2002

Effects of High Protein/low Carbohydrate Swine Diets During the Final Finishing Phase on Pork Muscle Quality

J.M. Leheska
South Dakota State University

D.M. Wulf
South Dakota State University

J.A. Clapper
South Dakota State University

R.C. Thaler
South Dakota State University

Effects of high protein/low carbohydrate swine diets during the final finishing phase on pork muscle quality

J.M. Leheska, D.M. Wulf, J.A. Clapper, R.C. Thaler, and R.J. Maddock
Department of Animal and Range Sciences

SWINE 2001-18

Introduction

Pork color and water-holding capacity defects (pale, soft and exudative, or PSE pork) are functions of muscle pH and cost the U.S. pork industry $60 million per year (Morgan et al., 1994). Pork with a low ultimate pH (pH<5.5) has a paler color and lower water-holding capacity. Lactic acid build-up is responsible for lowering pH from 7.0, at the time of death, to 5.2-6.0 at 24 h postmortem. Postmortem glycolysis produces lactic acid and can only occur in the presence of the substrate glycogen. Therefore, more glycogen in the muscle at slaughter will result in more lactic acid build up and a lower ultimate pH, which will result in a paler color and a lower water-holding capacity (Ellis et al., 1997). Consumption of carbohydrates is the main source of glucose in the blood (Guyton and Hall, 1996). In human studies conducted by Snitker et al., (1997) eight adult males were given one of two isoenergetic diets: a high-carbohydrate diet (75% of energy as carbohydrate, 15% as protein, and 10% as fat), or a low-carbohydrate diet (10% of energy as carbohydrate, 15% as protein, and 75% as fat) for three days. After the three d dietary manipulation, glycogen content in the vastus lateralis muscle was significantly lower for the low-carbohydrate subjects than for the high-carbohydrate subjects; 296 vs 426 mmol glucose/kg dry muscle, respectively ($P<0.001$) (Snitker et al., 1997). Therefore, this study was conducted to determine if feeding ultra-high protein/low carbohydrate swine diets during the final finishing phase could reduce muscle glycogen and thereby improve pork muscle quality.

Materials and Methods

Animals. Fifty barrows were allotted into five weight groups and randomly assigned to 10 pens (five pigs per pen; one pig from each weight group per pen). According to the genetic supplier, these pigs were all negative for the Halothane gene and did not have any Hampshire ancestry. This study consisted of five different treatments with two replications of each. Two diets were used in this study, a control diet and a high protein/low carbohydrate (HIPRO) diet (Table 1). All barrows consumed the control diet until a treatment began. A treatment was the number of days before harvest that a randomly assigned pen of pigs consumed the HIPRO diet. The five treatment times were 0, 2, 4, 7 and 14 d before harvest. All pigs were weighed at 14 d, 7 d and 0 d prior to harvest. Feed disappearance was measured daily for each pen. Feed was removed from feeders approximately 12 h before the barrows were harvested at the South Dakota State University Meat Laboratory. There was very minimal stress prior to harvest as pigs were transported approximately 200 m from pens to abattoir.

Carcass Traits. Temperature, pH, and electrical impedance (Py) were measured at 45 min, 3 h, and 24 h postmortem in the semimembranosus and longissmus lumborum muscle 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). At 24 h postmortem the left side of each carcass was ribbed between the 10^{th} and 11^{th} ribs and color, marbling, and firmness were assessed in the longissmuss thoracis according to the National Pork Producers Council 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. Additionally, fat thickness and loin eye area were measured at the 10^{th} rib, and 0.25 cm was added to each fat thickness measurement to adjust for skinning of the carcasses.

At 48 h postmortem the left longissmuss thoracis et lumborum (ribbed side) from each

carcass was removed. Chops were removed from the longissimuss thoracis et lumborum starting at the 11th rib location and continuing towards the caudal end for glycolytic potential assay, drip loss, and Warner-Bratzler shear force determination, respectively. The remainder of the longissimuss lumborum was used to measure purge loss.

Blood Glucose Analysis. Two blood samples were collected from each barrow at exsanguination in 7 ml vacutubes containing a glycolytic inhibitor (14 mg potassium oxalate and 17.5 mg sodium fluride). Samples were centrifuged at 1, 500 x g for 30 min, serum was removed and stored at -20°C. Prior to glucose analysis, samples were allowed to thaw at room temperature for 30 mins and then centrifuged. Glucose was measured from the serum samples using a YSI 2700 Biochemistry Analyzer (YSI Inc, Yellow Springs, OH).

Glycolytic Potential Analysis. Three grams of each pork loin were used to determine glycolytic potential as described by McKeith et al. (1998). Perchloric acid was used to deproteinate the muscle samples. The resulting perchloric extracts were used to quantify glycogen, glucose, glucose-6-phosphate (G6P) and lactate. Glycolytic intermediates were catalyzed to G6P using hexokinase, and then into 6-phosphogluconate in the presence of $NADP^+$. $NADP^+$ 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 µmole lactate/g and determined by [2 x (glucose + glycogen + glucose-6-phosphate)] + lactate.

Drip Loss. One chop from each loin was cut 2.5-cm-thick at 48 h postmortem, external fat and lip muscles were removed, and chops were weighed to the nearest 0.01 g. Color, firmness, and marbling were reassessed using NPPC Quality Standards, along with L*a*b* color values using a Minolta Chroma Meter. Each chop was retail wrapped on a styrofoam tray, arranged at an approximate 30-degree 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.

Purge Loss. After removing drip loss, shear force and glycolytic potential samples, the remainder of each boneless loin was weighed to the nearest 0.01 g, vacuum packaged, and stored at 1.4°C for 11 d. On the 13th d postmortem, the loin sections were removed from their vacuum package and allowed to drip on a grate for approximately 15 minutes. Next, loin sections were weighed to the nearest 0.01 g and percent purge loss was determined as a percentage of initial loin weight.

Cooking Loss. One 2.5-cm-thick chop was removed from the cranial end of each frozen loin section (approximate location was first lumborum vertabrae). 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 set at 190.5°C for 10.5 min resulting in an average final internal temperature of 71.1°C. 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 percentage of initial raw weight.

Warner-Bratzler Shear Force. A 7.5-cm-long section was removed from each loin at 48 h postmortem, vacuum packaged and allowed to age to d-eight postmortem at a temperature of 1.4°C. Samples were frozen at -18°C, sawed into two 2.5-cm-thick chops, repackaged and stored at -16.5°C. Chops were thawed at 1.4°C for 24 h prior to cooking. The chops were cooked for 10.5 min in an impingement oven that was set to 190.5°C resulting in an average final internal chop temperature of 71.1°C. 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. Average daily feed intake was analyzed as a split plot design with pen (10 pens) serving as the whole plot, and day on the HIPRO diet (15 levels; 0 to 14 days) serving as the split plot. Average weekly feed intake, weight gain, and feed conversion were expressed on a per day basis and analyzed as a

completely randomized design (experimental unit = pen) with week on the HIPRO diet (3 levels; 0, 1, and 2 weeks) being the only independent variable in the model.

All postmortem traits were analyzed as a randomized complete block design (experimental unit = animal) with a model that included independent variables of block (2 levels; Rep A and B) and dietary treatment (5 levels; 0, 2, 4, 7, and 14 d on HIPRO diet). Models for all postmortem traits except for blood glucose and glycolytic potential included slaughter order (within Rep; 1 to 24) as a linear covariate. Least squares means were calculated for all variables and separated using pairwise t-tests.

Results and Discussion

Table 1 shows the percentage of ingredients and nutrient composition on an as-fed basis for the control and the HIPRO diets. The control diet was 13.1% crude protein and was a typical corn and soybean meal finishing diet with dicalcium phosphate. The HIPRO diet consisted of extruded soybeans and a pellet binder and was 35.9% crude protein. Both diets were pelleted and contained limestone, salt, and SDSU premix (Table 1).

Average daily feed intake for all hogs on the control diet was 2.77 kg/d (Figure 1). Average daily intake was drastically reduced as soon as barrows were switched to the HIPRO diet. From the 2nd d to the 10th d of eating the HIPRO diet, average daily intake gradually increased. After the 11th d of eating the experimental diet, average daily feed intake began to decrease again. Average daily weight gain decreased the longer the hogs consumed the HIPRO diet (Figure 2). As a result, during the second week of consuming the HIPRO diet, feed conversion was substantially compromised (Figure 2). Feeding the HIPRO diet prior to harvest reduced feed intake, rate of gain, and feed conversion. A possible explanation for decreased feed intake while on the HIPRO diet was poor palatability. The energy level of the HIPRO diet must also be considered, as the HIPRO diet was 97% extruded soybeans (full-fat soybeans) making the HIPRO diet very high in energy. Therefore, the energy contained in the HIPRO diet may have met the caloric intake needs of the hogs with a smaller quantity of feed.

Normal swine blood contains 80 – 120 mg/dl of glucose (Reece, 1996). All of the hogs in this trial were close to or within this normal range for blood glucose level (Table 2). The HIPRO diet contained only 4% as much starch as the control diet (Table 1). Starch in the diet is a major source for glucose in the blood. Therefore, we would expect that the control pigs would have had higher blood glucose levels because they consumed substantially higher levels of starch. However, the longer the barrows consumed the HIPRO diet the higher blood glucose level they had (Table 2). The higher blood glucose levels for the 14 d treatment may be due to the large amount of protein in the HIPRO diet. When insufficient carbohydrate is ingested, protein is the major source for maintenance of normal blood glucose concentrations through gluconeogenesis (Mathews & van Holde, 1995). This may also explain why there was no difference in glycolytic potential of the muscle among dietary treatment groups (Table 2).

Because glycolytic potential was not altered, one would not expect meat quality traits to differ among dietary treatments. Muscle temperature decline and electrical impedance were not different (P>0.05) across dietary treatments in both the semimembranosus (SM) and the longissmus dorsi (LD) muscles (data not shown). There was no effect (P>0.05) of dietary treatment on pH decline or ultimate pH in either the SM or LD muscles (Figure 3). The temperature decline in the first three h postmortem was slower in the SM than in the LD (data not shown), and the rate of pH decline was much faster in the SM than it was in the LD (Figure 3). Knowing that higher temperatures result in faster pH decline (Milligan et al., 1998), it is logical that the SM pH decline was faster than the LD pH decline because the SM temperature was higher than the LD temperature during the first three h postmortem (data not shown).

Minolta L* value and visual color score were not different (P>0.05) among dietary treatments (Table 2). Likewise, firmness and marbling scores did not differ (P>0.05) among dietary treatments. Water holding capacity was not altered from feeding the HIPRO diet in the final finishing phases in swine as evidenced by no difference (P>0.05) among dietary treatments for 24 h drip loss, 11 day purge loss, or cooking loss. Finally, feeding the HIPRO diet in the final finishing phase of swine did not affect

tenderness as Warner-Bratzler shear force values were not different ($P>0.05$) among dietary treatments (Table 2).

Implications

Feeding a high protein/low carbohydrate diet, composed primarily of extruded soybeans, in the final finishing phase of swine reduced feed intake, weight gain, and feed conversion. Feeding the high protein/low carbohydrate diet did not reduce glycolytic potential, and therefore, did not affect pork muscle quality.

Literature Cited

Ellis, M., F.K. McKeith, and D.S. Sutton. 1997. Effect of the Napole Gene on quality. In: Proc. Pork Quality Summit, Ames, IA. p 49-58.

Guyton, A. C. and J. E. Hall. 1996. Multiple functions of the kidneys in homeostasis. In: Medical Physiology. 9th ed. p 316. W.B. Saunders Company, Philadelphia, PA.

Mathews, C.K., and K.E. Van Holde. 1995. Carbohydrate Metabolism II: Biosynthesis. In: Biochemistry. 2nd ed. p 554 –566. The Benjamin/ Cummings Publishing Company, Inc. Menlo Park, CA.

McKeith, F. K., M. Ellis, K. D. Miller, and D. S. Sutton. 1998. The Effect of RN Genotype on pork quality. In: Proc. 51st Reciprocal Meat Conference. Storrs, CT. p 118-124.

Milligan, S.D., C.B. Ramsey, M.F. Miller, C.S. Kaster, and L.D. Thompson. 1998. Resting of pigs and hot-fat trimming and accelerated chilling of carcasses to improve pork quality. J. Anim. Sci. 76:74-86.

Morgan, J. B., G. C. Smith, J. Cannon, F. K. McKeith, and J. Heavner. 1994. Pork chain quality audit: Pork distribution channel audit report. Prepared for National Pork Producers Council by Colorado State U. and U. of Illinois.

NPPC. 1999. Pork Quality Standards. National Pork Producers Council, Des Moines, IA.

Reece, W.O. 1996. Values of some constituents of blood from mature domestic animals. In: Physiology of Domestic Animals. 2nd ed. Table 6.4. p. 150. Williams & Wilkins. Baltamore, New York.

Snitker, S., D. E. Larson, P. A. Tataranni, and E. Ravussin. 1997 Ab libitum food intake in humans after manipulation of glycogen stores. Am J Clin Nutr. 65: 941-946.

TABLE 1. INGREDIENTS AND NUTRIENT COMPOSITION OF CONTROL AND HIGH PROTEIN/LOW CARBOHYDRATE (HIPRO) DIET. VALUES ARE PERCENTAGE DIET COMPOSITION ON AN AS-FED-BASIS.

Ingredient	Control diet	HIPRO diet
Corn	84.34	0.00
Soybean meal (44% CP)	13.35	0.00
Extruded soybeans (full-fat)	0.00	96.95
Limestone	0.88	0.80
Dicalcium phosphate	0.69	0.00
Salt	0.25	0.25
SDSU premix[a]	0.50	0.50
Pellet binder	0.00	1.50
Calculated nutrient composition		
Crude protein	13.10	35.90
Lysine	0.60	2.18
Valine	0.68	1.57
Tryptophan	0.16	0.54
Threonine	0.53	1.38
Calcium	0.55	0.56
Phosphorus	0.45	0.59
Chemical nutrient composition		
Total dry matter	90.1	92.9
Crude protein	12.7	33.7
Crude fat (ether extract)	3.6	19.6
Ash	3.3	6.3
Crude fiber	2.20	4.50
Nitrogen free extract	68.3	28.8
Starch	51.6	2.2

[a]SDSU premix had the following minimum vitamin potency per kg :13,636 IU vitamin E, 2,727 mg riboflavin, 18,181 mg niacin, 14 mg vitamin B-12, 1,818 mg menadione, 5,509 mg menadione – sodium bisulfite complex, 10,909 mg d – pantothenic acid, 11,858 mg d – calcuim pantothenate. 0.25 kg of SDSU premix were added per metric ton of feed.

TABLE 2. DIETARY TREATMENT EFFECTS ON BLOOD GLUCOSE, GLYCOLYTIC POTENTIAL, AND MEAT QUALITY TRAITS.

Trait	Days on Experimental Diet					
	0 (n=9)	2 (n=10)	4 (n=9)	7 (n=10)	14 (n=10)	RSE
Blood Glucose, mg/ dl	77.7[x]	84.5[xy]	81.9[xy]	86.2[xy]	90.4[y]	9.6
Glycolytic Potential [a]	132	136	130	134	135	21
L* [b]	56.0	56.4	55.1	56.4	56.7	2.4
Color score [c]	3.24	2.83	3.02	2.80	2.73	0.60
Firmness score [d]	2.14	1.75	1.97	2.03	1.96	0.61
Marbling score [e]	2.30	1.93	1.79	1.78	1.65	0.81
24-h Drip loss, %	0.84	1.25	0.88	1.08	0.92	0.52
11-d Purge loss, %	2.93	3.81	3.52	4.40	3.76	1.53
Cooking loss, %	26.2	26.3	25.1	26.3	27.4	2.0
Warner-Bratzler shear force, kg	3.79	3.52	3.58	3.41	3.44	0.38

[x,y]Means lacking a common superscript letter differ. (P<0.05)

[a]Glycolytic potential = 2 ([glycogen] + [glucose] + [glucose-6-phosphate]) + [lactate]; Measured in µmoles lactate/g

[b]L*; 0 = black, 100 = white

[c]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, 6.0 = dark purplish red

[d]Firmness score; 1 = soft, 2 = firm, 3 = very firm

[e]Marbling score; Visual scale approximates percent intramuscular fat; lower numbers refer to less marbling

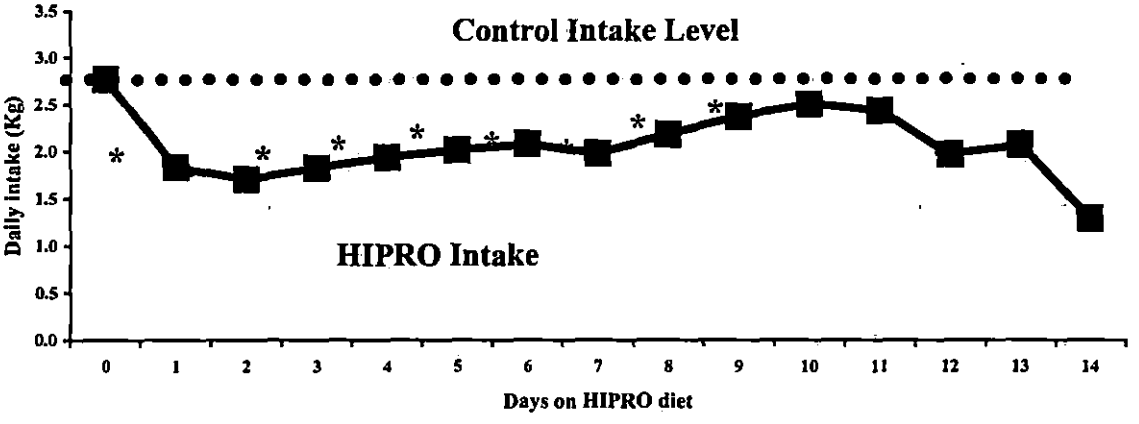


Figure 1. Average daily feed intake according to days on high protein/low carbohydrate (HIPRO) diet. An asterisk indicates a difference between HIPRO intake and control intake level ($P<0.05$).

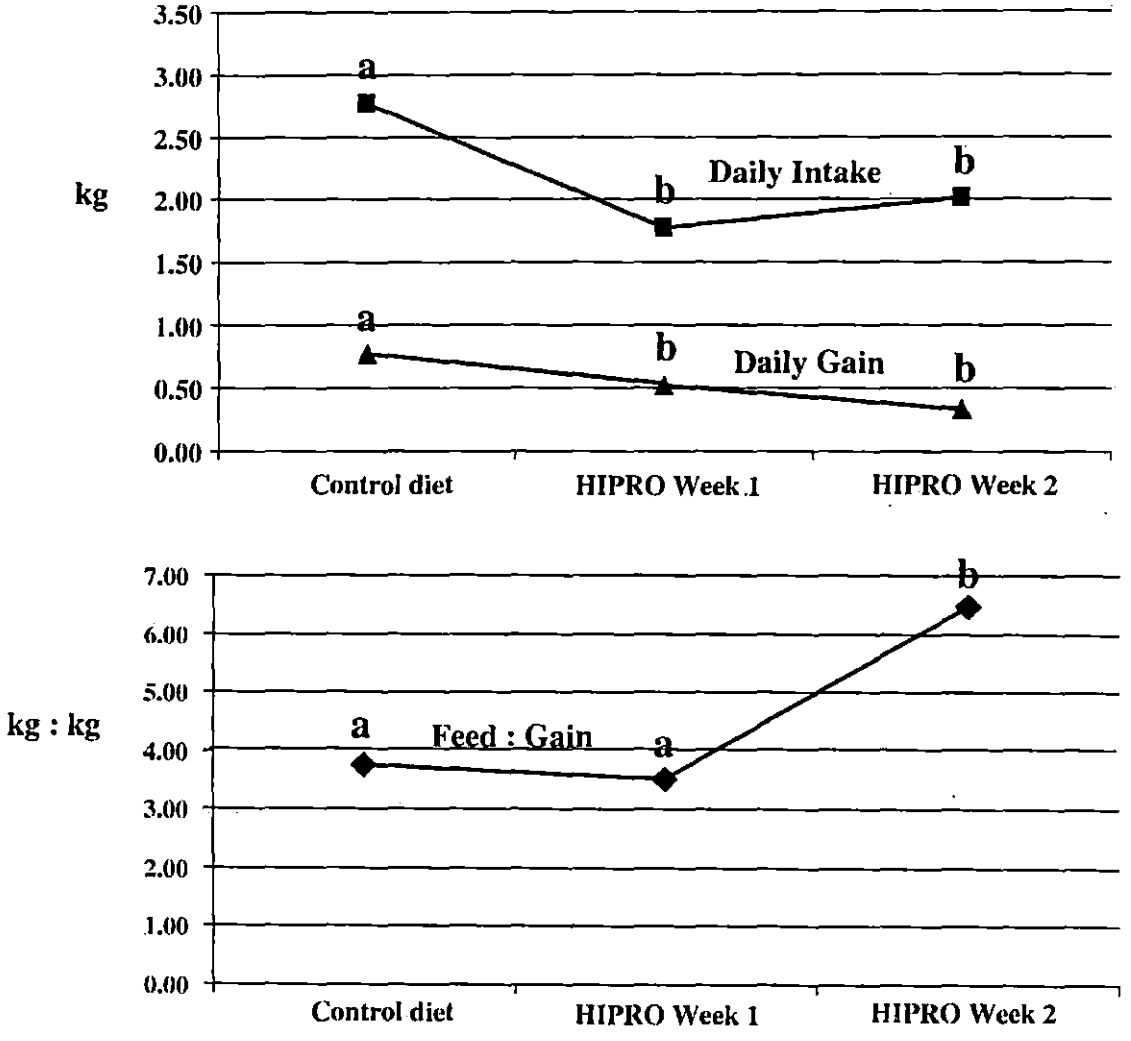
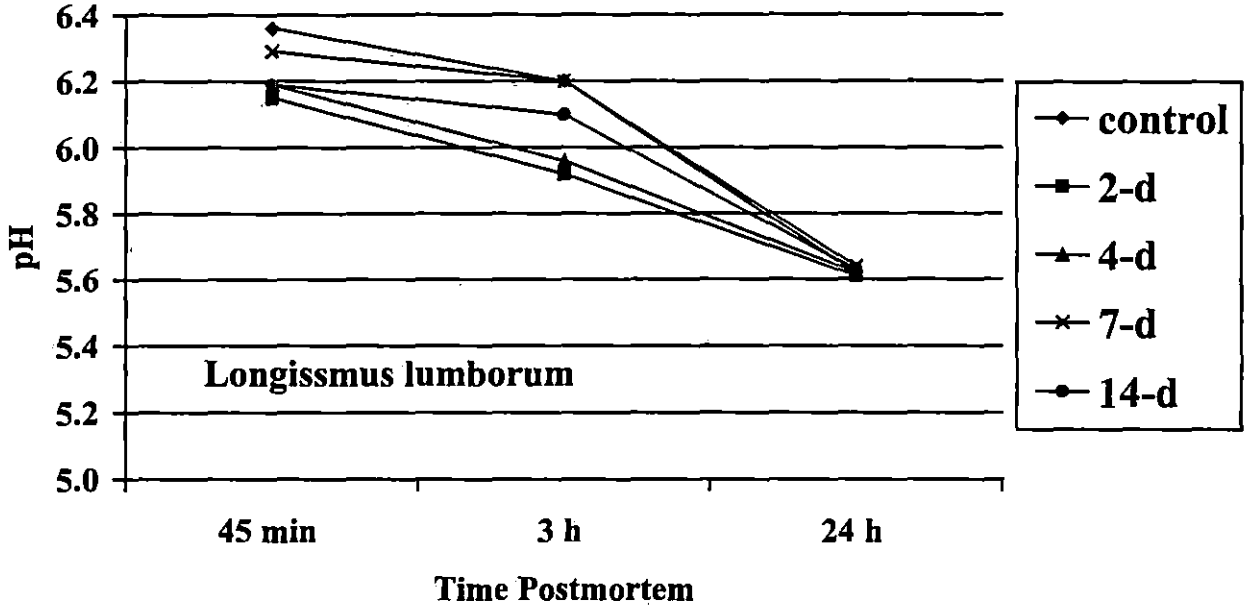


Figure 2. Feed intake, weight gain, and feed conversion while on the control diet, and during the first and second week of consuming the high protein/low carbohydrate (HIPRO) diet.
[a,b] Means for an individual trait lacking a common superscript letter differ. ($P<0.05$)



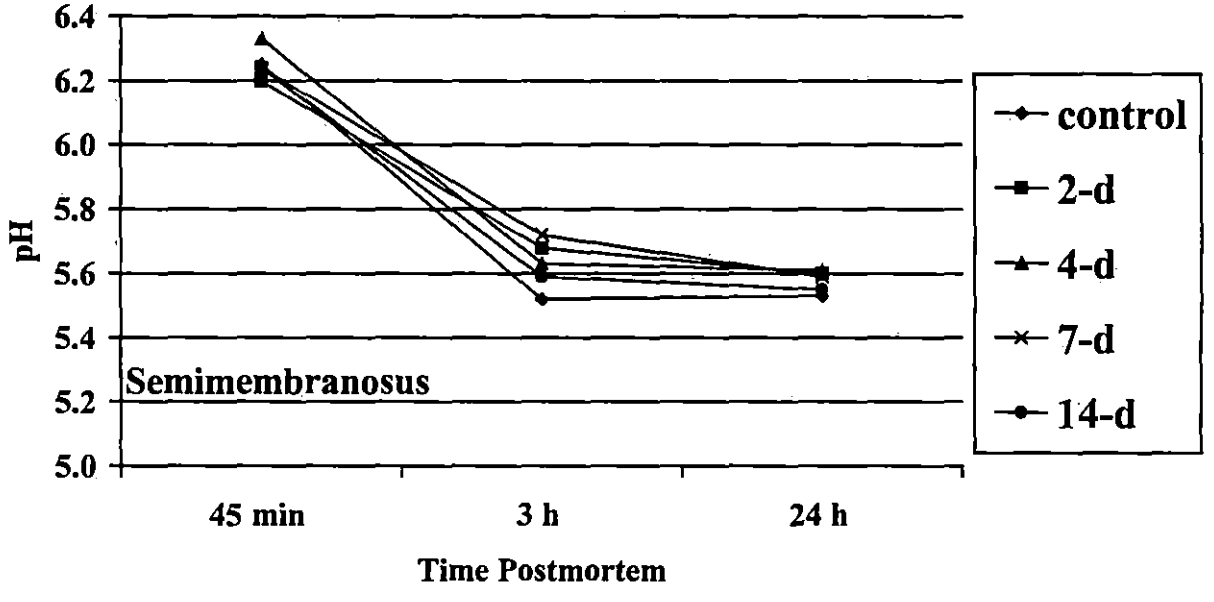


Figure 3. Muscle pH at 45 min, 3 h, and 24 h postmortem in the longissmus lumborum and semimembranosus by dietary treatment.