

Short communication

Effects of starch or fermented fiber based diets on performance, growth status, rumen fermentation and some blood metabolites in Holstein bull calves

M. Kazemi-Bonchenari*, M. Khodaei-Motlagh, H. A. Ghasemi and I. Hajkhodadadi

Department of Animal Science, Faculty of Agriculture and Natural Resources, Arak University, 38156-8-8349, Arak, Iran.

* Corresponding author, E-mail address: m-kazemibonchenari@araku.ac.ir

Abstract Starch (SS) and fermented fiber (FFS), as energy sources were included in Holstein bull calf diets to evaluate their growth performance, rumen fermentation pattern and concentration of insulin and selected blood metabolites. Fourteen Holstein bull calves (BW=94.5±2.1 kg; age 87±9 d) were allocated to treatments (n=7 calves per treatment) and the study lasted 10 weeks. The diets were based on barley grain and corn silage in SS and FFS treatments, respectively. Dry matter intake was decreased ($P < 0.05$) in SS compared to FFS treatment (7.83 vs. 8.21 kg/d), with SS treatment causing a lower feed conversion ratio (FCR). Growth indices (body length, withers height and heart girth) did not differ between two treatments ($P > 0.05$). Fecal score was more watery (= 3.1) in SS compared to FFS (= 2.4) treatment ($P < 0.05$). The SS diet increased propionate concentration but FFS increased acetate concentration in the rumen fluid. Blood glucose was increased, but beta-hydroxybutyrate (BHB) decreased in SS fed calves. Insulin concentration was greater by 2.1 $\mu\text{IU ml}^{-1}$ in SS compared to FFS fed calves. Results showed that although the high starch diet decreased the feed intake and caused feces to contain more water, it improved energy status of the calves via decreasing BHB, increasing propionate concentration and improving glucose concentrations. The SS-based diet showed greater efficiency compared to FFS in bull calves.

Keywords: Holstein bull calves, blood metabolites, energy source, insulin

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Introduction

High energy diets in growing animal should be supplied through concentrates to meet the requirements for fast growth rates (Robinson and Kennelly, 1989; Allen, 2009). High-concentrate diets, which are mostly based on starch, are rapidly fermented in the rumen, leading to high concentrations of volatile fatty acids (VFA) in the ruminal fluid and relatively low ruminal pH (Beauchemin et al., 2001). Barley grain, which is one of the main feedstuffs in growing and finishing feedlot cattle nutrition, is highly degradable in the rumen and often causes production of excess fermentation acids, decreasing the ruminal pH (McCarthy et al., 1989; Robinson and Kennelly, 1989; Nocek and Tamminga, 1991). Although carbohydrate fermentation in the rumen is desirable in providing energy for microbial growth and production of microbial protein, yet the fermentability of the diet must be limited to prevent excessive production of VFA. Inadequate effective fiber or excessive fermentability of the diet can decrease ruminal pH, feed intake,

diet digestibility, and microbial protein synthesis (Allen, 2009). Management practices aiming at mitigating the sub-acute ruminal acidosis are to decrease dietary starch concentration and ruminal starch degradability (Owens et al., 1998), or to increase salivary buffer flow by physically effective neutral detergent fiber (NDF) (Allen, 1997). One of the strategies to reduce the incidence of acidosis in beef cattle is to replace barley grain with a fermented fiber source (Burken, 2014). The conventional fiber used in the ruminant's diets is NDF. However, re-evaluation of fiber studies in ruminant nutrition has categorized the NDF into indigestible (INDF) and fermentable (FNDF) parts (Hogue, 1994; Schotthofer et al., 2007; Baker et al., 2009). Experiments with lactating ewes nursing twin or triplet lambs (Hogue, 1994; Schotthofer et al., 2007), lactating dairy cows, and feedlot cattle (Baker et al 2009) showed that FNDF prevented rumen metabolic disturbances. In contrast and in support of the necessity to balance for FNDF, in-

creased NDF fermentability resulted in higher feed intake in dairy cows consuming diets with the same level of NDF (Oba and Allen, 1999). Among the fermented fiber sources, corn silage is an important source of digestible effective fiber and can be an economical source of energy for ruminants (Allen, 2009). Insulin concentration which has been shown to have effect on meat deposition in feedlot cattle (Kimball et al., 1994) might also be influenced by carbohydrate sources in the diet (Lemosquet et al., 1997; Sano et al., 1999). Because corn silage and grains are commonly used in beef cattle diets as energy suppliers (Burken, 2014), more research is needed to evaluate and compare how these carbohydrate sources can affect animal health and productivity. In the present study, the effect of a starch source (SS; rolled barely grain) versus fermented fiber source (FFS; corn silage) on the performance, rumen fermentation pattern, concentration of energy status indicators (glucose, NEFA and BHB) and plasma insulin concentration in Holstein bull calves was investigated.

Materials and methods

Animals, treatments and management

Fourteen Holstein bull calves (BW 94.5±2.1 kg, 87±9 days old) were assigned to a completely randomized design receiving either of two dietary carbohydrate sources [7 animals per treatment; rolled barley grain ba-

Table 1. Feed ingredients and chemical composition of the experimental diets (% of DM)

Feed ingredients	Treatments ¹	
	SS	FFS
Alfalfa hay, chopped	30	30
Corn silage	15	33
Wheat straw	10	7
Barley grain, rolled	30	15
Wheat bran	13	13
Urea	0.75	0.75
Salt	0.25	0.25
Mineral and vitamin supplement ²	1	1
Chemical composition		
ME (Mcal/kg)	2.20	2.17
NEg (Mcal/kg)	0.84	0.81
CP (%)	13.8	13.5
NFC (%)	39.6	37.4
NDF (%)	42.3	43.6
Ca (%)	0.45	0.47
P (%)	0.40	0.41

¹Treatments were; SS, starch source based diet; FFS, fermented fiber source based diet

²Contained per kilogram of supplement: 200,000 IU of vitamin A, 75,000 IU of vitamin D, 2,500 IU of vitamin E, 2g of Mn, 160 g of Ca, 7.2 g of Zn, 60 g of P, 21 g of Mg, 20 g of Na, 1.75 g of Fe, 20 mg of Co, 1 g of Cu, 100 mg of I, and 3 mg of Se.

sed diet (SS) vs. corn silage based diet (FFS)]. The feed ingredients are listed in Table 1. The animals were kept in individual stanchions and had free access to water. The study lasted 10 weeks, with the first week as the adaptation period and 9 weeks for data collection. Orts were collected and weights recorded once daily at 07:30 h and the feeding rate was adjusted daily to yield Orts of about 5-10% of intake. The animals were cared for in accordance with the practices outlined in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

Experimental procedures and chemical analyses

Dry matter (DM) was determined in composites of feed by drying the samples at 60°C for 48 h (AOAC, 1995). Intake of DM was computed based on the 60°C DM determinations for total mixed ration (TMR) and Orts. After drying, ingredients and TMR were ground through a 1-mm screen (Wiley mill). The samples were analyzed for total nitrogen, DM, ash and organic matter (AOAC, 1995), sequentially for NDF (Van Soest et al., 1991). Feed conversion ratio (FCR) was calculated as kg of feed intake divided by BW gain. Structured growth indices (Lesmeister and Heinrichs, 2005) as well as body weights, were recorded on the first days of the experiment and at 20 day intervals thereafter until the end of the experiment. The indices included the body length (BL, distance between the points of shoulder and hip), heart girth (HG) and withers height (WH). Rectal temperature (RT), and fecal scores were determined on each occasion that growth data were recorded. Fecal scoring was performed using the following scales: 1 = normal; 2 = soft to loose; 3 = loose to watery; 4 = watery, mucous and slightly bloody; and 5 = watery, mucous and bloody (Heinrichs et al., 2003). Blood was sampled at 4 h after morning feeding from the jugular vein three times throughout the study. Blood samples were heparinized and stored at +2° C; plasma was prepared (3000 × g 4° C, 15 min) and stored at -20° C. Plasma samples were analyzed using commercial kits for glucose (Pars Azmoon Co), non-esterified fatty acids (NEFA) and beta-hydroxybutyrate (BHB) (Randox Laboratories, Randox, Co, UK.) and autoanalyzer (Hitachi 912). Insulin was measured based on radioimmunoassay (RIA) procedure using a sandwich, non-competitive immunoradiometric (IRMA) method via a commercial kit (Code No: RF07, RIAKEY Insulin IRMA Tube, Shin Jin Medics Inc.) [Sensitivity of 0.6 uIU/mL, no significant cross-reactivity was shown on C-peptide (200 uIU/mL), glucagon (10 ug/mL), and intra-assay and inter-assay CV < 3.5% and 4.8%, respectively]. Rumen fluid samples were collected using a stomach tube 3 h after

morning meal on day 30 of the experiment. Ruminant fluid samples were squeezed through a four-layer cheesecloth and pH was measured immediately using a portable pH meter with a combination electrode. Ruminant fluid (8-mL aliquots) was preserved with 0.2 mL of 50% sulfuric acid and stored at -20°C for VFA analysis. The VFA analysis was carried out by using gas chromatography (Varian 3700; Varian Specialties Ltd., Brockville, Ontario, Canada) with a 15 m (0.53 mm i.e.) fused silica column (DBFFAP column; J and W Scientific, Folsom, CA).

Statistical analysis

Data were analyzed using PROC Mixed (SAS, 2000). The following model was used for variables which there were repeated measurements over time:

$Y_{ijk} = \mu + C_i + T_j + Z_k + ZT_{jk} + \varepsilon_{ijk}$; where Y_{ijk} is the dependent variable, μ is the overall mean, C_i is the effect of calf i , T_j is the effect of treatment j , Z_k is the effect of sampling time k , ZT_{jk} is the interaction between time k and treatment j and ε_{ijk} is the residual error. All terms were considered fixed except for C_i and ε_{ijk} which was considered as random effects. Differences between least square means were considered significant at $P < 0.05$ and differences were considered to indicate a trend toward significance at $0.05 < P < 0.10$.

Results

Feed intake, daily gain and feed efficiency

Dry matter intake (Table 2) was greater in FFS compar-

Table 2. Least square means for the intake and feed conversion ratio in Holstein male calves fed starch based (SS) or fermented fiber (FFS) based diets

	Treatments ¹		SE	P-value
	SS	FFS		
Dry matter intake (kg d ⁻¹)	7.83	8.21	5.6	0.03
Daily gain (kg d ⁻¹)	1.18	1.09	0.3	0.07
Feed conversion ratio (FCR)	6.64	7.53	0.07	0.05

ed to SS-fed calves and average daily gain was tended to be different ($P = 0.07$). The mean FCR was 7.5 and 6.6 for FFS and SS treatments, respectively ($P < 0.05$). Although feed intake was greater in FFS group, better FCR was achieved in SS treatment, showing better feed efficiency in starch-based diets.

Growth rate, health parameters, rumen fermentation, and plasma metabolites

Growth indices (body length, withers height and heart girth) did not differ by feeding different experimental diets (Table 3). Rectal temperature was not statistically different between treatments ($P > 0.05$). The starch-fed animals produced feces of lower consistency (fecal score = 3.1) compared to the calves fed the fermented fiber diet (fecal score = 2.4) ($P < 0.05$). Total VFA production did not differ between experimental diets. Acetate was increased in FFS, propionate was increased in SS diet ($P < 0.05$) and the ratio of acetate to propionate was increased in FFS vs. SS fed group. No difference for branched-chain volatile fatty acids, i.e. valerate and iso-valeric acids, were found between treatments (Table

Table 3. Least square means for growth parameters, health indicators and rumen fermentation profile in Holstein male calves fed starch (SS) based versus fermented fiber (FFS) based diets

	Treatments ¹		SE	P-value
	SS	FFS		
Growth parameters				
Body length (cm)	90.6	89.9	2.56	0.73
Heart girth (cm)	116.5	116.2	4.08	0.87
Wither height (cm)	91.7	91.1	3.11	0.93
Health parameters				
Rectal temperature (C°)	38.9	38.8	0.35	0.65
Fecal scoring (1-5) ¹	3.1	2.4	0.06	0.04
Rumen fermentation profile				
Rumen pH	6.02	6.37	0.19	0.01
Total volatile fatty acids (mM)	79.9	76.7	2.92	0.23
Propionate (mM)	18.2	13.7	1.78	0.02
Butyrate (mM)	10.0	10.8	0.92	0.89
Acetate (mM)	49.2	52.3	2.67	0.02
Acetate: Propionate ratio	2.70	3.81	0.11	0.04
Valerate (mM)	1.08	1.10	0.04	0.79
Isovalerate (mM)	1.12	1.23	0.14	0.53

¹Fecal scoring was scales 1-5 as follow; scale: 1 = normal; 2 = soft to loose; 3 = loose to watery; 4 = watery, mucous and slightly bloody; and 5 = watery, mucous and bloody (Heinrichs et al., 2003)

Table 4. Least square means for blood metabolites and insulin concentrations in calves fed starch based (SS) or fermented fiber (FFS) based diets

	Treatments ¹		SE	P-value
	SS	FFS		
Glucose (mg dL ⁻¹)	86.21	73.57	1.26	0.01
NEFA (mmol L ⁻¹)	0.64	0.67	0.09	0.68
BHB (mmol L ⁻¹)	0.66	0.78	0.05	0.03
Insulin (μIU mL ⁻¹)	28.2	26.1	0.87	0.02

3). The ruminal pH was higher in FFS compared to SS treatment ($P < 0.05$). Plasma glucose and insulin concentrations were higher but BHB levels were lower in SS compared to FFS treatment (Table 4). Plasma NEFA levels were not affected by the diets (Table 4).

Discussion

A starch based diet was compared with a fermented fiber based diet in growing bull calves. The SS diet resulted in lower DMI compared to the FFS based diet. The high starch diets are rapidly fermented in the rumen, leading to high concentrations of VFA in the ruminal fluid which has potential to reduce the ruminal pH (Beauchemin et al., 2001). Barley grain is rapidly fermented in the rumen. Higher ruminal carbohydrate fermentation rates often result in DMI reduction (McCarthy et al., 1989; Aldrich et al., 1993; Mitzner et al., 1994), mostly due to high concentration of propionate in animal fed high levels of barley which is called with hypophagic effect and to lowered ruminal pH (Allen et al., 2009). Ruminal pH also was lower in SS calves which might be related to more substrate being present for microbial digestion (Oliveira et al., 1993; Plascencia et al., 1996).

Although feed intake was lower in SS calves compared to FFS based diet, feed efficiency was better, suggesting that starch based diets has the potential to improve weight gain and consequently feed efficiency, probably as a result of VFA profile produced in the rumen (Beever, 1993). In this study, propionate concentration was higher in SS calves compared with the higher acetate concentration in FFS-fed animals. In contradiction to our results, Popova et al. (2011) reported that high fiber diet increased acetate level in the feedlot bulls without affecting the propionate concentration. This might be related to the level of carbohydrate fed to animals in these studies. In the present study, the carbohydrate source did not affect the total VFA production. It may be suggested that FFS could produce the same amount of VFA in comparison to SS; but the individual VFA were different between the diets.

Plasma glucose concentration was higher by 17% in

SS compared with FFS diet, mainly as a result of higher propionate availability for gluconeogenesis. Corn silage fed to the calves in the present study is a rich source of FNDF. The fermented fiber source based diet increased plasma BHB and reduced glucose concentration. Ruminal butyrate concentration is mostly related to the fiber content of the diet (Silveira et al., 2007). Most of the acetate and all the propionate are transported to the liver, but a proportion of butyrate is converted to β-hydroxybutyrate in the ruminal epithelium (Rogers and Davis, 1982). Plasma insulin concentration was higher in SS calves. Typically ruminants obtain most of their glucose (43 to 77%) through hepatic gluconeogenesis, primarily from propionate (Amaral et al., 1990). Duodenal infusion of glucose increased basal plasma concentrations of glucose and insulin (Lemosquet et al., 1997); therefore, higher blood glucose concentration in SS calves may be a cause of higher plasma insulin secretion in these animals. Propionate appears to be more potent than glucose in stimulating insulin secretion (Brockman, 1978); therefore, it seems that in addition to the stimulatory effect of glucose, the effects of VFA pattern also need to be considered. Higher DMI in FFS calves did not compensate for lower glucogenic precursor and subsequently glucose concentration. Probably greater concentration of BHB in fermented fiber based diet negatively affected insulin secretion. Therefore, higher feed intake may not result in higher blood glucose and insulin concentrations in ruminants and probably VFA pattern produced in the rumen may contribute to the energy status of the animal.

Conclusions

The high fermentable fiber improved the fecal score, but the lower feed efficiency and plasma glucose concentration suggested lower efficiency compared to high starch diets in growing Holstein bull calves. Further research is needed to evaluate the effects of starch and fermentable fiber supplied by various feedstuffs.

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اثر جیره‌های برپایه‌ی نشاسته یا الیاف تخمیر شده بر کارایی رشد، تخمیر شکمبه‌ای و برخی

متابولیت‌های خونی در گوساله‌های نر هلشتاین

م. کاظمی بن‌چناری^{*}، م. خدایی مطلق، ح.ع. قاسمی و ا. حاج‌خدادادی

گروه علوم دامی، دانشکده کشاورزی دانشگاه اراک، اراک، ایران.

^{*}نویسنده مسئول، پست الکترونیک: m-kazemibonchenari@araku.ac.ir

چکیده اثر نشاسته (SS) و الیاف تخمیر شده (FFS) به‌عنوان دو منبع متفاوت انرژی در جیره‌ی گوساله‌های نر هلشتاین بر عملکرد رشد، روند تخمیر شکمبه‌ای و غلظت انسولین و برخی فراسنجه‌های خونی مورد بررسی قرار گرفت. بدین منظور، ۱۴ رأس گوساله نر هلشتاین (با میانگین وزن $94/5 \pm 2/1$ کیلوگرم و سن 87 ± 9 روز) به مدت ده هفته در قالب دو تیمار آزمایشی (هر تیمار با ۷ تکرار) مورد استفاده قرار گرفتند. جیره‌های غذایی در تیمارهای آزمایشی SS و FFS به‌ترتیب بر پایه‌ی دانه جو غلطک زده و ذرت سیلو شده، تهیه شد. مصرف ماده خشک در تیمار SS به‌طور معنی‌داری ($P < 0/05$) در مقایسه با تیمار FFS کاهش یافت ($7/83$ در مقابل $8/21$ کیلوگرم در روز). باوجود پایین‌تر بودن ضریب تبدیل غذایی در گروه SS در مقایسه با FFS ($P < 0/05$)، شاخصه‌های رشد (طول بدن، دور گردن و ارتفاع از جدوگاه) بین دو تیمار مشابه بود ($P > 0/05$). گروه مصرف‌کننده منبع انرژی نشاسته‌ای دارای مدفوع آبکی‌تری ($3/1 =$) در مقایسه با گروه FFS ($2/4$) بودند ($P < 0/05$) مصرف جیره SS سبب افزایش غلظت پروپینونات و جیره FFS سبب افزایش غلظت استات در مایع شکمبه شد. غلظت گلوکز خون در تیمار دریافت‌کننده منبع نشاسته‌ای بیشتر و میزان بتا‌هیدروکسی بوتیرات کمتر از گروه مصرف‌کننده الیاف تخمیر شده بود ($P < 0/05$). غلظت انسولین به میزان $2/1$ میکرو واحد بین‌المللی در هر میلی‌لیتر در تیمار دریافت‌کننده منبع نشاسته‌ای در مقایسه با الیاف تخمیر شده افزایش یافت. نتایج حاصل از این مطالعه نشان داد که با وجود کاهش میزان ماده خشک مصرفی و افزایش میزان رطوبت مدفوع در گروه دریافت‌کننده منبع انرژی نشاسته‌ای، استفاده از منبع انرژی نشاسته‌ای در مقایسه با منبع الیاف تخمیر شده دارای قابلیت مناسبی در زمینه بهبود وضعیت انرژی حیوان به واسطه کاهش میزان بتا‌هیدروکسی بوتیرات و افزایش غلظت پروپینونات و گلوکز بوده و در نتیجه منجر به بهبود کارایی مصرف خوراک در گوساله‌های نر هلشتاین در مقایسه با جیره‌های بر پایه‌ی الیاف تخمیر شده، می‌شود.