

Substituting oat hay or maize silage for portion of alfalfa hay affects growth performance, ruminal fermentation, and nutrient digestibility of weaned calves

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Objective: The impact of forage feeding strategy on growth performance, ruminal fermentation and nutrient digestibility in post-weaning calves was investigated.

Methods: Forty-five female Holstein calves (body weight [BW] = 79.79±0.38 kg) were enrolled in the 35-d study at one week after weaning and randomly assigned to one of three dietary treatments. All diets were fed as total mixed ration containing 60% (dry matter [DM] basis) of basal starter feed and 40% (DM basis) of forage, but varied in composition of forage source including i) alfalfa (40% DM, AH); ii) alfalfa hay (26.7% DM)+oat hay (13.3% DM; OH); iii) alfalfa hay (26.7% DM)+corn silage (13.3% DM; WS).

Results: Dry matter intake was not different among treatment groups ($p>0.05$). However, BW ($p<0.05$) and average daily gain ($p<0.05$) of calves fed AH and OH were greater than WS-fed calves, whereas heart girth was greater in OH-fed calves than those fed AH and WS ($p<0.05$). Ruminal fermentation parameters including proportion of butyric acid, acetated-to-propionate ratio, concentration of total volatile fatty acid, protozoal protein, bacterial protein, and microbial protein in rumen were the highest in OH ($p<0.05$) and the lowest in WS. Compared with the AH and WS, feeding oat hay to postweaning calves increased crude protein digestibility ($p<0.05$), and decreased duration of diarrhea ($p<0.05$) and fecal index ($p<0.05$).

Conclusion: Our results suggested that partially replacing alfalfa hay with oat hay improved ruminal fermentation, nitrogen utilization, and reduced incidence of diarrhea in post-weaning dairy calves.

Keywords: Diarrhea; Forage; Ruminal Development; Serum Metabolism; Weaned Calf

INTRODUCTION

Consumption of solid feed is critical to drive the maturation of functioning rumen in weaning dairy calves. Feeding forage to young dairy calves has been shown to stimulate rumination, promote musculature, and expansion of rumen volume [1,2], and reduce the keratinization of rumen papillae [3]. In addition, high-quality forage supplementation enhanced epithelial development in both rumen and lower gut (e.g. jejunum) [4], increased intestinal villus height [5] and intestinal mucosa area in lambs [6]. Alfalfa hay has been conventionally used in supplementation of grain starters to feed early post-weaning dairy calves in China. However, owing to high protein content of alfalfa hay, this feeding practice is associated with reduced nitrogen utilization, increased nitrogen output to environment, and even trophic diarrhea [7]. There is a lack of literature that investigated the impact of forage feeding strategies on rumen development and growth performance of post-weaning calves. Oat hay has greater contents of neutral detergent fiber (NDF) and pectin than alfalfa hay, whereas corn

silage contains higher level of starch which may improve microbial protein yield by providing more readily fermentable carbohydrate. In current study, we evaluated the effect of combined use of different forage sources on nutrient utilization and rumen fermentation of postweaning dairy calves. We hypothesize that partially replacing alfalfa hay with oat hay or corn silage may improve dietary protein efficiency and rumen fermentation and reduce the incidence of diarrhea.

MATERIALS AND METHODS

The study was conducted in National Dairy Industry and Technology System Sanyuan Farm (Beijing, China). The experimental protocol was performed in accordance with the practices outlined in the Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching [8].

Animals, treatments and management

Forty-five female Holstein calves (body weight [BW] = 79.79±0.38 kg) that were weaned at 60 d of age were enrolled in the study at one week after weaning and randomly assigned to one of three dietary treatments with five replicates of three calves for each kind of diet. All diets were fed as total mixed ration that contained 60.0% (dry matter [DM] basis) of texturized starter feed (36.3% pellet starter feed+23.7% flaked corn) and 40% of forage, but differed in forage composition including i) 40.0% alfalfa hay (AH); ii) 26.7% alfalfa hay+13.3% oat hay (OH); iii) 26.7% alfalfa hay+ 13.3% corn silage (WS) (Table 1). Alfalfa hay and oat hay were chopped to 2.5 cm, and the DM content of corn silage was 28%. Total mixed ration was delivered once daily at 0800 for *ad libitum* intake. Calves were kept in pens bedded with straws and had free access to water. Bedding was replenished and replaced every 1 or 2 d as required. The study lasted 35 days.

Sample collection, measurements and analysis

Growth performance and body measurement: Feed intake of each experimental group was recorded daily. The BW and body configuration including wither height (WH), heart girth (HG), body length (BL) [9], and cannon bone circumference (CC) [10] were measured before and after the experimental period, increment of body frame during the experimental days were calculated.

Digestibility: Nutrient digestibility was performed in five calves of each group during the last five days of the study. Feed offered and refusals from each calf were sampled daily. Total feces was collected, weighed daily and composited for each calf. Daily composite fresh feces were preserved in 1:10 diluted hydrochloric acid (100 mL concentrate hydrochloric acid per liter solution) for analysis of fecal nitrogen. Composite feed, refusal and fecal samples were stored at -20°C until analyses. These samples were dried in forced air oven at 65°C for 48 h,

Table 1. Chemical composition of the total mixed ration

Composition	Treatment ¹⁾		
	AH	OH	WS
Ingredient (% DM)			
Alfalfa hay	40.0	26.7	26.7
Oat hay	-	13.3	-
Maize silage	-	-	13.3
Flaked corn	23.7	23.7	23.7
Pellet	36.3	36.3	36.3
Pellet (% of DM)			
Corn	3.2	3.2	3.2
Wheat middling and reddog	2.4	2.4	2.4
Soybean meal	14.9	14.9	14.9
Wheat bran	2.1	2.1	2.1
DDGS	5.5	5.5	5.5
Extruded soybean	2.1	2.1	2.1
Extruded corn	1.8	1.8	1.8
Cottonseed meal	1.8	1.8	1.8
Atox ²⁾	0.1	0.1	0.1
4% premix ³⁾	2.4	2.4	2.4
Chemical composition			
DM	91.6	91.8	82.8
NDF (% DM)	34.9	35.7	34.2
ADF (% DM)	20.6	19.7	18.6
CP (% DM)	17.3	15.8	16.1
EE (% DM)	1.61	1.63	1.86
Ca (% DM)	0.93	0.82	0.81
P (% DM)	0.33	0.32	0.32

DM, dry matter; DDGS, dried distillers grains with solubles; NDF, neutral detergent fiber; ADF, acid detergent fiber; CP, crude protein; EE, ether extract.

¹⁾ AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage.

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³⁾ Premix composition: vitamin A 37,000 IU/kg; vitamin D₃, 10,000 IU/kg; vitamin E, 400 IU/kg; Cu, 50 mg/kg; Zn, 300 mg/kg; Mn, 300 mg/kg; Co, 0.5 mg/kg; Se, 1.76 mg/kg; I, 1.7 mg/kg.

air equilibrated and weighed. Dried samples were then finely ground by mortar and pestle to pass through a 1 mm screen and then retained in sealed containers for determination of DM, NDF, and acid detergent fiber (ADF).

The determination of DM, CP, NDF, and ADF were made according to AOAC methods [11]. Feed, orts and feces were dried at 105°C for 48 h in a forced air oven for determination of DM. Samples were analyzed for nitrogen according to Kjeldahl, and thereafter, CP was determined by total nitrogen (N) ×6.25. Contents of NDF and ADF were residual portion after rinsing according to Van Soest (A2000i, ANKOM, New York, USA) [12].

Diarrhea incidence: Incidences of diarrhea was recorded daily during the experimental period. Fecal score was determined using a 4-point scale system as follows: 1 = normal (firm, well-formed), 2 = mild (soft, pudding-like), 3 = moderate (run-

ny, pancake batter), 4 = severe (liquid, splatters), as described by Diaz et al [13] and Zhang [14]. A fecal of 2 and above was considered as diarrhea. Gentamycin sulfate injection were administered to calves only when feces scored 4. Diarrhea incidence, diarrhea frequency and fecal index were calculated as follows [14]:

Diarrhea incidence
= number of calf suffering diarrhea/total calf number×100%

Diarrhea frequency
= Σ (number of calf suffering diarrhea
×days of calf suffering diarrhea)
/(total calf number×experimental days)×100%

Fecal index = total fecal score/total calf number

Ruminal fermentation parameters: Ruminal samples of five calves randomly selected in each group were collected on d 7, d 14, d 21, d 28, and d 35 of experimental period before feeding. All samples were collected from different locations in the rumen using a rubber tube. Samples were filtered through eight layers of cheesecloth, pH was measured immediately by a digital pH meter (PHB-4, Shanghai Hongyi instrument Limited, Shanghai, China). Ten milliliters of filtrate were placed in a freezing tube and stored at -80°C for analysis of protozoal protein (PCP), bacterial protein (BCP), and microbial protein (MCP). Aliquots of filtrate were centrifuged at $3,000\times g$ for 15 min, and the supernatant was stored at -20°C until analyses for volatile fatty acid (VFA) and ammonia-N ($\text{NH}_3\text{-N}$) concentrations.

The PCP, BCP, and MCP were analyzed using a trichloroacetic acid protein precipitation kit with the method described by Wang [15]. One milliliter 25% (wt/vol) metaphosphoric acid was added into five milliliters filtrate to determine VFA concentrations using gas chromatography (Model 7980, Agilent Technology Inc., Santa Clara, CA, USA) [16]. Ammonia-N was determined using a phenol-hypochlorite assay [17].

Blood sample collection and analysis: Blood Samples of ten calves in each group were taken by jugular puncture on d 7, d 14, d 21, and d 35 prior to morning feeding. Samples were centrifuged at $3,500\times g$ for 15 min to harvest serum that was stored at -20°C until analysis. Serum concentration of glucose (GLU), triglycerides (TG), blood urea nitrogen (BUN), β -hydroxybutyrate acid (BHBA), and non-esterified fatty acid (NEFA), were determined using corresponding assay kits from Shandong BioBase Biotechnologies Inc. (Shandong, China) in an automated biochemistry analyzer (Model GF-D200, Rainbow, Shandong, China). Aliquots of plasma Serum were used to measure growth hormone (GH) by radioimmunoassay kits from Beijing Boruijie Technology Development Co. Ltd. (Beijing, China) in an absorbance microplate reader (EXL

800, Bio-tek, Winooski, VT, USA). Serum insulin-like growth factor I (IGF-I) was analyzed using a commercial ELISA kit as described by Hammon et al [18].

Calculations and statistical analysis

The apparent digestibility of DM, CP, NDF, and ADF was calculated using the following equation:

$$\text{Apparent digestibility} = (E1 - E2)/E1$$

Where, E1 = total amount (mg) of the nutrients (DM, CP, NDF, or ADF) ingested by each calf, E2 = total amount (mg) of the corresponding nutrient (DM, CP, NDF, or ADF) in feces collected by each calf.

Data were analyzed using the PROC MIXED procedure of SAS 9.0. The model for BW, body measurement, nutrient digestibility, and diarrhea status was:

$$Y_{ij} = \mu + C_i + TR_j + e_{ij}$$

Where, μ = overall mean; C_i = the effect of calf ($i = 1$ to 15); TR_j = the effect of treatment ($j = 1$ to 3); e_{ij} = random error.

For variables measured repeatedly (e.g. ruminal fermentation parameters and serum metabolite and hormones, we used the model as following:

$$Y_{ij} = \mu + C_i + TR_j + T_k + TRT_{jk} + e_{ijk}$$

Where, μ = overall mean; C_i = the effect of calf ($i = 1$ to 15); TR_j = the main effect of treatment ($j = 1$ to 3); T_k = the main effect of time ($k = 1$ to 5 wk for ruminal fermentation parameters, $k = 1$ to 4 wk for serum metabolites); TRT_{jk} = the interaction of TR and T; e_{ijk} = random error.

Mean separation was performed for variable with significant treatment effect using Duncan's multiple-range test. Significance of difference was declared at $p < 0.05$.

RESULTS

Growth performance

Dry matter intake (DMI) was not different among treatments ($p > 0.05$; Figure 1). Dietary treatment did not affect wither height ($p > 0.05$). Calves in AH and OH had greater average daily gain (ADG) ($p < 0.05$) and cannon bone circumference ($p < 0.05$) than those in WS, whereas calves in OH had greater heart girth ($p < 0.05$) than that in AH and WS. Body length was the greatest in calves of AH ($p < 0.05$) among three groups.

Total tract apparent digestibility and incidence of diarrhea

Total tract apparent digestibility of DM was not affected ($p > 0.05$) by forage feeding plane (Figure 2). Compared with AH

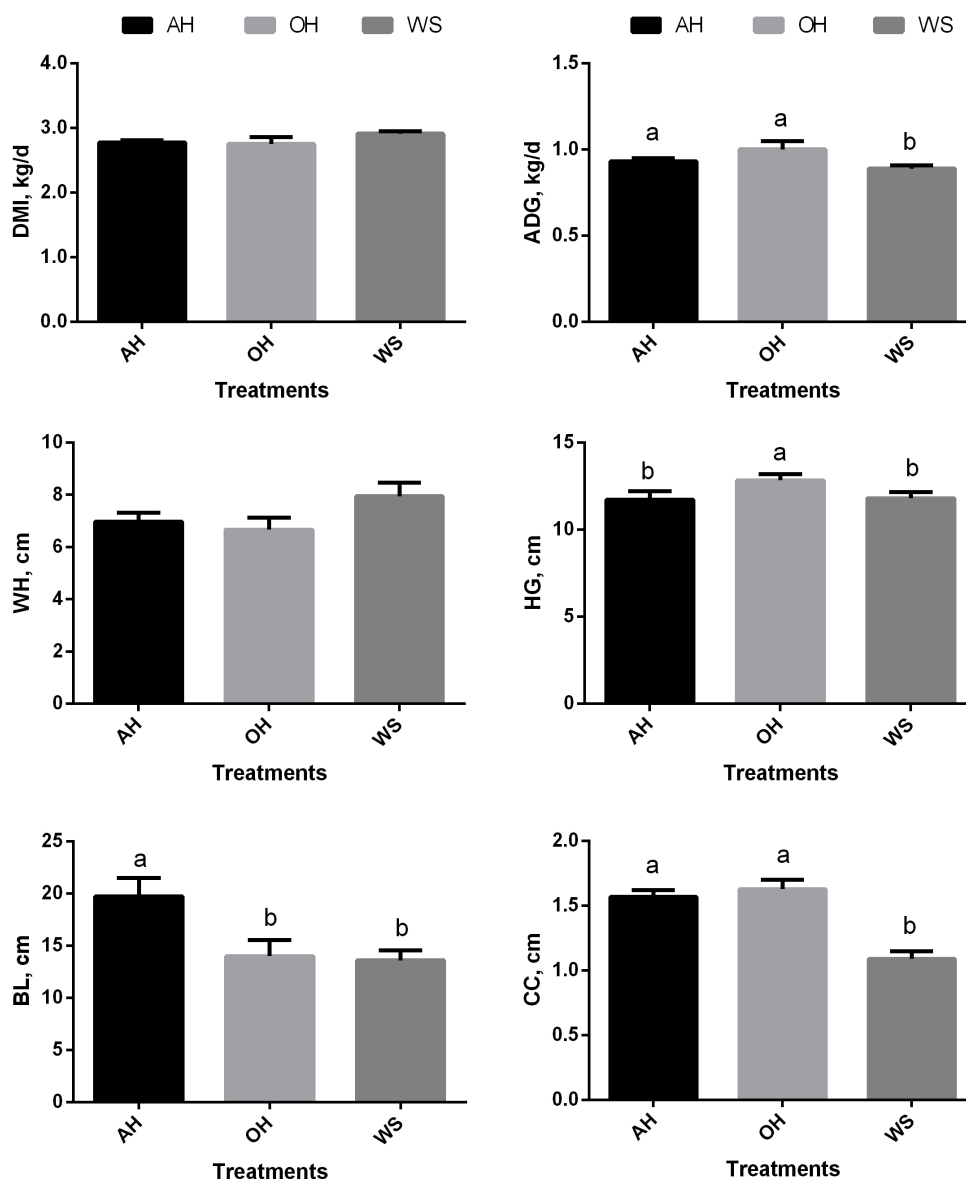


Figure 1. Dry matter intake, average daily gain and increment of body frame of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay. AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage. DMI, dry matter intake; ADG, average daily gain; WH, height at withers; HG, heart girth; BL, body length; CC, cannon bone circumference. ^{a,b} Means within a single figure not sharing a common superscript letter are significantly different ($p < 0.05$). ADG and CC increased ($p < 0.05$) in AH and OH. Also, HG in OH was significantly ($p < 0.05$) higher than AH and WS, however, BL in AH was highest ($p < 0.05$).

and OH, NDF and ADF digestibility was lower in WS ($p < 0.05$). Plane of forage feeding significantly affected CP digestibility ($p < 0.05$), which was the highest in OH followed by AH and the lowest in WS.

Severe diarrhea was observed during the first week (Figure 3). Feeding OH and WS significantly reduced ($p < 0.05$) incidence and frequency of diarrhea, and fecal index from wk 2 to wk 5.

Ruminal fermentation

Ruminal pH and percentage of acetic acid were not affected by

dietary treatment ($p > 0.05$; Table 2). Concentration of ammonia-nitrogen in ruminal fluid was the greatest in AH than the other two treatment groups ($p < 0.05$). Percentage of ruminal butyric acid, total volatile fatty acid (TVFA) concentration, acetate to propionate ratio, and BCP concentration were the highest in OH, intermediate in AH and the lowest in WS ($p < 0.05$; Figure 4). There was significant interaction of treatment by week on TVFA, which was increased in OH after wk1 of the study (Figure 4). Partially replacing alfalfa hay with corn silage decreased ($p < 0.05$) ruminal PCP and MCP.

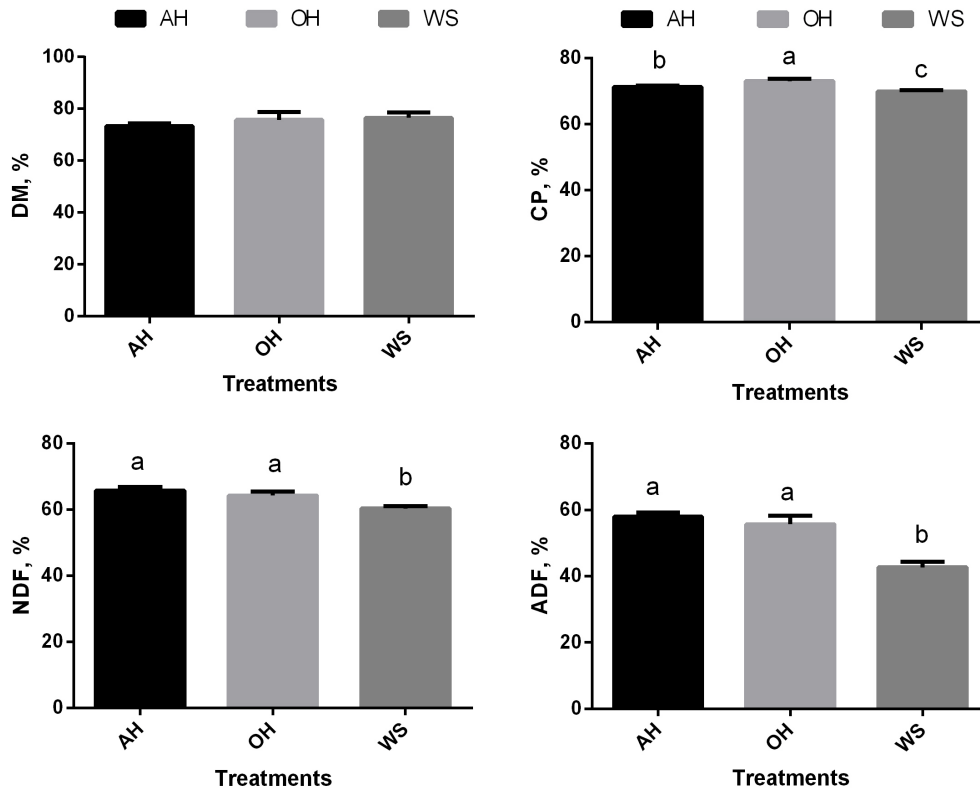


Figure 2. Nutrient digestibility of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay. AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+12.7% alfalfa hay+13.3% maize silage. DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber. ^{a,b} Means within a single figure not sharing a common superscript letter are significantly different ($p < 0.05$). NDF and ADF digestibility in WS decreased ($p < 0.05$). CP digestibility were significantly lower ($p < 0.05$) in AH compared to OH, but higher ($p < 0.05$) than in WS.

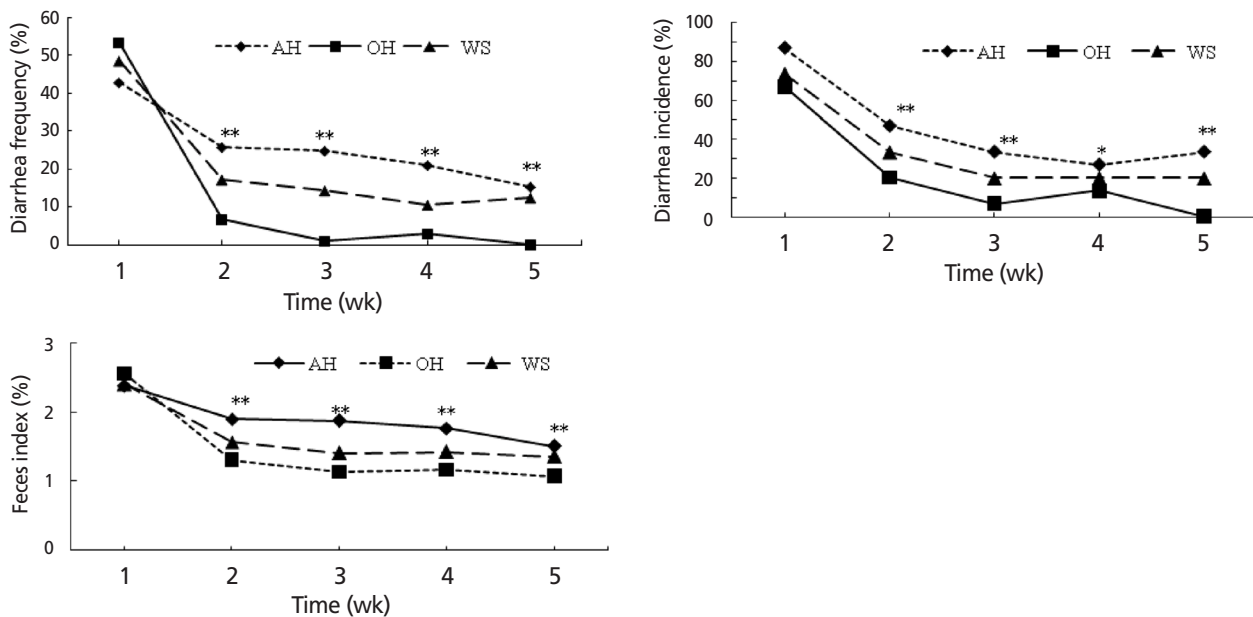


Figure 3. Diarrhea status of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay varied with week. AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage. For each time point, * indicates significance at the 0.05 level and ** indicates significance at the 0.01 level among three treatment groups. Calves expressed severely diarrhea in the first week, forage combination feeding of OH and WS reduced ($p < 0.05$) diarrhea incidence, frequency, and fecal index from the second week.

Table 2. Ruminal fermentation of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay

Items	Treatment ¹⁾			SEM	p-values		
	AH	OH	WS		Treatment	Time	Treatment×time
pH	6.89	6.91	6.95	0.05	0.74	0.72	0.40
NH ₃ -N (mmol/L)	5.58 ^a	5.16 ^b	5.20 ^b	0.10	0.03	0.90	0.10
Acetic acid (%)	64.95	64.99	65.69	0.71	0.71	0.03	0.08
Propionic acid (%)	20.45 ^b	19.55 ^c	21.76 ^a	0.25	<0.01	0.16	0.11
Butyric acid (%)	6.92 ^b	7.38 ^a	4.97 ^c	0.39	<0.01	0.14	0.08
TVFA (mmol/L)	60.97 ^b	64.95 ^a	48.39 ^c	2.26	<0.01	<0.01	<0.01
Acetate-to-propionate ratio	3.18 ^b	3.33 ^a	3.02 ^c	0.06	0.01	0.26	0.92
PCP (mg/mL)	2.35 ^a	2.54 ^a	2.03 ^b	0.08	<0.01	0.85	0.38
BCP (mg/mL)	2.00 ^{ab}	2.08 ^a	1.92 ^b	0.03	0.02	0.99	0.27
MCP (mg/mL)	4.35 ^a	4.62 ^a	3.96 ^b	0.09	<0.01	0.95	0.89

SEM, standard error of the mean; TVFA, total volatile fatty acid; PCP, protozoal protein; BCP, bacterial protein; MCP, microbial protein.

¹⁾ AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage.

^{a,b} Means within a row not sharing a common superscript letter are significantly different ($p < 0.05$).

Serum metabolites and hormones

Plane of forage feeding did not affect serum concentration of GLU, TG, BHBA, NEFA, and IGF-I (Table 3). Serum concentration of BUN was the highest in AH, followed by OH and the lowest in WS ($p < 0.05$). Concentration of GH was higher in OH ($p < 0.05$) than that in AH and WS. There was a significant time effect on serum concentration of GLU, BUN, NEFA, and IGF-I during the study ($p < 0.01$; Figure 5).

Greater fiber content may enhance ruminal peristalsis, increase ruminal passage rate and reversely increase feed intake [19]. Castells et al [20] has reported that feeding chopped grass hay together with pelleted starter increased DMI of young dairy calves. Furthermore, supply a certain amount of forage in calf starter could ameliorate the ruminal environment effectively, and improve daily DMI and feed conversion ratio [21]. To our knowledge, there is a paucity of research with regard to forage feeding strategy in early post-weaning calves. However, in present study, partially replacing alfalfa hay with oat hay or corn silage did not affect DMI of weaned calves, which could be explained by the consistent NDF content of all three diets.

DISCUSSION

Growth performance

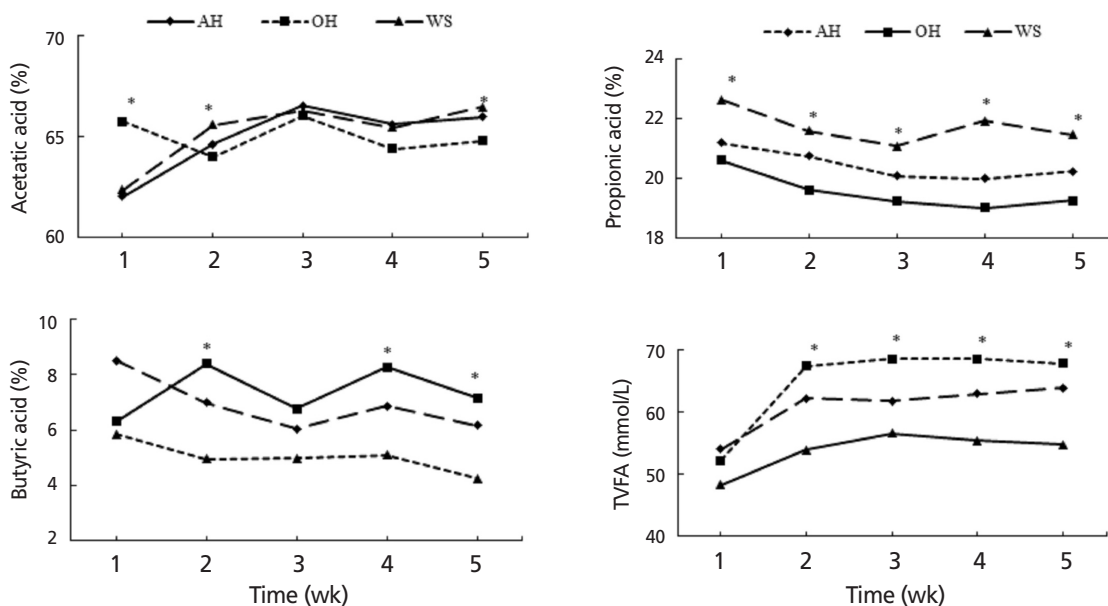


Figure 4. Ruminal volatile fatty acids of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay varied with week. AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage. For each time point, * indicates significance at the 0.05 level among three treatment groups. Proportion of acetic acid and total volatile fatty acid (TVFA) changed following forage supplementation during the experimental procedure ($p < 0.05$).

Table 3. Serum metabolism of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay

Items	Treatment ¹⁾			SEM	p-values		
	AH	OH	WS		Treatment	Time	Treatment×time
GLU (mmol/L)	5.63	5.54	5.67	0.07	0.41	<0.01	0.84
TG (mmol/L)	0.30	0.28	0.28	0.02	0.81	0.31	0.80
BUN (mmol/L)	2.40 ^a	1.94 ^b	1.65 ^c	0.14	0.01	<0.01	0.93
BHBA (mmol/L)	0.85	0.82	0.84	0.06	0.94	0.11	0.98
NEFA (μmol/mL)	99.89	93.93	92.20	6.42	0.69	<0.01	0.44
GH (ng/mL)	1.65 ^b	1.72 ^a	1.63 ^b	0.01	<0.01	0.95	0.17
IGF-I (ng/mL)	246.39	250.49	243.19	5.63	0.67	<0.01	0.33

SEM, standard error of the mean; GLU, glucose; TG, triglycerides; BUN, blood urea nitrogen; BHBA, β-hydroxybutyrate acid; NEFA, non-esterified fatty acid; GH, growth hormone; IGF-I, insulin-like growth factor I.

¹⁾ AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage.

^{a,b} Means within a row not sharing a common superscript letter are significantly different ($p < 0.05$).

The optimal ADG of weaned calves should be maintained at 0.82 to 0.93 kg/d [22], which has been achieved by all three treatments in current study. Stobo et al [23] suggested that forage feeding may improve BW gain through stimulation of gastrointestinal tract development of calves. Live BW was highly related to skeletal configuration, such as heart girth [24]. Cows with larger structural dimensions usually also had larger rumen capacities [25], in our study, larger HG was observed in OH group that had the greatest ADG, suggesting a better rumen development.

Nutrient digestibility and diarrhea

In our study, both DMI and digestibility were not affected by plane of forage feeding. Dietary NDF and ADF could provide substrate and energy for rumen fermentation [26]. Oat hay supplementation balanced the nitrogen content in diet, which could significantly increase nitrogen deposition of calves [27]. However, high organic acid, especially lactic acid, content in corn silage might limit the activity and reproduction of rumen microbes [28], consequently decreased nutrient digestibility. Digestibility of NDF and ADF mirrored ADG of calves. Calves in WS groups apparently displayed a lower HG, BL, and CC

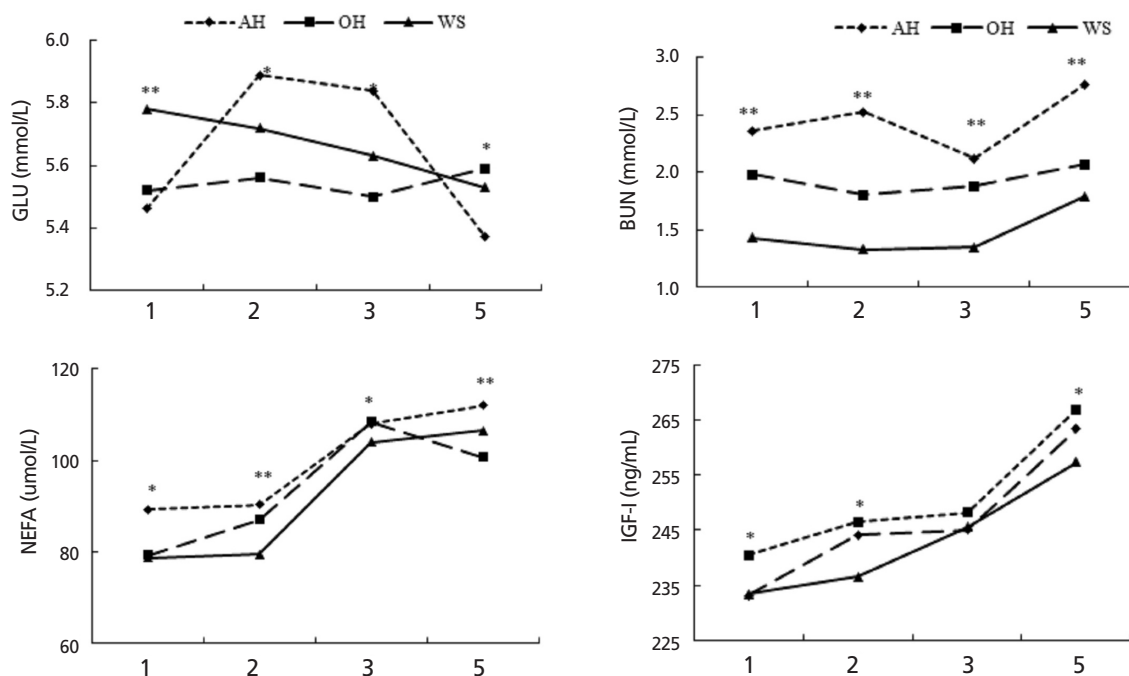


Figure 5. Serum metabolism of weaned calves feeding oat hay or maize silage substituting for portion of alfalfa hay varied with week. AH, 36.3% pellet starter feed+23.7% flaked corn+40.0% alfalfa hay; OH, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% oat hay; WS, 36.3% pellet starter feed+23.7% flaked corn+26.7% alfalfa hay+13.3% maize silage. For each time point, * indicates significance at the 0.05 level and ** indicates significance at the 0.01 level among three treatment groups. During the experimental procedure, concentrations of glucose (GLU), blood urea nitrogen (BUN), non-esterified fatty acid (NEFA), and insulin-like growth factor I (IGF-I) varied significantly following forage supplementation ($p < 0.05$).

values.

Calves experienced severe diarrhea during the first week of the study, which probably because of weaning stress and dietary change (Figure 1). Owing to high protein content of alfalfa hay, the higher protein content of AH diet exceeds the protein requirement of weaned calves [29] and potentially contributed to tropic diarrhea as observed for high incidence of diarrhea in AH group. Replacing alfalfa hay with oat hay diluted dietary protein content and led to increased protein digestion, BW gain, and less environmental nitrogen output.

Ruminal fermentation

The ruminal pH of all treatments groups fell into normal range of weaned calves [30]. VFA is the primary energy substrates for ruminant [31], of which butyric acid is the main energy source for the ruminal epithelial cells growth [32]. Previous research [33,34] suggested that feeding alfalfa and oat hay increased acetic acid and butyric acid production in rumen, and enhanced the development of ruminal papilla. Our study is in agreement with previous studies that proportion of butyric acid was higher in OH and AH group. The higher proportion of propionic acid in WS may result from higher starch content of corn silage [31,35].

Microbial protein contributes 60% to 70% of protein requirement of ruminant [36]. Many dietary factors may affect microbial protein yield, such as synchronized degradation of carbohydrate and protein, diet ruminal retention time, and ruminal pH. Owing to higher NDF content, using oat hay to partially replace alfalfa hay may increase ruminal retention time of the diet, which increased dietary CP digestibility, enhanced recycle of ruminal $\text{NH}_3\text{-N}$ and MCP production and improved dietary N utilization. Our result is in consistent with previous study [37]. It is not unexpected that MCP was also higher in AH than that in WS because of high protein content of alfalfa hay. The higher ruminal $\text{NH}_3\text{-N}$ may due to greater rapidly degraded protein, particularly the higher content of A and B protein fractions in AH than that in OH and WS [29].

Serum metabolites

Although feeding corn silage increased ruminal propionate concentration, the primary precursor of hepatic gluconeogenesis, plane of forage feeding did not affect blood GLU concentration. Most butyric acid is absorbed and metabolized in ruminal epithelial cells with the production of BHBA. Serum BHBA and TG concentration could be altered by ruminal VFA profile [38]. However, in current study, feeding oat hay increased ruminal butyric acid proportion without affecting serum BHBA concentration.

Previous study reported that ADG of heifers positively correlated with GH [39], which supported our results that feeding oat hay increased both serum GH and ADG in post-weaning calves.

The BUN as well as milk urea nitrogen typically mirrors the change of ruminal $\text{NH}_3\text{-N}$ and serves as an indicator of MP balance and dietary protein efficiency in lactating cows [40,41]. The higher BUN level in AH-fed calves agreed with greater ruminal $\text{NH}_3\text{-N}$ content, indicating the lower dietary N efficiency. However, partially replacing alfalfa hay with oat hay improved dietary N utilization and maintained growth performance in comparison with feeding alfalfa alone.

CONCLUSION

In comparison with conventional feeding practice (starter diet with alfalfa hay alone), our data suggest feeding mixed forage of alfalfa and oat hay with starter diet represent a better feeding strategy in postweaning dairy calves by improving dietary N efficiency and growth performance.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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