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Effects of Fasting and Transportation on Pork Quality Development and Extent of Postmortem Metabolism

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ABSTRACT: One hundred seventy-seven pigs were used to determine the interaction effects of fasting and length of transport prior to harvest on pork muscle quality. The study design was a 2 × 2 × 3 factorial, which involved two genetic sources, fasting (F) or no fasting (N) of pigs 48-h prior to harvest, and three transport times (0.5, 2.5, or 8.0 h) on a semitrailer to the packing plant. Genetic source was a significant source of variation ($P < 0.05$) for most composition and muscle quality variables. Fasting reduced hot carcass weight 3.6% ($P < 0.05$), but length of transport did not affect hot carcass weight ($P > 0.05$). There were no differences ($P > 0.05$) in percent lean among fasting and transport treatments. Fasted pigs had higher longissimus dorsi (LD) ultimate pH (pH_u), darker lean color, higher marbling score and lower 7-d purge loss, 24-h drip loss, and cooking loss ($P < 0.05$) than nonfasted pigs. Meat from pigs that were transported 8.0 h had lower glycolytic potential (GP), higher LD and semimembranosus (SM) pH_u, darker lean color, and lower L*, 7-d purge loss, 24-h drip loss, cooking loss, and shear force values than meat from pigs transported 0.5 h ($P < 0.05$). Meat from pigs transported 2.5 h had higher LD and SM pH_u and lower L*, 7-d purge loss, 24-h drip loss, and cooking loss than meat from pigs transported 0.5 h ($P < 0.05$). Meat from pigs transported 8.0 h had higher LD pH_u and color scores and lower L* and cooking loss than meat from pigs transported 2.5 h ($P < 0.05$). The fasting × transport interaction was significant for SM pH_u, L*, color score, and drip loss. Fasting improved SM pH_u, L*, color score, and drip loss for pigs that were transported 0.5 h ($P < 0.05$), but when pigs were transported for 2.5 h or 8.0 h, fasting had little or no effect on these muscle quality traits. Fasting lowered GP and increased LD pH_u for pigs from the genetic source with the higher initial pork quality ($P < 0.05$), while fasting had no effect on pork quality for pigs from the genetic source with the lower initial pork quality ($P > 0.05$). Longer transport times resulted in lower GP and higher LD pH_u regardless of genetic source. Fasting and length of transport each had positive effects on pork quality, but length of transport effects was greater in magnitude. When pigs were transported for 0.5 h, fasting for 48 h prior to harvest improved pork quality, but when pigs were transported 2.5 or 8.0 h, fasting had little effect on pork quality.

Key Words: Exercise, Fasting, Glycogen, Meat Quality, pH, Transport

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Introduction

Postmortem metabolism of intramuscular energy stores (glycogen) plays the primary role in the conversion of muscle to meat and the expression of different quality attributes of fresh pork (NPPC, 2000). Loss of blood circulation at death causes postmortem glycolysis to occur in an anaerobic state resulting in a build up of lactic acid (Lawrie, 1998). This lactic acid build-up causes the pH of muscle to decline after death. Greater amounts of muscle glycogen at the time of death result in a lower pH_u, which results in a paler color and a lower water-holding capacity (Ellis et al., 1997). Carbohydrates in the diet are the main source for glucose in the blood. During fasting no carbohydrates are consumed, and the body must find other means to maintain blood glucose homeostasis. Previous studies showed that fasting swine resulted in lower muscle glycogen and meat with a higher muscle pH_u (Jones et al., 1985; Warriss et al, 1987; Eikelenboom et al., 1991). Glycogen in the muscle is the first energy source for muscle contraction during exercise.

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Briskey et al. (1959) reported that exhaustive exercise of hogs produced dark, firm muscles that had high pH values, low glycogen concentrations, and relatively low expressible water ratios. Human muscle glycogen concentrations were reduced 20% at 15 min, 30% at 60 min, and 43% at 99 min of exercise in a study by Green et al. (1991). Based on numerous trials conducted in humans and swine, there is strong evidence that both fasting and exercise will decrease muscle glycogen stores and improve pork muscle quality. However, to our knowledge, no researchers have examined the interaction effects of fasting and exercise on pork quality. In the pork industry, the most typical form of exercise occurring 24 h preharvest would be elicited through transporting pigs on a truck to the packing plant. Therefore, this study was conducted to determine the interaction effects of fasting and length of transport prior to harvest on pork muscle quality.

Materials and Methods

Animals

One hundred sixty-two barrows and 15 gilts of two different genetic sources were housed in 12 pens (15 pigs per pen) in a 1,000-pig commercial confinement finishing facility. All pigs were weighed individually 3 d prior to transport, and their average BW was 116.4 kg. Genetic source A (**AGS**) pigs were reputed to be Rendement Napole gene and Halothane gene negative genetics that produce high quality pork, while genetic source B (**BGS**) pigs were reputed for high lean growth genetics. A $2 \times 2 \times 3$ factorial design was used for this study, which involved two genetic sources, fasting (**F**) or no fasting (**N**) of pigs 48-h prior to harvest, and three different transport times (0.5, 2.5, or 8.0 h) on the semitrailer to the packing plant. Two pens of pigs were assigned to each treatment. Pens were assigned, so there was approximately an equal distribution of genetic sources and sex classes in each treatment. All experimental procedures were approved by the South Dakota State Institutional Animal Care and Use Committee.

Transport

Pigs were transported from the hog facility to the packing plant in a commercial potbelly semitrailer. The area of each semitrailer compartment was determined. Pigs were loaded according to treatment and sorted so each pig would be allowed 1.3 m^2 in their respective semitrailer compartment. There were three different loading times. Pigs from treatments F8.0 and N8.0 were loaded at 0530, pigs from treatments F2.5 and N2.5 were loaded at 1045, and pigs from treatments F0.5 and N0.5 were loaded at 1245. The truck traveled on two-lane highways only, resulting in the truck's changing speeds, stopping, and starting periodically. Average hog barn temperature and humidity, along with average outside temperature, humidity, and barometric pressure were 19.3°C, 65.7%, –10.7°C, 66.3%, and 77.1 torr, respectively. Additionally, the number of pigs in the truck that were lying down was recorded periodically. At 3 h, 5 h, and 7 h of transport the number of pigs lying down was three, four, and three, respectively.

Packing Plant

The truck arrived at the packing plant at 1320. Pigs were unloaded in the opposite order that they were loaded at the hog facility. Therefore, the F0.5 and N0.5 treatments were unloaded first. Each lot of pigs was weighed and treatment weight averages were calculated. All pigs were unloaded by 1415 and allowed to rest for 2 h prior to harvest. Two pigs were injured during transport and, consequently, were removed from the study upon arrival at the packing plant. Additionally, the data of 15 pigs were lost during the chilling process at the packing plant and five samples were removed from the study due to lack of identity after the boning and packaging process was complete. As a result, 155 boneless loins remained in the study for further meat quality testing. The number of observations for meat quality traits in each treatment ranged from 23 to 32 and are shown in Table 3.

Carcass Traits

Percent lean was determined on the warm carcasses before chilling by a Fat-O-Meater S71 (SFK Technologies, Hvidovre, Denmark), which measures 10th rib fat depth and loin muscle depth. Temperature and pH were measured at 24 h postmortem in the semimembranosus (**SM**) and longissimus lumborum muscles of the right side of each carcass using a Meatcheck 160 pH (Sigma Electronic GmbH Erfurt, Erfurt, Germany), equipped with a Mettler-Toledo pH probe LoT406-M6-DXK-S7/25 (Mettler-Toledo, GmbH, Hackacker, Germany). Backfat thickness was measured at the last rib. Loins from the left side of each carcass were removed, boned, vacuum packaged, and taken to the South Dakota State University Meat Laboratory for meat quality testing.

Purge Loss

At 7 d postmortem, vacuum packaged boneless loins were weighed (initial weight) to the nearest 0.1g, removed from their bag, and allowed to drip for 15 min. The average dry bag weight was determined and subtracted from the initial loin weight. After 15 min of drip-time the loins were reweighed to the nearest 0.1g, and percent purge loss was determined as a percentage of initial loin weight.

Sample Fabrication

Following purge loss determination, chops were removed from the longissimus lumborum starting at the

Table 1. Fasting × transport interaction effects on hot carcass weight (**HCW**), loin muscle depth, 10th rib fat depth, and percent lean

	Fasting × transport (h)						*P*-value			
	No fast			Fast						
Trait	0.5 h n = 28	2.5 h n = 30	8.0 h n = 29	0.5 h n = 27	2.5 h n = 27	8.0 h n = 36	Fast	Transport	Fast × Transport	RSD[a]
Initial live wt, kg[b]	117.9	115.7	115.7	118.4	115.2	115.7	NA[f]	NA[f]	NA[f]	NA[f]
End live wt, kg[c]	115.7	112.0	113.9	109.3	108.0	106.6	NA[f]	NA[f]	NA[f]	NA[f]
HCW, kg	87.8	85.2	85.6	84.4	83.4	81.6	0.0085	0.1904	0.6913	15.5
Initial dressing percentage[d], %	74.5	73.6	74.0	71.3	72.4	70.5	NA[f]	NA[f]	NA[f]	NA[f]
End dressing percentage, %[e]	75.9	76.1	75.2	77.2	77.2	76.5	NA[f]	NA[f]	NA[f]	NA[f]
Loin muscle depth, cm	5.03	4.98	5.09	4.93	4.93	5.01	0.4298	0.6993	0.9702	0.61
10th rib fat, cm	1.94	1.88	2.01	1.99	1.90	1.84	0.5455	0.4773	0.1662	0.32
% lean	52.9	53.4	52.6	52.7	52.9	53.6	0.7365	0.6134	0.1790	2.2

[a]RSD = residual standard deviation.
[b]Weight determined 1 d prior to treatments beginning.
[c]Weight determined at the packing plant.
[d]Percentage of the initial live weight.
[e]Percentage of the end live weight.
[f]NA = not available. It was impossible to test for statistical differences among treatments for live weight and dressing percentage traits because the experimental unit was pen, leaving no degrees of freedom for the error term.

cranial end and continuing towards the caudal end for glycolytic potential assay (one 20-g chop) and drip loss (one 2.5-cm-thick chop). The remaining longissimus lumborum was vacuum packaged and stored at –18°C for cooking loss and Warner-Bratzler Shear determination.

Glycolytic Potential Analysis

A 20-g chop was removed from each longissimus lumborum at 7 d postmortem, placed in a whirl pack bag, and stored at –20°C. Chops were allowed to thaw at 1.4°C for 12 h prior to beginning the glycolytic po-

Table 2. Main effects of fasting and length of transport on glycolytic potential, pH, and meat quality traits

	Fast		Transport (h)			*P*-value		
Trait	No n = 76	Yes n = 79	0.5 h n = 49	2.5 h n = 50	8.0 h n = 56	Fast	Transport	RSD[a]
Glycogen + Glucose + Glucose-6-P, μmol/g	7.5	7.0	8.9	6.8	6.0	0.6728	0.1042	6.49
Lactate, μmol/g	91.5	87.7	94.5[z]	90.7[z]	83.6[y]	0.0775	0.0002	12.22
Glycolytic potential[b]	106.4	101.6	112.2[z]	104.4[y,z]	95.5[y]	0.2129	0.0022	21.8
24-h LD pH[c]	5.69[z]	5.81[y]	5.65[z]	5.74[y]	5.87[x]	0.0003	0.0001	0.20
24-h SM pH[c]	5.95	5.95	5.82[y]	5.97[z]	6.06[z]	0.9587	0.0003	0.29
L*[d]	53.49[z]	52.19[y]	54.61[z]	53.12[y]	50.80[x]	0.0154	0.0001	2.99
Color score[e]	3.42[z]	3.70[y]	3.21[z]	3.39[z]	4.08[y]	0.0462	0.0001	0.78
Firmness score[f]	2.17	2.24	2.24	2.09	2.30	0.4387	0.1599	0.51
Marbling score[g]	2.22[z]	2.54[y]	2.26	2.42	2.46	0.0476	0.5557	0.90
7-d purge loss, %	1.92[z]	1.45[y]	2.16[z]	1.58[y]	1.32[y]	0.0076	0.0004	0.99
24-h drip loss, %	0.80[z]	0.71[y]	0.81[z]	0.72[y]	0.72[y]	0.0035	0.0142	0.17
Cook loss, %	20.93[z]	19.52[y]	21.76[z]	20.44[y]	18.47[x]	0.0071	0.0001	2.91
Shear force, kg	3.31	3.28	3.46[z]	3.28[y,z]	3.15[y]	0.8087	0.0511	0.60

[a]RSD = residual standard deviation.
[b]GP (glycolytic potential) = 2([glycogen] + [glucose] + [glucose-6-phosphate]) + [lactate]; measured in μmol lactate/g.
[c]For 24-h LD and SM pH no fast (n = 80), yes fast (n = 80), 0.5 h (n = 50), 2.5 h (n = 51), and 8 h (n = 59).
[d]L*, 0 = black, 100 = white.
[e]Color score; 1.0 = pale pinkish gray to white, 2.0 = grayish pink, 3.0 = reddish pink, 4.0 = dark reddish pink, 5.0 = purplish red, and 6.0 = dark purplish red.
[f]Firmness score, 1 = soft, 2 = firm, and 3 = very firm.
[g]Marbling score; visual scale approximates percent intramuscular fat; lower numbers refer to less marbling.
[x,y,z]Means within a row, within a main effect, lacking a common superscript letter differ ($P < 0.05$).

Table 3. Effects of fasting × transport interaction on glycolytic potential, pH, and meat quality traits

	Fasting × transport (h)							
	No fast			Fast				
Trait	0.5 h n = 24	2.5 h n = 28	8 h n = 27	0.5 h n = 25	2.5 h n = 23	8 h n = 32	*P*-value	RSD[a]
Glycogen + Glucose + Glucose-6-P, μmol/g	10.0	7.2	5.1	7.7	6.4	6.8	0.2977	6.49
Lactate, μmol/g	98.3	91.3	85.0	90.7	90.1	82.2	0.4218	12.22
Glycolytic potential[b]	118.3	105.7	95.2	106.1	103.0	95.8	0.3199	21.8
24-h LD pH[c]	5.57	5.67	5.83	5.73	5.81	5.90	0.4588	0.20
24-h SM pH[c]	5.69^{x}	$6.02^{y,z}$	6.13^{z}	5.95^{y}	5.91^{y}	$5.99^{y,z}$	0.0006	0.29
L*[d]	55.94^{z}	53.87^{y}	50.66^{x}	53.27^{y}	$52.37^{x,y}$	50.94^{x}	0.0495	2.99
Color score[e]	2.93^{w}	$3.13^{w,x}$	4.21^{z}	$3.50^{x,y}$	3.66^{y}	$3.94^{y,z}$	0.0119	0.78
Firmness score[f]	2.21	2.00	2.31	2.26	2.18	2.29	0.6241	0.51
Marbling score[g]	2.19	2.13	2.34	2.34	2.70	2.58	0.4953	0.90
7-d purge loss, %	2.53	1.85	1.39	1.79	1.31	1.26	0.2929	0.99
24-h drip loss, %	0.93^{z}	0.72^{y}	0.74^{y}	0.70^{y}	0.71^{y}	0.71^{y}	0.0031	0.17
Cook loss, %	22.56	20.90	19.32	20.96	19.98	17.62	0.7742	2.91
Shear force, kg	3.46	3.28	3.18	3.46	3.28	3.11	0.9395	0.60

[a]RSD = residual standard deviation.
[b]GP (glycolytic potential) = 2([glycogen] + [glucose] + [glucose-6-phosphate]) + [lactate]; Measured in μmol lactate/g.
[c]For 24-h LD and SM pH no fast × 0.5 h (n = 25), no fast × 2.5 h (n = 28), no fast × 8.0 h (n = 27) fast × 0.5 h (n = 25), fast × 2.5 h (n = 23), fast × 8.0 h (n = 32).
[d]L*; 0 = black, 100 = white.
[e]Color score, 1.0 = pale pinkish gray to white, 2.0 = grayish pink, 3.0 = reddish pink, 4.0 = dark reddish pink, 5.0 = purplish red, and 6.0 = dark purplish red.
[f]Firmness score, 1 = soft, 2 = firm, 3 = very firm.
[g]Marbling score; visual scale approximates percent intramuscular fat; lower numbers refer to less marbling.
[w,x,y,z]Means within a row lacking a common superscript letter differ ($P < 0.05$).

tential (**GP**) assay. One gram of each longissimus lumborum was extracted to determine GP, as described by McKeith et al. (1998). Perchloric (0.6 N) acid was used to deproteinate the muscle samples. The resulting perchloric extracts were used to quantify glycogen, glucose, glucose-6-phosphate (**GGG**), and lactate. Glycolytic intermediates were catalyzed to glucose-6-phosphate using 5 μL of hexokinase and then into 6-phosphogluconate in the presence of $NADP^+$, which was reduced to NADPH and the absorbance measured spectrophotometrically at 340 nm. Lactate was measured by adding excess NAD^+ in a glycine and hydrazine buffer solution with lactate dehydrogenase, resulting in NADH being formed. Differences in absorbance were measured at 340 nm. Glycolytic potential was expressed as micromoles of lactate per gram of wet muscle and determined by [2 × (glucose + glycogen + glucose-6-phosphate)] + lactate.

Color, Firmness, Marbling, and Drip Loss

One 2.5-cm-thick chop was removed from each loin at 7 d postmortem. External fat and secondary muscles were removed, and each chop was weighed to the nearest 0.01 g. Color, firmness, and marbling were assessed using NPPC Quality Standards (NPPC, 1999). In addition, L*, a*, and b* color values were measured using a Minolta Chroma Meter CR-310 (Minolta Corp., Ramsey, NJ) set at D_{65} illuminant. Each chop was retail wrapped on a styrofoam tray, arranged at an approximate 30° angle to allow the exudate to flow away from the chop, and placed in a well-lit cooler at 1.4°C (simulation of retail case) for 24 h. After 24 h chops were removed from their package and exudate and reweighed to the nearest 0.01 g. The amount of drip loss was determined as a percentage of initial weight.

Cooking Loss and Warner-Bratzler Shear Force

Two 2.5-cm-thick chops were removed from the cranial end of each frozen loin section. Chops were vacuum packaged and allowed to thaw at 1.4°C for 24 h prior to cooking. Chops were cooked in an impingement oven (Lincoln Foodservice Products, Inc., Ft. Wayne, IN) set at 190°C for 11 min resulting in an average final internal temperature of 65.8°C ± 6.5°C. This final internal temperature is lower than the 71°C recommended by AMSA (1995). Our preliminary trials had shown that these oven settings (190°C for 11 min) resulted in an average final internal temperature of 71°C ± 3°C, but for some unknown reason, the average final internal temperature in this study was lower and more variable. The chops were weighed raw (prior to cooking) and again after cooking to the nearest 0.01 g; cooking loss was determined and expressed as a

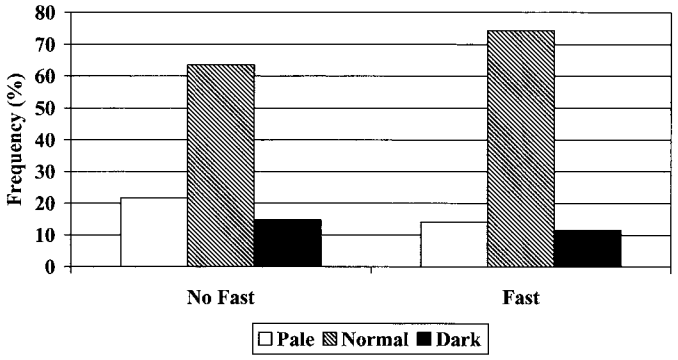

Figure 1. Percentage of pale (color score 1 and 2), normal (color score 3 and 4) and dark (color score 5 and 6) pork produced from fasted and nonfasted pigs; $P = 0.337$ for lack of fasting effects.

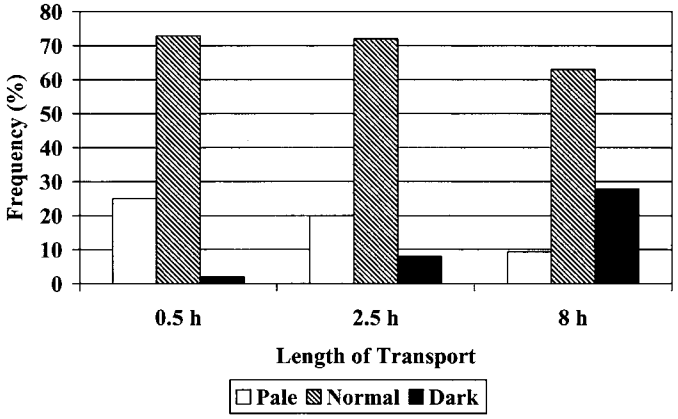

Figure 2. Percentage of pale (color score 1 and 2), normal (color score 3 and 4) and dark (color score 5 and 6) pork produced from fasted and nonfasted pigs; $P < 0.001$ for lack of transport effects.

percentage of initial raw weight. After chops cooled to room temperature, three 1.27-cm diameter cores were taken from each chop (six cores per pig) parallel to the muscle fiber orientation. Peak shear force was measured, once on each core, using a Warner-Bratzler shear force machine.

Statistical Analysis

All continuous data were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). All continuous data were analyzed as a completely randomized design (experimental unit = pig) with genetic source (2 levels; A or B), fasting (2 levels; 0 or 48 h), and transport (3 levels; 0.5, 2.5, and 8 h), serving as the main effects in the model, along with all three two-way interactions. The three-way interaction was analyzed but was not significant for any trait and thus removed from the statistical model. With data from all pigs included, GP residuals were not normally dis-

Table 4. Genetic source effects on carcass and meat quality characteristics

	Genetic source			
Trait	A (n = 49)	B (n = 106)	*P*-value	RSD[a]
Hot carcass wt, kg[b]	85.1	83.8	0.2775	7.0
Backfat, cm[b]	2.11	1.75	0.0001	0.32
Loin depth, cm[b]	4.90	5.08	0.0551	0.61
% Lean[b]	51.7	54.3	0.0001	2.2
Glycogen + glucose + glucose-6-P, μmol/g	6.3	8.1	0.1144	6.49
Lactate, μmol/g	86.2	93.0	0.0018	12.22
Glycolytic potential[c]	98.8	109.3	0.0071	21.8
24-h LD pH[d]	5.81	5.70	0.0015	0.20
L*[e]	52.53	53.15	0.2386	2.99
Color score[f]	3.80	3.32	0.0009	0.78
Firmness score[g]	2.36	2.06	0.0012	0.51
Marbling score[h]	2.93	1.84	0.0001	0.90
7-d purge loss, %	1.23	2.14	0.0001	0.99
24-h drip loss, %	0.72	0.78	0.0628	0.17
Cook loss, %	19.75	20.70	0.0652	2.91
Shear force, kg	3.08	3.51	0.0001	0.60

[a]RSD = residual standard deviation.
[b]For hot carcass weight, percent lean, backfat and loin depth genetic source A (n = 59) and genetic source B (n = 119).
[c]GP (glycolytic potential) = 2([glycogen] + [glucose] + [glucose-6-phosphate]) + [lactate]; measured in μmol lactate/g.
[d]For 24-h LD pH genetic source A (n = 53) and genetic source B (n = 107).
[e]L*, 0 = black, 100 = white.
[f]Color score, 1.0 = pale pinkish gray to white, 2.0 = grayish pink, 3.0 = reddish pink, 4.0 = dark reddish pink, 5.0 = purplish red, and 6.0 = dark purplish red.
[g]Firmness score, 1 = soft, 2 = firm, 3 = very firm.
[h]Marbling score; visual scale approximates percent intramuscular fat; lower numbers refer to less marbling.

tributed ($P < 0.0001$). Three pigs had GP residuals greater than 3.00 standard deviations above the mean. Additionally, when the GP residuals were added to the GP mean for nonfasted, 0.5-h treatment, these three pigs had adjusted GP values greater than 190 μmol lactate/g. Emnett et al. (2002) established a threshold GP value of 160 μmol lactate/g, above which pigs are considered to be Rendement Napole gene positive. Therefore, we assumed these three pigs to be Rendement Napole gene positive and excluded their data from the analysis of all muscle quality traits, resulting in a normal distribution of GP residuals. Least squares means were calculated for all variables and separated using pairwise *t*-tests. All frequency data were analyzed using chi-square.

Results

Carcass Traits

It was impossible to test for statistical differences among treatments for live weight and dressing percentage because these traits were measured by pen, resulting in no replication and leaving no degrees of freedom for the error term. Although this was not the main focus of the study, the live weights and dressing percentages are shown in Table 1. Fasting pigs for 48-h preharvest decreased hot carcass weight (**HCW**) ($P < 0.05$), but length of transport did not affect HCW ($P > 0.05$) (Table 1). Neither fasting nor transport time had an effect on 10th-rib fat depth, loin muscle depth, or percent lean ($P > 0.05$), which is consistent with earlier findings by Bowland and Standish (1966), Fausch et al. (1968), and Jones et al. (1985).

The main effects of fasting and length of transport on GP, sum of glycogen, free glucose, and glucose-6-phosphate, and lactate, as well as other meat quality traits are shown in Table 2. Fasting pigs for 48 h prior to harvest had no effect on GP, GGG, lactate, SM pH_u, firmness, and shear force. Pigs that were fasted compared to pigs that were not fasted had higher LD pH_u, darker-colored lean, higher marbling scores, and improved water-holding capacity. The frequency of pale (color score 1 or 2), normal (color score 3 or 4), and dark-colored (color score 5 or 6) pork between fasted pigs and nonfasted pigs was not different ($P = 0.337$) (Figure 1).

Transporting pigs for 0.5, 2.5, or 8.0 h had no effect on GGG, firmness, or marbling scores ($P > 0.05$) as shown in Table 2. Meat from pigs that were transported 8.0 h had lower GP and lactate, higher LD and SM pH_u, darker lean color, lower L*, lower 7-d purge loss, lower 24-h drip loss, lower cooking loss, and lower shear force values than meat from pigs transported 0.5 h ($P < 0.05$). Meat from pigs transported 2.5 h had higher LD and SM pH_u, lower L*, lower 7-d purge loss, lower 24-h drip loss, and lower cooking loss than meat from pigs transported 0.5 h ($P < 0.05$). Meat from pigs transported 8.0 h had lower lactate, higher LD pHu, higher color scores, lower L*, and lower cooking loss than meat from pigs transported 2.5 h ($P < 0.05$). As length of transport increased, the frequency of pigs that produced pale-colored pork decreased, and the frequency of pigs to produce dark-colored pork increased ($P < 0.001$) (Figure 2). Meat quality traits that were significantly affected by both fasting and length of transport showed a greater difference between 0.5-h and 8.0-h transport than between fasted and nonfasted pigs. In general, transportation affected meat quality to a greater extent than fasting.

Fasting × Transport

Semimembranosus pH_u, L*, color score, and drip loss were the only traits where the fasting × transport interaction was significant ($P < 0.05$) (Table 3). Fasting improved SM pH_u, L*, color score, and drip loss ($P < 0.05$) for pigs that were transported 0.5 h, but when pigs were transported for 2.5 h or 8.0 h, fasting had little or no effect on these muscle quality traits. The fasting × transport interaction was not significant ($P > 0.05$) for GP, GGG, lactate, 24-h LD pH_u, and purge loss indicating the fasting and transport effects were independent and additive for these traits.

Genetic Effects

Pigs from AGS were reputed to be Rendement Napole Gene and Halothane Gene-free genetics that produce high-quality pork, while pigs from BGS were reputed for high lean growth. The carcass and quality characteristics of pigs from AGS and BGS are presented in Table 4. There were no differences ($P > 0.05$) in HCW or loin depth between pigs from AGS vs BGS. Pigs from BGS had less backfat and a higher percent lean ($P < 0.05$) than the pigs from AGS. The longissmus dorsi (**LD**) muscle from AGS had lower GP, lower lactate, less purge loss, less drip loss, less cook loss, and lower shear force values, along with a higher 24-h LD pH and higher subjective color, firmness, and marbling scores than samples from BGS. There was an obvious difference in the genetic sources, and the results from this study confirm that AGS pigs produced higher quality pork than BGS pigs.

The genetic source × fasting interaction was significant for GP, lactate, LD pH_u, L*, and percent cook loss as shown in Table 5. Fasting pigs from AGS reduced GP and lactate, increased LD pH_u, lowered L*, and reduced cook loss ($P < 0.05$); however, fasting pigs from BGS did not change GP, lactate, LD pH_u, L*, or cook loss ($P > 0.05$) (Table 5). The genetic source × transport interaction was significant for tenth rib fat and percent lean as shown in Table 5. Pigs from AGS that were transported for 2.5 h had less tenth rib fat and a higher percent lean ($P < 0.05$) than the pigs from AGS that were transported for 0.5 h. However, length of transport did not effect tenth rib fat depth or percent lean in pigs from BGS ($P > 0.05$) (Table 5).

Table 5. Genetic source × fasting and genetic source × transport interaction effects on glycolytic potential, pH, and meat quality traits

	Genetic source × fasting				Genetic source × transport time								
	A		B		A			B			*P*-value		
Trait	No fast (n = 23)	Fast (n = 26)	No fast (n = 53)	Fast (n = 53)	0.5 h (n = 18)	2.5 h (n = 16)	8.0 h (n = 15)	0.5 h (n = 31)	2.5 h (n = 34)	8.0 h (n = 41)	Genetic source × fast	Genetic source × transport	RSD[a]
Hot carcass wt, kg[b,c]	86.8	83.4	85.2	82.5	87.2	84.6	83.5	84.6	83.7	83.3	0.7847	0.6840	7.04
10th rib fat, cm[b,c]	4.98	4.83	5.08	5.08	4.80^{z}	4.88^{y}	5.00^{y,z}	5.16^{x}	5.03^{x}	5.08^{x}	0.4409	0.5249	0.606
Loin muscle depth, cm[b,c]	2.16	2.06	1.73	1.78	2.26^{z}	1.98^{y}	2.08^{y,z}	1.68^{x}	1.78^{x}	1.78^{x}	0.1376	0.0067	0.323
% lean[b,c]	51.5	51.9	54.4	54.2	50.8	52.3	52.1	54.8	54.0	54.1	0.3398	0.169	2.16
Glycogen + Glucose + Glucose-6-P, μmol/g	7.6	5.0	7.3	9.0	8.1	5.5	5.2	9.6	8.1	6.7	0.0573	0.8964	6.49
Lactate, μmol/g	90.5^{z}	81.9^{y}	92.6^{z}	93.5^{z}	92.1	84.8	81.6	96.9	96.6	85.6	0.0289	0.2706	12.22
Glycolytic potential[d]	105.8^{z}	91.8^{y}	107.1^{z}	111.5^{z}	108.4	95.9	92.1	116.0	112.9	99.0	0.0185	0.4940	21.75
24-h LD pH[e,f]	5.70^{y}	5.91^{z}	5.68^{y}	5.72^{y}	5.68	5.80	5.94	5.62	5.68	5.79	0.0128	0.6280	0.197
24-h SM pH[e,f]	5.95	5.98	5.94	5.92	5.84	5.98	6.07	5.79	5.96	6.04	0.6176	0.9693	0.286
L*[g]	53.77	51.29	53.21	53.10	54.88	52.30	50.40	54.33	53.94	51.20	0.0265	0.2285	2.99
Color score[h]	3.54	4.05	3.31	3.34	3.37	3.72	4.30	3.05	3.07	3.85	0.0840	0.6242	0.783
Firmness score[i]	2.32	2.39	2.03	2.09	2.44	2.16	2.47	2.03	2.02	2.13	0.9571	0.4829	0.511
Marbling score[j]	2.63	3.22	1.81	1.86	2.81	3.08	2.88	1.72	1.75	2.04	0.946	0.4589	0.899
7-d purge loss, %	1.47	1.00	2.37	1.90	1.82	0.97	0.92	2.50	2.19	1.73	0.9731	0.4241	2.99
24-h drip loss, %	0.75	0.70	0.85	0.71	0.80	0.66	0.70	0.83	0.77	0.74	0.1782	0.5941	0.174
Cook loss, %	21.15^{z}	18.34^{y}	20.71^{z}	20.70^{z}	21.90	20.05	17.30	21.63	20.84	19.65	0.0077	0.1122	2.91
Shear force, kg	3.16	3.00	3.45	3.57	3.27	3.05	2.92	3.65	3.51	3.37	0.1938	0.9522	0.602

[a]RSD = residual standard deviation.
[b]For hot carcass weight, percent lean, backfat, and loin depth A × no fast (n = 28), A × fast (n = 31), B × no fast (n = 59), B × fast (n = 59).
[c]For hot carcass weight, percent lean, backfat and loin depth A × 0.5 h (n = 19), A × 2.5 h (n = 21), A × 8 h (n = 19), B × 0.5 h (n = 36), B × 2.5 h (n = 36), B × 8 h (n = 46).
[d]GP (glycolytic potential) = 2([glycogen] + [glucose] + [glucose-6-phosphate]) + [lactate]; measured in μmol lactate/g.
[e]For 24-h LD pH A × no fast (n = 25), A × fast (n = 28), B × no fast (n = 55), B × fast (n = 52).
[f]For 24-h LD pH A × 0.5h (n = 19), A × 2.5 h (n = 18), A × 8 h (n = 16), B × 0.5 h (n = 31), B × 2.5 h (n = 33), B × 8 h (n = 43).
[g]L*, 0 = black, 100 = white.
[h]Color score; 1.0 = pale pinkish gray to white, 2.0 = grayish pink, 3.0 = reddish pink, 4.0 = dark reddish pink, 5.0 = purplish red, and 6.0 = dark purplish red.
[i]Firmness score, 1 = soft, 2 = firm, and 3 = very firm.
[j]Marbling score; visual scale approximates percent intramuscular fat; lower numbers refer to less marbling.
[x,y,z]Means within in a row lacking a common superscript letter differ ($P < 0.05$).

Fasting lowered GP, lactate, and LD pH_u in pigs from AGS (a genetic source that had high initial pork quality), while fasting had no effect on pigs from BGS (a genetic source with lower initial pork quality). Increased transport times resulted in lower GP and higher LD pH_u regardless of genetic source.

Discussion

Carcass Traits

This study showed that fasting pigs causes a reduction in hot carcass weights. These results agree with the findings of Warriss (1982), Jones et al. (1985), and Becker et al. (1989).

Effects of Fasting

Consumed carbohydrates are the main source of glucose in the blood (Guyton and Hall, 1996). Insulin works to store excess blood glucose as glycogen in the muscle or liver or as adipose tissue. Of the glycogen stores in the liver and muscle, the glycogen stored in the liver is more readily available for glycogenolysis because the enzyme glucose-6-phosphotase is present in liver but not in muscle (Mathews and Van Holde, 1995; Murray et al., 2000). Sugden et al. (1976) showed that in terms of total loss of glycogen from liver plus carcass in rats, liver contributed 64% and the carcass 36% during deprivation of food for 19 h. The corresponding values over a 43-h food withdrawal were 61% for liver and 39% for the carcass (Sudgen et al., 1976). Previous livestock studies showed that fasting swine or bovine lowered muscle glycogen (Jones et al., 1985; Warriss et al., 1987) and increased meat pH (Warris, 1982; Crouse et al., 1984; Eikelenboom et al., 1991). The current study showed that pigs that were fasted had higher LD pH_u, and darker-colored lean, higher marbling scores, and higher water-holding capacity than pigs that were not fasted (Table 2). Visual marbling scores may have been higher in fasted pigs than notfasted pigs due to greater color contrast between fat and lean caused by the darker colored lean in fasted pigs (Wulf et al., 2002).

Effects of Transport

Neither fat nor blood glucose is a primary energy source at high exercise intensities; thus, muscle glycogen is the most readily available and easily metabolized fuel for exercise (Buchbinder et al., 1987; Murray et al., 2000). There have been many swine exercise studies conducted to try to improve pork quality (Lewis et al., 1989; Enfalt et al., 1997; Petersen et al., 1997). However, these studies did not show improvement in pork quality attributes or a decrease in muscle glycogen. The probable reason that these studies did not see any effects of exercise on pork quality is because the exercise, which lasted for 56 to 100 d or for the entire finishing period, resulted in trained pigs. A human study conducted by Green et al. (1991) showed extended periods of exercise training caused adaptations in muscle glycogen concentration that were 47.1% higher in the vastus lateralis muscle after 10 to 12 d of training. Training resulted in a persistently higher concentration of glycogen, but glycogen, still decreased at a similar rate during a single exercise bout (Green et al., 1991). On average muscle glycogen concentration was reduced 20% at 15 min, 30% at 60 min, and 43% by 99 min of exercise (Green et al., 1991).

Briskey et al. (1959) conducted a swine exercise study that involved one period of exhaustive exercise immediately prior to harvest and found exercised hogs produced muscle that had low glycogen concentrations, high pH values, dark color, and low expressible water ratios.

In the pork industry, the most typical form of exercise occurring within the 24 h prior to harvest would be elicited through transporting of pigs on a semitrailer to the packing plant. Therefore, this study involved different lengths of transport on the semitrailer. Becker et al. (1989) reported that transporting and associated handling impose an acute demand on the energy metabolism and fluid regulation of slaughter hogs. The consequence of this demand did not have a detrimental effect on meat quality (Becker et al., 1989). However, in the present study length of transport had a positive impact on pork quality. In general, as transport time was increased, GP, GGG, and lactate decreased, muscle pH increased, pork color became darker, and water-holding capacity increased (Table 2).

Genetic Effects

Pork from AGS had a lower GP and lactate, higher pH_u, and more desirable pork quality characteristics than pork from BGS. Pigs from AGS showed a greater response to fasting than pigs from BGS. Fasting may not be an effective method of improving pork quality in pigs with low muscle quality genotypes. Longer transportation times may be the most effective method of lowering muscle glycogen to improve pork quality in pigs with low muscle quality genetics.

Implications

We found that both fasting and transportation improved pork quality, but the transportation effects were greater than the fasting effects. A 48-h preharvest fast had approximately the same effect on pork quality as 2 h of transportation. The pork industry will likely not transport pigs for greater distances in order to improve pork quality; however, management decisions could be influenced by the results of this study in order to improve pork quality. For example, pork producers who are located within 1 h of the packing plant may utilize a preslaughter fast to improve

pork quality, whereas pork producers located greater distances from the packing plant may not need a pre-slaughter fast. For pork producers with multiple locations, those pigs with lower muscle quality genotypes should be finished at those locations furthest from the packing plant.

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