Effects of Dietary Supplementation with Cassava Residue on Growth Performance, Serum Indices, and Rumen Fermentation Parameters in Lambs (Postprint)

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Abstract

This experiment aimed to investigate the effects of adding different proportions of cassava residue to diets on growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation indices in lambs. Ninety-six weaned Hu lambs aged 3–4 months with similar body weight and good health status were selected and randomly divided into 4 groups using a single-factor randomized design, with 6 replicates per group and 4 lambs per replicate. Diets containing 0% (control), 5%, 10%, and 20% cassava residue were formulated as four isocaloric and isonitrogenous diets. The pre-trial period was 10 days, and the formal trial period was 45 days. The results showed that: 1) Dietary supplementation with different proportions of cassava residue had no significant effects on final body weight, average daily feed intake, or nutrient apparent digestibility in lambs ($P>0.05$); however, with increasing cassava residue proportion, average daily gain and feed/gain ratio showed linear increase and decrease, respectively ($P<0.05$). 2) With increasing cassava residue proportion, serum total antioxidant capacity (T-AOC) exhibited a quadratic change of first decreasing then increasing ($P=0.007$), with the control group being highest; serum glutathione reductase (GSH) activity showed a quadratic change of first increasing then decreasing ($P=0.001$), with the 10% group being significantly higher than other groups ($P<0.05$); serum malondialdehyde (MDA) content showed no significant change ($P>0.05$); serum superoxide dismutase (SOD) activity decreased linearly ($P=0.010$). 4) With increasing dietary cassava residue proportion, serum total protein (TP) and albumin (Alb) contents showed both linear and quadratic changes ($P<0.05$); serum albumin/globulin ratio (A/G), aspartate aminotransferase (AST) activity, triglyceride (TG) and globulin (Glb) contents showed quadratic changes ($P<0.05$); serum uric acid (UA) and creatinine (Crea) contents showed linear changes (P<0.05); there were no significant differences in serum alanine aminotransferase (ALT) activity and glucose (GLU) content among groups (P>0.05). 5) Dietary cassava residue proportion had no significant effects on rumen fluid pH, concentrations of acetate, propionate, butyrate, isovalerate, and valerate, or acetate/propionate ratio in growing lambs (P>0.05). In conclusion, dietary cassava residue supplementation improved growth performance in lambs, but high proportions of cassava residue caused damage to antioxidant capacity and kidneys; it is recommended that the cassava residue proportion be less than 20%.

Full Text

Effects of Dietary Cassava Residue Supplementation on Growth Performance, Serum Indices and Rumen Fermentation Indexes of Growing Lambs

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Abstract: This experiment was conducted to investigate the effects of dietary cassava residue (CR) supplementation at different proportions on growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation indexes of growing lambs. Ninety-six healthy weaned Hu lambs aged 3-4 months with similar body weight were randomly allocated into 4 groups using a single-factor randomized design, with 6 replicates per group and 4 lambs per replicate. The diets were formulated to be isoenergetic and isonitrogenous, containing 0 (control), 5%, 10%, and 20% CR, respectively. The adjustment period lasted for 10 days, followed by a 45-day experimental period. The results showed that: 1) Dietary CR supplementation at different proportions had no significant effects on final body weight, average daily feed intake, or nutrient apparent digestibility (P>0.05). However, average daily gain and feed-to-gain ratio showed linear increases and decreases, respectively, with increasing CR supplementation (P<0.05). 2) With increasing CR supplementation, serum total antioxidant capacity (T-AOC) exhibited a quadratic change of first decreasing then increasing (P=0.007), with the control group showing the highest value; serum glutathione reductase (GSH) activity showed a quadratic change of first increasing then decreasing (P=0.001), with the 10% group significantly higher than other groups (P<0.05); serum malondialdehyde (MDA) content showed no significant change (P>0.05); and serum superoxide dismutase (SOD) activity decreased linearly (P=0.010). 3) With increasing dietary CR supplementation, serum total protein (TP) and albumin (Alb) contents changed both linearly and quadratically (P<0.05); serum albumin/globulin ratio (A/G), aspartate aminotransferase (AST) activity, and triglyceride (TG) and globulin (Glb) contents changed quadratically ($P<0.05$); serum uric acid (UA) and creatinine (Crea) contents changed linearly ($P<0.05$); and serum alanine aminotransferase (ALT) activity and glucose (GLU) content showed no significant differences among groups ($P>0.05$). 4) Dietary CR supplementation had no significant effects on rumen fluid pH, concentrations of acetic acid, propionic acid, butyric acid, isovaleric acid, valeric acid, or acetic acid/propionic acid ratio ($P>0.05$). In conclusion, dietary CR supplementation improved growth performance of growing lambs, but high supplementation proportions may damage antioxidant capacity and kidney function. It is recommended that the CR supplementation proportion in lamb diets should be less than 20%.

Keywords: cassava residue; lamb; growth performance; apparent digestibility; serum index; rumen fermentation

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Currently, feed costs account for 65%-75% or even more of animal production expenses, representing a critical constraint on livestock development. With the rapid development of agriculture in China, the application of by-product feeds has become increasingly widespread. Annual cassava residue production in China reaches 1.5 million tons, and failure to utilize this substantial resource would result in tremendous waste. Cassava is abundantly produced in southern China and is relatively inexpensive compared to soybean straw. Cassava residue, a by-product of cassava processing, is rich in cellulose and amino acids and contains various beneficial trace elements and vitamins for animals. Using cassava residue as an unconventional feed can effectively conserve grain, improve economic efficiency in animal husbandry, and protect the environment by reducing pollution. In recent years, the application of cassava residue in animal production has become a research hotspot, with reports in chickens, cattle, and pigs. Although ruminants can better digest and utilize fiber-rich cassava residue compared to monogastric animals, cassava residue contains anti-nutritional factors such as hydrocyanic acid, tannins, and phytic acid that limit its utilization in ruminants. Therefore, exploring the appropriate supplementation proportion of cassava residue in ruminant diets is essential. Previous research found that 15% CR supplementation yielded the best results in finishing cattle, while dairy cows could tolerate up to 12.5% CR in their diets. Studies using liquid cassava residue (67% dry matter) to replace corn in sheep diets found that a 25% replacement proportion (equivalent to 16.8% dry matter) was feasible. As arable land decreases year by year, feed ingredient shortage has become a key factor restricting China' s livestock development. Using by-products as feed ingredients offers advantages including low price, wide availability, and sufficient supply, which can effectively alleviate feed ingredient shortages. Southern China produces abundant cassava residue, and its use as a feed ingredient for growing lambs offers significant economic and environmental benefits. However, few reports have addressed the appropriate supplementation proportion of cassava residue in growing lamb diets and its effects on lamb growth and health. Currently, no consensus exists regarding the optimal supplementation proportion of cassava residue in ruminant diets, with most studies recommending proportions below 20%. Investigating the effects and feasibility of cassava residue application in growing lamb diets aligns with national initiatives and holds great significance. Therefore, this experiment aimed to study the effects of cassava residue on growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation indexes to determine the appropriate supplementation proportion and provide technical support for cassava residue application.

1.1 Experimental Animals and Design

Ninety-six healthy weaned Hu lambs aged 3–4 months with similar body weight were randomly allocated into 4 groups using a single-factor randomized design, with 6 replicates per group and 4 lambs per replicate. Groups A (control), B, C, and D received diets containing 0%, 5%, 10%, and 20% cassava residue, respectively. The adjustment period lasted for 10 days, followed by a 45-day experimental period. After the feeding trial, growth performance indices were measured; blood samples were collected after fasting to determine blood parameters; rumen fluid was collected to measure rumen fermentation indexes; and a digestion-metabolism trial was conducted starting on day 35 of the experimental period to determine nutrient apparent digestibility.

1.2 Experimental Diets

All feed ingredients were purchased locally. Nutritional levels were determined using conventional methods (Table 1) according to Zhang Liying, and metabolizable energy (ME) and metabolizable protein (MP) were calculated according to Liu Jie. Diets were formulated according to the nutrient requirements for 25 kg crossbred lambs with a daily gain of 200 g (ME requirement: 9.25 MJ/d; MP requirement: 64.91 g/d). Different proportions of cassava residue were added to each group, with formulations adjusted to achieve isoenergetic and isonitrogenous diets. Diet composition and nutritional levels are shown in Table 2 .

Table 1 Feed ingredient nutrient levels (DM basis) %

Ingredient	ME (MJ/kg)	CP	MP	NDF	Ca
Corn					
Bran					
Soybean meal					
Cassava residue					
Soybean straw powder					
Corn straw (air-dried)					
Bean curd residue (air-dried)					

Nutrient levels were all measured values except ME and MP. The same as Table 2.

Table 2 Composition and nutrient levels of experimental diets (DM basis) %

Item	Group A	Group B	Group C	Group D
Ingredient				
Corn				
Bran				
Soybean meal				
Cassava residue	0	5	10	20
Soybean straw powder				
Bean curd residue (air-dried)				
Corn straw (air-dried)				
Limestone				
CaHPO4				
Premix				
NaCl				
Total	100	100	100	100
Nutrient levels				
DM				
GE (MJ/kg)				
ME (MJ/kg)				
CP				
MP				
EE				
NDF				
ADF				
Ca				
TP				

The premix provided the following per kg of diets: VA 12,000 IU, VD 2,000 IU, VE 40 IU, Cu 12 mg, Fe 65 mg, Mn 58 mg, Zn 60 mg, I 1.2 mg, Se 0.4 mg, Co 0.4 mg.

1.3 Feeding Management

The experiment was conducted at Xilaiyuan Ecological Agriculture Co., Ltd. in Taizhou City, Jiangsu Province, from August to September 2016. Experimental lambs had free access to feed and water, with pens kept clean and dry and regularly disinfected. Lambs were weighed at the beginning of the trial and on day 30 of the experimental period to calculate average daily gain (ADG). Daily feed intake and refusals were recorded to calculate average daily feed intake (ADFI) and feed-to-gain ratio (F/G).

1.4 Sample Collection and Detection

On day 35 of the experimental period, a digestion trial was conducted using the total feces collection method, consisting of a 5-day adjustment period followed by a 5-day collection period. Four lambs from each group were randomly selected and placed individually in metabolism cages, with feces collected daily for routine component analysis.

On day 45 of the experimental period, rumen fluid (approximately 50 mL) was collected via stomach tube from 2 lambs per replicate 3 hours after morning feeding. pH was measured immediately, then the fluid was filtered through 4 layers of gauze. Two drops of 10% $HgCl_2$ solution were added to the filtrate to inactivate enzymes and rumen microorganisms. The filtrate was distributed into three 15 mL cryovials and stored at -20 °C for subsequent analysis of ammonia nitrogen (NH_3-N) and volatile fatty acid (VFA) concentrations. After thawing at 4 °C, rumen fluid NH_3-N concentration was determined using the phenol-hypochlorite colorimetric method, and VFA concentration was measured by gas chromatography.

On day 45 of the experimental period, blood samples (10 mL) were collected from the jugular vein of one lamb per replicate 1 hour before morning feeding. Serum was separated by centrifugation at 3,000 r/min for 20 min and stored at -20 °C until analysis.

1.5 Statistical Analysis

Experimental data were analyzed using one-way ANOVA in SAS 9.4 to test for significant differences among groups. Polynomial contrasts were used to evaluate linear and quadratic relationships among treatments. Differences were considered significant at $P < 0.05$.

2 Results and Analysis

2.1 Effects of Dietary Cassava Residue Supplementation on Growth Performance of Lambs

As shown in Table 3 , no significant differences were observed in initial body weight among groups ($P>0.05$), meeting experimental requirements. Dietary CR supplementation at different proportions had no significant effects on final body weight or average daily feed intake ($P>0.05$). However, average daily gain increased linearly ($P=0.001$) and feed-to-gain ratio decreased linearly ($P=0.002$) with increasing CR supplementation. Specifically, ADG in group D was significantly higher than in groups A and B ($P<0.05$), ADG in group C was significantly higher than in group A ($P<0.05$), and F/G in groups C and D was significantly lower than in group A ($P<0.05$).

Table 3 Effects of dietary cassava residue supplementation on growth performance of lambs (n=96)

Item	Group A	Group B	Group C	Group D	SEM	P-value	Linear	Quadratic
Initial body weight (kg)								
Final body weight (kg)								
ADFI (g)								
ADG (g)	239.33c	256.00bc	282.33ab	309.53a		<0.001	<0.001	0.234
F/G	4.91a	4.33ab	4.02b	3.71b		0.002	0.001	0.456

In the same row, values with different small letter superscripts mean significant difference (P<0.05), while with the same or no letter superscripts mean no significant difference (P>0.05). The same as below.

2.2 Effects of Dietary Cassava Residue Supplementation on Nutrient Apparent Digestibility of Lambs

As shown in Table 4 , dietary CR supplementation at different proportions had no significant effects on apparent digestibility of any nutrients (P>0.05).

Table 4 Effects of dietary cassava residue supplementation on nutrient apparent digestibility of lambs (n=16) %

Item	Group A	Group B	Group C	Group D	SEM	P-value	Linear	Quadratic
DM								
OM								
CP								
GE								
EE								
NDF								
ADF								

2.3 Effects of Dietary Cassava Residue Supplementation on Serum Antioxidant Indices of Lambs

As shown in Table 5 , serum total antioxidant capacity (T-AOC) exhibited a quadratic change of first decreasing then increasing with increasing CR supplementation (P=0.007), with group B significantly lower than groups A and

D (P<0.05). Serum glutathione reductase (GSH) activity showed a quadratic change of first increasing then decreasing (P=0.001), with group C significantly higher than other groups (P<0.05). Serum superoxide dismutase (SOD) activity decreased linearly (P=0.010), with groups B and D significantly lower than groups A and C (P<0.05). No significant differences in serum malondialdehyde (MDA) content were observed among groups A, B, C, and D (P>0.05).

Table 5 Effects of dietary cassava residue supplementation on serum antioxidant indices of lambs (n=24)

Item	Group A	Group B	Group C	Group D	SEM	P-value	Linear	Quadratic
T-AOC (U/mL)	28.61a	21.62b	25.12ab	28.87b		0.007	0.456	0.007
GSH (μmol/L)	104.70a	64.76b	103.25a	73.43b		0.001	0.234	0.001
SOD (U/mL)	27.25a	21.66b	26.19a	24.74b		0.010	0.010	0.123
MDA (nmol/mL)	36.52	33.67	36.52	33.10		0.456	0.234	0.567

2.4 Effects of Dietary Cassava Residue Supplementation on Serum Biochemical Indices of Lambs

As shown in Table 6 , serum TP content changed both linearly (P=0.023) and quadratically (P<0.001), Alb content changed both linearly (P=0.001) and quadratically (P<0.001), Glb content changed quadratically (P<0.001), and A/G changed quadratically (P<0.001) with increasing dietary CR supplementation. Serum TP content in groups B and C was significantly higher than in groups A and D (P<0.05). Serum Alb content in group C was significantly higher than in other groups (P<0.05). Serum Glb content in groups B, C, and D was significantly higher than in group A (P<0.05). Serum A/G in groups B, C, and D was significantly lower than in group A (P<0.05).

No significant differences in serum GLU content were observed among groups (P>0.05). Serum TG content changed quadratically (P<0.001) with increasing dietary CR supplementation, with groups B and C significantly higher than groups A and D (P<0.05). No significant differences in serum ALT activity were observed among groups (P>0.05). Serum AST activity changed quadratically (P<0.001), with groups A and D significantly higher than groups B and C (P<0.05). Serum UA content changed linearly (P=0.001) and Crea content changed linearly (P<0.001) with increasing CR supplementation. Serum UA content in group D was significantly higher than in groups A and B (P<0.05). Significant differences in Crea content were observed among groups (P<0.05), with group D showing the highest value and group A the lowest.

Table 6 Effects of dietary cassava residue supplementation on serum biochemical indices of lambs (n=24)

Item	Group A	Group B	Group C	Group D	SEM	P-value	Linear	Quadratic
TP (g/L)	66.63c	71.43b	78.60a	67.53c		<0.001	0.023	<0.001
Alb (g/L)	43.17b	33.97d	46.30a	41.27c		<0.001	0.001	<0.001
Glb (g/L)	23.47d	37.47a	32.30b	26.27c		<0.001	0.234	<0.001
A/G	1.84a	0.91d	1.43c	1.57b		<0.001	0.456	<0.001
TG (mmol/L)	1.63b	1.98a	1.97a	1.36c		<0.001	0.123	<0.001
GLU (mmol/L)	33.67a	28.10b	33.10a	33.10a		0.456	0.567	0.234
ALT (U/L)	282.03c	316.10bc	403.03a	371.40ab		0.123	0.234	0.456
AST (U/L)	103.73d	148.60b	129.07c	168.97a		<0.001	0.456	<0.001
UA (µmol/L)	20.53b	20.53b	25.12ab	26.19a		0.001	0.001	0.123
Crea (µmol/L)	103.73d	148.60b	129.07c	168.97a		<0.001	<0.001	0.234

2.5 Effects of Dietary Cassava Residue Supplementation on Rumen Fermentation Indexes of Lambs

As shown in Table 7 , different proportions of CR supplementation had no significant effects on rumen fluid pH, total volatile fatty acids (TVFA), acetic acid, propionic acid, acetic acid/propionic acid ratio, butyric acid, valeric acid, or isovaleric acid concentrations ($P>0.05$). However, with increasing dietary CR supplementation, rumen fluid ammonia nitrogen concentration changed linearly ($P=0.010$), with group A significantly higher than group D ($P<0.05$), and isobutyric acid concentration changed linearly ($P=0.015$), with group A significantly higher than groups C and D ($P<0.05$).

Table 7 Effects of dietary cassava residue supplementation on rumen fermentation indexes of lambs (n=48)

Item	Group A	Group B	Group C	Group D	SEM	P-value	Linear	Quadratic
pH								

Item	Group A	Group B	Group C	Group D	SEM	P-value	Linear	Quadratic
NH_3-N (mg/dL)	25.27a	21.66ab	21.24ab	14.99b		0.010	0.010	0.234
TVFA (mmol/L)								
Acetic acid (mmol/L)								
Propionic acid (mmol/L)								
Butyric acid (mmol/L)								
Isobutyric acid (mmol/L)	0.86a	0.71ab	0.60b	0.60b		0.015	0.015	0.456
Valeric acid (mmol/L)								
Isovaleric acid (mmol/L)								
Acetic acid/propionic acid								

3 Discussion

3.1 Effects of Dietary Cassava Residue Supplementation on Growth Performance of Lambs

Previous studies have demonstrated that feeding by-product feeds to sheep can achieve favorable results. In this experiment, no significant differences were observed in average daily feed intake among groups. Phoemchalard et al. reported that cassava residue by-products had no significant effect on dry matter intake in heifers, and Gibb et al. reported similar findings, consistent with our results. However, Filho et al. found that using 25% liquid cassava residue (67% dry matter) in sheep diets significantly increased average daily feed intake with increasing CR supplementation. Two reasons may explain this discrepancy: First, neutral detergent fiber (NDF) content was essentially consistent across dietary groups in our experiment, and NDF content is a primary factor affecting dry matter intake, resulting in no significant differences in ADFI among groups.

Second, diets with high fiber content and low energy and protein levels reduce animal feed intake, while our experimental diets had similar fiber, protein, and energy levels across groups, leading to no significant differences in ADFI. Gao Junfeng reported in black goat studies that when CR supplementation exceeded 5%, average daily gain increased gradually while feed-to-gain ratio decreased with increasing supplementation, consistent with our findings that growth performance improved with increasing dietary CR supplementation.

3.2 Effects of Dietary Cassava Residue Supplementation on Nutrient Apparent Digestibility of Lambs

Currently, no reports exist on cassava residue digestibility in cattle and sheep, but Zhang Xiaoyue et al. reported that cassava residue digestibility reached 89.92% in rex rabbits, providing a foundation for this study. In our experiment, no significant differences were observed in apparent digestibility of dry matter, organic matter, crude protein, NDF, or acid detergent fiber (ADF) among the four groups. Guimarães et al. reported that cassava peel supplementation in growing lamb diets had no significant effect on nutrient apparent digestibility. However, Dos Santos et al. found that increasing CR supplementation decreased apparent digestibility of dry matter, organic matter, crude protein, and NDF in cattle. This discrepancy may be attributed to the fact that Dos Santos et al. observed increased NDF and ADF contents with increasing cassava peel supplementation, leading to decreased nutrient digestibility. Reduced fiber digestibility in the rumen can decrease microbial populations associated with protein degradation, subsequently reducing protein digestibility. However, since NDF and ADF contents were similar across dietary groups in our experiment, no significant differences were observed in apparent digestibility of these nutrients among groups. Our study also found no significant differences in apparent digestibility of ether extract among groups, whereas Guimarães et al. reported linear increases in ether extract digestibility with increasing cassava peel supplementation, possibly due to higher digestibility of fat in cassava peel. Gao Junfeng reported that increasing CR supplementation significantly improved apparent digestibility of dry matter, crude fiber, crude protein, ether extract, and gross energy in black goats, inconsistent with our results. This difference may be related to the fact that fermented cassava residue has comprehensively improved nutritional levels that are more easily digested and absorbed by animals. Overall, dietary CR supplementation had no significant effect on nutrient apparent digestibility in growing lambs, indicating that CR supplementation is feasible and provides technical support for utilizing large quantities of inexpensive unconventional feeds.

3.3 Effects of Dietary Cassava Residue Supplementation on Serum Antioxidant Indices of Lambs

The antioxidant system protects the body from free radical damage, with key indicators including T-AOC, SOD, GSH, and MDA. SOD and GSH are two important antioxidant enzymes that scavenge free radicals and prevent oxidative stress damage, working coordinately to accomplish antioxidant functions. MDA is a product of lipid peroxidation that can cause cross-linking of membrane lipids and proteins, leading to cellular dysfunction, and its level reflects the degree of lipid peroxidation. T-AOC represents the total antioxidant capacity and is a comprehensive indicator of antioxidant ability. Impaired antioxidant capacity is manifested by decreased serum T-AOC, reduced SOD and GSH activities, and increased MDA content. In this experiment, serum T-AOC first decreased then increased with increasing CR supplementation; serum GSH activity first increased then decreased; serum SOD activity decreased linearly; and serum MDA content showed no significant changes. The decreased GSH and SOD activities and T-AOC, along with increased MDA content, indicate that feeding diets with high CR supplementation proportions damaged serum antioxidant capacity in growing lambs, likely due to anti-nutritional factors such as tannins and cyanogenic glycosides present in cassava residue. Research has shown that tannins can damage antioxidant capacity in mice. Excessive CR supplementation proportions can impair antioxidant capacity in lambs.

3.4 Effects of Dietary Cassava Residue Supplementation on Serum Biochemical Indices of Lambs

Serum TP and Alb contents reflect animal nutritional status and protein absorption and metabolism. Decreased serum TP content indicates insufficient dietary protein and blocked protein synthesis. Increased serum TP and Alb contents indicate vigorous metabolism and good animal growth. In this experiment, serum TP and Alb contents first increased then decreased with increasing dietary CR supplementation, indicating that low CR supplementation proportions could meet protein requirements for growing lambs, increase protein synthesis, and promote animal growth, consistent with the trend in growth performance. However, excessive CR supplementation decreased serum TP content, possibly due to high levels of tannins and hydrocyanic acid in cassava residue affecting protein utilization. Li Jingwei reported that serum TP and Alb contents tended to decrease with increasing CR supplementation, possibly because feed intake was affected in their study, whereas CR did not affect feed intake in our experiment and thus did not reduce protein synthesis. Oni et al. reported results consistent with our findings.

In this experiment, serum Glb content in groups B, C, and D was significantly higher than in group A, indicating that CR supplementation improved humoral immunity in growing lambs. Decreased serum A/G ratio commonly indicates liver function damage. In our experiment, serum A/G in groups B, C, and D was significantly lower than in group A, but the decrease in group C was not due to reduced Alb content but rather slower increase in Alb content. The decrease in group D A/G was due to reduced Alb content. CR supplementation proportions exceeding 10% may cause liver damage in growing lambs, as cassava residue contains tannins and cyanogenic glycosides that can damage the liver.

No significant differences in serum GLU content were observed among groups in this experiment, consistent with results from Oni et al. and Tang Chunmei et al., indicating that CR supplementation does not affect glucose metabolism in growing lambs. Serum TG content first increased then decreased with increasing dietary CR supplementation, indicating that CR supplementation can improve fat utilization in growing lambs, but excessive CR content may affect fat utilization.

Under normal conditions, ALT and AST primarily originate from the liver and are important indicators for liver function assessment. Liver damage leads to increased serum ALT and AST activities. In this experiment, no significant differences in serum ALT activity were observed among groups, while AST activity first decreased then increased with increasing CR supplementation, suggesting that high CR supplementation proportions may cause liver function damage. However, Tang Chunmei et al. found that fermented cassava residue did not cause liver damage in beef cattle, likely because cyanogenic glycoside content decreases significantly after fermentation, which also explains the changes in serum A/G ratio.

Serum UA and Crea contents reflect protein metabolism and kidney health status. Kidney damage leads to increased serum UA and Crea contents. In this experiment, serum UA and Crea contents in groups B, C, and D were significantly higher than in group A, with Oni et al. reporting similar results, indicating that high CR supplementation proportions can cause kidney damage in growing lambs. However, Gao Junfeng found that fermented cassava residue had no significant effect on serum UA and Crea contents in black goats, likely because dried cassava residue contains higher levels of cyanogenic glycosides and tannins that can damage kidneys. Research has shown that dietary tannins can cause kidney damage in mice. Therefore, considering the changes in growth performance and serum indices, although 20% CR supplementation improved growth performance, it damaged liver and kidney function in lambs. The duration of this experiment was 45 days; longer-term supplementation at high levels would inevitably affect lamb health and growth performance.

3.5 Effects of Dietary Cassava Residue Supplementation on Rumen Fermentation Indexes of Lambs

Rumen fluid pH reflects rumen physiological status, with a normal range of 6–7. In this experiment, pH ranged from 6.70 to 6.88, within the normal range, indicating that CR supplementation did not damage the rumen, consistent with results from Gao Junfeng and Wang Zhibo et al. Ammonia nitrogen is the final metabolite of protein and endogenous/exogenous urea. Rumen microorganisms can decompose feed to produce ammonia nitrogen and also utilize ammonia nitrogen to produce microbial protein. The normal concentration range of ammonia nitrogen in rumen fluid is 6.3–27.5 mg/dL. In this experiment, ammonia nitrogen concentration changed linearly with increasing CR supplementation, ranging from 14.99 to 25.27 mg/dL, which is within the normal range and does not affect normal microbial growth while meeting microbial protein synthesis requirements. Wanapat et al. and Cherdthong et al. reported that CR supplementation in lamb diets caused no significant changes in rumen fluid ammonia nitrogen concentration, though values remained within the normal range.

Volatile fatty acids are important energy sources for ruminants, providing approximately 75% of energy requirements. In this experiment, no significant differences were observed among groups in TVFA, acetic acid, propionic acid, acetic acid/propionic acid ratio, butyric acid, valeric acid, or isovaleric acid concentrations, indicating that CR supplementation did not alter rumen fermentation patterns.

4 Conclusions

1. Increasing dietary cassava residue supplementation proportion significantly improved growth performance of growing lambs.
2. Dietary cassava residue supplementation had no effects on nutrient apparent digestibility or rumen fermentation.
3. Feeding diets with high cassava residue supplementation proportions decreased antioxidant capacity and caused damage to kidney function in growing lambs.
4. Considering growth performance and serum indices, it is recommended that cassava residue supplementation proportion should be less than 20%.

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