Source of carbohydrate and metabolizable lysine and methionine in the diet of recently weaned dairy calves on digestion and growth

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ABSTRACT

Two 56-d trials with weaned Holstein dairy calves (initially 72 ± 1.8 kg of body weight, 58 to 60 d of age) fed 95% concentrate and 5% chopped grass hay diets were conducted. Each trial used 96 calves (4 calves/pen). During 15 of the last 21 d of the first trial and 10 of 14 d of the second and third week of the second trial, fecal samples were taken to estimate digestibility using acid-insoluble ash as an internal marker. Digestibility estimates along with 56-d average daily gain (ADG), hip width change, body condition score, and fecal score were analyzed with pen as the experimental unit. In trial 1, a textured diet (19% crude protein) with high starch [52% starch, 13% neutral detergent fiber (NDF)] based on whole corn and oats or a pelleted low-starch (20% starch, 35% NDF), high-digestible fiber diet were used. Within starch level, diets were formulated from supplemental soybean meal or soybean meal with blood meal and Alimet (Novus International Inc., St. Charles, MO) to provide 2 metabolizable protein levels (1 and 1.07% metabolizable lysine plus methionine). The 4 treatments were analyzed as a completely randomized design with a 2 by 2 factorial arrangement (6 pens/diet). In trial 2, all pelleted diets (19% crude protein) were fed. Diets were based on soybean hulls, wheat middlings, or corn, which contained increasing concentrations of starch (13, 27, and 42% starch and 42, 23, and 16% NDF, respectively; 8 pens/diet). Contrast statements were constructed to separate differences in the means (soybean hulls plus wheat middlings vs. corn; soybean hulls vs. wheat middlings). In trial 1, intake of organic matter (OM) did not differ. Digestibility of OM was greater in calves fed high- versus low starch-diets. Digestibility of NDF and starch were less in calves fed the high- versus low-starch diets. Calf ADG and hip width change were greater for high- versus low-starch diets. Source of protein did not influence digestibility or ADG. In trial 2, intake of OM was not different.

Digestibility of OM was greater in calves fed corn versus other diets. Digestibility of NDF was greater for calves fed soybean hulls versus wheat middlings. Starch digestibility was not different among treatments. Calf ADG and hip width change were greater in calves fed corn versus other diets. High-starch diets were more digestible and supported more growth in 2- to 4-mo-old dairy calves than replacing starch with digestible fiber. Manipulating metabolizable protein compared with a control diet that was predominately corn and soybean meal did not alter growth or digestibility.

Key words: starch, fiber, protein, calf

INTRODUCTION

In the US dairy calf industry, a diversity of starter and grower feeds are fed to dairy calves less than 4 mo of age. These feeds vary greatly in their CP and digestible energy (DE) or ME concentration and ingredient composition. The NRC (2001) requirements mention the need for digestible fiber components, but limited data exist to substantiate this statement. The recently weaned calf or calf transitioning from milk or milk replacer to dry feed is an area of research in which limited knowledge has been gained since the NRC (2001) requirements were published (Hill et al., 2013).

Manipulation of nutrients offered to weaned calves within the dairy calf submodel of the NRC (2001) requirements suggest that energy, not CP, limits ADG in most circumstances. Digestible fiber sources such as soybean hulls, wheat middlings, and distillers dried grains with solubles have a lower DE (or ME) value than corn or other grains which are high in starch (NRC, 2001). The rumen of a weaned calf is small, leading to short retention times for digestion. Vazquez-Anon et al. (1993) reported mean retention of particles in the rumen of calves approximately double between 7 and 13 wk of age, relating to the increasing rumen size. Because digestible fiber is typically degraded in the rumen at a lower rate than starch, digestible fiber may increase in value to the calf diet as the calf ages; however, recent data suggests there are no benefits to reduced ADG from replacing corn with digestible fiber sources (Hill et al., 2008a, 2012; Suarez-Mena et al.,

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2011; Terré et al., 2013), substantiating lower DE or ME concentrations than corn in NRC (2001). Despite these data, a pelleted high-fiber diet is frequently fed to calves less than 5 mo of age in the US dairy industry.

Recent publications suggest a CP concentration of 20.5% of DM (63 g of CP/Mcal of ME) for calves less than 8 wk of age (Hill et al., 2007a, 2008b; Stamey et al., 2012) and less than 17 (to maximize ADG) to 18% of DM (to maximize feed efficiency; 52 to 56 g of CP/Mcal of ME) for calves 2 to 4 mo of age are adequate (Hill et al., 2008b); this supports the limited data from which NRC (2001) is based. Source of rumen-undegraded protein or high MP has not resulted in more calf growth than diets based on soybean meal and corn (Warner, 1984; Hill et al., 2007a, 2008b). The dairy calf submodel of the NRC (2001) requirements does not consider MP or AA. Additionally, many diets fed to calves in the US dairy market contain sources of undegraded protein and metabolizable Lys and Met beyond what is supplied by soybean meal, especially when high-fiber diets are fed.

The objectives of these trials were to investigate the effect of starch or digestible fiber concentration of a diet and its interaction with metabolizable Lys and Met content of a diet on calf growth and digestion of nutrients. The diets tested represent compositions and forms commonly fed in the United States. Use of digestibility measurements will assist in interpretation of growth data that might be skewed with gut fill. These data will help to fill a void of research before and after the NRC (2001) requirements were published.

MATERIALS AND METHODS

Calves were cared for by acceptable practices as described in the *Guide for the Care and Use of Agricultural Animals in Research and Teaching* (FASS, 2010). Two 56-d trials were conducted with weaned, male Holstein dairy calves (initially 72 ± 1.8 kg of BW, 58 to 60 d of age, sourced from 1 farm) fed 95% concentrate and 5% chopped grass hay diets. The calves had been weaned for 2 wk before the trials started. Each trial used 96 calves (4 calves/pen) with 2 starting times 5 wk apart as blocks (48 calves/block). During 15 of the last 21 d of trial 1 and 10 of 14 d of the second and third week of trial 2, fecal samples were collected to estimate the digestibility of the diets fed. Performance measurements were made over the 56-d trial. The calves were housed in group pens with 5.5 m² of outside pen space and 1.35 m² of inside pen space per calf. The inside pen space was bedded with straw and there was no added heat.

In trial 1, a textured diet (19% CP on DM basis) with high starch (52% starch, 13% NDF) based on whole corn and oats or a pelleted low-starch (20%

starch, 35% NDF), high-digestible fiber diet were used. Within starch level, diets were formulated from all supplemental soybean meal or soybean meal with blood meal and Alimet [Novus International Inc., St. Charles, MO; 84% 2-hydroxyl 4-(methylthio) butanoic acid, 88% methionine activity] to provide 2 MP levels (1 and 1.07% metabolizable Lys plus Met). The trial was conducted from June to September. The average temperature during the trial was 26°C (ranged from 9 to 40°C) and average humidity was 60% (ranged from 29 to 99%). The 4 treatments were analyzed as a completely randomized block design with a 2 by 2 factorial arrangement with pen (6 pens/treatment) as the experimental unit using a mixed procedure of SAS (ver. 8, SAS Institute Inc., Cary, NC). An auto-regressive type 1 covariance matrix was employed as determined using Akaike's information criteria. Factors were starch, protein, and their interaction; differences were declared at $P < 0.05$.

In trial 2, all ground, pelleted diets (19% CP) were fed. Diets were based on soybean hulls, wheat middlings, or corn, which contained increasing concentrations of starch (13, 27, and 42% starch, 42, 23, and 16% NDF, respectively; 8 pens/diet). The trial was conducted from August to November. The average temperature during the trial was 14°C (ranged from -4 to 34°C) and average humidity was 72% (ranged from 30 to 99%). The 3 treatments were analyzed as a completely randomized block design with pen as experimental unit using a mixed procedure of SAS. An auto-regressive type 1 covariance matrix was employed as determined using Akaike's information criteria. Contrast statements were constructed to separate differences in the means (soybean hulls plus wheat middlings vs. corn; soybean hulls vs. wheat middlings); differences were declared at $P < 0.05$.

Every second bag (22.7 kg) of starter feed and every bale of hay was sampled and composited. Composites of feeds were analyzed (AOAC International, 2000) for DM (oven method 930.15), ash (oven method 942.05), CP (Kjeldahl method 988.05), fat (alkaline treatment with Roese-Gottlieb method 932.06 for MR; diethyl ether extraction method 2003.05 for starters and hay), NDF with ash by the procedure of Van Soest et al. (1991) without sodium sulfite or α -amylase, ADF with ash (Robertson and Van Soest, 1981), starch (α -amylase method; Hall, 2009), and sugar (colormetric method; Dubois et al., 1956). Results are in Tables 1 and 2.

Calves were weighed, hip widths were measured, and body condition was scored initially (d 28) and at the end of the trial (d 56). Empty BW was estimated from fill as a percentage of BW = $10.4 - 0.39$ diet CP% + 0.41 diet ADF% (Jahn and Chandler, 1976). Feed offered and refused was weighed daily. Hip widths were

measured with a caliper. Calf BCS was based on a 1 to 5 system using 0.25-unit increments, with 1 being emaciated and 5 being obese (Wildman et al., 1982). Scores were based on changes around the vertical and transverse processes of the spine as palpated by one experienced technician and ranged from 2.0 to 3.5. Feces were scored using a 5-point system (1 being normal, thick in consistency; 2 being normal, but less thick; 3 being abnormally thin, but not watery; 4 being watery; 5 being watery with abnormal coloring; modified from Kertz and Chester-Jones, 2004). Pen was assigned a fecal score of 0 (normal fecal score day) if no feces on the pen floor had a score greater than 2. A pen score of 1 (abnormal fecal score day) was assigned if any feces with a score greater than 2 were observed. Pen scores were analyzed.

Feeds and fecal samples during the fecal collection phase of each trial were analyzed for acid-insoluble ash

(Van Keulen and Young, 1977), an indigestible marker. The concentration of acid-insoluble ash in the feces and feed were combined with intake to estimate digestion of nutrients analyzed. Feeds and feces were analyzed for DM, ash, CP, NDF, ADF, sugar, and starch to estimate their digestibility.

RESULTS

Trial 1

No differences ($P > 0.05$) were noted among treatments for initial BW, hip width, and BCS (Table 3). For the 56-d performance trial, calves fed the high-starch diets had greater ($P < 0.05$) ADG, empty BW ADG, feed efficiency, and change in hip width. No other differences were observed between starch levels, including no difference in days with abnormally loose feces.

Table 1. Ingredient and analyzed nutrients in feeds from trial 1

Item	High-starch textured feed		Low-starch pelleted feed		Hay
	Low MP	High MP	Low MP	High MP	
Ingredient, % as fed					
Corn ¹	49.5	49.5	11.0	11.0	—
Oats ¹	20.0	20.0	—	—	—
Soybean meal	15.8	14.5	2.1	0.9	—
Wheat middlings	8.2	8.9	33.0	33.0	—
Molasses	3.0	3.0	3.0	3.0	—
Calcium carbonate	0.9	0.9	0.8	0.8	—
Vitamin, trace mineral premix ²	0.8	0.8	0.8	0.8	—
Salt	0.8	0.8	0.8	0.8	—
Monocalcium phosphate	0.7	0.7	0.1	0.1	—
Decoquinat premix ³	0.5	0.5	0.5	0.5	—
Distillers dried grains	—	—	15.0	15.0	—
Soybean hulls	—	—	31.5	32.0	—
Blood meal	—	0.5	—	0.5	—
Alimet ⁴	—	0.1	—	0.1	—
Sodium sesquicarbonate	—	—	1.6	1.6	—
Nutrient					
DM, %	88.4	89	89	88.9	89.3
Ash, % of DM	5.5	5.9	8.1	7.7	10.2
ADF, % of DM	4.4	5.3	19.8	22.3	40.9
NDF, % of DM	12.6	13.6	35.6	35	65.1
Starch, % of DM	54.4	51.2	19.7	19.2	1.6
CP, % of DM	18.6	19.3	17.9	17.5	11.3
Sugar, % of DM	6.6	7.7	7.3	5.2	7.9
Fat, % of DM	3.7	3.4	4.7	4.3	2.6
DE, ⁵ Mcal/kg	3.58	3.54	3.18	3.17	2.52
Particle size, ⁶ μ m	3,176	3,192	934	920	—

¹Corn and oats were whole in the textured feeds and corn was ground in the pelleted feeds.

²1.60 g of Cu/kg, 0.13 g of Co/kg, 9.40 g of Fe/kg, 0.14 g of I/kg, 5.4 g of Mn/kg, 0.04 g of Se/kg, 6.70 g of Zn/kg, 1,800 kIU of vitamin A/kg, 600 kIU of vitamin D/kg, 16 kIU of vitamin E/kg, 0.01 g of biotin/kg, 2.93 g of obalamin/kg, 0.04 g of folic acid/kg, 1.77 g of niacin/kg, 1.32 g of pantothenic acid/kg, 0.24 g of pyridoxine/kg, 0.30 g of riboflavin/kg, 0.29 g of thiamin/kg; Provimi, Brookville, OH.

³0.5% decoquinat, Zoetis, Florham Park, NJ.

⁴88% methionine activity, Novus International Inc., St. Charles, MO.

⁵DE = digestible energy; calculated for analyzed nutrients using NRC (2001).

⁶Geometric mean particle size (ASAE, 1983) from wet sieving the complete diet (95% concentrate, 5% chopped hay) using a vibratory sieve shaker (Fritsch, Oberstein, Germany).

Table 2. Ingredient and analyzed nutrients in feeds from trial 2

Item	Soyhulls	Middlings	Corn	Hay
Ingredient, % as fed				
Soybean hulls	49.1	8.8	4.8	
Wheat middlings	20.0	60.0	20.0	
Soybean meal	19.3	15.1	23.3	
Maltodextrin (binder)	2.5	2.5	2.5	
Molasses	2.5	2.5	2.5	
Fat	2.0	2.0	2.0	
Salt	0.6	0.6	0.6	
Corn, ground	1.5	5.7	41.2	
Monocalcium phosphate	0.5	0.0	0.4	
Ameribond 2X (binder) ¹	0.5	0.5	0.5	
Decoquinat premix ²	0.5	0.5	0.5	
Vitamin, trace premix ³	0.8	0.8	0.8	
Calcium carbonate	0.3	1.1	0.9	
Nutrient				
DM, %	88.9	88.4	88.2	89.4
Ash, % of DM	6.7	7.1	6.4	10.3
ADF, % of DM	27.6	12.2	6.1	40.2
NDF, % of DM	42.9	23.7	16.4	63.6
Starch, % of DM	12.8	27	42.2	1.4
CP, % of DM	19	19.4	20.3	11.2
Sugar, % of DM	7.3	8.7	8.7	7.8
Fat, % of DM	3.6	5.1	4.7	2.1
DE, ⁴ Mcal/kg	3.10	3.42	3.56	2.52
Particle size, ⁵ μ m	3,176	3,192	934	920

¹LignoTech USA Inc., Rothschild, WI.²0.5% decoquinat, Zoetis, Florham Park, NJ.³1.60 g of Cu/kg, 0.13 g of Co/kg, 9.40 g of Fe/kg, 0.14 g of I/kg, 5.4 g of Mn/kg, 0.04 g of Se/kg, 6.70 g of Zn/kg, 1,800 kIU of vitamin A/kg, 600 kIU of vitamin D/kg, 16 kIU of vitamin E/kg, 0.01 g of biotin/kg, 2.93 g of cobalamin/kg, 0.04 g of folic acid/kg, 1.77 g of niacin/kg, 1.32 g of pantothenic acid/kg, 0.24 g of pyridoxine/kg, 0.30 g of riboflavin/kg, 0.29 g of thiamin/kg; Provimi, Brookville, OH.⁴DE = digestible energy; calculated for analyzed nutrients using NRC (2001).⁵Geometric mean particle size (ASAE, 1983) from wet sieving the complete diet (95% concentrate, 5% chopped hay) using a vibratory sieve shaker (Fritsch, Oberstein, Germany).**Table 3.** Performance of calves fed low- and high-starch grower diets with different amounts of MP in trial 1

Item	High-starch textured feed		Low-starch pelleted feed		SEM	Main effect <i>P</i> -value		
	Low MP	High MP	Low MP	High MP		Starch	MP	Starch $\times$ MP
Pens, no. (4 calves/pen)	6	6	6	6	—	—	—	—
Initial BW, kg	72.5	72.7	76.1	73.8	1.6	0.18	0.54	0.45
Final BW, kg	132.6	133.9	132.2	129.8	2.64	0.41	0.48	0.83
ADG, kg/d	1.07	1.09	1	1	0.032	0.02	0.79	0.72
Empty BW ADG, ¹ kg/d	1.00	1.03	0.81	0.8	0.0276	0.03	0.71	0.65
DMI, kg/d	3.11	3.18	3.32	3.29	0.152	0.25	0.85	0.72
DMI, % BW	3.03	3.08	3.17	3.23	0.0939	0.13	0.55	0.98
Feed efficiency, gain/feed	0.347	0.344	0.304	0.304	0.0096	0.001	0.89	0.87
Initial hip width, cm	21.3	21.5	21.7	21.5	0.23	0.47	0.89	0.31
Hip width change, cm	6	5.9	5.4	5.2	0.22	0.01	0.62	0.65
Initial BCS ²	2.4	2.3	2.3	2.3	0.04	0.55	0.39	0.73
BCS change	0.6	0.6	0.6	0.5	0.051	0.21	0.54	0.59
Abnormal fecal score days ³	4.3	4.3	4.7	4.8	0.34	0.22	0.81	0.82

¹Estimated from fill as a percentage of BW = 10.4 – 0.39 diet CP % + 0.41 diet ADF % (Jahn and Chandler, 1976).²1 to 5 point system (1 = thin, 5 = obese) modified from Wildman et al. (1982).³Days with any feces in pens with fecal scores >2; 1 to 5 system (1 being normal, thick in consistency; 2 being normal, but less thick; 3 being abnormally thin, but not watery; 4 being watery; 5 being watery with abnormal coloring).

Metabolizable protein or the interactions of starch level with MP were not significant ($P > 0.05$) for any measurements.

In the digestion measurement portion of the trial, starch, ADF, NDF, and fat intakes differed ($P < 0.05$) by starch level of the diet (Table 4). Fat and ADF intake differed ($P < 0.05$) by MP source. These nutrient intake differences were indicative of the nutrient concentration differences in the diet, as DMI was not different among treatments. Digestibility of DM, OM, and CP were greater ($P < 0.05$) for calves fed high- versus low-starch diets. Digestibility of ADF, NDF, and starch were less ($P < 0.05$) for calves fed the high- versus low-starch diets. Digestibility was not different by MP source. Amounts of ADF, NDF, and fat digested were less ($P < 0.05$) for calves fed the high- versus low-starch diets. Amount of starch digested was greater ($P < 0.05$) for calves fed the high- versus low-starch diets. Amount of ADF digested was greater ($P < 0.05$) for calves fed high- versus low-MP diets. Amount of starch and fat digested was less ($P < 0.05$) for calves fed high- versus low-MP diets.

Fecal output of DM, OM, ADF, NDF, and CP were less ($P < 0.05$) for calves fed high- versus low-starch

diets. Fecal output of starch was greater ($P < 0.05$) for calves fed high- versus low-starch diets. Fecal concentrations of ADF and NDF were less ($P < 0.05$) for calves fed high- versus low-starch diets. Fecal concentrations of starch and fat were greater ($P < 0.05$) for calves fed high- versus low-starch diets. Fecal concentrations of ash were less ($P < 0.05$) in calves fed high- versus low-MP diets.

The factor of MP had limited effects on digestion. The differences in amounts of ADF, starch, and fat digested between high- versus low-MP diets appeared mostly a function of diet concentration.

Fecal output of DM and OM was 38% greater for calves fed the high- versus low-starch diets (Table 5). Starch concentration in the manure was considerably greater (15 vs. 1% of DM) in calves fed high- versus low-starch diets, whereas NDF concentration of the manure was a similar magnitude less (40 vs. 57% of DM) in calves fed high- versus low-starch diets. High fecal starch in calves fed the high-starch diets could have been inflated by the use of whole corn and oats versus ground grains. Fecal starch output in the calves fed high-starch diets was 70 g compared with an intake of 1,442 g.

Table 4. Intake and digestion of nutrients by calves fed low- and high-starch grower diets with different amounts of MP during the last 2 wk of trial 1 when digestion measurements were made

Item	High-starch textured feed		Low-starch pelleted feed		SEM	<i>P</i> -value		
	Low MP	High MP	Low MP	High MP		Starch	MP	Starch × MP
Intake, kg/d								
DM	3.07	2.91	3.13	3.07	0.082	0.19	0.19	0.51
OM	2.90	2.73	2.87	2.83	0.076	0.61	0.21	0.41
ADF	0.19	0.21	0.65	0.71	0.011	0.001	0.02	0.15
NDF	0.47	0.47	1.16	1.12	0.020	0.001	0.39	0.35
Starch	1.60	1.42	0.60	0.57	0.035	0.001	0.04	0.16
CP	0.56	0.55	0.55	0.53	0.015	0.29	0.28	0.75
Sugar	0.21	0.22	0.23	0.16	0.006	0.27	0.16	0.12
Fat	0.11	0.10	0.14	0.13	0.003	0.001	0.001	0.97
Digestibility, %								
DM	84.3	84.7	79.7	78.8	0.51	0.001	0.71	0.23
OM	84.9	85.0	80.2	78.9	0.57	0.001	0.34	0.28
ADF	41.5	54.0	65.2	66.1	1.86	0.001	0.03	0.14
NDF	56.8	62.8	69.4	66.1	1.64	0.005	0.54	0.12
Starch	95.1	95.7	99.0	98.7	0.29	0.001	0.66	0.18
CP	84.9	84.6	79.5	78.6	0.54	0.001	0.71	0.6
Sugar	95.3	95.6	95.7	92.4	0.68	0.14	0.11	0.12
Fat	86.3	82.7	88.3	87.8	0.78	0.08	0.06	0.18
Digested, kg/d								
DM	2.59	2.46	2.49	2.42	0.078	0.21	0.27	0.72
OM	2.46	2.32	2.30	2.24	0.074	0.12	0.17	0.62
ADF	0.08	0.11	0.43	0.47	0.013	0.01	0.001	0.57
NDF	0.27	0.29	0.80	0.74	0.020	0.01	0.57	0.15
Starch	1.52	1.36	0.59	0.57	0.031	0.001	0.03	0.17
CP	0.48	0.47	0.44	0.42	0.015	0.01	0.27	0.72
Sugar	0.20	0.21	0.22	0.15	0.007	0.25	0.15	0.11
Fat	0.10	0.08	0.13	0.11	0.003	0.001	0.001	0.64

Table 5. Output of nutrients in the feces of calves fed low- and high-starch grower diets with different amounts of MP during the last 2 wk of trial 1 when digestion measurements were made

Item	High-starch textured feed		Low-starch pelleted feed		SEM	<i>P</i> -value		
	Low	High	Low	High		Starch	MP	Starch × MP
Fecal output, kg/d								
DM	0.483	0.443	0.635	0.651	0.017	0.001	0.49	0.11
OM	0.436	0.407	0.569	0.598	0.017	0.001	0.99	0.12
ADF	0.111	0.094	0.226	0.242	0.01	0.001	0.95	0.1
NDF	0.201	0.174	0.354	0.379	0.015	0.001	0.97	0.12
Starch	0.078	0.062	0.006	0.007	0.006	0.001	0.23	0.13
CP	0.085	0.084	0.113	0.113	0.003	0.01	0.95	0.89
Sugar	0.01	0.01	0.01	0.013	0.001	0.27	0.28	0.35
Fat	0.015	0.017	0.017	0.016	0.001	0.84	0.88	0.26
Concentration in feces, % (unless noted)								
DM	26	28.8	22	22.1	1.199	0.002	0.27	0.31
Ash, % of DM	9.7	8	10.5	8.3	0.5177	0.32	0.006	0.69
ADF	23	21.3	35.6	37.1	0.8618	0.001	0.85	0.11
NDF	41.6	39.3	55.7	58.2	1.4126	0.001	0.95	0.13
Starch	16.2	14	0.9	1.1	1.1787	0.001	0.42	0.34
CP	17.5	19	17.8	17.4	0.4723	0.19	0.28	0.09
Sugar	2	2.2	1.5	1.9	0.263	0.22	0.26	0.76
Fat	3.2	3.8	2.6	2.4	0.1658	0.001	0.31	0.06

Trial 2

Initial BW, hip width, and BCS of calves in trial 2 were not different (Table 6; $P > 0.05$). Calf ADG, hip width change, and BCS change was greater ($P < 0.05$) for calves fed diets with corn versus soyhulls and middlings over the 56-d performance trial. Other measurements were not different ($P > 0.05$).

During the digestion measurement portion of trial 2, starch intake ranked corn > middlings > soyhulls, whereas ADF and NDF ranked soyhulls > middlings > corn ($P < 0.05$; Table 7). These nutrient intakes

reflected diet composition. Intake of DM and OM did not differ among treatments. Digestibility of DM, OM, and CP were greater ($P < 0.05$) for calves fed corn versus other diets. Digestibility fractions of ADF and NDF were greater ($P < 0.05$) for calves fed soyhulls versus middlings. Amount of starch digested ranked corn > middlings > soyhulls, whereas amount of ADF and NDF digested ranked soyhulls > middlings > corn ($P < 0.05$).

Fecal output of DM, OM, ADF, NDF, and CP were less ($P < 0.05$) for calves fed corn versus other diets (Table 8). Fecal output of starch was greater ($P < 0.05$)

Table 6. Performance of calves fed diets with different amounts of starch in trial 2

Item	Soyhulls (S)	Middlings (M)	Corn (C)	SEM	<i>P</i> -value	
					S + M vs. C	S vs. M
Starch, % of DM	12.8	27	42.2			
Pens, no. (4 calves/pen)	8	8	8	—	—	—
Initial BW, kg	70.3	70.3	72.7	1.5	0.07	0.94
Final BW, kg	123.5	122.4	135.0	3.7	0.001	0.78
ADG, kg/d	0.95	0.93	1.11	0.05	0.01	0.74
Empty BW ADG, ¹ kg/d	0.68	0.80	1.02	0.05	0.01	0.08
DMI, kg/d	3.23	2.90	3.18	0.19	0.49	0.11
DMI, % of BW	3.33	3.03	3.07	0.23	0.61	0.21
Feed efficiency, gain/feed	0.301	0.332	0.355	0.0292	0.14	0.29
Initial hip width, cm	21.4	21.4	21.6	0.2	0.36	0.95
Hip width change, cm	5.1	5.0	5.6	0.2	0.01	0.76
Initial BCS ²	2.3	2.3	2.3	0.0	0.96	0.96
BCS change	0.3	0.2	0.4	0.085	0.02	0.49
Abnormal fecal score days ³	5.7	5.2	5.4	0.98	0.56	0.48

¹Estimated from fill as a percentage of BW = 10.4 – 0.39 diet CP % + 0.41 diet ADF % (Jahn et al., 1976).

²1 to 5 point system (1 = thin, 5 = obese) modified from Wildman et al. (1982).

³Days with any feces in pens with fecal scores >2; 1 to 5 system (1 being normal, thick in consistency; 2 being normal, but less thick; 3 being abnormally thin but not watery; 4 being watery; 5 being watery with abnormal coloring).

Table 7. Intake and digestion of nutrients by calves fed diets with different amounts of starch during wk 6 and 7 of trial 2 when digestion measurements were made

Item	Soyhulls (S)	Middlings (M)	Corn (C)	SEM	<i>P</i> -value	
					S + M vs. C	S vs. M
Starch, % of DM	12.8	27	42.2			
Intake, kg/d						
DM	2.36	2.27	2.17	0.100	0.13	0.39
OM	2.20	2.11	2.03	0.092	0.16	0.35
ADF	0.67	0.31	0.17	0.021	0.001	0.001
NDF	1.04	0.58	0.41	0.034	0.001	0.001
Starch	0.30	0.59	0.88	0.023	0.001	0.001
CP	0.44	0.43	0.43	0.019	0.82	0.68
Sugar	0.17	0.20	0.19	0.008	0.63	0.02
Fat	0.08	0.11	0.10	0.004	0.68	0.01
Digestibility, %						
DM	76.9	78.9	85.2	1.58	0.01	0.23
OM	77.5	79.6	85.8	1.56	0.001	0.21
ADF	65.5	53.5	55.4	3.48	0.2	0.01
NDF	70.7	56.1	66.2	3.13	0.34	0.002
Starch	97.6	98.9	97.0	0.57	0.13	0.15
CP	78.1	80.7	84.4	1.75	0.01	0.16
Sugar	94.2	95.6	94.2	1.79	0.63	0.47
Fat	84.1	86.3	89.6	2.61	0.08	0.42
Nutrients digested, kg/d						
DM	1.81	1.79	1.85	0.086	0.53	0.81
OM	1.70	1.68	1.74	0.082	0.48	0.76
ADF	0.44	0.17	0.09	0.016	0.001	0.001
NDF	0.73	0.33	0.27	0.027	0.001	0.001
Starch	0.29	0.58	0.85	0.021	0.001	0.001
CP	0.34	0.35	0.36	0.016	0.22	0.74
Sugar	0.16	0.19	0.18	0.009	0.81	0.22
Fat	0.07	0.10	0.09	0.005	0.25	0.21

for calves fed corn versus other diets. Fecal output of ADF and NDF was greater ($P < 0.05$) for calves fed soyhulls versus middlings. Fecal concentrations of ADF and NDF were less ($P < 0.05$) for calves fed corn versus other diets (Table 7). Fecal concentrations of starch, sugar, and CP were greater ($P < 0.05$) for calves fed

Table 8. Output of nutrients in the feces of calves fed diets with different amounts of starch during wk 6 and 7 of trial 2 when digestion measurements were made

Item	Soyhulls (S)	Middlings (M)	Corn (C)	SEM	<i>P</i> -value	
					S + M vs. C	S vs. M
Starch, % of DM	12.8	27	42.2			
Fecal output, kg/d						
DM	0.546	0.477	0.322	0.0406	0.001	0.13
OM	0.495	0.429	0.289	0.0365	0.001	0.11
ADF	0.23	0.143	0.076	0.0125	0.001	0.001
NDF	0.304	0.255	0.138	0.0211	0.001	0.05
Starch	0.007	0.007	0.026	0.0039	0.001	0.92
CP	0.096	0.083	0.068	0.0085	0.02	0.15
Sugar	0.01	0.009	0.011	0.0032	0.56	0.69
Fat	0.013	0.015	0.01	0.0026	0.12	0.47
Concentration in feces, %						
DM	21.2	20.4	23.7	1.68	0.08	0.66
CP	17.7	17.4	20.8	0.65	0.001	0.68
ADF	42.1	30.1	23.6	0.79	0.001	0.001
NDF	55.6	53.6	43	1.11	0.001	0.11
Sugar	1.8	1.7	3.5	0.56	0.008	0.86
Starch	1.3	1.4	8.3	1.3	0.001	0.96
Fat	2.4	3.2	3.2	0.45	0.29	0.15
Ash	9.3	10.3	10.1	0.65	0.61	0.13

corn versus other diets. Fecal concentrations of ADF were greater ($P < 0.05$) in calves fed soyhulls versus middlings.

DISCUSSION

In trial 1, high-starch diets resulted in 2.5 times more starch being digested than in low-starch diets. Low-starch (high-fiber) diets resulted in 3.7 times more NDF being digested daily than high-starch diets. Digestibility of NDF was 67% for low-starch (high-fiber) diets compared with 59% for high-starch diets. Comparatively greater than NDF, starch digestibility was 95% for high-starch diets and 99% for low-starch diets. Digestibility of OM was 85% for high-starch diets, 7% greater than the 79% digestibility of OM for low-starch diets. Calculated DE was 3.56 Mcal/kg for the high-starch diet, 11% greater than the calculated DE of 3.18 Mcal/kg for the low-starch diet.

In trial 2, starch digestibility was high (~98%) and not different among treatments, whereas NDF digestibility was lower (56 to 70%), with middlings diets (0.56) having lower digestibility than soyhulls diets (70%). Digestibility of OM was 8% greater for calves fed corn (85%) versus middlings (79%) and soyhulls (77%). Calculated DE of the diets were 3.56, 3.42, and 3.10 Mcal/kg for corn, middlings, and soyhull diets, respectively. The energy values in NRC (2001) relate well with the digestion and performance measurements in trials 1 and 2. Current results also relate well with results of trials where distillers dried grains (low starch, high NDF) replaced corn and soybean meal (high starch, low NDF). Suarez-Mena et al. (2011) reported the digestibility of starters high in distillers dried grains to be lower and support less ADG than diets high in corn and soybean meal.

Additionally, an issue in trial 1 was confounding of starch concentration with form of diet (all pelleted, low starch with textured, and high starch). The similar results for digestion and calf performance among treatments between trial 1 and 2 suggest that the effects in trial 1 were largely related to starch concentration.

Stobo et al. (1966) fed calves weaned at 5 wk of age 90 and 33% concentrate diets. Digestibility of crude fiber was 18.4 and 57.3% at 13 wk for calves fed 90 and 33% concentrate, respectively, and 14.5 and 54.0% digestible at 17 wk, respectively. Vazquez-Anon et al. (1993) reported mean retention of particles in the rumen of calves to increase from 22 h at 7 wk of age to 44 h at 13 wk of age in calves fed 15% chopped grass hay and 85% concentrate diets and weaned at 5 wk of age. This would indicate that slowly digested ingredients,

such as ingredients with high NDF concentrations, would yield more DE as the young calf ages.

In trial 1, fecal output of DM and OM in calves fed the low-starch diets was 38% greater than fecal output of the high-starch diets. In trial 2, fecal output of DM and OM was 48 and 70% greater for calves middlings and soyhulls versus corn diets, respectively. In both trials, intake of DM and OM were not different; yet, in both trials, fecal concentrations of starch were greater in calves fed high- versus lower-starch diets. This was especially true in trial 1, where the high-starch diets were whole grains.

The difference in calf ADG was 8% greater for high- versus low-starch diets in trial 1. However, the difference in empty BW ADG was 26% more for calves fed the high- versus low-starch diet. Similarly, in trial 2, the difference in ADG from the high-starch corn diet and the average of the low-starch diets based on soyhulls or wheat middlings was considerably less than difference in empty BW ADG. This reflects the effect that fiber can have on increasing digesta fill of the gut as well as a greater amount of gut tissue (Jahn and Chandler, 1976; Fokkink et al., 2009). In research and in practical farm situations, calves are typically weighed to calculate ADG, and differences in empty BW ADG are often not measured and overlooked.

Source of protein and amount of metabolizable Lys, Met, or protein did not change performance in pre- and postweaned calves (Hill et al., 2007a, 2008b). These references contained a fairly thorough review of the literature and reported that, in trials using corn and soybean as the base ingredients, performance or digestion in calves was not improved when alternative ingredients were used; this supported no response to increasing MP in trial 1.

Lalles and Poncet (1990) and Vazquez-Anon et al. (1993) each reported that rumen degradation of protein sources increase with age postweaning. These were large changes in degradation and indicate that sources of rumen undegraded proteins are less needed in young calves than older animals with more developed rumens. In addition to no changes in growth measures, Swartz et al. (1991) reported no difference in the carcass composition from feeding diets with varying concentration of undegraded protein out to 25 wk of age.

The diets in trial 1 were formulated near the optimum CP concentration, as reported by Hill et al. (2008b). If energy was the limiting nutrient, not CP or MP, this could explain the lack of response to added MP. However, no response to added MP was noted in the low-starch diet, where energy supply was less; this pointed to a conclusion that added MP was not beneficial.

CONCLUSIONS

High-NDF, low-starch diets high in digestible fiber sources in 95% concentrate diets were poorly digested in dairy calves from 8 to 16 wk of age that had been weaned at 6 wk of age compared with whole or ground high-grain, high-starch 95% concentrate diets. This lower digestibility largely explained the lower ADG and changes in hip widths observed and supports the limited data from which the NRC (2001) requirements are based. It supports the notion that energy, not protein, limits ADG, as in NRC (2001), but does not support the notion that digestible fiber sources are useful. Increasing the metabolizable Lys and Met concentration of high- and low-starch diets based on soybean meal protein did not change digestibility or performance in these calves less than 16 wk of age. These data are similar to other recent performance reports in weaned calves of similar ages and recent performance and digestibility reports pre- and early postweaned calves less than 2 mo of age.

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