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Research Article

Effects of High Rice Diet on Growth Performance, Nutrients Apparent Digestibility, Nitrogen Metabolism, Blood Parameters and Rumen Fermentation in Growing Goats

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Abstract

This study was conducted to evaluate the effects of high rice grain diet on apparent nutrient digestibility, growth performance, nitrogen digestion, blood parameters and rumen fermentation in goats. Sixteen growing goats were divided into 2 groups and fed a normal-concentrate diet (NC, 55% concentrate of dry matter; n=8) or a high concentrate diet (HC, 90% concentrate of dry matter; n=8) for 5 wk. Growth performance, nutrients digestibility, nitrogen digestion, blood parameters and ruminal fermentation were measured. Total weight gain and average daily gain increased in the HC group (P<0.01). Digestibility of Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF), nitrogen intake and digested nitrogen also increased (P<0.05) by HC feeding. Triglycerides, cholesterol, high density lipoprotein and low-density lipoprotein concentrations in the blood decreased (P<0.05). HC diet feeding decreased (P<0.01) the pH value, acetate level and ratio of acetate to propionate, but increased (P<0.05) the concentrations of propionate, valerate and total volatile fatty acids in the rumen. These findings revealed that the HC diet could promote the growth of growing goats, change the ruminal fermentation pattern and lipid metabolism in the blood, but cause subacute ruminal acidosis, which might increase the risk of body health.

Keywords: *High concentrate diet, Goats, Apparent digestibility, Metabolism, Fermentation*

Büyüme Dönemindeki Keçilerde Pirinç Ağırlıklı Diyetin Büyüme Performansı, Görünür Sindirilebilirlik, Nitrojen Metabolizması, Kan Parametreleri ve Rumen Fermentasyonu Üzerine Etkileri

Öz

Bu çalışma, keçilerde pirinç ağırlıklı diyetin, görünür sindirilebilirlik, büyüme performansı, azot sindirimi, kan parametreleri ve rumen fermentasyonu üzerindeki etkilerini değerlendirmek amacıyla yapıldı. Bu amaçla büyüme dönemindeki on altı keçi, 2 gruba ayrıldı ve 5 hafta boyunca normal konsantrasyon (NC, %55 kuru madde konsantrasyonu; n=8) veya yüksek konsantrasyondaki diyet (HC, %90 kuru madde konsantrasyonu; n=8) verildi. Büyüme performansı, besin sindirilebilirliği, azot sindirimi, kan parametreleri ve ruminal fermantasyon ölçüldü. Sonuçta, HC grubunun toplam kilo artışı ve ortalama günlük kilo artışı yüksek bulundu (P<0.01). Nötral Deterjan Lif (NDF) ve Asit Deterjan Lif (ADF)'in sindirilebilirliği, azot alımı ve sindirilmiş azot oranının da, HC beslemesi ile arttığı belirlendi (P<0.05). Kandaki trigliseritler, kolesterol, yüksek yoğunluklu lipoprotein ve düşük yoğunluklu lipoprotein konsantrasyonları azaldı (P<0.05). HC diyet beslemesi pH değerini, asetat seviyesini ve asetatın propiyonata oranını azaltırken (P<0.01), rumendeki propiyonat, valerat ve toplam uçucu yağ asitlerinin konsantrasyonlarını arttırdı (P<0.05). Bu bulgular, HC diyetinin büyüme dönemindeki keçilerin gelişimini destekleyebileceğini, kandaki ruminal fermentasyon düzenini ve lipid metabolizmasını değiştirebildiğini, ancak subakut ruminal asidoza neden olarak risk oluşturduğunu ortaya koydu.

Anahtar sözcükler: *Yüksek konsantrasyon diyet, Keçiler, Görünür sindirilebilirlik, Metabolizma, Fermantasyon*

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INTRODUCTION

Relative high fiber feeding and stable microbial flora are the necessary conditions for the health of ruminants [1]. However, at present, feeding high concentrate diet is widely adopted to provide adequate protein and energy supply for meeting higher performance needs at finishing stage of ruminants [2]. Non-fibrous carbohydrates in the concentrate of diets can provide ruminants with energy and small intestinal absorbable glucose to meet high production and energy needs. Appropriate increase of dietary concentrate level can improve the production performance of ruminant animals [3]. It is well known for feeding excessive amounts of non-structural carbohydrates and highly fermentable roughages easily result in a series of metabolic diseases in high-yield ruminants [4,5]. For instance, previous studies have shown that feeding high concentrate diets can induce subacute ruminal acidosis (SARA) in ruminants [6]. The presence of SARA is an important concern in terms of both productivity and animal welfare. The high rumen digestibility of most grains in the concentrate improved the ruminal VFA production, and the accumulation of volatile fatty acids (VFA) causes a decrease in ruminal pH [7]. Typically, when rumen pH is lower than normal level, then gram-negative bacteria in the rumen and intestinal tracts releases a lot of lipopolysaccharide (LPS) [3], also known as endotoxin, is a part of the outer membrane of the gram-negative bacteria [8], seriously disturbing the normal physiological function of gastrointestinal tracts and body health. Additionally, ruminal fermentation and digestion processes mediated by symbiotic microorganisms can convert dietary carbohydrates into available nutrients such as VFA and sugars [9].

Black goat is common in the south of China, by a wide range of breeds, mainly located in Hunan, Jiangxi, Guizhou and surrounding provinces and cities. Liuyang black goat is a rare pure black goat breed in China. Liuyang black goat has tender meat, delicious taste, leaner meat, less fat, high nutritional value and strong disease resistance. Therefore, Liuyang black goat has good research value. Previous evidence has suggested that rapid growth can be achieved by feeding the diets exceeding 50~65% proportions of concentrate (mainly containing ground corn grain) to ruminants [10]. In fact, because corn grain is commonly scarce in the traditional rice cropping region of southern Asia, rice grain is thereby used as an alternative feed applied in the goat diets. Howbeit few studies were conducted to explore the effects of dietary high rice grain proportion on the gastrointestinal nutrient digestion and metabolism. The aim of this research is to conduct a feeding trail to investigate whether a diet with high unhusked rice grain proportion would affect the growth performance, nutrients apparent digestibility, nitrogen metabolism, blood metabolites and ruminal fermentation, and to seek for the rational and practical approaches of rice grain in a ruminant production system.

MATERIAL and METHODS

The study was approved by the Animal Care Committee, Institute of Subtropical Agriculture, the Chinese Academy of Sciences, Changsha, China and the Animal Care and Use Committee of Hunan Agricultural University (HAU201408).

Animals, Diets and Management

Sixteen Liuyang Black goats (6 months old, a local breed in the south of China), with an average BW of 15.33±1.67 kg were randomly divided into two groups and fed normal -concentrate diet (NC, the ratio of concentrate to forage was 55:45) and high-concentrate diet (HC, the ratio of concentrate to forage was 90:10), respectively. The ingredients and nutrient levels of the diets are given in *Table 1*. Unhusked rice was in the form of dried powder and provided by the Hunan LiFeng Bio-Technology Company Ltd. (Changsha, China). Before formulating the diets, the rice straw was chopped to approximately 2 cm in length.

The experiment duration consisted of 35 days, with 7 days for diet adaptation and 28 days for sampling. Diets were equally offered at approximately 08:00 and 18:00 h,

Table 1. *Ingredients and nutrient levels of the experimental diets (air-dried basis)*

Item	NC[1]	HC[2]
Ingredients composition (%)		
Forage		
Rice straw	45.0	10.0
Concentrate		
Rice with shell	33.2	54.3
Soybean meal	9.60	15.7
Wheat bran	6.00	9.80
Fat powder	3.20	5.20
Calcium carbonate	0.50	0.80
Calcium bicarbonate	1.10	1.80
Sodium chloride	0.60	1.00
Premix[3]	1.00	1.40
Nutrient levels[4], % of DM		
Crude protein	13.5	17.6
Crude ash	9.34	9.12
Crude fat	4.18	6.01
Neutral detergent fiber	49.8	38.4
Acid detergent fiber	36.5	9.51
NFC[5]	14.83	24.35

[1] NC: normal-concentrate diet; [2] HC: High-concentrate diet; [3] Premix composition per kg diet: 68 mg $FeSO_4 \cdot H_2O$, 44 mg $CuSO_4 \cdot 5H_2O$, 411 μg $CoCl_2 \cdot 6H_2O$, 1.70 mg KIO_3, 211 mg $MnSO_4 \cdot H_2O$, 126 mg $ZnSO_4 \cdot H_2O$, 56 μg Na_2SeO_3, 462 mg $MgSO_4 \cdot 7H_2O$, 737 IU Vit. A, 8.29 mg Vit. E, 4.0 g $NaHCO_3$, 5.1 g carrier zeolite powder; [4] Nutrient levels were measured values; [5] NFC: Non-fibrous carbohydrate. NFC was calculated in accordance with *NFC = DM - (CP + EE + Ash + NDF)*

respectively. All goats were fed in separate cages. Goats had free access to water and feed intake of each goat was recorded daily.

Sampling and Collection

The goats were kept in metabolic cages which enabled the separation of urine from feces. Feces and urine were collected from goats twice daily before feeding (08:00 h and 18:00 h) and lasted for 7 days. For feces samples, further subsamples (2% of total weight) were acidified with 10% H_2SO_4 and stored at -20ºC for the determination of dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), and nitrogen (N). The fecal subsamples were dried at 65ºC for 48 h and stored in plastic bags until laboratory analysis. For each goat, the total volume of urine was recorded daily. A 10% urine subsample was taken, in which 10% H_2SO_4 was added to keep pH less than 3.0 for the determination of N. Samples of the diets were collected after feeding in the morning each week, and urine was stored at -20ºC until analysis.

Blood samples were collected aseptically in tubes with heparin sodium from the jugular vein of goats before feeding in two consecutive days (d34 and d35) of the sampling period, respectively. Plasma samples were separated by centrifugation by 1000 g for 15 min at 4ºC, and stored at -20ºC for further analysis. Rumen fluid samples were taken at 0h (before feeding in the morning), 3 h (3 h after feeding in the morning) and 6 h (6 h after feeding in the morning) on day 35 through the oral cavity. Meanwhile, pH values of rumen fluid were immediately determined after sampling using a pH meter (Model PHS-3C, Shanghai Precision Science Instrument Co., Ltd., China). Further subsamples were centrifuged at 15.000 g for 10 min and the supernatant fluids were acidified with 25% (w/v) metaphosphoric acid in a ratio of 10:1, vortexed and stored at -20ºC for VFA determination.

Chemical Analysis

The samples of diets and feces were dried at 105ºC overnight and ignited at 550ºC for 6 h for measuring DM, OM and Ash (method 942.05; AOAC, 1995), respectively [11]. Crude protein content was calculated as 6.25×N which was determined using the Kjeldahl method [12]. The NDF and ADF were measured by using the procedures of Van Soest et al.[13]. The plasma biochemical components including lactate dehydrogenase (LDH), lactate (LACT), glucose (Glu), triglycerides (TG), cholesterol (CHOL), high density lipoprotein (HDL), low density lipoprotein (LDL), total protein (TP), and albumin (ALB)were determined using an Automatic Biochemistry analyzer (Cobas c 311, Roche). Insulin-like growth factor 1 (IGF-1) in the plasma was measured by ELISA kits (Cusabio, Wuhan, China) according to the instructions of the manufacturer. LPS and growth hormone (GH) in the plasma were also detected using corresponding ELISA kits (Jian Cheng Bioengineering Institute, Nanjing, China).

The ingested N (IN, g/d), fecal N (FN, g/d) and urinary N (UN, g/d) were used to calculate N balance as following:

Digested N (DN) [g/d] = IN–FN,

Retained N (RN) [g/d] = IN–FN–UN,

Availability of RN [%] = (IN–FN–UN)/IN × 100%,

Availability of DN [%] = (IN–FN–UN)/(IN–FN) × 100%,

Apparent N digestibility [%] = (IN–FN)/IN × 100%.

The rumen fluid samples were thawed and centrifuged at 10.000 g and 4ºC for 15 min. The supernatant solution was used for VFA determination by gas chromatography (HP5890, Agilent Technologies Co. Ltd., USA).

Statistical Analyses

Statistical analyses of data were evaluated through independent sample T-test, and animal were used as experimental unit. Values are expressed as the mean ± standard error of the mean (SEM). Statistical significance was set at $P<0.05$ and tendencies at $0.05 \leq P \leq 0.10$. All statistical analyses were conducted with SPSS 19.0 (SPSS Inc., Chicago, IL, USA, 2009).

RESULTS

As shown in *Table 2,* the total weight gainand average daily gain wereincreased by HC ($P<0.01$). But HC diet significantly decreased the FCR (feed conversion ratio). Mean while, no significant differences in final weight and DMI were noted between groups ($P>0.10$). As shown in *Table 3,* the intake, fecal output and apparent digestibility of OM were not affected ($P>0.05$) by HC. HC decreased the intake of NDF ($P<0.01$), but increased the fecal output ($P<0.01$), and finally reduced the digestibility of NDF ($P<0.01$). ADF intake was not influenced by HC ($P>0.05$), but the fecal output was greater ($P<0.01$) and the digestibility was reduced ($P<0.01$) in the HC group.

Nitrogen intake, fecal nitrogen, urinary nitrogen excretion and DN were increased ($P<0.05$) by the HC diet *(Table 4)*. However, there were no significant differences in the RN, DN and their availability, and N digestibility ($P>0.05$).

Table 2. *Effects of high-concentrate diet on growth performance in goats*

Items	NC[1]	HC[2]	SEM	P-value
Initial weight/kg	15.5	15.2	0.51	0.78
Final weight/kg	17.4	18.7	0.64	0.34
Total weight gain/kg	1.88	3.50	0.33	<0.01
Average daily gain (g/d)	67.1	125	12	<0.01
DMI (g/d)	572	602	13	>0.10
FCR[3]	11.46	7.27	1.09	0.032

[1] NC: normal-concentrate diet, [2] HC: High-concentrate diet, [3] FCR: feed conversion ratio

Table 3. *Effects of high-concentrate diet on nutrients apparent digestibility in goats*

Items	NC[1]	HC[2]	SEM	P-value
OM[3]				
Intake, g/d	523	563	12	0.12
Fecal output, g/d	131	168	11	0.078
Apparent digestibility, %	74.9	70.0	1.7	0.15
NDF[4]				
Intake, g/d	317	265	10	<0.01
Fecal output, g/d	72.2	131	12	<0.01
Apparent digestibility, %	77.2	50.6	5.0	<0.01
ADF[5]				
Intake, g/d	173	166	3.4	0.36
Fecal output, g/d	58.2	88.6	5.3	<0.01
Apparent digestibility, %	66.3	46.6	3.3	<0.01

[1] NC: normal-concentrate diet; [2] HC: High-concentrate diet, [3] OM: organic material; [4] NDF: neutral detergent fiber, [5] ADF: acid detergent fiber

Table 4. *Effects of high-concentrate diet on nitrogen digestion in goats*

Items	NC[1]	HC[2]	SEM	P-value
Nitrogen intake, g/d	12.1	17.4	0.93	<0.01
Fecal nitrogen, g/d	2.66	4.88	0.51	0.018
Urinary nitrogen, g/d	1.95	4.77	0.63	0.014
Digested nitrogen, g/d	9.47	12.5	0.67	0.014
Retained nitrogen, g/d	7.53	7.70	0.72	0.91
Availability,% of RN[3]	62.0	44.0	4.8	0.055
Availability,% of DN[4]	79.4	60.2	5.3	0.067
Digestibility,%	78.1	71.7	2.3	0.18

[1] NC: normal-concentrate diet, [2] HC: High-concentrate diet, [3] RN: retained nitrogen, [4] DN: digested nitrogen

HC increased the concentration of LACT (P=0.040), while LACT was not detected in the NC group *(Table 5)*. Meanwhile, no significant differences were observed (P>0.05) between the dietary treatments in contents of LPS, LDH, Glu, TP, ALB and GH. Concentrations of TG (P<0.01), CHOL (P=0.029), HDL (P=0.035) and LDL (P=0.034) in blood were decreased in HC goats.

Variation of pH values in the rumen fluid was shown in *Fig. 1*. It is obvious that goats fed the NC diet had greater ruminal pH than that of the HC group (P<0.01). Ruminal pH in the HC group was affected by sampling hour (P<0.01). The pH values in rumen samples of two groups were the same before feeding in the morning (0 h), but it was declined in the HC group at 3 h or 6 h after feeding (P<0.01). During the time period from 3 h after the feeding until the sampling at 6 h, the average ruminal pH was below 5.7 in the HC group and remained significantly lower than that of the NC goats.

Data of metabolites in the ruminal fluid are displayed in

Table 5. *Effect of high-concentrate diet on blood parameters in goats*

Items	NC[1]	HC[2]	SEM	P-value
LPS[3] (EU/mL)	1.84	1.77	0.049	0.52
LDH[4] (U/L)	289	305	33	0.83
LACT[5] (mmol/L)	0	1.02	0.25	0.040
Glu[6] (mmol/L)	4.09	4.05	0.087	0.85
TG[7] (mmol/L)	0.683	0.378	0.061	<0.01
CHOL[8] (mmol/L)	2.64	1.72	0.23	0.029
HDL[9] (mmol/L)	1.76	1.19	0.14	0.035
LDL[10] (mmol/L)	1.02	0.480	0.13	0.034
TP[11] (g/L)	73.0	69.6	2.4	0.51
ALB[12] (g/L)	30.3	34.6	2.3	0.39
IGF-1[13] (ng/mL)	29.8	64.4	8.5	0.040
GH[14] (ng/mL)	1.57	1.41	0.13	0.56

[1] NC: normal-concentrate diet, [2] HC: High-concentrate diet, [3] LPS: lipopolysaccharide, [4] LDH: lactate dehydrogenase, [5] LACT: lactate, [6] Glu: glucose, [7] TG: triglycerides, [8] CHOL: cholesterol, [9] HDL: high density lipoprotein, [10] LDL: low density lipoprotein, [11] TP: total protein, [12] ALB: albumin, [13] IGF-1: insulin-like growth factor 1, [14] GH: growth hormone

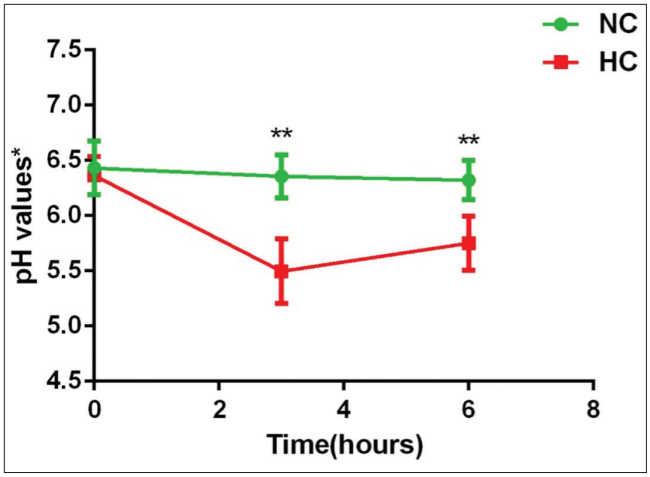


Fig 1. Effects of high-concentrate diet on pH values in ruminal fluid of goats

* The pH value was measured on day 35, ** indicates a very significant difference in two groups at the same time

Table 6. Ther e was no difference in the LACT concentration of ruminal fluid in two groups (P=0.77). The acetate level was lower in the HC group (P<0.01), but the propionate (P<0.01), valerate (P=0.023), and total VFA (P<0.01) concentrations were higher in the HC group. There were no differences in isobutyrate, butyrate, and isovalerate between the two groups (P>0.05). Additionally, the ratio of acetate and propionate in the ruminal fluid in the HC group was lower than that of the NC group (P<0.01).

DISCUSSION

In the present study, the HC diet increased the total weight gainand average daily gain of goats, indicating that HC

Table 6. *Effects of high-concentrate diet on the ruminal lactate, molar proportions of VFAs in goats*

Items	NC[1]	HC[2]	SEM	P-value
LACT[3] (mmol/L)	0.125	0.144	0.030	0.77
Total VFA[4] (mmol/L)	97.4	164	11	<0.01
Acetate: Propionate	4.24	2.20	0.34	<0.01
Individual VFA (mol/100 mol total VFA)				
Acetate	73.3	61.9	1.7	<0.01
Propionate	18.0	28.6	1.7	<0.01
Isobutyrate	0.642	0.692	0.039	0.55
Butyrate	6.92	7.27	0.61	0.79
Isovalerate	0.636	0.849	0.074	0.16
Valerate	0.530	0.732	0.046	0.023

[1] NC: normal-concentrate diet, [2] HC: High-concentrate diet, [3] LACT (lactate), [4] VFA (volatile fatty acids)

diet can promote the growth performance of goats. In our study, the total live weight gain of HC diet group was increased by a large amount of concentrate containing rich carbohydrates, and more carbohydrates produced more protein and energy for the goats, which led to a higher weight gain in the HC diet group. Higher total weight gain also leads to higher average daily gain. Meanwhile, the result is consistent with that of Mahgoub that study proved that the final weight and dry matter intake are not affected by the ratio of dietary concentrates to forge [14]. Because the NC group fed a large amount of forge to the goat in the study and a little concentrate, contrary to HC group fed a large amount of concentrate, finally, the FCR of the HC group was lower than NC group. We speculate that an increase of VFA in the rumen might partly be contributed to the overall weight and average daily gain of goats. The rumen absorbs energy material (i.e., SCFA), which accounts for about 70% of the energy required for ruminant growth, maintenance and production [15]. Additionally, we found that DMI in the HC group was not varied, which is agreed with previous research which has performed in Omani goats [16].

Dietary nutrients, such as fiber, is also essential for digestion mediated by chewing nutrients, microbial fermentation in the rumen and the rate of passage in the gastrointestinal tract [17]. In this study, the decreases in NDF intake and apparent digestibility and increase in fecal output of NDF were observed in the HC group. ADF fecal output was greater and the digestibility was reduced in the HC group. These results suggest that growing goats are less able to digest and degrade NDF and ADF of diet in the HC group. Our data agree with that Walsh et al.[18] which observed that the digestibility of fiber decreased with the increase of concentrate. The explanation of the decrease in NDF and ADF digestibility can be ascribed to two points. Firstly, changes in the rumen pH does not help to fiber digestion [19], since we also observed the less pH value in the rumen of HC goats. Low pH values in rumen leads to changes in rumen microbial population and reduces fiber digestion [20]. Secondly, the high levels of fat in the diet decrease the digestibility of the total digestive tract of NDF, ADF and cellulose in lambs [21] and dairy cows.

We find significant changes in fecal and urinary N among the two groups. Losses of N in feces and urine may be the result of low efficiency of protein utilization in the rumen. Meanwhile, according to Nocek and Russell [22], when protein degradation rate exceeds carbohydrate fermentation rate, a large number of N can be used as ammonia loss, and excess ammonia in the rumen may have been excreted in the urine. Additionally, the HC diet tends to reduce the availability of RN. The fecal N, urinary N, digested N and retained N were directly related to dietary N levels. According to Lallo [23], N retention showed a curvilinear response to energy intake but showed a linear response to increasing N levels. This means that N retention is more closely related to N intake rather than energy intake. Besides, urea can also recirculate through saliva and reenter the rumen [24]. Usually ruminants synthesize urea Nbeyond the N apparently digested [25], and it suggested that the N balance in ruminants is positive. Nitrogen recirculated to the gastrointestinal tract can be used to synthesize the microbial proteins in the rumen and provide amino acids to the host [26].

In this study, HC did not influence plasma LPS concentration. Gozho et al.[27] also did not observe increased LPS in the peripheral blood plasma of lactating dairy cows with SARA. This is partly attributable to the fact that lipoprotein can neutralize LPS in the body. There was evidence that lipoproteins can neutralize LPS *in vivo* [28]. Several experiments have also demonstrated that plasma lipoprotein, especially HDL, can be combined with LPS and preferentially shunt liver cells away from liver macrophages, thereby increasing LPS excretion through the bile and preventing immune responses [29]. HC diet reduced TG, CHOL, HDL and LDL, indicating that the metabolism of lipid in blood was changed. These data are very important in preventing hyperlipidemia and the heart and liver diseases [30].

Ruminal propionate produced during ruminal fermentation is used as a substrate in the gluconeogenesis pathway to produce glucose [31]. In the current study, although propionate in the rumen feeding HC was higher than NC, there were no significant differences on the concentration of glucose between NC and HC suggesting that ALB is the main protein produced in the liver and usually accounts for more than 50% of the total blood protein content [32]. Both TP and ALB were not influenced by HC in our study. TP is more sensitive to the effects of nutrition, but the changes are often subtle and difficult to detect and explain. The level of serum protein depends on a number of factors, including the presence of inflammatory or metabolic liver processes and other organ diseases [33].

Hormones can regulate various physiological and behavioral activities. The synthesis, storage and secretion of GH by the somatotropin cells, stimulate the growth of animals and the production of IGF-1 [34]. There is a positive correlation between the concentration of IGF-1 and the growth rate of animals [35]. Though the HC diet did not rise the plasma GH level, there is a significant increase in IGF-1, suggesting that the HC diet promotes growth development in goats, which can explain the increases in the total weight gainand average daily gain. The enzyme LDH is widely found in body tissues. As a marker of common injury and disease, it is released during tissue damage. In particular, feedback inhibition by LDH can reduce the rate of conversion of pyruvate to lactic acid at high lactate concentration [36]. Our data display the significant rise in plasma LACT content in response to the HC diet, but there was no significant influence in LDH between treatments. Further exploration is needed to explain this phenomenon.

The pH value is an extremely important indicator of the epithelial barrier and the ruminal metabolic state [10]. In this study, the rumen pH of NC group ranged from 6.07 to 6.73, and it was ideal for optimum rumen metabolism [37]. The rumen pH thresholds of 5.8 or lower were usually used to define a clinical diagnosis of SARA [38]. In this study, the data in *Fig. 1* indicated that NC-fed goats have a higher rumen pH. We observed that the duration of rumen pH below 5.8 in the SARA group was approximately 4 h after the first feeding, which meant that SARA occurred in goats by feeding the HC diet. The sampling time also affected the rumen pH. Briefly, the data indicated that HC-raised induced SARA in growing goats.

LACT is one of the main products in the rapid fermentation of rumen, and a large number of LACT can cause SARA has been widely recognized [39]. As we know, LACT can cross the rumen wall and dissolve in the blood to cause an increase in plasma. Although the concentration of LACT was found to be negligible in the rumen, we found a significant difference in the blood. This may mean that LACT was produced and immediately converted to VFA as suggested by some authors, thus preventing the accumulation of LACT in the rumen [40]. Previous studies have shown that long-term HC feeding increased the production of VFA in the rumen. Accumulation of these acids reduces the pH of the rumen and may cause SARA [9]. For many years, researchers have been looking for markers of SARA caused by HC feeding. Feeding goats with the HC diet can cause abnormal fermentation of the rumen. Data of the ratio A:P showed a decrease in HC fed goats compared to the NC group. The result was in agreement with Zervas [21] that the higher fat content in the diet reduces the rate of A:P, indicating that the rumen fermentation was developing towards propionate production. It was reported that the lower proportion of A:P was caused by the lower fermentation of cellulose in the rumen [41]. HC diet not only increased the concentration of propionate and valerate, but also increased the concentration of total VFA. The concentration of VFA in this study is similar to that reported previously, which indicated that the concentration of total VFA increases with the HC diet [42]. These data showed that the HC diet increased the production of VFA in the rumen. Accumulation of VFA decreased the ruminal pH and led to SARA. Therefore, an HC diet destroyed the balance of the rumen fermentation.

This study is the first in using unhusked rice as HC diet to survey the growth performance, nutrients apparent digestibility, nitrogen digestion, blood parameters and rumen fermentation of growing goats. In summary, these findings revealed that the HC diet could promote the growth of growing goats, changed the ruminal fermentation pattern and lipid metabolism in the blood, but cause subacute ruminal acidosis, which increases the risk of body health. The exact mechanism of this relationship between the blood parameters and the rumen microbial metabolites is needed to explore.

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Conflict of interest

There is no conflict of interest.

REFERENCES

1. Fluharty FL, McClure KE: Effect of dietary energy intakes and protein concentration on performance and visceral organ mass in lambs. *J Anim Sci*, 75, 604-610, 1997. DOI: 10.2527/1997.753604x

2. Boerman JP, Potts S, VandeHaar MJ, Allen MS, Lock AL: Milk production responses to a change in dietary starch concentration vary by production level in dairy cattle. *J Dairy Sci*, 98, 4698-4706, 2015. DOI: 10.3168/jds.2014-8999

3. Zebeli Q, Ametaj BN: Relationships between rumen lipopolysaccharide and mediators of inflammatory response with milk fat production and efficiency in dairy cows. *J Dairy Sci*, 92, 3800-3809, 2009. DOI: 10.3168/jds.2009-2178

4. Aikman PC, Henning PH, Humphries DJ, Horn CH: Rumen pH and fermentation characteristics in dairy cows supplemented with *Megasphaera elsdenii* NCIMB 41125 in early lactation. *J Dairy Sci*, 94, 2840-2849, 2011. DOI: 10.3168/jds.2010-3783

5. Plaizier JC, Khafipour E, Li S, Gozho GN, Krause DO: Subacute ruminal acidosis (SARA), endotoxins and health consequences. *Anim Feed Sci Technol*, 172, 9-21, 2012. DOI: 10.1016/j.anifeedsci.2011.12.004

6. Khafipour E, Krause DO, Plaizier JC: A grain-based subacute ruminal acidosis challenge causes translocation of lipopolysaccharide and triggers inflammation. *J Dairy Sci*, 92, 1060-1070, 2009. DOI: 10.3168/jds.2008-1389

7. Yusuf AL, Adeyemi KD, Samsudin AA, Goh YM, Alimon AR, Sazili AQ: Effects of dietary supplementation of leaves and whole plant of *Andrographis paniculata* on rumen fermentation, fatty acid composition and microbiota in goats. *BMC Vet Res*, 13:349, 2017. DOI: 10.1186/s12917-017-1223-0

8. Eckel EF, Ametaj BN: Invited review: Role of bacterial endotoxins in the etiopathogenesis of periparturient diseases of transition dairy cows. *J Dairy Sci*, 99, 5967-5990, 2016. DOI: 10.3168/jds.2015-10727

9. Zhang RY, Zhu WY, Jiang LS, Mao SY: Comparative metabolome analysis of ruminal changes in Holstein dairy cows fed low- or high-concentrate diets. *Metabolomics*, 13:74, 2017. DOI: 10.1007/s11306-017-1204-0

10. Tao S, Duanmu Y, Dong H, Tian J, Ni Y, Zhao R: A high-concentrate diet induced colonic epithelial barrier disruption is associated with the activating of cell apoptosis in lactating goats. *BMC Vet Res*, 10:235, 2014. DOI: 10.1186/s12917-014-0235-2

11. AOAC: Official methods of analysis. Washington, DC: Association of Official Analytical Chemists. 16th ed., 2002.

12. Lynch JM, Barbano DM: Kjeldahl nitrogen analysis as a reference method for protein determination in dairy products. *J AOAC Int*, 82, 1389-1398, 1999.

13. Van Soest PJ, Robertson JB, Lewis BA: Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. *J Dairy Sci*, 74, 3583-3597, 1991. DOI: 10.3168/jds.S0022-0302(91)78551-2

14. Mahgoub O, Lu CD, Early RJ: Effects of dietary energy density on feed intake, body weight gain and carcass chemical composition of Omani growing lambs. *Small Ruminant Res*, 37, 35-42, 2000. DOI: 10.1016/s0921-4488(99)00132-7

15. Bergman EN: Energy contributions of volatile fatty acids from the gastrointestinal tract in various species. *Physiol Rev*, 70, 567-590, 1990. DOI: 10.1152/physrev.1990.70.2.567

16. Mahgoub O, Lu CD, Hameed MS, Richie A, Al-Halhali AS, Annamalai K: Performance of Omani goats fed diets containing various metabolizable energy densities. *Small Ruminant Res*, 58, 175-180, 2005. DOI: 10.1016/j.smallrumres.2004.09.008

17. Lu CD, Kawas JR, Mahgoub OG: Fiber digestion and utilization in goats. *Small Ruminant Res*, 60, 45-52, 2005. DOI: 10.1016/j.smallrumres.2005.06.035

18. Walsh K, O'Kiely P, Taweel HZ, McGee M, Moloney AP, Boland TM: Intake, digestibility and rumen characteristics in cattle offered whole-crop wheat or barley silages of contrasting grain to straw ratios. *Anim Feed Sci Techol*, 148, 192-213, 2009.DOI: 10.1016/j.anifeedsci.2008.03.013

19. Can A, Denek N, Seker M: Effect of harsh environmental conditions on nutrient utilization and blood parameters of Awassi sheep and kilis goat fed different levels of concentrate feed. *J Appl Anim Res*, 33, 39-43, 2008. DOI: 10.1080/09712119.2008.9706893

20. Plaizier JC, Keunen JE, Walton JP, Duffield TF, McBride BW: Effect of subacute ruminal acidosis on in situ digestion of mixed hay in lactating dairy cows. *Can J Anim Sci*, 81, 421-423, 2001. DOI: 10.4141/A00-106

21. Zervas G, Feggeros K, Karopuntzou E, Papadopoulos G: Nutritive evaluation of whole cotton seed for sheep. *Epitheorese Zootehnikes Epistemes*, 11, 25-38, 1990.

22. Nocek JE, Russell JB: Protein and energy as an integrated system-Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. *J Dairy Sci*, 71, 2070-2107, 1988. DOI: 10.3168/jds.S0022-0302(88)79782-9

23. Lallo CHO: Feed intake and nitrogen utilization by growing goats fed by-product based diets of different protein and energy levels. *Small Ruminant Res*, 22, 193-204, 1996. DOI: 10.1016/s0921-4488(96)00890-5

24. Bach A, Calsamiglia S, Stern MD: Nitrogen metabolism in the rumen. *J Dairy Sci*, 88 (Suppl. 1): E9-E21, 2005. DOI: 10.3168/jds.S0022-0302(05)73133-7

25. Lapierre H, Lobley GE: Nitrogen recycling in the ruminant: A review. *J Dairy Sci*, 84, E223-E236, 2001. DOI: 10.3168/jds.s0022-0302(01)70222-6

26. Marini JC, Klein JD, Sands JM, Van Amburgh ME: Effect of nitrogen intake on nitrogen recycling and urea transporter abundance in lambs. *J Anim Sci*, 82, 1157-1164, 2004.

27. Gozho GN, Krause DO, Plaizier JC: Ruminal lipopolysaccharide concentration and inflammatory response during grain-induced subacute ruminal acidosis in dairy cows. *J Dairy Sci*, 90, 856-866, 2007. DOI: 10.3168/jds.s0022-0302(07)71569-2

28. Contreras-Duarte S, Varas P, Awad F, Busso D, Rigotti A: Protective role of high density lipoproteins in sepsis: Basic issues and clinical implications. *Rev Chil Infectol*, 31, 34-43, 2014. DOI: 10.4067/S0716-10182014000100005

29. Baumberger C, Ulevitch RJ, Dayer JM: Modulation of endotoxic activity of lipopolysaccharide by high-density lipoprotein. *Pathobiology*, 59, 378-383, 1991. DOI: 10.1159/000163681

30. Abdel-Maksoud M, Sazonov V, Gutkin SW, Hokanson JE: Effects of modifying triglycerides and triglyceride-rich lipoproteins on cardiovascular outcomes. *J Cardiovasc Pharmacol*, 51, 331-351, 2008. DOI: 10.1097/fjc.0b013e318165e2e7

31. Howlett CM, Vanzant E, Anderson L, Burris W, Fieser B, Bapst R: Effect of supplemental nutrient source on heifer growth and reproductive performance, and on utilization of corn silage-based diets by beef steers. *J Anim Sci*, 81, 2367-2378, 2003. DOI: 10.1080/09637480310001595261

32. Kuwahata M, Kido Y: Branched chain amino acid supplementation and plasma albumin. **In,** Rajendram R, Preedy V, Patel V (Eds): Branched Chain Amino Acids in Clinical Nutrition. Nutrition and Health, Humana Press, New York, NY, 2015. DOI: 10.1007/978-1-4939-1914-7_12

33. Kaneko JJ, Harvey JW, Bruss ML: Clinical Biochemistry of Domestic Animals. Vth ed., Academic Press, San Diego, California, USA, 1997.

34. Liu H, Bravata DM, Olkin I, Nayak S, Roberts B, Garber AM, Hoffman AR: Systematic review: The safety and efficacy of growth hormone in the healthy elderly. *Ann Intern Med*, 146, 104-115, 2007. DOI: 10.7326/0003-4819-146-2-200701160-00005

35. Medrano JF, Bradford GE: Growth performance and plasma insulin-like growth factor-1 concentrations in sheep selected for high weaning weight. *J Anim Sci*, 69, 1912-1918, 1991.

36. Selwood T, Jaffe EK: Dynamic dissociating homo-oligomers and the control of protein function. *Arch Biochem Biophys,* 519, 131-143, 2012. DOI: 10.1016/j.abb.2011.11.020

37. Khaing KT, Loh TC, Ghizan S, Jahromi MF, Halim RA, Samsudin AA: Profiling of rumen fermentation and microbial population changes in goats fed with napier grass supplemented with whole corn plant silage. *Asian J Anim Sci*, 10, 1-14, 2016.

38. Ghorbani GR, Morgavi DP, Beauchemin KA, Leedle JAZ: Effects of bacterial direct-fed microbials on ruminal fermentation, blood variables, and the microbial populations feedlot cattle. *J Anim Sci*, 80, 1977–1985, 2002. DOI: 10.2527/2002.8071977x

39. Nagaraja TG, Titgemeyer EC: Ruminal acidosis in beef cattle: The current microbiological and nutritional outlook. *J Dairy Sci*, 90, E17–E38, 2007. DOI: 10.3168/jds.2006-478

40. Oetzel GR, Nordlund KV, Garrett EF: Effect of ruminal pH and stage of lactation on ruminal lactate concentrations in dairy cows. *J Dairy Sci*, 82 (Suppl. 1): 38, 1999. DOI: 10.3168/jds.2015-9721

41. Ribeiro CVDM, Karnati SKR, Eastridge ML: Biohydrogenation of fatty acids and digestibility of fresh alfalfa or alfalfa hay plus sucrose in continuous culture. *J Dairy Sci*, 88, 4007-4017, 2005. DOI: 10.3168/jds.s0022-0302(05)73087-3

42. Mao SY, Huo WJ, Zhu WY: Microbiome-metabolome analysis reveals unhealthy alterations in the composition and metabolism of ruminal microbiota with increasing dietary grain in a goat model. *Environ Microbiol*, 18, 525-541, 2016. DOI: 10.1111/1462-2920.12724