



Original Research Article

Growth performance, nutrient digestibility, and slaughter traits of male fattening lambs under different feeding standards

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ABSTRACT

This study compared the growth performance, nutrient utilization, and slaughter traits of Dorper crossbred male lambs fed as per the established nutrition recommendations for sheep, with an aim to verify the efficacy of different feeding standards. A total of 576 lambs (4 months of age, 28.3 ± 0.86 kg BW) were randomly allotted to 3 treatments with 12 replicates per treatment (16 lambs per replicate). The lambs were fed diets formulated according to the following 3 nutritional systems: the nutrient requirements of Dorper crossbred lambs established by Chinese Academy of Agricultural Sciences (CAAS), NRC (National Research Council), (2007), and AFRC (Agricultural and Food Research Council) (1993). The experiment lasted for 81 d. Feed intake was recorded every 3 days, and lambs were weighed every 20 days. Digestibility trials were conducted with 6 lambs each group from d 42 to 53 and d 70 to 81. At the end of the experiment, 10 lambs randomly chosen from each group were sacrificed to determine the carcass traits and meat quality. The results indicated that the lambs in the NRC group had the highest dry matter intake (DMI), followed by those in the AFRC and CAAS groups ($P < 0.05$). The average daily gain, carcass weight, and dressing percentage were higher for lambs in the CAAS group than those in the NRC group ($P < 0.05$). The lambs in the CAAS group had the lowest feed conversion ratio, followed by those in the AFRC and NRC groups ($P < 0.05$). The apparent digestibility of DM was higher for the lambs in the CAAS group than those in the NRC group ($P < 0.05$). Water losing rate, as well as the lightness (L^*), redness (a^*), and yellowness (b^*) values of the *longissimus thoracis* were not different among groups ($P > 0.05$). In conclusion, Dorper crossbred lambs fed diets formulated according to the CAAS recommendations exhibited superior growth performance than those fed diets formulated according to the American or British feeding standards.

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1. Introduction

Feeding standards play an important role in improving animal performance and reducing feed cost, which accounts for 50% to 70%

of the total cost in the livestock production industry (Verbeke et al., 2015). In developed countries such as United States (NRC (National Research Council), 2007) and United Kingdom (AFRC (Agricultural and Food Research Council), 1993), feeding standards for sheep have already been established. China has a long history of sheep production and was the global leader in both sheep population and meat production in 2014 (FAO, 2015). The Dorper × thin-tailed Han crossbred sheep, a dual-purpose breed (Du, 2011) with good meat yield (Cloete et al., 2000), is one of the most important sheep breeds for lamb production in China. Recently, the energy and protein requirements of Dorper × thin-tailed Han crossbred sheep were reported (Deng et al., 2012, 2014; Xu et al., 2015; Ma et al., 2015). However, little is known regarding the efficacy of those

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requirements in intensive production system. Furthermore, there is limited study in terms of the comparison between different feeding regimes proposed by different countries.

Therefore, the current study was therefore conducted to compare the growth performance, nutrient utilization, slaughter performance, and meat quality of Dorper × thin-tailed Han crossbred lambs fed diets formulated according to the feeding standards proposed by Chinese Academy of Agricultural Sciences (CAAS), AFRC (Agricultural and Food Research Council) (1993) and the NRC (National Research Council), 2007. The current study aimed not only to verify the efficacy proposed by CAAS, but also to examine if the recommendations from AFRC (Agricultural and Food Research Council) (1993) and NRC (National Research Council), 2007 were suitable for the growth of Dorper × thin-tailed Han crossbred lambs under current feeding regimes.

2. Materials and methods

This study was conducted at the Experimental Station in Bayannur of Inner Mongolia Autonomous Region, China, from September to December 2015. The minimum and maximum temperatures observed during the experimental period were -29°C and -10°C , respectively, and the average humidity was 31%. The experimental procedures were approved by the Animal Ethics Committee of CAAS, and humane animal care and handling procedures were followed throughout the study.

2.1. Animals and diets

Five hundred and seventy-six Dorper × thin-tailed Han crossbred ram lambs (28.3 ± 0.86 kg BW) were randomly divided into 3 treatment groups. Each treatment group contained 12 replicates with 16 lambs in each replicate. Three total mixed rations (TMR) were formulated to achieve an average daily gain (ADG) of 250 g according to the following 3 feeding standards: the nutrient requirements of sheep proposed by CAAS based on the study by Deng

et al. (2012), Deng et al. (2014), Xu et al. (2015), and Ma et al. (2015), NRC (National Research Council), 2007, and AFRC (Agricultural and Food Research Council) (1993); the formulas are shown in Table 1. The lambs were fed twice daily at 04:00 and 16:00 and allowed 10% of orts. Clean water was available *ad libitum* throughout the experiment. The experimental period was 95 days, including 14 days of adaptation, and the amount of feed offered was adjusted every 3 days.

2.2. Measurements and sample collection

Lambs of each replicate were weighed on d 0, 20, 40, 60, and 80 of the trial to calculate the ADG based on the slope of BW against time and the feed conversation ratio. Six lambs with similar BW were chosen from each treatment group and used in 2 digestibility trials from d 42 to 53 and from d 70 to 81. The duration of each digestibility trial was 12 days, including 7 days of adaption and 5 days of total collection of feces and urine. In the digestibility trial, feces were collected daily for 5 continuous days. A sub-sample of 10% of the total fecal output was collected and pooled for each animal, dried at 65°C , and ground through a 1-mm sieve for analysis. Samples of feed and orts were collected daily, combined, dried at 65°C for 72 h, and ground through a 1-mm sieve. Urine from each lamb was also collected daily in a bucket containing 100 mL of 3.6 mol/L H_2SO_4 . The volume was measured and then diluted to 5 L using tap water, and a sample of 20 mL was collected, pooled for each animal, and stored at -20°C for analyzing the total nitrogen (N).

At the end of the experiment, 10 lambs from each treatment were slaughtered to determine slaughter traits and meat quality. The feed and orts were sampled daily and frozen at -20°C until analyses. The lambs were sacrificed by inhalation of CO_2 (99.99%; Beijing AP BAIF Gases Industry Co. Ltd., Beijing, China) through a canine anesthesia mask connected to a gas cylinder equipped with a flow controller followed by exsanguination using conventional humane procedures, and hot carcass weight was recorded.

Table 1

Ingredients and chemical composition of the total mixed diets formulated based on the standard established by Chinese Academy of Agriculture Sciences (CAAS), National Research Council (NRC) standards (2007), and Agricultural and Food Research Council (AFRC) standards (1993).

Item	CAAS		NRC		AFRC	
	30 to 40 kg	40 to 50 kg	30 to 40 kg	40 to 50 kg	30 to 40 kg	40 to 50 kg
Ingredients, as fed						
Cracked corn grain	30.0	40.0	30.0	30.0	30.0	30.0
Bran	2.00	2.00	2.00	2.00	2.00	2.00
Soybean meal	5.00	7.50	0.00	2.50	5.00	5.00
Greaves	7.50	5.00	5.00	2.50	5.00	2.50
Silage	13.0	10.0	13.0	10.0	13.0	10.0
Corn germ	5.00	5.00	5.00	5.00	5.00	5.00
Chinese wild rye hay	34.5	27.5	42.0	45.0	37.0	42.5
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Calcium carbonate	0.90	0.90	0.90	0.90	0.90	0.90
Dicalcium phosphate	0.60	0.60	0.60	0.60	0.60	0.60
Mineral/vitamin premix ¹	1.00	1.00	1.00	1.00	1.00	1.00
Chemical composition						
ME ² , MJ/kg DM	7.80	7.70	8.60	8.00	10.4	11.5
DM, % as fed	90.9	89.3	91.8	91.2	91.2	91.5
MP ³ , g/kg DM	88.8	96.6	92.0	94.4	94.4	97.6
EE, %DM	1.97	1.97	1.94	2.04	2.04	2.18
Ash, %DM	6.24	6.32	6.58	6.54	6.54	6.01
NDF, %DM	48.4	53.7	55.7	53.6	53.6	58.9
ADF, %DM	22.0	22.0	24.9	24.5	24.5	24.2
Ca, %DM	0.73	0.67	0.77	0.62	0.62	0.68
P, %DM	0.44	0.42	0.41	0.36	0.36	0.37

ME = metabolizable energy; DM = dry matter; MP = metabolizable protein; CP = crude protein; EE = ether extract; NDF = neutral detergent fiber; ADF = acid detergent fiber.

¹ Manufactured by Precision Animal Nutrition Research Centre, Beijing, China. The premix contained (per kg): 22.1 g Fe, 13.0 g Cu, 30.2 g Mn, 77.2 g Zn, 19.2 g Se, 53.5 g I, 9.10 g Co, 56.0 g vitamin A, 18.0 g vitamin D3, and 170 g vitamin E. The same as below.

² ME (CAAS) = $\text{GE} \times 0.47$ (Deng et al., 2012; Xu et al., 2015); ME (NRC) = $\text{GE} \times 0.5$ (NRC, 2007); ME (AFRC) = $\text{GE} \times 0.69$ (AFRC (1993)).

³ MP (CAAS) = $0.27 \times \text{CP intake (CPI)} + 49.88$ (Ma et al., 2015); MP (NRC) = $0.7 \times \text{CP}$ (NRC, 2007); MP (AFRC) = $0.7 \times \text{CP}$ (AFRC (1993)).

Meat quality were measured using the right side of each carcass. At the sixth rib, the muscle pH was measured using a pH meter (PB-10, Sartorius, Beijing, China) equipped with a penetrating electrode. Immediately after 1 h of blooming, instrumental color (L^* [lightness], a^* [redness], and b^* [yellowness]) (CIE, 1986) readings were taken in the *longissimus thoracis* muscle at the 13th rib using a chroma meter (C-2002, Opto-star, Shanghai, China). The eye muscle area was measured at the 6th rib position by outlining on a transparency and using a planimeter (Areometer MK2, Burwell, Cambridge, UK). Water-holding capacity was measured according to the method described by Grau and Hamm (1953).

2.3. Chemical analysis

Dry matter (DM) was determined by drying feed, Orts, and fecal samples in an air-forced oven at 135 °C for 2 h (method 930.15; AOAC, 1990); the crude ash content was measured by placing the samples into a muffle furnace at 550 °C for 24 h (method 938.08; AOAC, 1990). Gross energy (GE) was measured using a bomb calorimeter (C200, IKA Works Inc., Staufen, Germany). Nitrogen was determined using the Kjeldahl method, using selenium as a catalyst (Marshall and Walker, 1978), and crude protein (CP) was calculated using the formula $6.25 \times N$. The ether extract (EE) was measured by calculating the weight loss of the DM on extraction with diethyl ether using the Soxhlet extraction apparatus for 8 h (method 920.85; AOAC, 1990). Neutral-detergent fiber (NDF) and acid-detergent fiber (ADF) were determined according to the method described by Van Soest et al. (1991) and Goering and Van Soest (1970), respectively.

2.4. Statistical analysis

The data regarding live weight, ADG, feed intake, and nutrient digestibility were analyzed using a completely randomized design with one-way analysis of variance (ANOVA) (version 9.2, SAS Institute Inc., Cary, NC, USA). Duncan's method for multiple comparisons was used for variables where the treatment effect was significant ($P < 0.05$).

3. Results

3.1. Nutrient intake and growth performance

The DM intake (DMI) was higher in the NRC group than in the CAAS group ($P < 0.05$; Table 2); however, no difference was found between the DMI of NRC and AFRC groups ($P > 0.05$). The metabolizable energy (ME) intake of the NRC group was significantly higher than that of the CAAS and AFRC groups ($P < 0.001$), and the metabolizable protein (MP) intake in the CAAS group was higher than that in the NRC and AFRC groups ($P < 0.001$). The lambs from the CAAS group had higher ADG than those from the NRC group ($P = 0.002$); however, the ADG of the CAAS and AFRC groups was not significantly different ($P > 0.05$). The feed conversion ratio was lower in the CAAS group than that in the NRC and AFRC groups ($P < 0.001$).

3.2. Digestibility and metabolizability of energy and protein

The apparent digestibility of DM ($P = 0.006$) and organic matter (OM; $P = 0.006$) of lambs from the CAAS group was significantly higher than that from the NRC and AFRC group from d 42 to 53 (Table 3). The apparent digestibility of CP in the NRC group was significantly higher ($P < 0.05$) than that in the AFRC group; however, no difference was observed between the apparent digestibility of the NRC and CAAS group ($P > 0.05$). The GE intake ($P = 0.125$), fecal energy ($P = 0.142$), and urinary energy ($P = 0.199$) was not

Table 2

Intake of dry matter, metabolizable energy and metabolizable protein, average daily gain, and feed conversion ratio of Dorper \times thin-tailed Han crossbred ram lambs.

Items	Groups			SEM	P-value
	CAAS	NRC	AFRC		
DMI, kg/d	1.20 ^b	1.29 ^a	1.23 ^{ab}	0.02	0.043
MEI, MJ/d	11.8 ^c	12.3 ^a	12.1 ^b	0.06	<0.001
MPI, g/d	118 ^a	100 ^c	113 ^b	2.17	<0.001
ADG, g/d	224 ^a	173 ^b	197 ^a	5.52	0.002
Feed conversion ratio	5.61 ^c	7.68 ^a	6.81 ^b	0.23	<0.001

SEM = standard error of the mean; DMI = dry matter intake; MEI = metabolizable energy intake; MPI = metabolizable protein intake; ADG = average day gain.

^{a,b,c} Mean values within a row with different superscripts differed ($P < 0.05$).

different among groups. However, the DE ($P = 0.008$) content of the CAAS diet was significantly higher than that of the other diets. The apparent digestibility of GE ($P = 0.005$) was higher in the CAAS group than that in the NRC and AFRC group. The N intake of the CAAS group was greater ($P = 0.017$) than that of the NRC group, and the urinary N ($P < 0.05$) and absorbed N ($P < 0.05$) of the CAAS group was significantly higher than that of the other two groups.

From d 70 to 81, the apparent digestibility of DM ($P = 0.016$) and CP ($P = 0.002$) of the CAAS group was significantly higher than that of the NRC and AFRC group. However, the apparent digestibility of OM ($P = 0.009$) was not significantly different among the groups ($P > 0.05$; Table 4). The GE intake ($P = 0.877$), fecal energy ($P = 0.121$), and urinary energy ($P = 0.143$) were not different among the groups; however, the DE ($P = 0.002$) content of the CAAS group was higher than that of the other diet. The apparent digestibility of GE ($P = 0.007$) was higher in the CAAS group than that in the other groups. The N intake ($P = 0.032$), urinary N ($P = 0.010$), absorbed N ($P = 0.002$), and retained N ($P = 0.053$) of the CAAS group were higher than that of the other two groups. No significant difference was found in N intake, absorbed N, and retained N of the CAAS and AFRC group ($P > 0.05$).

The metabolizable protein intake (MPI) was significantly correlated with dietary DM, OM, and GE, and had a significant correlation with apparent N digestibility (Table 5). The MEI was significantly correlated with dietary OM, GE, and ADF. In this study, we found that nutrient digestibility in Dorper \times thin-tailed

Table 3

Apparent digestibility, energy and nitrogen balance of Dorper \times thin-tailed Han crossbred ram lambs from d 41 to 52.

Items	Groups			SEM	P-value
	CAAS	NRC	AFRC		
Apparent digestibility, %					
DM	65.4 ^a	58.5 ^b	61.1 ^b	1.03	0.006
OM	68.2 ^a	61.1 ^b	63.5 ^b	1.08	0.006
CP	59.4 ^{ab}	66.8 ^a	54.3 ^b	2.42	0.095
Energy balance, MJ/kg					
GE intake	22.8	22.0	20.9	0.40	0.125
Fecal energy	8.39	9.73	9.09	0.22	0.142
Urinary energy	0.72	0.68	0.65	0.04	0.199
DE, MJ/kg DM	10.7 ^a	9.79 ^b	9.27 ^b	0.23	0.008
DE/GE	0.64 ^a	0.56 ^b	0.57 ^b	0.01	0.005
Nitrogen balance, g/d					
Intake N	24.1 ^a	22.2 ^b	23.1 ^{ab}	0.31	0.017
Fecal N	9.81	9.90	10.5	0.19	0.273
Urinary N	6.72 ^a	3.96 ^b	4.53 ^b	0.44	0.006
Absorbed N	14.3 ^a	12.3 ^b	12.5 ^b	0.30	0.001
Retained N	7.53	8.30	8.02	0.37	0.732

CAAS = Chinese Academy of Agricultural Sciences; NRC = National Research Council; AFRC = Agricultural and Food Research Council; SEM = standard error of the mean; DM = dry matter; OM = organic matter; CP = crude protein; DE = digestible energy; GE = gross energy.

^{a,b} Mean values within a row with different superscript letters were significantly different ($P < 0.05$).

Han lambs was mainly determined by feed factors, and lamb growth was influenced by the type of feed. Although different feeding standards had different recommendations for energy and protein requirement, the nutrient intake and digestibility of lambs in the CAAS group were higher than those in the NRC and AFRC groups.

3.3. Slaughter performance and meat quality

At the end of the feeding trial, the BW of the lambs in CAAS group was higher than that of NRC and AFRC group ($P < 0.001$). The hot carcass weight was lower in NRC group than that in the other two groups ($P < 0.001$), while no difference was observed in the hot carcass weights between CAAS and AFRC group ($P > 0.05$). The dressing percentage was lower in NRC group than that in CAAS group ($P < 0.001$). No difference in eye muscle areas ($P = 0.200$), GR values ($P = 0.571$), and pH ($P = 0.535$) were observed among groups. The water losing rate of the *longissimus thoracis* muscle ($P = 0.064$) and meat color values of L^* ($P = 0.121$), a^* ($P = 0.476$), and b^* ($P = 0.605$) was unaffected by the treatments.

4. Discussion

4.1. Growth performance

The average DMI of the lambs was 1.24 kg/d in our study, which was similar to that of the Dorper × Santa Inês crossbred sheep (1.2 kg/d) reported in an earlier study (Souza et al., 2013). However, our result was higher than that of Dorper × Brazilian Somali crossbred sheep (0.9 kg/d) reported by Souza et al. (2013), and lower than that of the Dorper × Hu crossbred male lambs (1.4 and 1.33 kg/d) reported by Nie et al. (2015) and Zhang et al. (2015), and Dorper × Hu crossbred female lambs (1.76 kg/d) reported by Zhang et al. (2015). The discrepancy in DMI at similar growth stage could be mainly attributed to the difference in the genotypes and dietary components. The daily DMI scaled to g/kg of survival body weight (SBW) was 71.0, 80.2, and 73.3 for lambs in CAAS, NRC, and AFRC group, respectively, which was within the range reported by Xu et al. (2015) (50.3 to 86.9 g/kg SBW^{0.75}) and Deng et al. (2012) (58.9 to 123.6 g/kg SBW^{0.75}) in Dorper × thin-tailed Han crossbred lambs from 20 to 50 kg of BW. However, the average DMI for the

Table 4

Apparent nutrient digestibility and energy balance of Dorper × thin-tailed Han crossbred ram lambs from d 70 to 81.

Items	Groups			SEM	P-value
	CAAS	NRC	AFRC		
Apparent digestibility, %					
DM	68.1 ^a	59.4 ^b	62.6 ^b	1.35	0.009
OM	70.8 ^a	63.2 ^b	65.2 ^b	1.25	0.016
CP	62.9 ^a	51.6 ^b	60.1 ^a	1.69	0.002
Energy balance, MJ/kg					
GE intake	21.5	21.9	21.1	0.61	0.877
Fecal energy	7.30	9.40	8.90	0.23	0.121
Urinary energy	0.70	0.66	0.69	0.03	0.143
DE, MJ/kg DM	10.4 ^a	8.90 ^b	8.82 ^b	0.25	0.002
DE/GE	0.66 ^a	0.57 ^b	0.58 ^b	0.02	0.007
N balance, g/d					
Intake N	27.9 ^a	23.0 ^b	25.5 ^{ab}	0.82	0.032
Fecal N	10.3	11.1	10.2	0.33	0.528
Urinary N	5.03 ^a	1.95 ^b	2.46 ^b	0.51	0.010
Absorbed N	17.6 ^a	11.9 ^b	15.3 ^a	0.81	0.002
Retained N	12.6 ^a	10.0 ^b	12.8 ^a	0.56	0.053

CAAS = Chinese Academy of Agricultural Sciences; NRC = National Research Council; AFRC = Agricultural and Food Research Council; SEM = standard error of the mean; DM = dry matter; OM = organic matter; CP = crude protein; DE = digestible energy; GE = gross energy; N = nitrogen.

^{a,b} Mean values within a row with different superscripts differed significantly.

Table 5

Correlation coefficient between nutrient intake and digestibility.

Items	DMI, kg/d	OMI, kg/d	CPI, g/d	MPI, g/d	MEI, MJ/d
Apparent digestibility, %					
DM	-0.035	-0.072	0.527**	0.507*	-0.359
OM	-0.069	-0.095	0.479*	0.458*	-0.424*
N	0.148	0.099	0.647**	0.657**	-0.377
GE	0.001	-0.030	0.488*	0.478*	-0.443*
NDF	-0.052	-0.064	0.332	0.291	-0.330
ADF	-0.020	0.043	0.309	0.300	-0.510*

DMI = dry matter intake; OMI = organic matter intake; CPI = crude protein intake; MPI = metabolizable protein intake = MEI, metabolizable energy; DM = dry matter; OM = organic matter; N = nitrogen; GE = gross energy; NDF = neutral detergent fiber; ADF = acid detergent fiber.

* $P < 0.05$; ** $P < 0.01$.

CAAS group in the present study was only comparable to that of sheep fed at 60% of the *ad libitum* intake reported by Xu et al. (2015) and Deng et al. (2012). This could mainly be attributed to the large difference in temperature between day and night in Inner Mongolia during most of the experimental period, as Chen and Jin (1997) reported that a sharp decrease in the temperature may reduce the intake in sheep.

In our study, the DMI linear correlated with the BW of the lambs, and the regression equation was shown as follows: $DMI = 0.471 + 0.024 BW$, $R^2 = 0.68$ ($n = 576$), $P < 0.01$. Previous studies also showed that DMI could be predicted using the BW value. Vieira et al. (2013) predicted the DMI from the BW with a R^2 value of 0.52 in feedlot Santa Ines rams. Similarly, Moorby et al. (2015) reported a linear correlation between the DMI and the BW with a R^2 value of 0.554 using different breeds of sheep in the United Kingdom.

The ADG of the lambs in the current study was 198 g, which was 18% lower than that in pure Dorper sheep (Bunch et al., 2003), 25% lower than that in Dorper × Santa Inês crosses sheep (Souza et al., 2013), but 11% higher than that in Dorper × Brazilian Somali crosses sheep (Souza et al., 2013). The difference in the reported ADG of Dorper sheep may be due to the difference in the genotypes, feeding regime, and dietary components; furthermore, the low temperature in the current study could lead to increased energy requirement for maintenance, and thus decreased ADG.

The lower DMI observed in CAAS group compared with NRC group, as well as the lower MEI observed in CAAS group compared with NRC and AFRC group, could be explained by the difference in energy density of diets formulated according to those two feeding standards. Increasing feed intake could be due to the increase in palatability of the diet with rising energy density (Ebrahimi et al., 2007). Similarly, Mahgoub and Early (2000) also observed a significant increase of MEI with increasing energy density in Omani growing lambs. Along with the higher ADG and improved feed conversion ratio of lambs in CAAS group compared with those in NRC group, it can be suggested that diets formulated according to CAAS feeding standard were more efficiently used by the growing lambs, which had a superior growth performance than those fed diets formulated according to NRC or AFRC standard.

4.2. Apparent nutrient digestibility

The average apparent DM digestibility of the lambs in the current study was 62.5%, which was numerically higher than that reported in Dorper × thin-tailed Han lambs by Deng et al. (2012; 60.8%) and Xu et al. (2015; 60.23%). The apparent DM digestibility of the CAAS group was higher than that of the other groups. This could mainly be attributed to the higher dietary concentrate to forage ratio between the current study (52.5:47.5, 30 to 40 kg BW;

62.5:37.5, 40 to 50 kg BW; CAAS), (45:55, 30 to 50 kg BW; NRC group), (50:50, 30 to 40 kg BW; 47.5:52.5, 40 to 50 kg BW; AFRC group) and the previous study by Deng et al. (2012) (44:56, 35 to 50 kg BW) and Xu et al. (2015) (45:55, 20 to 35 kg BW). The average apparent OM digestibility of the lambs in our study was 65.34% and this value falls within those reported in Dorper crossbred ram lambs by Deng et al. (2012) (68.07%, 35 to 50 kg BW) and Xu et al. (2015) (60.37%, 20 to 35 kg BW).

The average apparent digestibility of CP in our study (59.19%) was lower than that reported in ram lambs (64.10%) (Xu et al., 2015; Deng et al., 2012), but was similar to that reported (59.93%) in Santa Inês × Dorper ram lambs (Sena et al., 2015). The discrepancy in the nutrient digestibility could be explained by the differences in the dietary concentrate to forage ratio in the current study (55:45, 30 to 40 kg BW; 65:35, 40 to 50 kg BW) and in the previous studies by Deng et al. (2012) (44:56, 35 to 50 kg BW) and Xu et al. (2015) (45:55, 20 to 35 kg BW). This could mainly be attributed to the fact that the Dorper × thin-tailed Han lambs in our study had lower DMI than that in previous studies. However, apparent nutrient digestibility of nutrition matter in the low-DMI group was higher than that in the high-DMI group (Xu et al., 2015; Deng et al., 2012; Nie et al., 2015).

The higher DM and OM digestibility of sheep consuming CAAS diet comparing with those consuming NRC or AFRC diet could be explained by the lower NDF contents, and thus higher amount of digestible carbohydrates in the diet formulated according to CAAS feeding standard. Diets formulated according to NRC and AFRC feeding standards contain relatively higher NDF concentration due to the higher concentration of Chinese wild rye hay. Diets with high NDF concentration have a higher rate of passage through the gastrointestinal tract, which could cause a decrease in the digestibility of the DM or OM components (Fimbres et al., 2002).

4.3. Energy and protein metabolism

In the current study, the apparent digestibility (DE/GE) of energy was 0.60, and the DE (10.7 or 10.4 MJ/kg DM) observed in CAAS group was comparable to that in our previous work (averaged 9.38 to 11.1 MJ/kg DM; Deng et al., 2012; Xu et al., 2015). In addition, the DE of the lambs in CAAS group was higher than that of the NRC and AFRC group. The ME intake of the CAAS group lambs was 2.48% and 4.07% lower than that in the AFRC and NRC groups, respectively. Furthermore, the MPI of the CAAS group lambs was 4.24% and 15.25% higher than that of the AFRC and NRC groups, respectively. Although the NRC recommendations play an important role in establishing nutrient requirements for animals, they were mainly based on the minimum nutrient requirement of animals (Lcromwell, 2008). The maintenance requirement of ME (ME_m) of AFRC (Agricultural and Food Research Council) (1993) is lower than calculated values of other standards in sheep with the same weight. In our study, the metabolizability of GE (q_m , 0.47) was calculated according to the results of previous studies by Deng et al. (2012) and Xu et al. (2015), which further verified that the energy requirement of Dorper crossbred lambs was lower than that recommended by the NRC (National Research Council), 2007 and the AFRC (Agricultural and Food Research Council) (1993).

Several feeding standards or feed evaluation systems for sheep and goats based on different mathematical models have been developed by different countries. The NRC (National Research Council), 2007 and the AFRC (Agricultural and Food Research Council) (1993) have formulated appropriate feeding standards that were based on the requirements of the animals in their own country. The NRC (National Research Council), 2007 system used methods described by Cannas et al. (2004) for sheep and goats. The AFRC (Agricultural and Food Research Council) (1993) system was

based on research data from meat and wool breeds of sheep and on dairy breeds of goats. The CAAS was based on data from comparative slaughter trials, digestibility trials, methane production trials, and slaughter trials conducted using the traditional method for the study of nutrient requirement study in Dorper × thin-tailed Han lambs (Xu et al., 2015; Deng et al., 2012, 2014), and the feeding standards for nutrient requirement, including ME and MP for Dorper × thin-tailed Han lambs, were specifically designed for those sheep. Hence, the feeding standard established by CAAS was considered to be most appropriate for the Dorper × thin-tailed Han lambs in our study.

4.4. Slaughter performance and meat quality

The dressing percentage of lambs ranged from 40% to 44.5% in the current study, which was similar to that reported by Xu et al. (2015) (43.3% to 44.5%). Dressing percentage was lower in the NRC group than that in the CAAS group, probably because BW is the most important influencer of dressing percentage (Macedo et al., 1999). In our study, the eye muscle area of the Dorper × thin-tailed Han crossbred ram lambs of the CAAS group was 15.03% higher than that of the Dorper × Brazilian Somali lambs reported in an earlier study (Souza et al., 2013); however, the eye muscle area in the CAAS group was 10% lower than that reported in Dorper × Santa Inês crossbred lambs with similar slaughter weight (Souza et al., 2013). The discrepancy in the eye muscle area at a similar growth stage could be mainly due to the different genotypes and dietary components. The pH values of the *longissimus thoracis* in our study were similar to those reported in earlier studies: pH value 5.86 in the Dorper × Santa Inês (Monaco et al., 2014) and 5.58 in Dorper × thin-tailed Han crossbred ram lambs (Wang et al., 2015).

Although meat color is only slightly correlated with the consumption characteristics (Moore and Young, 1991), it is very important for consumer choice (Priolo et al., 2001). In the current study, no differences were observed among groups in the meat color of the *longissimus thoracis* muscle. Therefore, it can be concluded that different feeding standards for feeding Dorper × thin-tailed Han crossbred ram lambs did not influence meat quality.

5. Conclusion

Under the current experimental conditions, the administration of feed designed as per the nutrient requirements established by the CAAS had significantly better effects in Dorper × thin-tailed Han crossbred ram lambs in terms of growth performance, feed conversion ratio, nutrient utilization, and slaughter performance than the feed formulated as per the NRC or the AFRC. The CAAS feeding standard is more suitable for local, crossbred lambs in China than the NRC or the AFRC feeding standards.

Conflicts of interest

The authors declare no conflicts of interest.

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