimental to pork quality since loading and

Table 9
Effect of environmental temperature and slaughter day on trial by day interactions for loin pH, visual and instrumental color (Means ± SE).

Trial	Day	Loin *b*	Ham *L*	Ham *a*	Color[1]
1	1	4.64^{a} ± .18	42.17^{d} ± .94	16.16^{a} ± .26	3.7^{ab} ± .2
1	2	4.01^{bc} ± .18	42.28^{c} ± .94	15.77^{ab} ± .26	4.0^{a} ± .2
2	1	4.46^{ab} ± .16	44.79^{b} ± .84	15.59^{ab} ± .23	3.6^{abc} ± .2
2	2	3.85^{d} ± .16	48.23^{a} ± .84	14.37^{d} ± .23	3.2^{c} ± .2
3	1	4.46^{ab} ± .16	44.62^{bc} ± .82	15.13^{bc} ± .23	3.2^{c} ± .2
3	2	4.70^{a} ± .16	44.59^{bc} ± .83	16.09^{a} ± .23	2.5^{d} ± .2
4	1	3.94^{cd} ± .17	42.53^{bcd} ± .86	15.30^{b} ± .24	3.6^{ab} ± .2
4	2	3.57^{d} ± .17	42.56^{bcd} ± .90	14.54^{cd} ± .25	3.3^{bc} ± .2

[1]NPPC color score: 1 = pale pinkish gray and 6 = dark purplish red (NPPC, 1998).
[a,b,c,d]Means within a column that do not have a common superscript differ ($P < 0.05$).

unloading are more stressful activities than the actual transport; therefore, lairage time could affect differences seen in pork quality in this study. Although there were no drastic differences in pork quality between lengths of lairage, the results suggested the length of lairage best suited short distances to slaughter is less than 1 h to maximize carcass weight. However, dressing percentage was improved when pigs were rested for greater than 3–5 h in the current study. Aaslyng and Gade (2001) found that initial temperature of the LT was elevated for animals given less than 30 min of lairage, as well as an increase in drip loss from the *Biceps femoris* (BF), and lighter colored LT and BF muscles also occurring. A shorter lairage of less than 3 h produced lower shear force values in the LT.

Pigs spent less time in lairage on the second slaughter day due to increased efficiency on the kill floor allowing pig carcasses to reach the cooler faster and lowering the 60 min loin temperature on day 2. There were also fewer pigs that spent 3–5 h in lairage on slaughter day 2 of each trial compared to day 1.

5. Conclusion

In the current study supplementing swine diets with 3.2 g*pig-1*d-1 $MgSO_4$ and 1.5% $NaHCO_3$ independently or in combination prior to slaughter had no beneficial impact on growth performance, carcass traits, or ultimate pork quality. The current study reinforced the fact that seasonality and temperature variation in the finishing barn and during transport to slaughter plays a significant role in pork quality. The Duroc and Berkshire × Duroc pigs in the current study were procured from a swine producer with a history of producing exceptional meat quality animals, this coupled with the fact that the pigs were given ample room per head in the finishing barn, allowed time to rest after weighing and loading the night prior to slaughter and transported a very short (48 km) distance to the processing facility could have possibly attributed to the inability of observing beneficial impact from dietary supplements $MgSO_4$ and $NaHCO_3$ in improving pork quality.

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