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The growth performance and meat quality of goats fed diets based on maize or wheat grain*

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ABSTRACT

A total of 24 four-month-old Liuyang Black wether goats (10±0.2 kg) were allotted to two diets based on wheat and maize to investigate effects of starch sources on the growth performance and meat quality. The experimental period lasted for 100 days, including 10 days for adaptation. Five representative goats from each group were selected for slaughter on the last experimental day. The final body weight and body weight gain of goats in wheat group were lower than those of goats in maize group ($P<0.05$), however, the marbling score of the *Longissimus dorsi* of goats in wheat group was greater than that of goats in maize group ($P<0.05$). Fatty acid composition of *Longissimus dorsi* muscle was also different between wheat group and maize group, for example, the proportion of C14:0 in *Longissimus dorsi* muscle of goats in wheat group was greater than that of goats in maize group ($P<0.05$), and the proportion of C18:3 in *Longissimus dorsi* muscle of goats in wheat group was smaller than that of goats in maize group. Results indicate that growth performance of the goats

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fed the diet based on maize was better and the proportion of 18:3 fatty acids and marbling score of *Longissimus dorsi* muscle was smaller in comparison with the goats fed the diet based on wheat.

KEY WORDS: goat, meat quality, starch sources, growth performance, diet

INTRODUCTION

It is well known that seed structure and chemical composition vary among plant species, and among varieties within species. Starch granules within a seed vary in size, amorphous or crystalline structure, and type of polysaccharide, amylose, or amylopectin (Svihus et al., 2005). The differences in structure and chemical composition would cause different ruminal degradation characteristics of nutrients among plant species, and among varieties within species. The starch from maize and wheat are fermented in different ways in the rumen, the soluble starch (% total starch) of maize and wheat was 26% and 68%, and the potentially degradable starch (% total starch) of maize and wheat was 64% and 32% in the rumen, respectively (Mills et al., 1999). The soluble nitrogen (N) (% crude protein, CP) was 28% and 27%, and the potentially degradable N (% CP) was 65% and 71% for maize and wheat in the rumen, respectively (NRC, 2001). Obviously, the degradation characteristics of starch and N in the rumen differ between wheat and maize.

The degradability and digestibility of dietary starch in the rumen influence not only the extent of microbial fermentation and protein synthesis in the rumen (Ørskov, 1975; Hoover and Stokes, 1991), but also the availability of nutrients in the post ruminal digestive tract (Taniguchi et al., 1995), whole-body nitrogen metabolism and milk yield and composition in ruminant (Khan et al., 2007). The portal-drained viscera (PDV) net fluxes of total free amino acids, glycine, isoleucine, leucine, phenylalanine, proline, serine, threonine, tryptophan and valine were greater in cows fed steam-flaked maize than those of cows fed steam-rolled maize (Tagari et al., 2004). The differences in PDV net fluxes of amino acids of diets based on the various starch sources may be one of main reasons for the differences in whole-body nitrogen metabolism and milk yield and composition in ruminants.

Nutritional factors have significant influences on the growth performance, structural and biochemical characteristics of carcass and on meat quality traits (Szabó et al., 2001). Previous studies have demonstrated energy is the key factor for carcass and meat quality traits of meat ruminants (McEwen et al., 2007; Rhoades et al., 2007; Huuskonen, 2009). Ørskov et al. (1974 a,b) found the differences in growth performance and the carcass fatty acid composition of lambs fed diets based on maize and wheat. Hereafter, scientific researches to evaluate the differences in growth performance and meat quality of meat ruminants fed diets based on different starch sources, especially on maize and wheat, are few.

We found that the goats fed the diet based on maize was associated with higher net fluxes of lysine, methionine and valine across the portal drained viscera (PDV), and lower urea-N concentration in the portal vein and net PDV flux of ammonia-N when compared with the goats fed the diet based wheat (Sun et al., 2011). On the basis of the above-mentioned study, the present study was carried out to investigate the growth performance and meat quality of goats fed the diets based on maize and wheat.

MATERIAL AND METHODS

Animals and management

The use of animals and the procedure of the experimentation with animals were in accordance to the Animal Care and Guidelines of Chinese Southwest University.

The 4-month-old Liuyang Black goats were obtained from Liuyang Black Goat Reproduction Center, Liuyang city, Hunan province (China). A total of 24 castrated male goats (10±0.2 kg) were involved in the present experiment. The goats were randomly divided into two groups, and assigned to two diets (Table 1).

Table 1. Ingredients and nutrient composition of experimental diets, % DM basis[1]

Indices	Starch sources	
	wheat	maize
Ingredients, %		
maize stover	60	60
maize	-	25
wheat	25	-
soyabean meal	10	11
rice bran	3	0
fish meal	0	2
NaCl	1	1
premix[2]	1	1
Nutrient composition		
ME[3], MJ kg^{-1}	9.90	10.2
crude protein	13.0	12.8
starch	15.0	14.9
NDF	40.5	40.2
Ca	0.68	0.65
P	0.29	0.28

[1] values, expressed on a DM basis, are the average of duplicates; [2] premix contained per kg: g: $MgSO_4 \cdot H_2O$ 119, $FeSO_4 \cdot 7H_2O$ 2.5, $CuSO_4 \cdot 5H_2O$ 0.8, $MnSO_4 \cdot H_2O$ 3, $ZnSO_4 \cdot H_2O$ 5; mg: Na_2SeO_3 10, KI 40, $CoCl_2 \cdot 6H_2O$ 30; IU: vit. A 95.000, vit. D 17.500, vit. E 18.000

[3] metabolizable energy values were as reported by Zhang and Zhang (1998), the others were determined values

The amounts of the feeds offered to goats were controlled to provide nutrition at a plane of approximately 1.3 times the metabolizable energy requirement for maintenance (Lu et al., 1996). Both the concentrate and maize stover were fed separately, and the daily supply of feed was divided into two equal portions fed at 08.00 and 18.00 h during the entire experimental period. The experiment lasted 100 days, including 10 days for adaptation.

Sampling and measurements

Samples of feeds (concentrates and maize stover) were taken daily, pooled and sub-samples were taken. The feed refusals were collected daily, weighed, pooled, and sub-samples were stored at 4°C for later analysis. The initial body weight (the body weight of goats after adaptation) and final body weight were recorded to calculate body weight gain.

The goats were slaughtered at the last experimental day after a 12-h fasting period, and hot carcass weight was recorded. After removing the skin, instrumental colour CIE L* (lightness), a* (redness) and b* (yellowness) (CIE, 1986) readings were taken in *Rectus abdominis* muscle using a MIMOLAT CM 2002 colorimeter (illuminant: D65; visual angle: 10°). Carcass fat colour was also measured at caudal level according to the colour system described above. Carcasses were subsequently ribbed between the 12th and 13th ribs. *Longissimus dorsi* area was traced upon acetate paper and measured with a compensating planimeter (Burke and Apple, 2007). The pH value of the *Longissimus dorsi* between the 10th and 11th rib from the right side was measured using a pH meter equipped with a penetrating glass electrode at 40 min post-mortem. After finishing the above analysis, the *Longissimus dorsi* at the right side was collected and then stored at 4°C. At 24 h post-mortem, the pH value of the *Longissimus dorsi* at the same position was determined. After finishing pH determination, the samples of *Longissimus dorsi* were vacuum-packed and frozen at -20°C for later analysis of moisture, crude fat, ash, and intramuscular fatty acid composition.

Analytical procedures

Moisture, crude fat and protein of the *Longissimus dorsi* between the 5th and 7th rib junction were assessed according to AOAC (1995) procedures, after 24 h thawing at 4°C. Ash was analysed by burning oven-dried samples in a muffle furnace at 550°C according to ISO 5984 (1978).

Fatty acid profiles of the *Longissimus dorsi* between the 9th and 11th rib junction was determined with gas chromatography (Wiegand et al., 2002). Firstly, lipids were extracted from the respective liquid nitrogen pulverized samples using the

Folch extraction method (Folch et al., 1957). Fatty acid methyl esters (FAME) were prepared for gas chromatography determination using sodium methoxide (Li and Watkins, 1998). One ml of hexane was added to each of the scintillation vials from the Folch extraction, and 2 ml of sodium methoxide was added to each vial, and the vials were vortexed at low speed for 30 s. Vials were incubated in a heat block at 50°C for 10 min, and 5 ml of deionized water and 0.1 ml of glacial acetic acid were added to each vial. Lipids were extracted with two successive washings of 3 ml of hexane per vial, and 0.5 g of anhydrous sodium sulphate was added to each vial to remove any residual water. One ml of the FAME was transferred to a gas chromatography vial and stored at 4°C until analysis. All FAME was analysed with a gas chromatography system (G-3000, Tokyo, Japan). The apparatus was equipped with a flame ionization detector and fitted with a 0.3 mm×30 m glass column packed with DB-wax. The carrier gas was helium and the flow rate was 3.3 ml min^{-1}. The temperature was programmed at 75°C for 4 min then increased at 20°C min^{-1} to 180°C, followed by an increase of 2°C min to 230°C and held for 8 min. One ml of sample was injected onto the column. The temperatures of the injector and detector were 250°C and 220°C, respectively. Peaks were identified by comparing their retention times with individual reference standard fatty acids (Nu-Chek-Prep, Elysian, MN).

Statistical analysis

To examine the difference between two diets, the t-test of two independent samples was performed. The P value of less than 0.05 was taken as statistical significance.

RESULTS AND DISCUSSION

Growth performance

There were no differences in dry matter (DM) intakes of concentrate and maize stover between maize group and wheat group ($P>0.05$), and the final body weight and body weight gain of goats in maize group were greater than those of goats in wheat group ($P<0.05$) (Table 2).

The results of this study indicate that there was a difference in growth performance of goats between two diets based on maize and wheat, respectively. Previous studies have investigated the effects of the physical form of starter feed (Abdelgadir and Morrill, 1995; Beharka et al.,1998), type and level of hay, and grain processing on feed consumption, growth performance, and ruminal

Table 2. Effects of starch sources on intakes and growth performances of goats

Indices	Starch sources		SEM [1]	P
	wheat	maize		
Concentrate intake, g d^{-1}	190	191	1.6	0.427
Maize stover intake, g d^{-1}	214	218	1.7	0.128
Initial body weight, kg	10.9	11.0	0.17	0.427
Final body weight, kg	17.4[b]	18.2[a]	0.10	0.002
Body weight gain, g d^{-1}	72.2[b]	80.0[a]	2.4	0.024

[a,b] means in the same row not bearing a common superscript letter differ significantly (P<0.05)

[1] SEM - the pooled standard error of means

development of ruminants (Coverdale et al., 2004; Lesmeister et al., 2004; Suárez et al., 2007). A greater growth rate for the lambs given maize as opposed to wheat was reported by Ørskov et al. (1974a). The body weight at post-weaning was greatest in calves fed a maize diet followed by those fed a wheat diet and then in those on barley and oat diets, with the differences being ascribed to differences between the cereal sources in rumen starch degradability (Khan et al., 2007). McEwen et al. (2007) reported that maize-fed steers grew faster than those fed barley and suggested that differences in gain due to grain source may be due to the higher net energy values of maize vs barley. Also Tiffany and Spears (2005) attributed greater gains and better feed conversion for maize- vs barley-fed steers to lower ME in barley diets due to higher NDF concentrations. It is well known that complicated interrelationships between starch and protein affected ruminal fermentation products (Ørskov, 1975), microbial synthesis (Hoover and Stokes, 1991), whole-body N metabolism, and milk yield and composition in ruminants (Khan et al., 2007). Starch digested in the small intestine can produce up to 42% more energy than fermentation because of a more efficient use of digestive end products: glucose vs volatile fatty acid (Owens et al., 1998). The site of starch digestion along the gastrointestinal tract affects performance and feed efficiency in cattle (Swan et al., 2006). The soluble starch (% total starch) of maize and wheat was 26% and 68%, respectively (Mills et al., 1999). Therefore, in the present study, the higher body weight gain in maize group may be ascribed to the differences in the characteristics of starch degraded in rumen between the diet based on maize or on wheat.

Meat colour

The results of slaughter performance are presented in Table 3. The carcass weight of goats fed the diet based on maize was greater than that of goats fed the diets based on wheat (P<0.05). There were no differencs in L*, a* and b* of *Rectus abdominis* and caudal fat of goats between two diets.(P>0.05).

Table 3. Effects of starch sources on slaughter performance of goats

Indices	Starch sources		SEM[1]	P
	wheat	maize		
Carcass weight, kg	9.42[b]	9.97[a]	0.15	0.046
L* *Rectus abdominis*	48.1	47.1	1.20	0.556
a* *Rectus abdominis*	18.7	18.6	0.47	0.815
b* *Rectus abdominis*	12.1	12.4	0.28	0.613
L* caudal fat	67.5	68.1	1.41	0.745
a* caudal fat	6.86	6.75	0.16	0.647
b* caudal fat	6.24	6.38	0.15	0.528

[a,b] means in the same row not bearing a common superscript letter differ significantly (P<0.05)
[1] SEM - the pooled standard error of means; [2] L* lightness (0 = black, 100 = white), a* redness (positive values = red, negative values = green), b* yellowness (positive values = yellow, negative values = blue)

The results of L*, a* and b* in present study indicate that starch sources had no effect on the colour profiles of *Rectus abdominis* and caudal fat. However, previous studies have found that different rumen starch degradability would cause differences in meat colour. Starch as an energy source for veal calves resulted in a higher pigment content in the meat than lipids, the explanation being a better absorption of iron in the small intestine due to a lower pH in the starch-fed calves (Valin et al., 1978). A lower rumen starch degradability of diets caused a higher pigment content in the meat of finishing bulls, the argument being that the different meat colour may be due to an effect on the pigment concentration (Fiems et al., 1999).

Physical and chemical characteristics of Longissimus dorsi muscle

The marbling score of *Longissimus dorsi* muscle in wheat group was grater than that of in maize group, and there were no differences in other parameters of physical and chemical characteristics of *Longissimus dorsi* muscle determined in this study between maize group and wheat group (P>0.05) (Table 4).

Table 4. Effects of starch sources on physical and chemical characteristics of *Longissimus dorsi* muscle of goats

Indices	Starch sources		SEM[1]	P
	wheat	maize		
Longissimus dorsi area, cm^2	9.30	9.17	0.24	0.723
Marbling score	3.10[a]	2.70[b]	0.05	0.002
pH, at 40 min post-mortem	6.77	7.00	0.16	0.380
pH, at 24 h post-mortem	5.78	6.12	0.15	0.149
Moisture, %	77.1	77.4	0.24	0.268
Crude fat, %	1.67	1.52	0.23	0.328
Protein, %	19.8	19.6	0.47	0.898
Ash, %	1.43	1.38	0.03	0.272

[a,b] means in the same row not bearing a common superscript letter differ significantly (P<0.05)
[1] SEM - the pooled standard error of means

Some physical and chemical characteristics of *Longissimus dorsi* muscle may be related to the proportion of degradable starch in rumen. Post ruminal starch digestion occurs mainly in the small intestine and results in free glucose that is available for absorption by all adipose tissue depots (Owens et al.,1986; Gilbert et al., 2003; Schoonmaker et al., 2003). However, apart from marbling score, the proportions of moisture, protein and fat in the *Longissimus dorsi* muscle were not significantly different in the present study. Our results are in agreement with several studies over the past decade (Miller et al., 1996; Boles et al., 2005; Koenig and Beauchemin, 2005; McEwen et al., 2007), which found no differences in Warner-Bratzler shear force measurements, and taste panel evaluations for tenderness, juiciness, and flavour when comparing beef from cattle finished on maize vs barley. Fiems et al. (1999) also found that the proportion of rumen degradable starch in the diet had no effects on the proportions of moisture, protein and fat in the *Longissimus thoracis* muscle. The differences in the physical and chemical characteristics of *Longissimus dorsi* muscle of ruminant as affected by different starch sources need further study.

Fatty acid composition of Longissimus dorsi muscle

The C14:0 proportion of *Longissimus dorsi* muscle in the wheat group was greater than that of goats in the maize group ($P<0.05$), however, the C18:3 proportion of *Longissimus dorsi* muscle in wheat group was lower than that of goats in maize group ($P<0.05$). The other parameters of fatty acid composition of *Longissimus dorsi* muscle determined in this study between the two groups were not significantly different ($P>0.05$) (Table 5).

Table 5. Effects of starch sources on fatty acid composition of *Longissimus dorsi* muscle fatty acid methyl esters of goats, g/100 g

Fatty acid	Starch sources		SEM[1]	P
	wheat	maize		
C14:0	5.32[a]	4.30[b]	0.14	0.001
C16:0	22.8	22.7	1.7	0.987
C18:0	12.7	12.8	0.19	0.697
C18:1	37.5	38.1	0.64	0.522
C18:2	13.3	13.4	0.58	0.870
C18:3	1.53[b]	2.14[a]	0.07	<0.001
C20:4	6.82	6.51	0.13	0.133
Saturated	39.6	38.2	1.31	0.469
Monounsaturated	31.2	31.7	0.56	0.541
Polyunsaturated	29.2	30.1	0.76	0.425
P/S	0.93	0.95	0.01	0.309

[a,b] means in the same row not bearing a common superscript letter differ significantly ($P<0.05$)
[1] SEM - the pooled standard error of means

The results indicate that there was difference in fatty acids composition of the *Longissimus dorsi* muscle between maize group and wheat group. Feeding systems can play a significant role in improving meat dietetic quality, as the changes in fatty acid composition of body fats and lipid stability during storage are primarily linked to the respective fatty acid contents in the pastures or concentrate and hay (Popova, 2007). Despite rumen hydrogenation, it has been shown that pasture feeding increases the concentration of meat n-3 PUFA, compared with grain feeding (Ørskov et al., 1974b; Aurousseau et al., 2004; Gatellier et al., 2005). Bas and Morand-Fehr (2000) showed that the carcass of lambs fed a diet based on maize contained more odd-numbered fatty acids than the lambs given wheat. Gill et al. (2008) reported that a diet based on maize or sorghum distiller grains increased steak n-6 fatty acid and linoleic acid concentrations of beef compared with the diet based on a steam-flaked maize. In a previous study with lambs it was found that lipids in different fat depots (endogenous and subcutaneous) of grazing ruminants contained relatively more linolenic acid, with a lower C18:2n-6/C18:3n-3 ratio, than the concentrate fed animals (Banskalieva et al., 2005). The fatty acid compositions of the *Longissimus thoracis* muscle in finishing bulls among diets with different starch level or different rumen degradable starch were different, especially with regard to C14:0 and C18:0 (Fiems et al., 1999). To our knowledge, scientific studies carried out to investigate the effects of starch sources on fatty acid composition of muscle or adipose tissues of meat of ruminants are limited. Therefore, the results of this study need further study.

CONCLUSIONS

In conclusion, the present study has shown that the goats fed the diet based on maize achieved a greater growth performance and a lower proportion of C18:3 fatty acids and marbling score of *Longissimus dorsi* muscle when compared with those of goats fed the diet based on wheat. Therefore, in terms of growth performance, maize is preferable to wheat as a starch source for meat ruminants. In contrast, wheat is the preferable starch source for the fatty acid content of the meat. In practice the application of these scientific findings in the formulation of diets is likely to be influenced by the relative cost of the two starch sources.

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