

Effects of different methods of wheat grain processing on skeletal growth, blood metabolites, feed consumption and digestion in neonatal Holstein calves

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Abstract

Fifty six neonatal Holstein calves (22 male and 34 female) were fed calf starters and post weaning diets containing 35 and 21.90% Popped (PW), steam flaked (SFW), dry-rolled (DRW) or ground (GW) to 12 weeks of age. Particle size distribution of processed wheat grains, skeletal growth measures, starter digestibility, starter intake, health status, and blood metabolites of neonatal calves were assessed in weeks 4, 8 and 12 to assess rumen development and find the optimum method of wheat processing for calves. The experiment started when calves were 3 ± 1 d old and studied for 90 days. Calves were weaned at the end of 9th week and a post weaning specific starter diets were fed for one month. PW and SFW dramatically decreased fine particles in comparison to GW or DRW. PW had the most proportion of larger particles (93.52% >3.38 mm) where GW had the finest texture (70.71% <2 mm). Health status parameters of calves did not affected by treatments, but respiratory index was affected by time. Skeletal growth measures including body length, body barrel, wither height and hip width did not affected by treatments, but these measures progressed by age. Calves received PW had the highest body weight and daily gain, but feed; gain ratio was not affected by treatments. These parameters were also affected by age. Although, calves received DRW had the lowest starter intake, but the highest digestibility coefficients for dry matter, organic matter, crude protein, NDF and energy. This higher digestibility was attributed to lower starter intake resulted in probably higher rumen retention time and thus the most rumen degradation of nutrients. Calves received PW, had the highest serum glucose, BHBA and insulin concentrations which may indicate that PW could cause a better rumen development and performance in comparison with other types of processed wheat.

Keywords: Wheat, Grain Processing, Calves, Digestion, Blood Metabolites

Introduction

Solid feed consumption is necessary to motivate rumen development in neonatal calves (Suarez, et al., 2007). Recently, vast numbers of studies have been carried out to determine optimum physical, chemical and nutritional specifications of calf starters (Maiga et al., 1994; Covardale et al., 2004; Lesmeister and Heinrichs, 2004; Suarez et al., 2006; Khan et al., 2007 & 2008). Some Experiments showed that forage intake is vital for development of rumen. Also, forage form and particle size affect the process of rumen development (Covardale et al., 2004). On the other hand, grains as carbohydrate sources are necessary ingredients of starter diets (Maiga et al., 1994; Suarez et al., 2006).

The starch content in cereal grains is highest in wheat (77%) followed by sorghum (72%) and barley (57-58%) (Huntington, 1997). Rumen degradation of starch and subsequent intestinal digestibility of cereal grains in starter diets alters neonatal calf rumen development which in turn affect timing of transition from simple gastric digestion to functional rumen (Lesmeister and Heinrichs, 2004; Khan et al., 2008). Khan et al. (2008) found that calves fed corn and wheat diets experienced more rumen development as they had higher, heavier, thicker and more functional papillae compared to those fed barley or oats. Khan et al. (2007) noted that due to higher feed intake in corn fed calves, they had higher skeletal growth and blood volatile fatty acids (VFA) concentrations than those fed wheat,

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barley and oats. Dehghan-banadaky et al. (2007) suggested that grain processing affects ruminal starch degradability. Moreover, it may limit feed intake and optimum manipulation of the site and extent of digestion by different processing methods and conditions can reduce starch passage rate, with no change in total tract digestibility. Lesmeister and Heinrichs (2004) examined different processing methods and found that "steam flaking" is the best method of corn processing for calf starter diets.

Cereal grains are processed to improve their nutritional value. Grain Processing alters the site and extent of digestion and cereal acceptability by animals without detrimental effects on rumen pH. Processing is more effective when starch content of grain is higher. It has been shown that processing in wheat, corn and sorghum (higher starch contents) is more effective than in barley and oats (Huntington, 1997; Owens, 2005).

Extensive processing of corn resulted in faster rumen development in neonatal calves (Lesmeister and Heinrichs, 2004). This may not be the case for wheat grain since wheat grain was not as effective as corn for development of rumen when it was included in the calf starter diets as a ground form (Khan et al., 2007; Khan et al., 2008). Therefore, this study was carried out to study the effect of wheat grain processing method on intake, growth parameters and blood serum parameters of neonatal Holstein calves.

Materials and Methods

The experiment was carried out in a commercial farm in Varamin, Iran. All animals were cared for according to state animal experimental ethics. Neonatal Holstein calves (n = 56, 22 male and 34 female) were separated from their dams within 3 hours after birth and examined for health parameters. Calves were fed 10% of their birth weight with colostrum for three days. Calf starters contained 30% white hard wheat grain in different forms including ground wheat (GW) (density = 0.82 kg/L), dry rolled wheat (DRW) (0.58 kg/L), steam-flaked wheat (SFW) (0.44 kg/L) or popped wheat (PW) (0.33 kg/L); 35% steam flaked corn and the rest of starter as pellets (4 mm diameter, 2cm long and conditioned in 75°C). Experimental diets were formulated to meet daily nutrient requirements of a neonatal calf according to NRC (2001; Table 1). Calves were grouped in four blocks and randomly assigned to one of four treatments when they were 3±1 d old. Calves were housed in individual pens (2.4 × 1.4m) bedded with chopped wheat straw. All calves had free access to water through an automatic metal nipple. They received starter diets *ad libitum* after they were housed at pens. Calves fed with a commercial (Provimi®) milk replacer twice daily (in equal aliquots) in a step-up and then step-down pattern. They received

3, 4, 5, 6, 5, 4, 3, 2 and 1 L/d of milk replacer in week one till nine of their life and weaned according to their body weight at week nine. Milk replacer was fed to the calves using mobile plastic bottles (3L capacity) fitted with soft robber nipples. After weaning, the calves received a post weaning diets (Table 1) which were contained the same type of processed wheat to assess post weaning performance of calves. The experiment was continued for 90 days.

Table 1: Diet composition of calf starter and post-weaning diet containing ground, dry rolled, steam flaked or popped wheat

Ingredients	Calf starter (% DM)	Post weaning diet (% DM)
Steam flaked corn	30.00	25.55
Wheat (white, hard)	35.00	21.90
Soybean meal	25.00	10.60
Beet pulp	—	4.40
Wheat bran	5.61	4.00
Beet molasses	2.00	1.46
Dicalcium phosphate	0.84	0.60
Calcium carbonate	0.69	—
Sodium bicarbonate	0.5	—
Vitamin premix ¹	0.28	0.20
Mineral premix ²	0.08	0.06
Alfalfa hay (mid-bloom)	—	27.00

¹Contained: 21.98% Ca, 4g Cu, 20g Fe, 0.41g I, 40.4g Mn, 37.5g Zn and 80 mg Se per kg; ²Contained: Vitamin A 3600 IU, Vitamin D 800 IU and Vitamin E 7200 IU per kg.

Samples from diets (100 g) were taken from a pooled mixture taken of ten bags of mixed starters. Also, fecal samples (200 g, wet) were taken from twenty calves in a random manner every day in weeks 4, 8 and 12 of the experiment. The feeds and feces samples were analyzed for dry matter (DM, AOAC 930.15), ash (AOAC 942.05), ether extract (AOAC 954.02) crude protein (CP, AOAC 984.13) (AOAC 2000), NDF (neutral detergent fiber) and ADF (Van Soest et al., 1991) in triplicates. Neutral detergent fiber and ADF were expressed exclusive of residual ash. Alpha amylase was used for determination of NDF (Sigma No. A3306, Sigma Chemical Co. St. Louis, MO), but sodium sulfate was not used. Chemical compositions of starters are shown in Table 2.

Metabolizable energy, net energy for maintenance, and net energy for gain were calculated according to NRC (2001) dairy. Calcium (Ca) concentration of feed samples determined by Atomic Absorption Spectroscopy system (Varian, SpectrAA - 300) (AOAC No. 975.03). Phosphorous (P) was measured with a Spectroscopy Coleman Junior 2 device (AOAC No. 965.17) according to AOAC (2000) (6). Apparent digestibilities of the diets were evaluated weeks 4, 8 and 12. Acid insoluble ash (AIA) was used as an internal marker (AOAC, 2000). AIA content of diets and feces were measured according to AOAC (2000).

Table 2: Nutrient composition (\pm SD) of calf starters containing ground wheat (GW), dry-rolled (DRW), steam-flaked (SFW) and popped wheat (PW) wheat (n = 3).

Diet type	Starter					Post-weaning diet				
	GW	DRW	SFW	PW	SEM	GW	DRW	SFW	PW	SEM
Nutrients										
DM %	90.58	91.39	89.09	91.02	4.75	88.50	90.12	89.00	90.41	3.22
CP %	19.20	19.21 \pm	19.19	19.17	1.01	16.01	16.19	17.07	16.39	1.05
ME Mcal/kg *	2.84	2.85	2.85	2.86	0.20	2.63	2.75	2.62	2.68	0.31
NEm Mcal/kg *	2.13	2.14	2.14	2.16	0.04	1.87	1.91	1.89	1.91	0.04
NEg Mcal/kg	1.47	1.45	1.46	1.48	0.02	1.23	1.27	1.25	1.28	0.02
NDF %	13.56	13.41	13.70	12.98	0.02	25.30	26.12	24.48	24.87	0.02
ADF %	6.42	6.39	6.78	5.91	1.53	15.81	15.92	14.94	15.31	1.74
Ash %	5.62	5.75	6.08	5.81	0.25	5.75	5.88	6.45	6.29	0.76
Ca %	0.70	0.78	0.86	0.76	0.07	0.66	0.69	0.69	0.72	0.05
P %	0.45	0.43	0.51	0.49	0.04	0.40	0.45	0.49	0.42	0.03

* Energy values calculated according to NRC (2001) model equations.

Apparent digestibilities of DM, CP, NDF and energy digestibility were measured according to Pond et al. (2005).

Particle size distribution was measured (Table 3) using a sieving system device (Iran Pouya, IRAN). Approximately 500 g (DM) of processed wheat samples were placed on a series of five sieves arranged according to their mesh sizes (Table 3) and shaken for 8 min. Retained particles were collected and weighed and percentage of each part calculated.

Health of calves was observed according to procedure described by Heinrichs et al. (2003). Fecal scoring was as follows: 1 = normal, 2 = soft to loose, 3 = loose to watery and 4 = watery, mucous, slightly bloody, 5 = watery, mucous, and bloody. Respiratory scoring was done according to a 5 scale scoring system as 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 higher than 3. Scoured calves received electrolyte treatments and calves with respiratory problems were undergone veterinary control including antimicrobial therapy.

Feed intake for two consecutive days and skeletal growth of calves were recorded in three periods including weeks 4, 8 and 12 of the experiment. Body weight (before morning feeding), body length (BL, distance between shoulder bones and rump), body barrel (BB, circumference of belly before morning feeding), and height of withers (WH, the height from withers to base of front feet) were measured to assess skeletal growth

Blood samples were obtained from Jugular vein. Blood sampling performed 3 hours after morning feeding in evacuated tubes (10 mL) without an anticoagulant agent. Samples were immediately centrifuged for 10 min (3000 \times g) and obtained serum

were used to determine total protein (Pars azmoon kit No. 1-500-028), albumin (Pars azmoon kit No. 1-500-001), glucose (Pars azmoon kit No. 1-500-017), β -hydroxy butyrate (BHBA) (Ranbut kit RB 1007), blood urea nitrogen (BUN)(Darman Kave kit No. 111), lactate dehydrogenase (LDH) (Pars azmoon kit No. 1-050-022), triglycerides (Pars azmoon kit No. 1-500-032) and insulin (Mercodia Cat No. 10-1201-01).

Table 3: Particle size distribution of ground wheat (GW), dry-rolled (DRW), steam-flaked (SFW) and popped wheat (PW) wheat

Particle size % retained	Mesh size	GW	DRW	SFW	PW
4.00 mm	5	1.25	18.99	47.33	79.23
3.38 mm	6	28.04	30.79	30.28	14.29
2.00 mm	10	23.22	19.81	8.47	3.93
1.00 mm	18	28.41	19.78	7.43	2.10
0.25 mm	60	11.95	6.69	4.25	0.38
Pan	-	7.13	3.95	2.23	0.07

Statistical analysis

Data for feed intake and skeletal growth were analyzed using REPEATED methods of MIXED procedure of SAS 9.0 (SAS institute, 2002). The following statistical model used was:

$$Y_{ptc} = \mu + \alpha_p + \beta_t + (\alpha\beta)_{pt} + e_{ptc}$$

where Y_{ptc} is an observed measurement for feed intake or skeletal growth parameters taken from a calf received processed wheat with a specific processing method p at time t ($t = 4, 8$ or 12 weeks of recording). μ = overall mean of population; α_p = the fixed effect of processing; β_t = the fixed effect of time of recording; $(\alpha\beta)_{pt}$ = the effect of interaction between time of measurement and processing method; e_{ptc} = the error of measurements recorded for calf c received processed wheat p at time t . The fisher protected LSD test was used to compare multiple treatments using the LSMEAN statement of SAS. For all statistical analyses, significance level was declared as $p < 0.05$.

Results and Discussion

All the starter diets had identical chemical composition (Table 2). Grains processing dramatically changed particle size distribution of wheat grain (Table 3). Popped wheat had the least fine particles, but it was the bulkiest grain of all (Table 3). The results showed that more fine particles were produced by grinding, dry rolling and steam flaking, respectively. Grinding and

dry-rolling made more than half of wheat grains (51.63 and 50.23% for GC and DRW, respectively) finer than 2.00 mm which may escalate the incidence of rumen acidosis (Owens, 2005). However, this portion was 22.38 and 6.48% for SFW and PW, respectively (Table 3). Fine particles produced in grinding and to a lesser extent in dry-rolling may limit physical removing of epithelial cells which could result in rumen parakeratosis (Beharka et al., 1998).

Table 4: Least square means for respiratory score, fecal score and general aspect of Holstein calves receiving popped wheat (PW), steam flaked wheat (SFW), dry rolled wheat (DRW) or ground wheat (GW) in a calf starter.

Parameter	PW	SFW	DRW	GW	SEM	P Value		
						Treatment	Time	Treatment × Time
Respiratory score ¹	1.24	1.24	1.34	1.15	0.11	NS	0.02	NS
Fecal score	1.79	1.79	1.46	1.87	0.13	NS	NS	NS
General appearance	1.36	1.57	1.38	1.91	0.17	NS	NS	NS

Respiratory scoring, 1 = normal, 2 = slight cough, 3 = moderate cough, 4 = moderate to severe cough, 5 = severe and chronic cough Fecal scoring was as follows: 1 = normal, 2 = soft to loose, 3 = loose to watery and 4 = watery, mucous, slightly bloody, 5 = watery, mucous, and bloody.; 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

Table 5: Least square means (±SE) for skeletal growth measurements, body weight, weight gain and feed intake of Holstein calves receiving popped wheat (PW), steam flaked wheat (SFW), dry rolled wheat (DRW) or ground wheat (GW) in a calf starter.

	wk	n	PW	SFW	DRW	GW	SEM	P Value		
								Treatment	Time	Treatment × Time
Body length (cm)	4	56	74.07	72.90	74.68	73.61	1.43	NS	<0. 01	NS
	8	56	83.27	79.61	81.61	80.32	1.06			
	12	44	87.14	88.19	88.50	87.91	1.70			
Body Barrel (cm)	4	56	101.02	99.17	99.64	101.72	1.48	NS	<0. 01	NS
	8	56	116.02	116.32	112.28	116.97	1.82			
	12	44	132.38	131.12	126.12	131.47	2.54			
Wither height (cm)	4	56	83.61	84.62	83.36	84.69	0.54	NS	<0. 01	NS
	8	56	90.38	89.05	88.86	91.08	0.84			
	12	44	91.84	90.10	90.63	90.54	1.00			
Hip width (cm)	4	56	21.69	20.94	21.27	21.67	0.40	NS	<0.01	NS
	8	56	23.00	22.52	22.84	23.60	0.52			
	12	44	23.11	22.86	22.40	23. 10	0.56			
Body weight (kg)	4	56	58.45	56.61	56.87	59.09	1.44	NS	<0.001	NS
	8	56	80.38	76.06	75.61	82.41	2.23			
	12	44	101.54	101.32	97.14	105.28	4.02			
DMI* (g/d)	4	56	245	174	136	216	23	0.04	<0.001	NS
	8	56	781	765	731	945	79			
	12	44	2798	2490	1899	2385	228			
Daily gain (g/d)	4	56	454	371	383	445	33	0.05	<0.001	NS
	8	56	662	648	609	723	45			
	12	44	895	869	778	1002	76			
Feed : Gain	4	56	0.553	0.491	0.401	0.496	0.60	NS	<0.001	NS
	8	56	1.199	1.212	1.164	1.401	0.127			
	12	44	3.224	2.843	2.597	3.083	0.347			

^{a,b} Means in a row without different superscripts are significantly different (P < 0.05); *DMI, dry matter intake

Health status of calves in this trial as determined by respiratory score, fecal score and general appearance are presented in Table 4. Calves were almost healthy throughout the experiment and treatments had no effect on health status parameters. Calves only experienced respiratory problems in the third month of experiment (Respiratory scores were 1.17, 1.17 and 1.40 for 1st, 2nd and 3rd months of the experiment respectively). Lesmiester and Heinrichs (2004) also did not observe a change in health status of Holstein calves received starters including corn grain processed differently. Also, Khan et al. (2007) who used different grains (corn, barley, wheat and oats) as starch sources of starter diets did not observe a significant difference on health status of neonatal calves.

Skeletal growth including BL, BB, WH and HW were highly affected by time as growth was ongoing in all treatments ($P < 0.001$), but treatments did not significantly affect skeletal growth ($P \geq 0.3$). Despite that none of skeletal measurements were affected by treatments. Calves received PW had significantly ($P < 0.05$) higher starter intake (1189, 1160, 1118 and 1078 g/d in PW, GW, SFW and DRW respectively). Popping wheat most probably made it more palatable for calves so that they consumed more PW in spite of

its bulky nature. Calves received GW had more starter intake than other two treatments most likely because of its higher bulk density than those of the other types of processed wheat. Lesmiester and Heinrichs (2004) reported that corn processing significantly ($P < 0.05$) altered skeletal growth in young calves. They reported that calves received dry rolled or steam flaked corn had higher wither height, hip width, heart girth (comparable with body barrel in the current trial). Khan et al. (2007) observed higher body length, body barrel, heart girth, wither height and body weight in calves received high starch content grains including corn and wheat. They concluded that higher intake of starter resulted in higher rate of rumen growth and development. In the current experiment, higher intake of starter resulted in higher daily gain. Calves received GW or PW had higher BW compared to those fed with DRW and SFW. Therefore, the efficacy of a processing method or an energy source on skeletal growth of calves is very much dependent on its voluntary intake by the animal. The results showed that calves fed with PW had the highest DMI and in turn the highest daily gain compared to the other calves (Table 5). However, such an elevated DMI and daily gain did not improve feed efficiency (Table 5).

Table 6: Least square means of apparent dry matter (DM), organic matter (OM), crude protein (CP), NDF and gross energy (GE) digestibility (%) and Digestible energy (DE) of calf starters fed to Holstein calves receiving popped wheat (PW) (n = 20), steam flaked wheat (SFW) (n = 20), dry rolled wheat (DRW) (n = 20) or ground wheat (GW) (n = 20).

	wk	PW	SFW	DRW	GW	SEM	P Value		
							Treatment	Time	Treatment × Time
DM	4	76.48	82.24	88.36	84.06	1.18	<0.001	<0.001	NS
	8	78.78	85.27	88.92	85.75	1.28			
	12	81.28	86.50	88.87	85.14	3.09			
OM	4	87.68 ^b	89.05 ^{ab}	92.15 ^a	87.14 ^b	1.11	0.015	<0.001	0.005
	8	82.31 ^b	85.27 ^a	88.15 ^a	84.66 ^a	1.33			
	12	82.72	87.89	89.99	85.98	2.98			
CP	4	74.09 ^b	74.81 ^b	77.93 ^a	77.71 ^a	1.20	0.008	<0.001	<0.001
	8	77.60 ^c	79.62 ^{bc}	86.61 ^a	82.19 ^b	1.29			
	12	79.73	84.71	88.30	84.05	3.46			
NDF	4	68.06 ^b	69.01 ^b	72.51 ^a	72.89 ^a	1.14	NS	<0.001	<0.001
	8	89.01	90.79	90.27 ^a	86.99	1.33			
	12	97.25	98.11	96.69	97.77	0.41			
GE	4	78.81 ^c	81.90 ^b	86.66 ^a	80.40 ^{bc}	1.13	0.005	<0.001	0.004
	8	80.12 ^b	84.96 ^a	86.48 ^a	83.09 ^a	1.32			
	12	80.66	85.72	88.72	83.56	3.54			
DE, Mcal/kg	4	3.15	3.39	3.36	3.30	0.13	NS	0.039	NS
	8	3.48	3.32	3.65	3.47	0.13			
	12	3.38	3.59	3.72	3.50	0.14			

^{a,b} Means in a row without different superscripts are significantly different ($P < 0.05$); * Twenty calves on each starter diet were randomly selected and were analyzed for starter digestibility.

Also, in the current trial the highest DMI values were for PW and GW (1190 and 1160 g/d respectively) ($P < 0.05$) in comparison to SFW and DRW (1119 and 1078 g/d respectively) where in the first and third months of age calves received PW had numerically the highest DMI which also led them to the highest gain (698 and 681 g/d for GW and PW respectively) ($P < 0.05$) compared to 622 and 615 g/d for SFW and DRW and this can be attributed to a well-developed functional rumen.

Data for Feed: gain ratio also showed the higher starter intake in calves resulted in more weight gain, and higher starter intake did not affect feed efficiency. Lesmiester and Heinrichs (2004) reported that steam flaked corn was utilized more efficiently than other three methods of processed corn (whole, dry rolled or popped rolled corn).

Processing of wheat grain significantly changed digestibility of dry matter, organic matter, crude protein and gross energy ($P < 0.01$), but had no effect on NDF digestibility and DE content of starter diets. Rumen digestion of NDF is mostly depended on rumen microbial activity and the most increase in digestion of NDF was observed post-weaning when rumen was fully functional. (Owens, 2005) The highest DM digestibility

was observed for DRW contained starter followed by SWF, GW and PW (Table 6). In addition, DRW contained starter had the highest OM, CP, NDF and GE digestibility in day 30 of experiment when the rumen was not fully functional and almost most of the digestion occurred in the small intestine. The same pattern on digestibility of OM, CP, NDF and GE was observed at two months of age when the rumen was functional enough to wean the calves (Table 6). These findings indicate that rumen development occurred sooner in calves received DRW compared to the other calves. Also, Table 3 shows that PW had the least fine particles in comparison to GW and DRW which can be readily solved and fermented in rumen. Then PW digestion was more depended on intestinal starch digestion than other types of processed wheat which could result in higher serum glucose concentrations (Table 7). Although the DRW contained starter had the highest digestibility for DM, OM and CP, but generally high rumen starch degradability can cause rumen pH drop resulted in declined feed consumption and fibre digestion. This in turn led to the lowest NDF digestibility in calves fed with DRW compared to the other calves at three months of age (Table 6). Unlike the present study other researchers suggested that the

Table 6: Least square means of apparent dry matter (DM), organic matter (OM), crude protein (CP), NDF and gross energy (GE) digestibility (%) and Digestible energy (DE) of calf starters fed to Holstein calves receiving popped wheat (PW) (n = 20), steam flaked wheat (SFW) (n = 20), dry rolled wheat (DRW) (n = 20) or ground wheat (GW) (n = 20)

	Wk	PW	SFW	DRW	GW	SEM	P Value		
							Treatment	Time	Treatment × Time
DM	4	76.48	82.24	88.36	84.06	1.18	<0.001	<0.001	NS
	8	78.78	85.27	88.92	85.75	1.28			
	12	81.28	86.50	88.87	85.14	3.09			
OM	4	87.68 ^b	89.05 ^{ab}	92.15 ^a	87.14 ^b	1.11	0.015	<0.001	0.005
	8	82.31 ^b	85.27 ^a	88.15 ^a	84.66 ^a	1.33			
	12	82.72	87.89	89.99	85.98	2.98			
CP	4	74.09 ^b	74.81 ^b	77.93 ^a	77.71 ^a	1.20	0.008	<0.001	<0.001
	8	77.60 ^c	79.62 ^{bc}	86.61 ^a	82.19 ^b	1.29			
	12	79.73	84.71	88.30	84.05	3.46			
NDF	4	68.06 ^b	69.01 ^b	72.51 ^a	72.89 ^a	1.14	NS	<0.001	<0.001
	8	89.01	90.79	90.27 ^a	86.99	1.33			
	12	97.25	98.11	96.69	97.77	0.41			
GE	4	78.81 ^c	81.90 ^b	86.66 ^a	80.40 ^{bc}	1.13	0.005	<0.001	0.004
	8	80.12 ^b	84.96 ^a	86.48 ^a	83.09 ^a	1.32			
	12	80.66	85.72	88.72	83.56	3.54			
DE, Mcal/kg	4	3.15	3.39	3.36	3.30	0.13	NS	0.039	NS
	8	3.48	3.32	3.65	3.47	0.13			
	12	3.38	3.59	3.72	3.50	0.14			

^{a,b} Means in a row without different superscripts are significantly different ($P < 0.05$); * Twenty calves on each starter diet were randomly selected and were analyzed for starter digestibility.

highest DM and OM digestibility was seen when corn steam flaked, while the lowest was observed when corn dry-rolled (Theurer et al., 1986; Huntington, 1997; Owens et al., 1998). Swan et al. (2006) suggested that passage rate of digesta and the site of grain digestion can affect energy utilization and calves performance. Although DRW had the highest GE digestibility among the processed wheat, but it did not improve calves' performance as they only consumed limited quantity of DRW contained starter. In spite of PW low digestion, probably its more efficient site of digestion (ruminal and intestinal) or higher starter intake caused higher body weight and also higher insulin and BHBA which are key factors in rumen development (Baldwin et al., 2004).

Data for Digestible energy estimation showed that energy utilization well progressed along with the age of calves, but did not affected by method of processing. The current study showed that technological processing

of did not have any effect on DE as there were no significant differences among the processed wheat (Table 6). However as the calves grew, they digested GE more efficiently (Table 6).

Serum glucose concentrations in the present study were in agreement with those reported by Khan et al. (2007). They also used a step up – step down procedure for feeding milk which led to a dramatic drop in serum glucose concentration of calves at weaning. Postprandial serum glucose concentration decreased ($P < 0.05$) as the age of calves progressed. Calves received PW had the highest serum glucose concentrations compared to the others throughout the experiment (Table 7). Numerically higher serum glucose of PW fed calves was attributable to higher starter intake and thus more starch intake in this treatment. Serum glucose concentrations for SFW fed calves was significantly ($P < 0.05$) lower than others and serum glucose concentration of calves received PW

Table 7: Serum metabolites of calf receiving starters fed to Holstein calves receiving popped wheat (PW), steam flaked wheat (SFW), dry rolled wheat (DRW) or ground wheat (GW).

Wk	PW	SFW	DRW	GW	SEM	P Value		
						Treatment	Time	Treatment × Time
Glucose, mg/dL								
4	92.97	86.31	91.87	84.88	4.74	0.046	<0.001	NS
8	85.32	75.96	82.69	77.66	3.88			
12	64.54	50.06	59.61	55.96	4.84			
Albumin, g/dL						0.033	<0.001	0.045
4	3.19	3.16	3.28	3.36	0.11			
8	3.54 ^a	2.88 ^b	2.86 ^b	2.76 ^b	0.17			
12	2.58 ^a	2.82 ^a	2.36 ^b	2.36 ^b	0.22			
Total protein, g/dL						NS	NS	NS
4	6.64	6.05	6.26	6.16	0.24			
8	6.26	6.26	6.25	6.61	0.23			
12	6.19	6.19	6.39	6.30	0.41			
Triglycerides, mg/dL						NS	<0.001	0.045
4	10.87 ^a	10.79 ^a	8.43 ^b	8.68 ^b	0.83			
8	12.52	14.60	15.14	17.13	0.22			
12	9.22 ^a	7.91 ^b	11.12 ^a	7.81 ^b	1.06			
BUN, mg/dL						0.04	0.017	0.024
4	9.93	9.94	10.57	10.34	0.52			
8	8.92 ^b	14.13 ^a	10.37 ^b	11.77 ^a	1.12			
12	12.64 ^a	13.69 ^a	14.60 ^a	8.84 ^b	1.65			
BHBA mmol/L						<0.001	<0.001	0.07
4	0.241	0.169	0.177	0.146	0.014			
8	0.166	0.122	0.155	0.128	0.019			
12	0.343	0.229	0.233	0.273	0.039			
Insulin, Units/L						0.002	<0.001	<0.001
4	45.09 ^a	18.51 ^d	35.75 ^b	26.01 ^c	3.28			
8	9.77 ^b	9.20 ^b	14.17 ^a	11.92 ^{ab}	1.61			
12	13.59	14.66	13.63	17.11	3.35			
LDH, Units/L						NS	<0.001	NS
4	580.45	590.69	634.34	550.42	35.77			
8	726.16	794.48	744.42	743.44	34.32			
12	681.39	706.32	749.47	695.55	37.01			

^{a,b} Means in a row without different superscripts are significantly different ($P < 0.05$); * Twenty calves on each starter diet were randomly selected and blood samples were taken to assess serum metabolites.

was numerically the highest (80.62, 70.34, 78.00 and 72.74 g/dL for PW, SFW, DRW and GW respectively). In weeks 8 and 12, serum albumin concentration of calves fed with PW were higher than the other calves ($P<0.05$). Neither age nor treatments had any effect on serum total protein of calves (Table 7). Khan et al. (2007) observed an increased serum total protein by advancing age or when corn or wheat was fed to calves compared to barley or oats. Calves fed PW had the highest serum triglycerides concentration among the treatments ($P<0.05$). However, serum triglycerides concentration dropped when calves were fed less milk replacer and then remained unchanged. Blood urea nitrogen was increased by age when feed intake increased. This was mainly due to an increased nitrogen intake. At 12 weeks of age, calves fed with PW, SFW and DRW had a significantly higher BUN than those fed with GW (Table 7). This may indicate that less nitrogen retained in the calves when they fed starters contained thermally processed wheat compared to ground wheat. Serum BHBA was affected by method of processing ($P<0.01$). As calves got older, serum concentration of BHBA, as a rumen development stimulator, increased (Baldwin et al., 2004). A higher BHBA for in PW fed calves compared to the other calves (80.62 mmol/L) was due to a higher starter intake which may lead to a faster rumen development. Insulin activity was significantly higher in PW and DRW fed calves (Table 7). Also, serum insulin concentration dramatically decreased in the second month of calves' age. Baldwin et al. (2004) suggested a mediatory effect for insulin in rumen epithelium mitosis. They noticed that in vivo and in vitro injections of insulin resulted in a faster rumen epithelium development. In present study, such an effect was detected too, but insulin activity dropped at end of the second month of age when rumen epithelium was fairly developed. Serum concentration of LDH increased by age when more probably lactate produced in rumen (Baldwin, et al. 2004) as a result of microbial activity ($P<0.01$). LDH did not significantly affected by method of processing ($P>0.1$).

Conclusions

Higher starter intake results in a faster rumen development. Then any means that help calves to eat more and have higher nutrient intakes especially starch intake, and higher VFA, BHBA and glucose concentrations when rumen is not developed enough may lead to a faster rumen development and a younger age for weaning. Greater BW, daily gain, serum glucose, albumin, Triglycerides and BHBA concentrations and higher insulin activity were results of a better rumen development in PW fed calves, but calves fed DRW because of the lowest feed intake and higher rumen retention time experienced the highest digestibility coefficients.

References

- AOAC. 2000. Official Methods of Analysis. 17th (ed.) Association of Official Analytical Chemists, Gaithersburg, MD.
- Baldwin, R.L., McLeod, K.R., Klotz, J.L. and Heitmann, R.N. 2004. Rumen development, intestinal growth and hepatic metabolism in the pre- and post-weaning ruminant. *Journal Dairy Science*, 87 (E Suppl.):E55–E65.
- Beharka, A.A., Nagaraja, T.G., Morrill, J.L., Kennedy, G.A. and Klemm, R.D. 1998. Effects of form of the diet on anatomical, microbial, and fermentative development of the rumen of neonatal calves. *Journal of Dairy Science*, 81:1946–1955.
- Coverdale, J.A., Tyler, H.D., Quigley, J.D. and Brumm, J.A. 2004. Effect of various levels of forage and form of diet on rumen development and growth in calves. *Journal of Dairy Science*, 87:2554–2562.
- Dehghan-banadaky, M.R., Corbett, R. and Oba, M. 2006. Effects of barley grain processing on productivity of cattle. *Animal Feed Science and Technology*, 137: 1–24.
- Heinrichs, A.J., Jones, C.M., Van Roekel, L.R. and Fowler, M.A. 2003. Calf track: A system of dairy calf workforce management, training, and evaluation and health evaluation. *Journal of Dairy Science*, 86(Suppl. 1):115.
- Huntington, G.B. 1997. Starch utilization by ruminants: From basics to the bunk. *Journal of Animal Science*, 75:852–867.
- Khan, M.A., Lee, H.J., Lee, W.S., Kim, H.S., Kim, S.B., Ki, K.S., Park, S.J., Ha, J.K. and Choi, Y.J. 2007. Starch Source Evaluation in calf starter: i. feed consumption, body weight gain, structural growth, and blood metabolites in Holstein calves. *Journal of Dairy Science*, 91:5259–5268.
- Khan, M.A., Lee, H.J., Lee, W.S., Kim, H.S., Kim, S.B., Ki, K.S., Park, S.J., Ha, J.K. and Choi, Y.J. 2008. Starch source evaluation in calf starter: II. ruminal parameters, rumen development, nutrient digestibilities, and nitrogen utilization in Holstein calves. *Journal of Dairy Science*. 91:1140–1149.
- Lesmeister, K.E. and Heinrichs, A.J. 2004. Effects of corn processing on growth characteristics, rumen development and rumen parameters in neonatal dairy calves. *Journal of Dairy Science*, 87:3439–3450.
- Maiga, H.A., Schingoethe, D.A., Ludens, F.C., Tucker, W.L. and Casper, D.P. 1994. Response of calves to diets that varied in amounts of ruminally degradable carbohydrate and protein. *Journal of Dairy Science*, 77:278-283.
- National Research Council (NRC). 2001. Nutrient Requirements of Dairy Cattle. 7th (rev. ed.) National. Academy of Science, Washington, DC.

- Owens, F.N., Secrist, D.S., Hill, W.J. and Gill, D.R. 1998. Acidosis in cattle: A review. *Journal of Animal Science*, 76:275–286.
- Owens, F. 2005. Corn grain processing and digestion. [http://www.ddgs.umn.edu/articles-proc-storage-quality/2005-Owens%20\(MNC\)%20Corn%20grain%20proc.pdf](http://www.ddgs.umn.edu/articles-proc-storage-quality/2005-Owens%20(MNC)%20Corn%20grain%20proc.pdf)
- Pond, W.G., Church, D.C. Pond, K.R. and Schoknecht, P.A. 2005. Basic Animal Nutrition and Feeding. New Jersey: John Wiley and Sons Inc.
- SAS Institute, 2002. SAS User's Guide, Version 9.0 ed. SAS Inst., Inc., Cary, NC.
- Sua'ez, B.J., Van Reenen, C.G., Beldman, G., Van Delen, J., Dijkstra, J. and Gerrits, W.J.J. 2006. Effects of supplementing concentrates differing in carbohydrate composition in veal calf diets: I. Animal performance and rumen fermentation characteristics. *J of Dairy Science*, 89:4365-4375.
- Swan, C.G., Bowman, J.G.P., Martin, J.M. and Giroux, M.J. 2006. Increased puroindoline levels slow ruminal digestion of wheat (*Triticum aestivum* L.) starch by cattle. *Journal of Animal Science*, 84:641–650.
- Theurer, C.B. 1986. Grain processing effects on starch utilization by ruminants. *Journal of Animal Science*, 63: 1649-1662.
- Van Soest P.J., B. and Lewis, B.A. 1991. Methods for dietary fiber neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, 74:3583-3597.