Starch Source Evaluation in Calf Starter: I. Feed Consumption, Body Weight Gain, Structural Growth, and Blood Metabolites in Holstein Calves

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ABSTRACT

Holstein calves were fed pelleted iso-starch (25% of starter dry matter) diets containing barley ($n = 16$), corn ($n = 16$), oat ($n = 16$), and wheat ($n = 16$) starch for 12 wk of age. Feed consumption, nutrient intake, body weight (BW) gain, skeletal growth, and selected blood metabolites in calves during preweaning (d 1 to 49) and postweaning (d 50 to 84) periods were measured. Average daily starter consumption during preweaning and postweaning periods was the greatest in calves fed corn diet followed by those fed a wheat diet and then in those fed barley and oat diets. During the preweaning period, the calves provided corn and wheat diets consumed greater amount of mixed grass hay than those fed barley and oat diets. During the postweaning period, mixed grass hay intake was the greatest in calves provided corn diet followed by those fed a wheat diet and then in those fed barley and oat diets. Nutrients (dry matter, crude protein, starch, and neutral detergent fiber) intake followed the solid feed consumption pattern in calves. Body weight and body measurements (body length, body barrel, heart girth, wither height, and hip height) at birth and at weaning (d 49) in calves fed different starch sources were similar. Body weight and body measurements at postweaning (d 84) were the greatest in calves fed a corn diet followed by those fed a wheat diet and then in those fed barley and oat diets. Overall average BW gain and total dry matter intake were the greatest in calves fed a corn diet than in those fed wheat, barley, and oat diets. Feed efficiency was greater in calves fed corn and wheat diets than in those fed barley and oat diets. Blood glucose, blood urea N, triglycerides, cholesterol, and creatinine were reduced with the advancing age of calves. Lesser blood glucose and greater blood urea N concentrations at wk

8, 10, and 12 of age were noticed in calves fed corn diet than in those fed barley, oat, and wheat diets. Occurrence of diarrhea was more frequent in calves fed oat diet than in those provided barley, corn, and wheat diets. Starch sources did not influence respiratory score, rectal temperature, and general appearance score. In conclusion, the calves on corn diet consumed more solid feed and gained greater BW than those fed barley, oat, and wheat diets.

Key words: starch, calf starter, growth

INTRODUCTION

Early transition from simple gastric digestion to functional ruminal digestion in dairy calves is essential for their health and growth (Khan et al., 2007b). This transition involves a number of anatomical and physiological changes in the fore-stomach. These changes and thus ruminal development in preweaned calves are essentially affected by the intake of solid feed and its composition (Baldwin et al., 2004; Khan et al., 2007a). Especially cereal grains or carbohydrate diets stimulate rumen microbial proliferation and VFA production, subsequently initiating rumen development (Baldwin et al., 2004).

Cereal grains are the primary source of starch in ruminant diets. Corn, rice, barley, wheat, oats, and sorghum are commonly used worldwide as a starch source in all animal feeds and especially in calf starters (Huntington, 1997). These sources differ in their starch contents with wheat (77% starch) being the highest of the grains, followed by 70 to 73% starch in corn, sorghum, and rice (Huntington, 1997), then by 57 to 58% starch in barley and oats (Poore et al., 1993). Indeed, the physical form of starch, its relation to proteins, and the cellular integrity of starch-containing units affect grain availability to microbes and nutrient digestibility (Theurer et al., 1999). Grain texture plays a major role in the rate and location of starch digestion in ruminants (Philippeau et al., 1999). Small grains (wheat, barley, or oats) are more rapidly fermented than corn and sorghum. Variations in starch granule structure among

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species of cereal grains may account for distinct rates of digestion patterns (Swan et al., 2006). Slower rates of digestion increase the amount of starch bypassing the rumen. Starch digested in the small intestine can produce up to 42% more energy than fermentation (Owens et al., 1998) because of a more efficient use of digestive end products (glucose vs. VFA). Therefore, the site of starch digestion along the gastrointestinal tract affects performance and feed efficiency in cattle (Swan et al., 2006). These variations may affect the solid feed consumption, quantity, and proportion of VFA in the rumen and thus its development and performance of calves during preweaning and early postweaning periods.

Many studies have recently investigated the effects of the physical form of calf starters (Abdelgadir and Morrill, 1995; Beharka et al., 1998), type and level of hay (Coverdale et al., 2004; Suárez et al., 2007), and grain processing (Lesmeister et al., 2004) on feed consumption, growth performance, and ruminal development of dairy calves. However, scientific research to evaluate effects of different starch sources in calf starter on solid feed consumption, nutrient intake, BW gain, skeleton growth, and metabolic response is limited. Ruminal parameters, rumen development, nutrients digestibilities, and nitrogen utilization in Holstein calves fed different starch sources were also evaluated [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data].

This study was conducted to evaluate the effects of starch sources (corn, wheat, oat, and barley) in calf starter (iso-starch) on feed consumption, BW gain, skeletal growth, and selected blood metabolites in Holstein calves during preweaning and postweaning periods.

MATERIALS AND METHODS

Animals, Housing, and Diets

The experiment was carried out at Dairy Science Division, National Institute of Animal Science, South Korea. All experimental procedures were reviewed and approved by the ethics committee on the use of animals in research, National Livestock Research Institute, South Korea. Holstein calves ($n = 64$, 32 male and 32 female) born during February 2006 to May 2006 were separated from their mothers within 2 h of birth, weighed, and moved into individual pens (1.5×2.5 m; bedded with wood shavings) where they were fed 10% colostrum of their BW for the first 3 d. The individual pens were interspersed evenly throughout the calf barn. Pens had solid iron rod sides, with openings in the front and rear to allow calves free access to calf starter and chopped mixed grass hay (MGH) from feeding buckets.

Table 1. Ingredient composition of calf starter diets¹

Ingredient, % DM	Barley	Corn	Oat	Wheat
Ground barley	40.00	—	—	—
Ground corn	—	30.00	—	—
Crimped oat	—	—	50.00	—
Ground wheat	—	—	—	40.00
Wheat mill run	15.00	15.00	5.00	15.00
Rice polish	1.00	2.00	2.00	2.00
Gluten feed	4.73	13.96	2.87	1.12
Soybean meal	9.92	15.00	8.57	13.91
Corn germ meal	—	—	2.00	—
Corn gluten	16.67	11.93	14.47	15.06
Soy hulls	—	—	1.55	—
Milk powder	6.00	6.00	6.00	6.00
Isolated soy protein	—	—	1.14	—
Salt	0.2	0.2	0.05	0.2
Molasses	1.00	1.00	1.00	1.00
DCP	0.10	0.10	0.30	0.30
CaCO ₃	2.15	2.05	0.96	1.93
MgO (50%)	0.13	0.13	0.06	0.13
KCl	0.14	0.07	0.4	0.4
L-Lysine (78%)	0.21	0.11	1.00	0.11
L-Threonine (98%)	0.02	0.01	0.05	0.02
Bentonite	1.41	1.12	1.26	1.50
Neomycin (11%)	0.05	0.05	0.05	0.05
Teramycin (OTC ² 20%)	0.05	0.05	0.05	0.05
Vitamin and mineral premix	1.22	1.22	1.22	1.22

¹Pelleted (20 mm in length and 3 mm in diameter) starter diets were formulated to contain equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat. Corn, barley, and wheat were ground through a 2-mm mesh and oats were crimped using a roller mill (gap between rolls 0.4 and 0.8 mm).

²OTC = oxytetracycline.

All calves were fed whole milk using mobile plastic bottles (2 L capacity) fitted with soft rubber nipples according to a step-down procedure (Khan et al., 2007a,b). Briefly, a steel bottle stand was attached to an iron rod at the front side of individual pen at 70 cm above the floor. Milk was provided at the rate of 20% of calves BW until d 23 of age and then between d 24 to 28; this rate was gradually reduced by diluting the milk with water (10% of volume on each feeding) until a milk feeding rate of 10% of their BW was achieved. Calves were fed at this rate for the remaining 16 d of the weaning period. All the calves were weaned between d 44 and 49.

Ground corn, ground barley, ground wheat, and crimped oat were used to formulate 4 iso-starch, isonitrogenous, and isocaloric diets (pelleted calf starter). The pellets were 20 mm in length and 3 mm in diameter. Corn, barley, and wheat were ground through a 2-mm mesh, and oats were crimped using a roller mill (gap between rolls 0.4 and 0.8 mm). The calf starters were randomly allocated to calves (16 calves per treatment, 8 male and 8 female). Calves were allowed to have free access to water from a bowl drinker in each pen. Ingredient composition of calf starter diets is presented in Table 1. Feed intake, BW, and skeletal growth of the calves was monitored till d 84 of age.

Table 2. Mean ($\pm$ SE) chemical composition of starters (% of DM), mixed grass hay (% of DM), and milk (%)

Parameter	Starter diet ¹				MGH ²	Milk ³
	Barley	Corn	Oat	Wheat		
DM	89.60 $\pm$ 1.22	89.40 $\pm$ 1.43	90.20 $\pm$ 2.11	88.20 $\pm$ 1.51	87.80 $\pm$ 1.70	12.21 $\pm$ 0.21
CP	23.40 $\pm$ 0.88	23.00 $\pm$ 0.75	23.2 $\pm$ 0.78	23.30 $\pm$ 0.54	13.20 $\pm$ 0.91	3.52 $\pm$ 0.07
NDF	15.50 $\pm$ 1.2	15.44 $\pm$ 1.1	20.09 $\pm$ 0.87	13.43 $\pm$ 0.75	65.00 $\pm$ 3.2	ND ⁴
ADF	5.44 $\pm$ 0.22	5.24 $\pm$ 0.25	8.11 $\pm$ 0.40	3.87 $\pm$ 0.35	37.0 $\pm$ 2.31	ND
NFC	41.18 $\pm$ 2.01	38.84 $\pm$ 1.25	36.60 $\pm$ 1.98	41.63 $\pm$ 2.08	ND	ND
Starch	25.00 $\pm$ 1.35	25.60 $\pm$ 1.20	24.90 $\pm$ 1.40	25.00 $\pm$ 1.50	ND	ND
Fat	2.63 $\pm$ 0.20	3.65 $\pm$ 0.21	4.87 $\pm$ 0.20	2.54 $\pm$ 0.24	1.85 $\pm$ 0.15	3.72 $\pm$ 0.15
Ash	7.30 $\pm$ 0.44	7.50 $\pm$ 0.50	6.65 $\pm$ 0.50	8.14 $\pm$ 0.64	7.68 $\pm$ 0.82	ND
Lactose	ND	ND	ND	ND	ND	4.77 $\pm$ 0.03
Ca	0.90 $\pm$ 0.01	0.88 $\pm$ 0.05	0.84 $\pm$ 0.02	0.98 $\pm$ 0.01	0.80 $\pm$ 0.02	112 $\pm$ 1.81
P	0.48 $\pm$ 0.05	0.50 $\pm$ 0.06	0.48 $\pm$ 0.04	0.54 $\pm$ 0.05	0.38 $\pm$ 0.05	76 $\pm$ 1.52
GE, kcal/g of DM	4.67 $\pm$ 0.12	4.72 $\pm$ 0.20	4.87 $\pm$ 0.25	4.64 $\pm$ 0.20	4.63 $\pm$ 0.30	ND

¹Pelleted starter diets contained equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat.

²Mixed grass hay contained 43% orchard grass, 43% tall fescue, and 14% white clover on DM basis.

³Milk storage tank samples (n = 20).

⁴ND = not determined.

Sampling and Analysis

Intake of starter and MGH was recorded weekly for 2 consecutive days throughout the experiment. Polythene sheets were attached around each feeding bucket to account for wastage of calf starter and hay. Samples of each calf starter diet (n = 5) and MGH (n = 5) were analyzed for DM content by drying them at 60°C for 48 h. Dried feed samples were ground using a Wiley mill through a 1-mm screen and stored at -20°C until analyzed for CP using the CuSO₄/TiO₂ mixed catalyst Kjeldahl procedure (AOAC, 1990), NDF (Van Soest et al., 1991) using α -amylase (Sigma No. A3306, Sigma Chemical Co., St. Louis, MO) and sodium sulfite and corrected for ash concentration adapted for Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY), ADF (AOAC, 1990), ether extract (AOAC, 1990), and ash (AOAC, 1990). Starch content of the feeds was determined according to the procedure of Hall (2001). Calcium and P were measured by inductively coupled plasma emission spectroscopy using an Atom Scan 25 Plasma Spectrometer (Thermo Jarrell Ash Corp., Grand Junction, CO) after acid digestion. Weekly samples of calf starters, MGH and their refusal were also analyzed for DM, CP, NDF, and starch using methods described above. Milk samples were analyzed with Lactoscope (MK2), Delta Instruments, Drachten, the Netherlands. Chemical composition of calf starters, MGH, and milk is presented in Table 2.

Intakes of calf starter, MGH, dry feed DM, CP, NDF, and starch by the calves were calculated for preweaning (d 1 to 49) and postweaning (d 50 to 84) periods. Overall average BW gain, total DMI (milk solids, starter, and hay), and feed efficiency (feed efficiency = kg of BW gain/kg of total DMI) were also calculated. Body weight,

body length (BL, distance between the points of shoulder and rump), heart girth (HG, circumference of the chest), body barrel (BB, circumference of the bally before feeding), withers height (WH, distance from base of the front feet to the withers), hip height (HH, distance from base of the rear feet to hook bones) measurements of the calves were recorded at birth, at weaning (d 49), and at postweaning (d 84).

Jugular blood samples were collected 30 min before morning feeding (0730 h) fortnightly throughout the experiment in evacuated tubes (10 mL) without any anticoagulant. These samples were centrifuged at 1,000 $\times$ g for 20 min, and serum was partitioned into aliquots and stored at -20°C until analyzed for glucose, total protein, albumin, BUN, triglycerides, cholesterol, creatinine, and lactate dehydrogenase (LDH) by serum analyzer (Arco PC, Biotenica Instruments, Rome, Italy).

Health of calves was monitored using procedure described by Heinrichs et al. (2003). Scoring was as follows: for scour scoring, 1 = normal, 2 = soft to loose, 3 = loose to watery, 4 = watery, mucous, slightly bloody, 5 = watery, mucous, and bloody; for respiratory scoring, 1 = normal, 2 = slight cough, 3 = moderate cough, 4 = moderate to severe cough, 5 = severe and chronic cough; and for general appearance scoring, 1 = normal and alert, 2 = ears drooped, 3 = head and ears drooped, dull eyes, slightly lethargic, 4 = head and ears drooped, dull eyes, lethargic, 5 = severely lethargic. A scour day was considered if the scour score was >3. Scours were also treated with electrolyte therapy (Eltradd, 3 g/L in drinking water; Byer Animal Health Co., Suwan, South Korea).

Statistical Analysis

Body weight, BW gain, skeletal growth, feed consumption, milk consumption, nutrients intake, feed ef-

Table 3. Average daily intake of milk, starter, mixed grass hay (MGH), and nutrients by Holstein calves (n = 16 per treatment) fed starch from different sources during preweaning (d 1 to 49) and postweaning (d 50 to 84) periods

Intake	Starter diet ¹				SEM
	Barley	Corn	Oat	Wheat	
Milk, kg	7.38	7.45	7.40	7.36	0.32
Starter, g					
Preweaning	215.69 ^b	287.20 ^a	226.71 ^b	251.35 ^{ab}	12.33
Postweaning	976.83 ^c	1,402.02 ^a	1,017.17 ^c	1,187.42 ^b	20.26
MGH, ² g					
Preweaning	102.35 ^b	159.17 ^a	111.10 ^b	146.48 ^a	10.52
Postweaning	508.29 ^c	713.67 ^a	548.33 ^c	622.67 ^b	24.40
DM, ³ g					
Preweaning	318.04 ^c	446.17 ^a	337.81 ^c	397.82 ^b	15.24
Postweaning	1,485.12 ^c	2,115.67 ^a	1,565.50 ^c	1,810.08 ^b	54.67
CP, ³ g					
Preweaning	64.07 ^b	86.86 ^a	67.15 ^b	79.40 ^a	4.23
Postweaning	295.16 ^c	401.63 ^a	307.81 ^c	358.79 ^b	14.14
Starch, ⁴ g					
Preweaning	53.92 ^b	73.47 ^a	56.23 ^b	62.84 ^{ab}	3.20
Postweaning	244.21 ^c	343.55 ^a	252.26 ^c	289.85 ^b	7.71
NDF, ³ g					
Preweaning	100.89 ^c	147.77 ^a	117.76 ^b	137.14 ^a	5.67
Postweaning	481.79 ^c	668.49 ^a	560.77 ^b	595.54 ^b	15.90

^{a-c}Within traits, means with different superscript letters are significantly different ($P < 0.05$).

¹Pelleted starter diets containing equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat were fed to calves.

²Mixed grass hay contained 43% orchard grass, 43% tall fescue, and 14% white clover on DM basis.

³Intake of DM, CP, and NDF from both starter and hay.

⁴Starch intake from only starter diets.

iciency, and health scoring data were analyzed as a randomized complete block design using the GLM procedure of SAS (SAS Institute, 1994). Calves were blocked by the week in which they began the study. The differences in treatment means were tested using Duncan's multiple range test. For time and treatment differences, concentrations of blood metabolites were evaluated using the RANDOM and REPEATED methods of the MIXED procedure of SAS (SAS Institute, 1994). Treatment (calf starter diets) and time were used as fixed effects, and the individual calves were used as random effects. For analyses of differences in time pattern among groups, the interaction (treatment $\times$ time) was included in the model. Significance was declared at $P < 0.05$ unless otherwise noted.

RESULTS

Average daily milk consumption, starter, MGH, and nutrients intakes are presented in Table 3. Daily milk intake was similar in calves fed calf starter diets containing starch from barley, corn, oat, and wheat. Starter and hay consumption was increased in calves with their advancing age. A rapid increase in the consumption of both starter and hay was observed in calves after d 28 of age. Another pronounced surge in solid feed consumption was noticed in calves during weaning and within

few days of postweaning. During preweaning period, the calves offered corn diet consumed greater amount of calf starter than those fed barley oat and wheat based diets. Preweaning starter intake was similar in calves fed barley-, oat-, and wheat-based diets. During postweaning period, starter intake was the greatest ($P < 0.05$) in calves fed a corn diet followed by those fed a wheat diet and then in those on barley and oat diets. Hay intake was greater ($P < 0.05$) in calves fed corn and wheat diets than in those fed barley and oat diets during the preweaning period. During the postweaning period, hay consumption was the greatest ($P < 0.05$) in calves offered a corn diet followed by those fed a wheat diet and then in those fed oat and barley diets.

During preweaning and postweaning periods, average daily solid feed DM intake was the greatest ($P < 0.05$) in calves offered corn diet followed by those fed wheat diet and then in those fed barley and oat diets. During preweaning period, average daily CP intake was greater ($P < 0.05$) in calves fed corn and wheat diets than in those fed barley and oat diets. During the postweaning period, daily intake of CP was the greatest ($P < 0.05$) in calves offered a corn diet followed by those fed a wheat diet and then in those on barley and oat diets. Daily starch intake during preweaning period was greater ($P < 0.05$) in calves fed a corn diet than in those fed wheat, barley, and oat diets. During post-

Table 4. Average BW and body measurements in Holstein calves fed starch from different sources

Parameter	Starter diet ¹				SEM
	Barley	Corn	Oat	Wheat	
BW, kg					
at birth	39.88	38.93	39.21	38.79	2.21
at weaning (d 49)	64.13	68.71	64.14	66.67	2.98
at postweaning (d 84)	88.33 ^c	110.2 ^a	90.59 ^c	105.0 ^b	2.50
Body length, cm					
at birth	68.95	68.47	69.03	69.05	2.23
at weaning	80.75	84.29	81.13	83.57	1.95
at postweaning	87.33 ^b	94.80 ^a	88.60 ^b	93.40 ^a	3.54
Body barrel, cm					
at birth	76.00	75.88	76.25	76.57	2.88
at weaning	95.50	99.50	94.50	98.14	2.90
at postweaning	114.67 ^b	128.17 ^a	113.67 ^b	122.80 ^a	3.52
Heart girth, cm					
at birth	75.88	74.75	75.05	76.16	3.64
at weaning	89.63	93.00	91.00	92.71	4.12
at postweaning	101.17 ^b	115.17 ^a	103.33 ^b	110.60 ^a	2.88
Wither height, cm					
at birth	76.05	75.71	74.98	76.16	2.91
at weaning	84.25	88.29	83.25	87.14	3.74
at postweaning	89.17 ^b	99.80 ^a	90.67 ^b	97.85 ^a	3.25
Hip height, cm					
at birth	78.75	79.29	79.14	79.14	2.14
at weaning	88.38	90.43	87.57	89.43	3.01
at postweaning	92.50 ^b	101.01 ^a	93.40 ^b	100.14 ^a	3.12

^{a-c}Within traits, means with different superscript letters are significantly different ($P < 0.05$).

¹Pelleted starter diets containing equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat were fed to calves.

weaning period, the greatest ($P < 0.05$) consumption of starch was noticed in calves provided a corn diet followed by those fed a wheat diet and then in those fed barley and oat diets. Daily NDF intake during the pre-weaning period was greater ($P < 0.05$) in calves fed corn and wheat diets than in those fed oat and barley diets. Consumption of NDF during postweaning was greater ($P < 0.05$) in calves fed a corn diet followed by those fed wheat and oat diets and then in those on a barley diet.

Average BW and structural growth parameters (BL, BB, HG, WH, and HH) are presented in Table 4. Body weight at birth and at weaning in calves fed calf starter diets containing barley, corn, oat, and wheat starch was similar. Body weight at postweaning (d 84) was the greatest ($P < 0.05$) in calves fed corn diet followed by those fed wheat diet and then in those on barley and oat diets. Postweaning BW of calves fed barley and oat diets were similar. Body length, BB, HG, WH, and HH at birth and at weaning were similar in calves fed barley, corn, oat, and wheat diets. Body length, BB, HG, WH, and HH at postweaning were greater ($P < 0.05$) in calves fed corn and wheat diets than in those fed barley and oat diets.

Average BW gain, total DMI, feed efficiency, days scoured, respiratory score, rectal temperature, and general appearance score are given in Table 5. The calves remained healthy and exhibited no sign of distress or

illness other than diarrhea during the experiment. Occurrence of diarrhea was more frequent ($P < 0.05$) in calves fed an oat diet than in those fed barley, corn, and wheat diets. Respiratory score, rectal temperature, and general appearance score were similar in calves fed barley, corn, oat, and wheat diets. Average overall BW gain and total DMI were the greatest ($P < 0.05$) in calves fed a corn diet followed by those fed a wheat diet and then in those fed barley and oat diets.

Mean serum glucose, BUN, total protein, and albumin concentrations in calves are presented in Table 6. Serum glucose was decreased ($P < 0.02$) in all calves with advancing age. Serum glucose concentration was the lowest ($P < 0.03$) in calves on a corn diet than in those fed wheat, barley, and oat diets at wk 6, 8, 10, and 12 of age. Blood urea N was decreased ($P < 0.01$) in all calves with advancing age. The highest ($P < 0.02$) BUN concentration was noticed in calves fed a corn diet followed by those fed a wheat diet and then in those fed barley and oat diets at wk 6, 8, 10, and 12 of age. Treatment $\times$ time interaction for serum glucose and BUN in calves during experimental period was not significant. Serum glucose and BUN concentration were similar in calves fed barley, corn, oat, and wheat diets at wk 2 and 4 of age.

Serum total protein and albumin concentration were increased ($P < 0.03$) in calves with their age. Greater

Table 5. Average overall BW gain, total DMI, feed efficiency, rectal temperature, days scoured, respiratory, and general appearance scores in Holstein calves fed starch from different sources¹

Parameter	Starter diet ²				SEM
	Barley	Corn	Oat	Wheat	
BW gain, kg	48.46 ^c	71.27 ^a	51.29 ^c	66.21 ^b	2.80
Total DMI, ³ kg	111.70 ^c	140.47 ^a	115.91 ^c	126.87 ^b	4.56
Feed efficiency ⁴	0.43 ^b	0.51 ^a	0.44 ^b	0.52 ^a	0.02
Days scoured	6.75 ^b	6.34 ^b	9.15 ^a	7.01 ^b	0.35
Respiratory score	1.08	1.10	1.11	1.09	0.08
Rectal temperature	38.72	38.80	38.77	35.82	0.11
General appearance	1.11	1.04	1.10	1.09	0.04

^{a-c}Within traits, means with different superscript letters are significantly different ($P < 0.05$).

¹Scour scoring: 1 = normal, 2 = soft to loose, 3 = loose to watery, 4 = watery, mucous, slightly bloody, 5 = watery, mucous, and bloody. Scour day considered if score >3 . Respiratory scoring: 1 = normal, 2 = slight cough, 3 = moderate cough, 4 = moderate to severe cough, 5 = severe and chronic cough. General appearance scoring: 1 = normal and alert, 2 = ears drooped, 3 = head and ears drooped, dull eyes, slightly lethargic, 4 = head and ears drooped, dull eyes, lethargic, 5 = severely lethargic.

²Pelleted starter diets containing equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat were fed to calves.

³Total DMI = milk, starter and hay DMI.

⁴Feed efficiency = kg of BW gain/kg of total DMI.

concentrations of total protein ($P < 0.03$) and albumin ($P < 0.04$) were noticed in calves fed corn and wheat diets than in those fed barley and oat diets. Concentrations of serum total protein and albumin were similar in calves fed barley, corn, oat, and wheat diets at wk 2, 4, and 6 of age. Treatment $\times$ time interaction for serum total protein and albumin in calves during experimental period was not significant.

Mean blood triglycerides, cholesterol, creatinine, and LDH are given in Table 7. Serum triglycerides and cholesterol concentrations were decreased ($P < 0.02$ and $P < 0.02$, respectively) in all calves with advancing age. However, a sharp decline in the concentrations of serum triglycerides and cholesterol in calves was observed between wk 6 and 8 of age. Greater concentration of serum triglycerides ($P < 0.04$) was noticed in calves on corn

Table 6. Mean ($\pm$ SE) blood glucose, urea nitrogen, total protein, and albumin concentration in Holstein calves fed calf starter diets¹ containing starch from different sources

Parameter	Age of calves (wk)						Fixed values, P		
	2	4	6	8	10	12	Treatment	Time	Treatment $\times$ time
Glucose, mg/dL							0.03	0.02	0.18
Barley	102.61 $\pm$ 2.1	96.62 $\pm$ 2.4	86.80 ^b $\pm$ 2.5	81.40 ^b $\pm$ 2.2	76.15 ^a $\pm$ 1.5	70.97 ^a $\pm$ 1.3			
Corn	103.12 $\pm$ 1.8	93.44 $\pm$ 2.5	79.14 ^c $\pm$ 2.3	70.20 ^d $\pm$ 1.9	63.20 ^c $\pm$ 1.8	57.25 ^c $\pm$ 1.2			
Oat	103.35 $\pm$ 2.2	95.12 $\pm$ 2.7	89.12 ^a $\pm$ 2.7	84.13 ^a $\pm$ 2.1	78.74 ^a $\pm$ 1.7	72.21 ^a $\pm$ 2.0			
Wheat	101.40 $\pm$ 3.1	94.65 $\pm$ 2.1	81.67 ^c $\pm$ 2.4	74.97 ^c $\pm$ 2.2	67.22 ^b $\pm$ 2.1	62.40 ^b $\pm$ 1.2			
BUN, mg/dL							0.2	0.01	0.22
Barley	8.72 $\pm$ 0.37	9.82 $\pm$ 0.35	10.32 ^b $\pm$ 0.51	12.04 ^b $\pm$ 0.55	15.17 ^c $\pm$ 0.45	18.27 ^b $\pm$ 0.61			
Corn	8.55 $\pm$ 0.44	8.39 $\pm$ 0.25	12.94 ^a $\pm$ 0.33	15.30 ^a $\pm$ 0.52	20.70 ^a $\pm$ 0.78	23.91 ^a $\pm$ 0.77			
Oat	8.62 $\pm$ 0.31	9.58 $\pm$ 0.29	11.09 ^b $\pm$ 0.25	12.51 ^b $\pm$ 0.44	14.74 ^c $\pm$ 0.50	16.92 ^c $\pm$ 0.58			
Wheat	8.62 $\pm$ 0.25	8.61 $\pm$ 0.31	13.01 ^a $\pm$ 0.24	16.77 ^a $\pm$ 0.52	18.77 ^b $\pm$ 0.64	22.75 ^a $\pm$ 0.75			
Total protein, g/dL							0.03	0.03	0.32
Barley	5.77 $\pm$ 0.23	6.35 $\pm$ 0.33	6.50 $\pm$ 0.19	6.50 ^b $\pm$ 0.22	6.47 ^b $\pm$ 0.35	6.65 ^b $\pm$ 0.37			
Corn	5.94 $\pm$ 0.25	6.37 $\pm$ 0.17	6.60 $\pm$ 0.22	6.90 ^a $\pm$ 0.19	7.06 ^a $\pm$ 0.41	7.02 ^a $\pm$ 0.35			
Oat	5.69 $\pm$ 0.15	6.45 $\pm$ 0.19	6.55 $\pm$ 0.25	6.40 ^b $\pm$ 0.20	6.45 ^b $\pm$ 0.34	6.56 ^b $\pm$ 0.26			
Wheat	5.82 $\pm$ 0.18	6.37 $\pm$ 0.20	6.60 $\pm$ 0.32	6.87 ^a $\pm$ 0.27	6.92 ^a $\pm$ 0.33	6.94 ^a $\pm$ 0.27			
Albumin, g/dL							0.04	0.03	0.27
Barley	3.72 $\pm$ 0.12	4.11 $\pm$ 0.20	4.02 $\pm$ 0.10	4.13 $\pm$ 0.14	4.27 ^b $\pm$ 0.14	4.26 ^b $\pm$ 0.12			
Corn	3.87 $\pm$ 0.15	4.23 $\pm$ 0.14	4.28 $\pm$ 0.12	4.45 $\pm$ 0.16	4.69 ^a $\pm$ 0.10	4.88 ^a $\pm$ 0.14			
Oat	3.87 $\pm$ 0.13	4.15 $\pm$ 0.11	4.09 $\pm$ 0.16	4.14 $\pm$ 0.12	4.30 ^b $\pm$ 0.13	4.36 ^b $\pm$ 0.11			
Wheat	3.98 $\pm$ 0.19	4.13 $\pm$ 0.12	4.10 $\pm$ 0.12	4.31 $\pm$ 0.15	4.58 ^a $\pm$ 0.12	4.78 ^a $\pm$ 0.09			

^{a-d}Means of a parameter in a column bearing different superscript are significantly ($P < 0.05$) different.

¹Pelleted starter diets containing equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat were fed to calves.

Table 7. Mean ($\pm$ SE) blood triglycerides, cholesterol, creatinine, and lactate dehydrogenase (LDH) concentration in Holstein calves fed calf starter diets¹ containing starch from different sources

Parameter	Age of calves (wk)						Fixed values, <i>P</i>		
	2	4	6	8	10	12	Treatment	Time	Treatment $\times$ time
Triglycerides, mg/dL							0.04	0.02	0.15
Barley	44.02 $\pm$ 2.9	45.59 $\pm$ 1.9	41.42 $\pm$ 1.8	30.68 $\pm$ 1.5	24.10 ^c $\pm$ 1.2	25.27 ^b $\pm$ 1.1			
Corn	43.12 $\pm$ 2.5	45.85 $\pm$ 1.8	40.77 $\pm$ 1.5	31.87 $\pm$ 1.7	32.03 ^a $\pm$ 1.4	32.92 ^a $\pm$ 1.6			
Oat	45.22 $\pm$ 3.2	46.50 $\pm$ 2.5	42.72 $\pm$ 2.2	29.70 $\pm$ 1.9	27.47 ^b $\pm$ 1.5	25.14 ^b $\pm$ 1.3			
Wheat	44.98 $\pm$ 3.2	47.12 $\pm$ 2.6	42.07 $\pm$ 1.9	30.38 $\pm$ 1.6	31.52 ^a $\pm$ 1.2	31.98 ^a $\pm$ 1.5			
Cholesterol, mg/dL							0.03	0.01	0.19
Barley	111.82 $\pm$ 4.8	129.91 $\pm$ 6.2	127.37 $\pm$ 8.2	108.77 $\pm$ 7.0	79.05 ^b $\pm$ 3.7	72.52 ^c $\pm$ 2.9			
Corn	110.38 $\pm$ 6.2	132.07 $\pm$ 5.1	132.8 $\pm$ 7.8	105.17 $\pm$ 6.1	95.95 ^a $\pm$ 4.1	91.67 ^a $\pm$ 3.1			
Oat	117.85 $\pm$ 5.9	142.10 $\pm$ 7.8	120.9 $\pm$ 6.2	103.81 $\pm$ 5.9	82.14 ^b $\pm$ 3.5	70.27 ^c $\pm$ 3.5			
Wheat	108.14 $\pm$ 5.5	137.92 $\pm$ 6.8	135.6 $\pm$ 7.5	104.70 $\pm$ 7.5	91.22 ^a $\pm$ 3.3	86.61 ^b $\pm$ 2.2			
Creatinine, mg/dL							0.08	0.02	0.35
Barley	0.91 $\pm$ 0.05	0.88 $\pm$ 0.07	0.86 $\pm$ 0.05	0.78 $\pm$ 0.10	0.76 $\pm$ 0.02	0.76 $\pm$ 0.03			
Corn	0.95 $\pm$ 0.04	0.87 $\pm$ 0.08	0.88 $\pm$ 0.07	0.79 $\pm$ 0.08	0.77 $\pm$ 0.06	0.75 $\pm$ 0.02			
Oat	0.94 $\pm$ 0.08	0.85 $\pm$ 0.06	0.84 $\pm$ 0.06	0.80 $\pm$ 0.05	0.78 $\pm$ 0.05	0.77 $\pm$ 0.05			
Wheat	0.92 $\pm$ 0.06	0.87 $\pm$ 0.08	0.83 $\pm$ 0.06	0.77 $\pm$ 0.04	0.78 $\pm$ 0.05	0.78 $\pm$ 0.06			
LDH, units/L							0.02	0.02	0.21
Barley	151.8 $\pm$ 14.2	199.2 ^a $\pm$ 16.8	210.9 ^a $\pm$ 16.0	205.0 ^c $\pm$ 22.4	213.6 ^d $\pm$ 12.5	226.5 ^b $\pm$ 18.1			
Corn	143.1 $\pm$ 12.7	162.9 ^b $\pm$ 10.8	184.3 ^b $\pm$ 13.5	244.7 ^a $\pm$ 19.8	257.9 ^a $\pm$ 17.7	264.1 ^a $\pm$ 11.8			
Oat	148.9 $\pm$ 10.5	173.3 ^b $\pm$ 11.9	183.5 ^b $\pm$ 11.4	220.3 ^b $\pm$ 16.8	227.8 ^c $\pm$ 16.5	222.2 ^b $\pm$ 13.6			
Wheat	154.8 $\pm$ 11.8	195.4 ^a $\pm$ 10.7	190.2 ^b $\pm$ 14.9	237.1 ^a $\pm$ 17.5	243.0 ^b $\pm$ 13.2	254.0 ^a $\pm$ 17.5			

^{a-d}Means of a parameter in a column bearing different superscript are significantly ($P < 0.05$) different.

¹Pelleted starter diets containing equal amount of starch (25% of feed DM) from barley, corn, oat, and wheat were fed to calves.

and wheat diets than in those fed barley and oat diets at wk 10 and 12 of age. Serum cholesterol concentration was greater in calves provided a corn diet followed by those fed a wheat diet and then in those fed barley and oat diets. Treatment $\times$ time interaction for serum triglycerides and cholesterol in calves during experimental period was not significant.

Serum creatinine concentration in calves was not affected by the treatments however; its concentration was decreased ($P < 0.02$) in older calves. Serum LDH concentration was increased with the age of calves and differed significantly among calves fed barley, corn, oat, and wheat diets at wk 4, 6, 8, 10, and 12 of age. Treatment $\times$ time interactions for serum creatinine and LDH concentrations in calves during experimental period were not significant.

DISCUSSION

All calves in this experiment safely consumed a greater amount of milk than that generally provided to dairy calves under a restricted milk feeding (conventional) system. Present results indicated that calves can consume and digest greater amounts of milk than typically given under a conventional feeding system, particularly when provided in small but frequent meals that are similar to those observed under natural conditions (Albright and Arave, 1997). Similar results were demonstrated in our previous experiments where female (Khan et al., 2007b) and male (Khan et al., 2007a)

Holstein calves on a step-down feeding system consumed a significantly greater amount of milk than those fed through a conventional system.

All calves in this study started rumination between d 8 to 13 of age except for 3 calves on an oat diet in which regurgitation movement was observed on d 17 of age. Delay in the initiation of rumination in oat fed calves may be attributed to less starter intake during first 2 wk of age because of its greater NDF contents or some unknown organoleptic factors.

Similar to present results, a slow increase in solid feed consumption with age during the preweaning period has been demonstrated by other workers (Albright and Arave, 1997; Khan et al., 2007a,b). A rapid increase in starter and MGH intake during few days after d 28 and weaning in all experimental calves may be attributed to a hyperphagic response due to a reduced milk and nutrient supply. Khan et al. (2007a) also reported a rapid surge in solid feed consumption and reduced blood glucose levels in Holstein calves with reduced milk supply. Low consumption of starter and hay during preweaning and postweaning periods in calves fed barley, oat, and wheat diets than in those fed corn diet may be related to the low ruminal pH [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data] because acidosis generally depresses the DMI (Owens et al., 1998; Huntington et al., 2006; Khan et al., 2006). Ruminal pH at d 50 and 70 of age was lower in calves fed barley (5.46 and 5.66, respec-

tively), oat (5.68b and 5.96, respectively), and wheat (5.62 and 5.95, respectively) diets than in those fed corn (5.79 and 6.16, respectively) diet. The rumen pH values observed in calves were similar to those reported by others (Wheeler et al., 1980; Lesmeister et al., 2004). Greater intake of DM, CP, starch, and NDF in calves fed a corn diet than in those fed barley, oat, and wheat diets during preweaning and postweaning periods may be ascribed to the differences in ruminal development and thus its metabolic and structural capacity to accommodate and digest solid feed. Rumen weight, papillae concentration, VFA, and blood BHBA concentrations were greater in calves fed corn diet than in those fed wheat, oat, and barley diets [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data]. Significantly greater nutrients intake in calves fed corn diet than in those fed other experimental diets may be ascribed to structurally and metabolically developed rumen in the former.

Greater protein intake during preweaning and postweaning periods in calves fed a corn diet than in those fed barley, oat, and wheat diets was the function of greater starter consumption. Significantly greater intake of hay and NDF in calves fed corn diet may be ascribed to greater starch consumption. Conversely, lesser NDF consumption in calves on barley, oat, and wheat diets may be attributed to lesser starch intake. Several investigators (Stobo et al., 1966; Coverdale et al., 2004) have reported a positive relationship between starter and hay consumption during preweaning and postweaning periods in calves. However, others have found a negative correlation between intake of starter and hay in the ration (Whitaker et al., 1957; Leibholz, 1975). This controversy could possibly be attributed to the nature of starch and its fermentation pattern, composition, and physical form of starter and type of hay used in these studies. Small grains (wheat, barley, or oats) are more rapidly fermented than corn and sorghum (Huntington, 1997). Variations in starch granule structure among species of cereal grains may account for distinct rates of digestion patterns (Swan et al., 2006). In present study, expected rapid fermentation of starch and related lower pH at least for few hours postprandial in calves on barley, oat, and wheat diets have probably depressed the DM and hay consumption. Decreased DM and fiber digestibility have been reported with inclusion of rapidly fermentable carbohydrates in ruminant diets (Brown and Johnson, 1991), possibly due to microbial substrate substitution of fiber with soluble carbohydrates (Hoover, 1986). Therefore, decreased diet digestibility may have decreased passage rate, subsequently limiting the consumption of solid feed in barley-, oat-, and wheat-fed calves.

Lesser serum glucose and greater BUN at wk 8, 10, and 12 of age may be attributed to better ruminal functions in calves fed corn diet than in those fed barley, oat, and wheat diets. Furthermore, plasma BHBA and ruminal ammonia concentrations were also greater at weaning and postweaning (d 70) in calves fed corn diet than in those fed barley, oat, and wheat diets [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data]. Blood urea nitrogen concentration has positive linear relationship with dietary CP intake, its ruminal degradability, and resultant ruminal ammonia concentration in cattle (Broderick and Clayton, 1997; Lohakare et al., 2006). More protein intake because of greater solid feed consumption and its ruminal degradation have probably resulted in greater concentrations of ruminal ammonia and BUN in calves fed a corn diet. Greater concentration of BUN is also an index of the renal dysfunction (Khan et al., 2007b); however, in this study the blood creatinine concentration in all calves was in the safe range, reduced with age, and did not differ between treatments.

A rapid drop and lesser serum glucose concentration at weaning and postweaning were observed in all calves when compared with some other studies (Quigley et al., 1994; Klotz and Heitmann, 2006). This may be attributed to differences in milk feeding methods used in present and earlier studies. In present study, early initiation of solid feed intake and the start of some ruminal fermentation in calves fed milk through step-down procedure probably resulted in lesser serum glucose concentration. Khan et al. (2007a,b) also reported lesser serum glucose concentration at weaning and during several weeks postweaning in calves fed milk through a step-down procedure than in those fed a restricted or ad libitum amount of milk.

Greater concentrations of serum total protein and albumin in older calves and differences among calves on barley, corn, oat, and wheat diets may be ascribed to variation in CP consumption. Greater concentration of LDH in calves is usually related to the anomalies of liver metabolism and diarrhea; however, in the present study, the concentration of this enzyme was within the normal and safe range as previously described by Rauprich et al. (2000). Lactate in the peripheral circulation can originate from ruminal fermentation, propionate metabolism in the ruminal wall, and endogenous production from glycolysis. Stevens and Stettler (1966) reported that a reduced capacity for glycolysis in liver and muscle of calves was associated with a functional rumen. Lactate was not estimated in this study; however, greater blood LDH concentration in older calves may be attributed to the initiation of ruminal fermentation and more reliance on its end products. Lesser se-

rum triglycerides and cholesterol concentrations in older calves may be ascribed to reduced milk supply. More fat absorption because of greater milk consumption resulted in greater serum triglycerides and cholesterol concentrations during preweaning period (Khan et al., 2007a,b). Serum triglycerides concentration was reduced in older calves because of diminishing milk supply (Quigley et al., 1994). Greater concentrations of serum triglycerides and cholesterol at wk 10 and 12 of age in calves provided a corn diet than in those fed barley, oat, and wheat diets may be the ascribed to greater starter and thus fat consumption.

Similar milk consumption during preweaning in calves fed barley, corn, oat, and wheat diets resulted in similar BW, BL, BB, HG, WH, and HH at weaning. Differences in growth parameters among calves fed starch from different sources were apparent during the postweaning period. The process of transitioning calves from their neonatal reliance on nutrients supplied from milk to nutrients supplied from grain is of significant importance for their growth (Baldwin et al., 2004; Khan et al., 2007a). Greater BW, BL, BB, HG, WH, and HH in calves fed a corn diet than those fed wheat, barley, and oat diets may be attributed to greater solid feed intake, metabolically and physically better forestomach, and thus more supply of nutrients from ruminal fermentation. Greater ruminal weight, papillae length, papillae width, and papillae concentration were noticed in calves fed corn diet than in those fed barley, oat, and wheat diets [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data]. Greater ruminal total VFA, acetate, propionate, butyrate, plasma BHBA [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data], and BUN concentrations along with lesser serum glucose concentration in calves fed a corn diet than in those fed other experimental diets have indicated a metabolically more functional rumen in the former. It may be suggested that a physically and metabolically developed rumen resulted in greater solid feed consumption and supply of more nutrients to support greater BW gain in calves fed a corn diet than in those fed barley, oat, and wheat diets. Greater solid feed intake and thus supply of more nutrients resulted in better feed conversion efficiency in corn- and wheat-fed calves.

Starch digested in the small intestine can produce up to 42% more energy than its ruminal fermentation (Owens et al., 1998) because of a more efficient use of digestive end products (glucose vs. VFA). Therefore, the site of starch digestion along the gastrointestinal tract affects performance and feed efficiency in cattle (Swan

et al., 2006). Huntington et al. (2006) summarized that within the range of starch intakes that do not cause rumen upsets, increasing starch (and energy) intake increases the amount of starch digested in the rumen, increases the supply of starch to the small intestine, and increases starch digested in the small intestine. Furthermore, greater starch consumption can trigger hepatic glucogenic activity in growing and lactating cattle (Huntington et al., 2006) because of greater availability of glucogenic precursors (particularly propionate). Higher hepatic glucogenic activity and consequently greater glucose supply in cattle resulted in greater glucose irreversible loss, with a significant portion lost as CO₂. In the present study, greater starch intake, possibly greater availability and oxidation of glucose (Huntington et al., 2006) might have partly contributed to improve the energetic efficiency (by sparing other oxidizable substrates, like amino acids) and thus BW gain in calves fed corn diet than those fed wheat, barley, and oat diets.

CONCLUSIONS

Greater solid feed and nutrients consumption in calves fed corn diet than in those fed barley, oat, and wheat diets during preweaning and postweaning periods may be ascribed to the differences in ruminal development and thus its metabolic and structural capacity to accommodate and digest solid feed. Rumen weight, papillae concentration, VFA, and blood BHBA concentrations were greater in calves fed corn diet than in those fed wheat, oat, and barley diets [S. B. Park, K. S. Baek (Dairy Science Division, National Institute of Animal Science, Cheonan, Korea) and the authors; unpublished data]. Greater BW gain and skeletal measurements in calves fed a corn diet may be ascribed to greater supply of nutrients because of greater DM and nutrient intake.

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REFERENCES

- Abdelgadir, I. E. O., and J. L. Morrill. 1995. Effect of processing sorghum grain on dairy calf performance. *J. Dairy Sci.* 78:2040–2046.
- Albright, L. L., and C. W. Arave. 1997. *The behaviour of cattle*. CAB Int., Wallingford, UK.
- AOAC. 1990. *Official Methods of Analysis*. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.
- Baldwin, R. L., VI, K. R. McLeod, J. L. Klotz, and R. N. Heitmann. 2004. Rumen development, intestinal growth and hepatic metabo-

- lism in the pre- and post-weaning ruminant. *J. Dairy Sci.* 87 (E Suppl.):E55–E65.
- Beharka, A. A., T. G. Nagaraja, J. L. Morrill, G. A. Kennedy, and R. D. Klemm. 1998. Effects of form of the diet on anatomical, microbial, and fermentative development of the rumen of neonatal calves. *J. Dairy Sci.* 81:1946–1955.
- Broderick, G. A., and M. K. Clayton. 1997. A statistical evaluation of animal and nutritional factors influencing concentrations of milk urea nitrogen. *J. Dairy Sci.* 80:2964–2971.
- Brown, W. F., and D. D. Johnson. 1991. Effects of energy and protein supplementation of ammoniated tropical grass hay on the growth and carcass characteristics of cull cows. *J. Anim. Sci.* 69:348–357.
- Coverdale, J. A., H. D. Tyler, J. D. Quigley, III, and J. A. Brumm. 2004. Effect of various levels of forage and form of diet on rumen development and growth in calves. *J. Dairy Sci.* 87:2554–2562.
- Hall, M. B. 2001. Neutral detergent-soluble carbohydrates nutritional relevance and analysis (A laboratory manual). Pages V-1–V-9 in *Univ. Florida Bull.* 339. Dep. Anim. Sci., Inst. Food Agric. Sci., Gainesville, FL.
- Heinrichs, A. J., C. M. Jones, L. R. VanRoekel, and M. A. Fowler. 2003. Calf Track: A system of dairy calf workforce management, training, and evaluation and health evaluation. *J. Dairy Sci.* 86(Suppl. 1):115. (Abstr.)
- Hoover, W. H. 1986. Chemical factors involved in ruminal fiber digestion. *J. Dairy Sci.* 69:2755–2766.
- Huntington, G. B., D. L. Harmon, and C. J. Richards. 2006. Sites, rates, and limits of starch digestion and glucose metabolism in growing cattle. *J. Anim. Sci.* 84(E Suppl.):E14–E24.
- Huntington, G. B. 1997. Starch utilization by ruminants: From basics to the bunk. *J. Anim. Sci.* 75:852–867.
- Khan, M. A., Z. Iqbal, M. Sarwar, M. Nisa, M. S. Khan, H. J. Lee, W. S. Lee, H. S. Kim, and K. S. Ki. 2006. Urea treated corn cobs ensiled with or without additives for buffaloes: Ruminal characteristics, digestibility and nitrogen metabolism. *Asian-australas. J. Anim. Sci.* 19:705–712.
- Khan, M. A., H. J. Lee, W. S. Lee, H. S. Kim, K. S. Ki, T. Y. Hur, G. H. Suh, S. J. Knag, and Y. J. Choi. 2007a. Structural growth, rumen development, metabolic and immune response of Holstein male calves fed milk through step-down and conventional methods. *J. Dairy Sci.* 90:3376–3387.
- Khan, M. A., H. J. Lee, W. S. Lee, H. S. Kim, S. B. Kim, K. S. Ki, J. K. Ha, H. G. Lee, and Y. J. Choi. 2007b. Pre- and post-weaning performance of Holstein female calves fed milk through step-down and conventional methods. *J. Dairy Sci.* 90:876–885.
- Klotz, J. L., and R. N. Heitmann. 2006. Effects of weaning and ionophore supplementation on selected blood metabolites and growth in dairy calves. *J. Dairy Sci.* 89:3587–3598.
- Leibholz, J. 1975. Ground roughage in the diet of the early-weaned calf. *Anim. Prod.* 20:93–100.
- Lesmeister, K. E., P. R. Tozer, and A. J. Heinrichs. 2004. Development and analysis of a rumen tissue sampling procedure. *J. Dairy Sci.* 87:1336–1344.
- Lohakare, J. D., A. K. Pattanaik, and S. A. Khan. 2006. Effect of dietary protein levels on the performance, nutrient balances, metabolic profile and thyroid hormones of crossbred calves. *Asian-Aust. J. Anim. Sci.* 19:1588–1596.
- Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: A review. *J. Anim. Sci.* 76:275–286.
- Philippeau, C., F. Le Deschault de Monredon, and B. Michalet-Doreau. 1999. Relationship between ruminal starch degradation and the physical characteristics of corn grain. *J. Anim. Sci.* 77:238–243.
- Poore, M. H., J. A. Moore, T. P. Eck, R. S. Swingle, and C. B. Theurer. 1993. Effect of fiber source and ruminal starch degradability on site and extent of digestion in dairy cows. *J. Dairy Sci.* 76:2244–2253.
- Quigley, J. D., III, J. K. Bernard, T. L. Tyberend, and K. R. Martin. 1994. Intake, growth, and selected blood parameters in calves fed calf starter via bucket or bottle. *J. Dairy Sci.* 77:354–357.
- Rauprich, A. B., H. M. Hammon, and J. W. Blum. 2000. Influence of feeding different amounts of first colostrum on metabolic, endocrine, and health status and on growth performance in neonatal calves. *J. Anim. Sci.* 78:896–908.
- SAS Institute. 1994. SAS User's Guide. Statistics, Version 6.11 edition. SAS Inst., Inc., Cary, NC.
- Stevens, C. E., and B. K. Stettler. 1966. Factors affecting the transport of volatile fatty acids across rumen epithelium. *Am. J. Physiol.* 210:365–372.
- Stobo, I. J. F., J. H. B. Roy, and H. J. Gaston. 1966. Rumen development in the calf. 1. The effect of diets containing different proportions of concentrates to hay on rumen development. *Br. J. Nutr.* 20:171–188.
- Suárez, B. J., C. G. Van Reenen, N. Stockhofe, J. Dijkstra, and W. J. J. Gerrits. 2007. Effect of roughage source and roughage to concentrate ratio on animal performance and rumen development in veal calves. *J. Dairy Sci.* 90:2390–2403.
- Swan, C. G., J. G. P. Bowman, J. M. Martin, and M. J. Giroux. 2006. Increased puroindoline levels slow ruminal digestion of wheat (*Triticum aestivum* L.) starch by cattle. *J. Anim. Sci.* 84:641–650.
- Theurer, C. B., O. Lozano, A. Alio, A. Delgado-Elorduy, M. Sadik, J. T. Huber, and R. A. Zinn. 1999. Steam-processed corn and sorghum grain flaked at different densities alter ruminal, small-intestinal, and total tract digestibility of starch by steers. *J. Anim. Sci.* 77:2824–2831.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Wheeler, T. B., P. J. Wangsness, L. D. Muller, and L. C. Griel, Jr. 1980. Addition of sodium bicarbonate to complete pelleted diets fed to dairy calves. *J. Dairy Sci.* 63:1855–1863.
- Whitaker, R. T., W. J. Miller, J. L. Carmon, and H. L. Dalton. 1957. Influence of level and source of crude fiber in calf starters on weight and feed consumption. *J. Dairy Sci.* 40:887–892.