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Effects of fiber sources in lamb starter feed on performance, chewing behavior, and blood energy metabolites

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Abstract In this study, the effects of partially replacing cereal grains (corn and barley) by forage (straw) or non-forage (beet pulp) source in lamb starter diets were investigated on performance, chewing behavior, nutrient digestibility, and blood energy parameters. Thirty Ghezel lambs (body weight of 5.3 ± 0.5 kg) from 2 to 65 days of age were assigned to 3 starter feeds: 1) with no fiber source [NF, 16.3 % neutral detergent fiber (NDF), 48.7% starch], 2) containing 7 % wheat straw (WS, 20.5 % NDF, 43.7% starch), and 3) containing 15 % beet pulp (BP, 19.7 % NDF, 39.1 % starch). Lambs were free to suckle their dams until d 30 and were then pair-housed and allowed to suckle at night until weaning on d 45 of age. Lambs had free access to starter creep feeds during pre- and postweaning periods. The results showed that offering both fiber sources improved starter intake by 15%. Feeding BP decreased total tract dry matter (DM) digestibility from 77.6 to 70.1%, but NDF digestibility was similar across the treatments. Postweaning body weight (27.5 kg), average daily gain (341 g/d), and postweaning feed efficiency (0.41) were not affected by the treatments. Further, dietary treatments did not affect serum concentrations of cholesterol, total protein, albumin, and globulin, but WS inclusion increased triacylglycerol, glucose, and beta-hydroxybutyrate concentrations. Eating (221 vs. 174 min) and ruminating (383 vs. 278 min) activities were also greater in lambs on WS as compared with lambs on NF or BP. These results indicated that decreasing starch content in the starter with the inclusion of a fiber source, in particular WS, did not negatively affect the growth performance, but appeared to be associated with better chewing activity and rumen metabolic development.

Keywords: suckling lamb, rumen development, wheat straw, beet pulp

Introduction

At birth, the reticulorumen is essentially non-functional and forms 25 to 35 % of the total stomach mass (Van Soest, 1994). Early starter feeding is not only critical for rumen development and successful weaning, but also improves the daily gain, and provides milk for commercial dairy farming (Alcock, 2006; Liu et al., 2016). In intensive production systems (without grazing), feeding starter creep rations based on starch source can stimulate ruminal microbial proliferation yielding short chain fatty acids (SCFA) especially propionate and butyrate (Cavini et al., 2015; Yáñez-Ruiz et al., 2015; Khan et al., 2016). These acids subsequently have positive effects on ruminal epithelial development which is characterized by the differentiation and growth of papillae and their metabolic activities (SCFA transport and metabolism, and pH regulation) (Cavini et al., 2015; Liu et al., 2016). However, high-starch diets often reduce ruminal pH and microbial diversity, decrease rumen motility, lead to parakeratosis, and can compromise gastrointestinal function (Kay et al., 1969; Khan et al., 2016). In extensive systems, lambs remain with their dams and milk and grazing fresh forages supply the main portion of the nutrients required for the animal growth and health. Evidence exists in the literature that provision of forage in the starter feed stimulates muscular development of rumen and its motility, maintains epithelial health, promotes rumination behavior, and helps in maturation of the salivary glands in pre-ruminants (Khan et al., 2016). However, there is controversy with respect to forage provision in the starter as forage intake shifts the rumen fermentation in favor of acetate and thus may delay the development of ruminal papillae (Baldwin, 1999; Maktabi et al., 2016; Khan et al., 2016; Soltani et al., 2017). More importantly, the low neutral detergent fiber (NDF) digestion rate of forage in the rumen during the pre-weaning period increases the gut fill, thus reducing voluntary intake of the more energy-dense starter feed (Drackley, 2008). This may explain why feeding hay reduces the starter fed intake (Norouzian et al., 2011; Maktabi et al., 2016) or digestibility (Mojahedi et al., 2018). As a forage alternative, the more digestible non-forage fiber sources are retained for shorter duration in the rumen and are less filling especially for animals with fill-limited intake (Kalscheur, 2017). For example, beet pulp is high in digestible soluble fiber (pectins) and insoluble fiber (cellulose and hemicellulose with low lignin content), that can be extensively used by ruminal microbes (Van Soest, 1994). In addition, beet pulp has been traditionally recommended to replace cereal grains to decrease dietary starch level which may increase fiber digestibility (Firkins, 1997). The substitution also provides more butyrate, which can be a metabolic fuel stimulating ruminal development and therefore improving the animal performance (Maktabi et al., 2016). The aim of the present study was to investigate the potential benefits of partially replacing starch source (grains) with a forage (wheat straw) or non-forage (beet pulp) fiber source in the starter on rumen and blood parameters, chewing activity, nutrient digestibility, and performance of young Ghezel lambs.

Materials and methods

Lambs, diets, and management

According to the Ethics Committee rules, sampling, caring, and handling of the animals were confirmed by the Research Affairs of the Isfahan of University of Technology, Isfahan, Iran. The study was conducted at

Table 1. Ingredients (%) of the starter creep feeds containing no fiber sources (NF), or supplemented with 7 % wheat straw (WS) or 15% beet pulp (BP)

	Fiber sources		
Item	NF	WS	BP
Wheat straw	-	7.0	-
Beet pulp, shredded	-	-	15.0
Corn grain, cracked	37.0	33.0	29.4
Barley grain, cracked	37.5	33.0	29.4
Soybean meal	22.5	23.7	23.1
Calcium carbonate	1.7	1.5	1.3
Sodium bicarbonate	1.0	1.0	1.0
Premix (vitamins and minerals)[1]	0.4	0.4	0.4
Salt	0.4	0.4	0.4

[1]Contained per kg: 1,300,000 IU vitamin A, 360,000 IU vitamin D, 12,000 IU vitamin E, 16 g Zn, 10 g Mn, 0.8 g Fe, 3 g S, 120 mg Co, 1.25 g Cu, 150 mg I, and 80 mg Se.

Bano Amin, a 2000-sheep commercial farm (Varzaneh, Isfahan, Iran) in autumn 2016. A total of 30 single-raised Ghezel lambs (1-2 d old; 5.3 ± 0.5 kg of BW; 12 males and 18 females) were used in this study. Lambs were blocked by sex and then allocated randomly to 3 starter diets containing: no additional fiber source (NF), or the diets in which the grain sources (corn and barley) were partially substituted with 7% wheat straw (WS), or 15% beet pulp (BP). These levels of WS and BP were chosen for provision of similar NDF concentrations (~20%; Tables 1 and 2). The starter diets contained approximately 17.5 % crude protein. However, the replacement of cereal grains in the WS and BP starters reduced starch and ME contents, but increased NDF and physically effective NDF concentrations (Table 2). The dietary content of starch was the lowest in BP, while that of physically effect NDF was the highest in WS. Starter diets were similar in terms of their geometric mean particle size. Until d 30, ewes and their lambs were penned in 6 groups (5 ewes/pen) and lambs had free access to their dams. After that, lambs were separated from their dams and housed in pens containing 2 lambs per pen, being allowed to remain with their dams overnight (20:00 to 08:00) after milking at 16:00. Lambs were weaned on d 45 but remained in the study until d 65 of age.

Data and sample collection

Lambs were allowed *ad libitum* access to the starter diets which were fed twice daily at 08:00 and 16:00. The amount of feed and orts were measured daily for estimation of feed intake on the basis of 5 lambs per groups up to d 30, after which the feed intake was determined daily on a pair-lamb basis. Lambs were weighed

Table 2. Chemical composition and physical characteristics of the starter creep feeds containing no additional fiber sources (NF), or 7% wheat straw (WS) or 15% beet pulp (BP)

	Fiber sources		
Item	NF	WS	BP
Chemical composition (% DM, unless otherwise stated)			
Dry matter (% as-fed)	89.0	89.2	89.3
Crude protein	17.5	17.5	17.8
Neutral detergent fiber	16.3	20.5	19.7
Acid detergent fiber	5.48	9.3	8.9
Non-fiber carbohydrate	58.9	54.7	55.8
Starch	48.7	43.7	39.1
Ca	0.84	0.79	0.82
P	0.45	0.44	0.42
Estimated metabolizable energy (Mcal/kg DM[1])	3.0	2.9	2.9
Physical characteristics			
Particle size distribution (mm pore size, %)			
6.35	0.84	1.04	0.46
4.75	0.69	0.71	0.63
2.36	24.8	23.4	18.3
1.18	34.3	34.6	31.3
0.60	21.6	20.5	27.2
0.30	13.6	15.2	17.1
Pan	3.52	4.51	4.51
Mean particle size (mm)	1.35	1.30	1.15
Physically effective neutral detergent fiber[2]	9.5	12.7	10.4

[1]Based on NRC (2007).

[2]Physically effective neutral detergent fiber = neutral detergent fiber multiplied by DM >1.18 mm (Mertens, 1997).

every 2 wk throughout the study to estimate the average daily gain (ADG). Fecal samples were obtained on d 58, 60 and 62 every 9 h to determine total tract DM, CP, and NDF digestibility. On d 53 of the study, jugular blood samples were collected in evacuated tubes (5 mL) 3 h after the morning feeding. Blood samples were centrifuged at 1500 × g for 20 min, and serum samples stored at −20°C until subsequent analysis. Lambs were visually monitored for 24 h on d 61 at 5-min intervals to record the time spent ruminating, eating and resting. Each activity was assumed to persist for the entire 5-min interval. Total chewing time represented the sum of the time spent eating and ruminating in 24 h.

Physicochemical analyses

Feeds, orts, and fecal samples were ground to pass a 1-mm screen in a Wiley mill (Ogaw Seiki Co., Ltd., Tokyo, Japan) and analyzed (AOAC, 1990) for dry matter (DM; method 934.01), CP (method 920.87), and ash (method 924.05). The method of Van Soest et al. (1991) was used to determine aNDF with heat stable alpha amylase in the absence of sodium sulfite and expressed including the residual ash. Total tract digestibility of DM, CP, and NDF, ADF was measured using acid insoluble ash (AIA) as an internal marker (Van Keulen and Young, 1977) based on the relative amounts of these nutrients and of AIA in the starter feeds, orts, and feces. The particle size distribution and geometric mean diameter of the starter diets were determined using the US Standard Sieve Series (numbers 1 to 5) with openings of 4.75, 2.36, 1.18, 0.60, and 0.30 as well as the pan (number 6). Serum levels of glucose, total cholesterol, triacylglycerol, albumin, total protein, and urea nitrogen (BUN) were measured using commercial kits (Parsazemun Co. Lts., Karaj, Iran). Globulin was calculated by subtracting albumin form total proteins. Concentration of β-hydroxybutyrate (BHB) was determined as indicated in the kit (Randox Laboratories Ltd., Ardmore, UK).

Statistical analysis

The data were analyzed using the MIXED procedure (version 8, SAS Institute Inc., Cary, NC) as a completely randomized design. Lamb within treatment was included as a random effect in the model. Time was modeled as a repeated measurement for the starter intake, total intake, ADG, and feed efficiency from d 2 to 45 (preweaning), d 46 to 65 (postweaning), and d 2 to 65 (overall period). Pen feed intake (n=5) was used to estimate the individual feed intake per head before d 30. The initial BW was used as the covariate. The statistical model was $Y_{ijklm} = \mu + P_i + T_j + P\times T_{ij} + L_{kij} + S_l + \beta l(Cov)_m + e_{ijklm}$; where, Y_{ijklm} = observation or the dependent variable, μ = the overall mean, P_i = the effect of period *i*, T_j = the effect of treatment *j*, $P\times T_{ij}$ = the effect of the interaction between period *i* and treatment *j*, L_{kij} = lambs random effect, S_i = the effect of sex *i*, βl = regression coefficient of observations on birth weight as a covariate, and e_{ijklm} = random residual effect. Contrast statements were used to determine the effects of fiber supplementation (NF vs. WS, NF vs. BP, and WS vs. BP). Treatment differences were declared at $P \leq 0.05$, with trends towards significance at $P \leq 0.10$.

Results

Performance and nutrient digestibility

Starter feed intake, BW, ADG, and total tract nutrient digestibility are presented in Table 3. Before weaning, starter intake tended to be greater in lambs fed WS (*P* = 0.10) and BP (*P* = 0.14) than lambs fed NF. The source of fiber in the starter feed increased (*P* = 0.001) the feed intake after weaning (d 46-65) and over the whole duration of the experiment (d 2-65). There were no differences in BW (weaning and d 65), ADG (preweaning and postweaning), and feed efficiency (postweaning) between dietary treatments. The apparent total tract digestibility of DM and CP decreased (*P*= 0.03) by inclusion of BP, while that of NDF was similar across treatments.

Blood parameters

The mean values for serum cholesterol, albumin, globulin, and total protein remained the same across treatments (Table 4). Concentrations of serum glucose (*P* = 0.08), triacylglycerol (P = 0.09), and BHB (*P* = 0.01) were higher in lambs offered WS than in those offered NF diets. Moreover, BHB concentration tended to be higher (*P* = 0.09) in lambs receiving BP than in those receiving NF. Concentration of BUN was lower in lambs on WS (*P* = 0.01) and BP (*P* = 0.06) compared with the NF diet.

Chewing behavior

Total eating, ruminating, lying, and chewing times are reported in Table 5. No differences were observed in chewing activity between NF and BP treatments. Lambs receiving WS spent more time eating (*P* = 0.02), ruminating (*P* = 0.003), and total chewing (*P* = 0.001) than those receiving NF. Furthermore, lambs fed WS had greater ruminating (*P* = 0.001) and total chewing (min/d; *P* = 0.004), total chewing activity as a function of intake (min/g DM intake; *P* = 0.07) than lambs fed BP. Total chewing activity, when expressed as a function of physically effective NDF intake, was similar across treatments.

Discussion

Consumption of high starch diets can decrease ruminal pH which may adversely affect the feed intake and per-

Table 3. Starter intake, body weight, average daily gain, feed efficiency, and total tract digestibility in lambs fed starter creep feeds containing no additional fiber sources (NF), or 7% wheat straw (WS) or 15% beet pulp (BP)

Item	Fiber sources			SEM	Contrast P-value		
	NF	WS	BP		NF vs. WS	NF vs. BP	BP vs. WS
Starter intake (g/d)							
Pre-weaning (d 2-45)	190	232	229	1.75	0.10	0.14	0.90
Post-weaning (d 46-65)	758	868	871	2.09	0.001	0.001	0.91
Total period (2-65)	515	595	596	1.58	0.001	0.001	0.98
Body weight (kg)							
Birth	5.32	5.35	5.24	0.163	0.90	0.72	0.63
Weaning (d 45)	20.3	21.3	20.9	0.467	0.12	0.37	0.52
Postweaning (d 65)	26.7	28.4	27.6	0.713	0.12	0.41	0.48
Average daily gain (g/d)							
Pre-weaning (d 2-45)	333	357	344	1.13	0.14	0.51	0.43
Post-weaning (d 46-65)	324	352	338	2.51	0.43	0.72	0.68
Total period (d 2-65)	329	355	341	1.40	0.20	0.56	0.49
Feed efficiency (kg ADG per kg dry matter intake)							
Post-weaning (d 46-65)	0.43	0.41	0.39	0.033	0.63	0.39	0.69
Total tract digestibility (%)							
Dry matter	77.6	72.3	70.1	1.79	0.12	0.03	0.23
Crude protein	66.6	65.5	57.8	2.39	0.56	0.03	0.04
Neutral detergent fiber	34.6	37.5	36.7	4.49	0.46	0.85	0.51

Table 4. Blood parameters in lambs fed starter creep feeds containing no additional fiber sources (NF), or 7% wheat straw (WS) or 15% beet pulp (BP)

Item	Fiber sources			SEM	Contrast P-value		
	NF	WS	BP		NF vs. WS	NF vs. BP	BP vs. WS
Glucose (mg/dL)	90.1	97.1	84.7	2.73	0.08	0.18	0.004
Beta-hydroxybutyrate (mM)	0.279	0.466	0.409	0.051	0.01	0.09	0.45
Cholesterol (mg/dL)	37.5	39.4	35.6	2.56	0.60	0.60	0.31
Triacylglycerol (mg/dL)	26.7	29.6	21.2	2.15	0.35	0.09	0.01
Urea nitrogen (mg/dL)	29.8	24.4	25.7	1.43	0.01	0.06	0.55
Total protein (g/dL)	5.62	5.50	5.48	0.067	0.22	0.16	0.82
Albumin (g/dL)	3.33	3.37	3.32	0.050	0.57	0.91	0.52
Globulin (g/dL)	2.29	2.13	2.16	0.073	0.13	0.21	0.81

Table 5. Behavior of lambs fed starter creep feeds containing no additional fiber sources (NF), or 7% wheat straw (WS) or 15% beet pulp (BP)

Item	Fiber sources			SEM	Contrast P-value		
	NF	WS	BP		NF vs. WS	NF vs. BP	BP vs. WS
Eating, min	160	211	188	13.9	0.02	0.20	0.28
Ruminating, min	289	383	268	20.7	0.003	0.50	0.001
Laying, min	989	845	984	28.9	0.02	0.89	0.004
Total chewing, min	450	595	456	30.8	0.001	0.88	0.004
Total chewing, min/g DM intake	5.28	5.98	4.80	0.419	0.24	0.45	0.07
Total chewing, min/g peNDF intake	55.6	47.2	46.2	3.85	0.13	0.12	0.86

formance (Khan et al., 2016). Therefore, we hypothesized that reducing starch or increasing fiber contents in the lamb starter feed would stabilize the ruminal environment, and thereby improve its feed intake and performance. Numerous researchers have reported that forage intake increased the ruminal pH in pre-ruminant animals (Maktabi et al., 2016; Soltani et al., 2017; Mojahedi et al., 2018). Moreover, provision of forage in the starter diet has been shown to improve the chewing activity (Maktabi et al., 2016). In the current study, lambs fed WS spent 32% more time eating and ruminating per day compared to lambs on NF starter. Nevertheless, increasing the dietary NDF level (~20% DM) with BP inclusion by the same amount as WS failed to increase the ruminating and eating times. Similar to our results, an increase in chewing activities was reported by Maktabi et al. (2013) in young calves when chopped alfalfa hay, but not BP, was included in the starter diet. It is clear that the coarse fiber portion of the feed is effective in stimulating the chewing activity and salivary buffer production resulting in higher ruminal pH (Kononoff, 2005). Terré et al. (2013) concluded that physical form (i.e. physically effective NDF) of the starter diet is more important than the total NDF content to initiate rumination and to maintain normal ruminal fermentation. The concentration and ruminal fermentability of starch can also affect the ruminal fermentation (Khan et al., 2008). In the current study, inclusion of both fiber sources increased the starter intake by 15% before weaning. There are contradictory reports in the literature on the relationship between forage level in the diet and starter intake. Starter intake by newborn lambs was not affected when it was supplemented with 10% alfalfa hay (Kazemi et al., 2017), or reduced with 7.5 or 15% alfalfa hay (Norouzian et al., 2011). This discrepancy might be caused by differences in forage types and levels. Castells et al. (2012) reported that feeding chopped grass hay or barley straw improved total dry feed intake and ADG, but no benefits were observed when alfalfa hay was supplemented in the diet. Increasing the starch intake or fermentability increases the concentrations of propionate which might reduce feed intake since it has been suggested to play an important role in feed intake regulation by affecting satiety and hunger (Oba and Allen, 2003). Feeding BP instead of grain has been shown to reduce the concentration of propionate or increase the acetate to propionate ratio (Maktabi et al., 2016). Therefore, the greater starter consumption by lambs fed BP compared to NF in the present study may be due to lower starch intake, and thus concentration of propionate or glucose.

Despite increased starter intake due to feeding the starters containing the fiber sources, we did not detect any significant treatment effects on the growth performance. The provision of fiber source in starters did not affect the weaning and post-weaning BW, thus feed efficiency was not altered by the treatments. The data obtained from the current study are in line with those reported in forage-fed lambs (Norouzian et al. 2011; Soltani et al., 2017). To the best our knowledge, no data are available regarding the effect of non-forage fiber (BP) provision in starter diets on the performance of pre-weaning lambs. Dennis et al. (2018) reported that replacing corn with BP (0, 15, and 30%) in high-concentrate diets of weaned dairy calves reduced ADG largely through reducing the diet digestibility and increased dietary NDF and ADF contents. In our work, total tract DM and CP digestibilities were significantly (BP) or numerically (WS) decreased in lambs fed fiber sources while there was no effect on NDF digestibility. This may explain the absence of differences in BW, ADG and feed efficiency between treatments despite the differences in feed intake. Our results are consistent with previous studies reporting that increasing the starch intake enhanced quaratically the DM and CP digestibility and decreased linearly that of NDF digestion (Kalscheur, 2017). The mean apparent digestibility of starch is almost twice that of fiber fractions (Vranić et al., 2017; Dennis et al., 2018). As a result, replacing the more highly digestible starch with fiber sources could reduce the overall diet digestibility. On the other hand, replacing starch with non-fiber forage sources can increase fiber digestibility as a result of a decrease in negative associative effects (Firkins, 1997). Likewise, a greater digestibility value for lambs on WS compared to those on BP may be to the physical fiber characteristics of the fiber as forages provide longer particles than other feed ingredients, which form a rumen mat that entraps smaller particles, thus increasing their digestibility.

Lambs fed WS showed higher serum BHB and glucose concentrations compared with the lambs on the NF starter. Supplementation of the starter with BP also tended to increased BHB concentrations which is usually an indicator of rumen metabolic development in young calves (Quigley et al., 1991). Increasing BHBA concentrations with ageing in calves indicate a shift in the sources of physiological fuel during transition from liquid to solid diets. The higher BHBA (WS and BP) and glucose (WS) levels observed in lambs feeding on the starters containing fiber sources are likely due to increased starter intake (Quigley et al., 1991). Concentration of BUN decreased as a results of forage and non-forage fiber supplementation. BUN concentration showed a positive linear relationship with renal dysfunction, CP intake and its ruminal degradability, and resultant ruminal ammonia concentration in cattle (Broderick and Clayton, 1997). Improved ruminal environment or function may have resulted in greater ammonia utilization and thus lower concentrations of ruminal ammonia and BUN in lambs fed on the diets supplemented with a fiber source.

Conclusions

Feeding a fiber rich starter to young lambs was beneficial as it improved rumen development and function. Reducing starch content of the starter by providing either forage (7% WS) or non-forage (15% BP) fiber tended to increase the ruminal pH and starter intake. Although lamb performance (daily gain and feed efficiency) was not affected, feeding 7% WS was effective in term of increasing the physically effective NDF and chewing activity and possibly increasing the digestive capacity, without negative effects on nutrient digestibility. Thus, feeding forage NDF by including wheat straw in the lamb starter might be an effective strategy to foster ruminal maturation and activity.

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