Associative Effects of Roughage on Nutrient Apparent Digestibility in Sibu Yaks (Postprint)

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Abstract

This experiment aimed to investigate the associative effects of feeding three roughages (oat hay, corn silage, and alfalfa, with the alfalfa proportion held constant at 10% and the corn silage + oat hay proportion held constant at 60%) to Sibu yaks, and to determine the apparent digestibility of nutrients in different dietary combinations to screen for suitable combination diets for Sibu yaks. Thirty dry-period Sibu yaks with similar body weight were selected and randomly divided into 5 groups, with 2 replicates per group and 3 yaks per replicate, to conduct a digestion trial. Five experimental diets were formulated with the following compositions: Group , 60% oat hay + 10% alfalfa + 30% concentrate; Group , 45% oat hay + 15% corn silage + 10% alfalfa + 30% concentrate; Group , 30% oat hay + 30% corn silage + 10% alfalfa + 30% concentrate; Group , 15% oat hay + 45% corn silage + 10% alfalfa + 30% concentrate; Group , 60% corn silage + 10% alfalfa + 30% concentrate. The results showed that Group had the highest feed intake and total weight gain, and the lowest feed-to-gain ratio. The apparent digestibility of crude protein and crude ash in Groups , , and was significantly higher than that in Groups and ($P<0.05$); the apparent digestibility of neutral detergent fiber in Group was significantly higher than that in Groups , , and ($P<0.05$); the apparent digestibility of acid detergent fiber in Group was significantly higher than that in all other groups ($P<0.05$); the apparent digestibility of calcium in Groups and was significantly higher than that in Group ($P<0.05$); the apparent digestibility of total phosphorus in Group was significantly higher than that in Groups and ($P<0.05$). Using the proportion of corn silage as the independent variable (X) and the apparent digestibility of crude protein and neutral detergent fiber as dependent variables (Y) to fit models, cubic equations were obtained, with strong correlations between the independent and dependent variables, and correlation coefficients (R^2) of 0.987 and 0.937, respectively. It was concluded that mixed feeding of oat hay and corn silage had associative effects on the apparent digestibility of nutrients in Sibu yaks. When the proportion of corn

silage was 30% and oat hay was 30%, the feed-to-gain ratio, weight gain, and apparent digestibility of various nutrients in the diet of Sibu yaks achieved better results, particularly for protein and fiber utilization.

Full Text

Impact of Roughage Combination Effect on Nutrient Apparent Digestibility of Sibu Yak

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Abstract: This experiment investigated the combination effects of three roughages (oat hay, silage corn, and alfalfa, with alfalfa fixed at 10% and oat+silage corn fixed at 60%) on nutrient apparent digestibility in Sibu yak to identify optimal dietary combinations. Thirty dry-period Sibu yaks of similar body weight were randomly allocated to five groups with two replicates per group and three yaks per replicate for a digestion trial. Five experimental diets were formulated: Group I, 60% oat + 10% alfalfa + 30% concentrate; Group II, 45% oat + 15% silage corn + 10% alfalfa + 30% concentrate; Group III, 30% oat + 30% silage corn + 10% alfalfa + 30% concentrate; Group IV, 15% oat + 45% silage corn + 10% alfalfa + 30% concentrate; Group V, 60% silage corn + 10% alfalfa + 30% concentrate. Results showed that Group III achieved the highest feed intake and total weight gain with the lowest feed-to-gain ratio. Groups I, II, and III exhibited significantly higher apparent digestibility of crude protein and crude ash than Groups IV and V ($P<0.05$). Group IV showed significantly higher neutral detergent fiber apparent digestibility than Groups I, II, and III ($P<0.05$). Group III demonstrated significantly higher acid detergent fiber apparent digestibility than all other groups ($P<0.05$). Calcium apparent digestibility in Groups I and II was significantly higher than in Group V ($P<0.05$), while total phosphorus apparent digestibility in Group IV was significantly higher than in Groups II and V ($P<0.05$). Using silage corn proportion as the independent variable (X) and crude protein or neutral detergent fiber apparent digestibility as dependent variables (Y), cubic equations were fitted showing strong correlations with R^2 values of 0.987 and 0.937, respectively. In conclusion, mixed feeding of oat hay and silage corn exerts combination effects on nutrient apparent digestibility in Sibu yak. When silage corn and oat each comprise 30% of the diet, Sibu yak achieve optimal feed-to-gain ratio, weight gain, and nutrient apparent digestibility, particularly for protein and fiber utilization.

Keywords: Sibu yak; digestion experiment; apparent digestibility; combination effect

Sibu yak possess advantages including strong cold resistance, robust constitution, good meat quality, and suitability for grazing with extensive management. However, their high carcass fat percentage, thick hide, underdeveloped hindquarter muscles, and slow weight gain constrain market development. Deng et al. [**?**] investigated Sibu yak body measurements and weight, finding that breed characteristics and related production performance indicators are degenerating. Another study by Deng et al. [**?**] on age and sex distribution revealed severe imbalances in age structure, sex ratio, and production structure, with low economic trait indices rooted in nutritional deficiency. Supplementing grazing female yak with simple dry hay during late pregnancy can reduce weight loss during cold seasons and improve calf birth weight, survival rate, and daily gain [**?**, **?**]. Low dietary nutrient levels, unreasonable feed structure, and poor management remain primary factors restricting yak industry development in Tibet. Therefore, feed formulation technology is fundamental to addressing these root causes, as reasonable concentrate input and roughage ratios potentially benefit rumen environment optimization and milk fat maintenance. However, conventional animal diet formulation assumes additive nutritional values without considering interaction effects between feeds or nutritional measures. Research increasingly shows that aggregated properties of feed components cannot explain higher-level system behavior [**?**]. This study aimed to identify optimal dietary ratios with positive combination effects for Sibu yak, measure nutrient apparent digestibility across different ratios, and improve nutritional status, weight gain rate, and farming economic benefits.

1.1 Experimental Materials

Oat, alfalfa, silage corn, and concentrate were purchased from Lhasa Hebeqi Co., Ltd.

1.2 Experimental Period and Location

The experiment was conducted in September 2016 at the Qunipa Yak Experimental Base in Lhasa, Tibet.

1.3 Experimental Animals

Thirty dry-period Sibu yaks aged 3–5 years with body weights of 180–220 kg were selected from the Qunipa Yak Experimental Base in Tibet.

1.4 Experimental Design

Thirty dry-period Sibu yaks of similar weight were randomly divided into five groups with two replicates per group and three yaks per replicate for a digestion trial. Five experimental diets with different roughage combinations were formulated using three roughages (oat, alfalfa, silage corn) at a constant concentrate-

to-roughage ratio of 7:3. Diet compositions are shown in Table 1 . Except for silage corn, all ingredient proportions in Table 1 are expressed on a dry matter basis. Diets were fed as total mixed rations. Oat and alfalfa were unprocessed dry hay. Concentrate composition is presented in Table 2 , and dietary nutrient levels are shown in Table 3 . The experiment consisted of a 15-day preliminary period followed by a 15-day formal trial period (30 days total). Body weight was measured once before morning feeding at the beginning and end of the formal trial. Daily feed offered and refused were recorded, and fecal samples were collected and weighed using the total collection method.

1.5 Animal Management

All experimental yaks were housed in pens with *ad libitum* access to feed and water. Before the trial, yaks were numbered, ear-tagged, vaccinated, and dewormed. Sanitation and disinfection procedures followed standard farm protocols, with weekly pen disinfection and daily manure removal.

1.6 Measurement Methods and Calculations

Diet and fecal samples were analyzed for conventional nutrient contents. Crude ash was determined according to GB/T 6438-2007, crude protein by semi-micro Kjeldahl method (GB/T 6432-1994), neutral and acid detergent fiber by GB/T 6434-1994, total phosphorus by GB/T 6437-2002, and calcium by EDTA disodium titration. Gross energy was measured using bomb calorimetry via complete oxidation combustion, with detailed analytical methods referenced from literature [**?**]. Nutrient apparent digestibility was calculated as:

Apparent digestibility of nutrient (%) = 100 × [nutrient intake (g) -fecal nutrient (g)] / nutrient intake (g).

1.7 Calculation of Combination Effect

Combination effect refers to interactions among nutrients in mixed diets that improve (positive) or reduce (negative) feed intake or utilization efficiency [**?**]. Calculation followed the method of Zhang et al. [**?**]:

Combination effect value = 100 × (measured value -weighted estimated value) / weighted estimated value.

Where measured value is the actual apparent digestibility of a nutrient, and weighted estimated value = measured value of Feed A × proportion of Feed A + measured value of Feed B × proportion of Feed B.

This experiment aimed to investigate combination effects between oat and silage corn under current feeding conditions, ignoring effects involving concentrate, alfalfa, and other ingredients. Let A represent oat and B represent silage corn; concentrate and alfalfa proportions were constant at 30% and 10%, respectively,

with their digestibility represented by constant *a*. The measured apparent digestibility values for Groups I and V (as single-feed measurements) can be expressed as: Group I measured value = A × 60% + *a*; Group V measured value = B × 60% + *a*.

Accordingly, weighted estimated values for Groups II ( ), III ( ), and IV ( ) are: = × 0.75 + × 0.25; = × 0.5 + × 0.5; = × 0.25 + × 0.75. Substituting measured and weighted estimated values into the combination effect formula yields combination effect values for each group.

1.8 Correlation Analysis

Using silage corn proportion as the independent variable (X) and crude protein apparent digestibility (or neutral detergent fiber apparent digestibility) as the dependent variable (Y), seven model equations were fitted: linear, quadratic, cubic, composite, growth, exponential, and logistic. Correlation coefficients (R^2) were calculated to identify the most suitable model.

1.9 Data Processing and Analysis

Data are expressed as mean ± standard deviation. SPSS 21.0 software was used for statistical analysis and modeling. One-way ANOVA was performed using the ANOVA procedure in SPSS 21.0. Differences were considered significant at $P<0.05$, with Duncan' s multiple comparison test applied for post-hoc analysis.

2.1 Feed Intake and Weight Gain

As shown in Table 4 , feed intake and dry fecal weight in Groups II and V were significantly higher than in Groups I, III, and IV ($P<0.05$), with no significant difference between Groups II and V ($P>0.05$). Group III had the lowest feed-to-gain ratio at 7.36, significantly lower than all other groups ($P<0.05$), followed by Group V at 9.19, which was significantly lower than Groups I, II, and IV ($P<0.05$). Total body weight gain was lowest in Group I (1.86 kg), significantly lower than Groups II (2.47 kg), III (2.75 kg), IV (2.44 kg), and V (2.32 kg) ($P<0.05$), while Group V was significantly lower than Group III ($P<0.05$).

2.2 Nutrient Apparent Digestibility

Table 5 shows that crude protein apparent digestibility in Groups I, II, and III was significantly higher than in Groups IV and V ($P<0.05$). Neutral detergent fiber apparent digestibility was lowest in Group II (16.85%), significantly lower than all other groups ($P<0.05$), and highest in Group IV (29.05%), significantly higher than Groups I, II, and III ($P<0.05$). Acid detergent fiber apparent digestibility was highest in Group III (18.53%), significantly higher than all other groups ($P<0.05$). Crude ash apparent digestibility in Groups I, II, and III was significantly higher than in Groups IV and V ($P<0.05$). Calcium apparent digestibility was lowest in Group V (70.29%), significantly lower than Groups I

and II ($P<0.05$). Total phosphorus apparent digestibility was highest in Group IV (81.39%), significantly higher than Groups II and V ($P<0.05$).

2.3 Combination Effects of Oat and Silage Corn Proportions on Nutrient Apparent Digestibility

Table 6 reveals that combination effect values for nutrient apparent digestibility among the three oat-to-silage corn ratios were all significantly different ($P<0.05$). The combination effect value for crude protein apparent digestibility decreased with increasing silage corn proportion, while values for neutral detergent fiber and total phosphorus apparent digestibility increased. Values for acid detergent fiber and crude ash apparent digestibility initially increased then decreased, while calcium apparent digestibility values first decreased then increased with rising silage corn proportion. The comprehensive combination effect value reached maximum when oat and silage corn each comprised 30% of the diet.

2.4 Correlation Analysis of Oat and Silage Corn Proportions with Crude Protein and Neutral Detergent Fiber Apparent Digestibility

Based on experimental results of different oat-to-silage corn ratios, silage corn proportion was used as the independent variable (X) and crude protein apparent digestibility as the dependent variable (Y) to fit models. Among seven different models (Table 7), the cubic equation showed the highest R^2 value: $Y = 39.079 + 0.854X - 0.044X^2 + 0.000447X^3$ ($R^2 = 0.987$) (X and Y units: %), representing the most suitable correlation model. This indicates crude protein apparent digestibility peaks when silage corn proportion is 10–20% and oat proportion is 40–50% (with silage corn + oat fixed at 60% of diet).

Using the same approach with silage corn proportion as X and neutral detergent fiber apparent digestibility as Y yielded the equation $Y = 25.582 - 1.18X + 0.053X^2 - 0.001X^3$ ($R^2 = 0.937$). Neutral detergent fiber apparent digestibility peaked at 50% silage corn and 10% oat, while a secondary peak occurred at 15% silage corn and 45% oat.

3.1 Impact of Oat and Silage Corn Proportions on Feed Intake and Weight Gain

Results showed Group II had the lowest feed intake (4.62 kg/d) during the digestion trial. However, Group III demonstrated the best feed conversion efficiency at 12.88% from a feed-saving perspective. For total weight gain, Groups II (2.47 kg) and III (2.75 kg) were significantly higher than Group I (1.86 kg). All groups showed satisfactory weight gains, consistent with findings that concentrate supplementation improves production performance in growing yak [**?**, **?**, **?**].

3.2 Impact of Oat and Silage Corn Proportions on Nutrient Apparent Digestibility

Crude protein apparent digestibility in Groups I, II, and III (39.25%, 42.87%, and 38.42%, respectively) exceeded that of Groups IV (28.97%) and V (29.56%). Conversely, fiber apparent digestibility (acid and neutral detergent fiber) was higher in Groups IV and V than in Groups I, II, and III. Digestible energy was highest in Group III (12.29 MJ/kg). As silage corn gradually replaced oat, crude protein apparent digestibility was inversely related to crude fiber apparent digestibility. This may occur because silage corn microflora promotes fiber utilization, while microbial proliferation synthesizes bacterial protein or amine metabolites that supplement protein requirements, reducing dietary protein dependency and consequently lowering apparent protein digestibility.

3.3 Impact of Oat and Silage Corn Proportions on Combination Effects

Crude protein apparent digestibility peaked at 10–20% silage corn and 40–50% oat, while neutral detergent fiber apparent digestibility peaked at 50% silage corn and 10% oat. However, Group III (30% oat + 30% silage corn) showed superior overall performance, likely because silage corn enhances ruminal neutral detergent fiber utilization while reducing dietary protein dependency, creating a positive combination effect [**?**]. Shi [**?**] demonstrated significant positive combination effects between crude protein and neutral detergent fiber in dairy cow diets. Yuan et al. [**?**] and Sun et al. [**?**] reported favorable combination effects between silage corn and various roughages (soybean straw, peanut vine, and Leymus chinensis) using in vitro rumen fermentation methods.

Model fitting and correlation analysis confirmed combination effects between silage corn and oat on crude protein and neutral detergent fiber apparent digestibility in Sibu yak. To balance crude protein and neutral detergent fiber digestibility, the optimal proportions are 30% silage corn and 30% oat, validating Group III' s superior feed-to-gain ratio, weight gain, and nutrient apparent digestibility, particularly for protein and fiber.

Overall, silage corn and oat combinations exhibit positive combination effects. This simple combination study suggests that more precise ratios or mixed silage of oat and whole-plant corn may yield better results, as Guo et al. [**?**] found that oat-to-whole-plant corn silage at a 3:7 mass ratio produced lower acid detergent fiber and higher crude protein and nitrogen-free extract content with greater nutritional value.

4 Conclusion

Mixed feeding of oat hay and silage corn exerts combination effects on nutrient apparent digestibility in Sibu yak. When silage corn and oat each constitute 30% of the diet, dry-period Sibu yak achieve optimal feed-to-gain ratio, weight gain, and nutrient apparent digestibility, particularly for protein and fiber utilization.

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Note: Figure translations are in progress. See original paper for figures.