Effects of Whole-Plant Sugarcane on Growth Performance, Nutrient Apparent Digestibility, Serum Biochemical Indices, and Rumen Fermentation Parameters in Goats (Postprint)

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Abstract

This experiment aimed to investigate the effects of dietary supplementation with different proportions of whole-plant sugarcane on growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation parameters in goats. Ninety-six weaned goats aged 4–5 months with similar body weight and good health status were randomly divided into 4 groups with 3 replicates per group and 8 goats per replicate. The control group (CON group) was fed a basal diet, while the experimental groups (SC33, SC66, and SC100 groups) were fed diets in which 33%, 66%, and 100% of whole-plant corn silage was replaced by whole-plant sugarcane, respectively. The preliminary period lasted 5 days, and the formal experimental period lasted 30 days. The results showed that: 1) There were no significant differences in final body weight, average daily gain (ADG), or feed conversion ratio (FCR) among groups ($P > 0.05$). With increasing proportion of whole-plant sugarcane supplementation, the average daily feed intake (ADFI) of goats increased linearly ($P < 0.05$), and the ADFI in the SC100 group was significantly higher than in the other three groups ($P < 0.05$). 2) With increasing proportion of whole-plant sugarcane supplementation, the apparent digestibility of dry matter, organic matter, gross energy, neutral detergent fiber (NDF), and acid detergent fiber (ADF) decreased linearly ($P < 0.05$), and both the CON and SC33 groups were significantly higher than the SC66 and SC100 groups ($P < 0.05$). 3) With increasing proportion of whole-plant sugarcane supplementation, serum total antioxidant capacity (T-AOC) and superoxide dismutase (SOD) activity increased linearly ($P < 0.05$), and both the SC66 and SC100 groups were significantly higher than the CON and SC33 groups ($P < 0.05$); serum malondialdehyde (MDA) content decreased linearly ($P < 0.05$), and the SC66 and SC100 groups were significantly lower than the

CON and SC33 groups ($P < 0.05$). 4) Serum immunoglobulin G content in the SC100 group was significantly lower than in the CON and SC66 groups ($P < 0.05$), serum immunoglobulin A content in the SC66 group was significantly lower than in the other three groups ($P < 0.05$), and serum immunoglobulin M content in the SC66 and SC100 groups was significantly higher than in the CON and SC33 groups ($P < 0.05$). Serum uric acid content in the CON and SC100 groups was significantly higher than in the SC33 and SC66 groups ($P < 0.05$), and serum creatinine content in the SC100 group was significantly higher than in the other three groups ($P < 0.05$). 5) Rumen fluid total volatile fatty acids concentration in the CON group was significantly higher than in the SC66 group ($P < 0.05$), the acetate proportion in the CON group was significantly higher than in the other three groups ($P < 0.05$), the propionate proportion in the SC100 group was significantly higher than in the other three groups ($P < 0.05$), and the acetate/propionate ratio in the CON group was significantly higher than in the other three groups ($P < 0.05$). In summary, dietary supplementation with whole-plant sugarcane is beneficial for improving feed intake performance and enhancing antioxidant capacity and immunity in goats. The recommended appropriate supplementation proportion of whole-plant sugarcane is 33%-66%.

Full Text

Effects of Whole Sugarcane on Growth Performance, Nutrient Apparent Digestibility, Serum Indices, and Rumen Fermentation Parameters in Goats

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Abstract

This experiment investigated the effects of dietary supplementation with different proportions of whole sugarcane on growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation parameters in goats. Ninety-six healthy weaned goats aged 4–5 months with similar body weight were randomly allocated into four groups with three replicates per group and eight goats per replicate. The control group (CON) received a basal diet, while the experimental groups (SC33, SC66, and SC100) had 33%, 66%, and 100% of whole silage corn replaced by whole sugarcane, respectively. The pre-experimental period lasted 5 days, followed by a 30-day formal experimental period.

The results showed: (1) No significant differences were observed in final body weight, average daily gain, or feed-to-gain ratio among groups ($P > 0.05$). However, average daily feed intake (ADFI) increased linearly with increasing sugarcane proportion ($P < 0.05$), with the SC100 group showing significantly higher ADFI than the other three groups ($P < 0.05$). (2) The apparent digestibility of dry matter, organic matter, gross energy, neutral detergent fiber (NDF), and acid detergent fiber (ADF) decreased linearly with increasing sugarcane proportion ($P < 0.05$), with the CON and SC33 groups significantly higher than the SC66 and SC100 groups ($P < 0.05$). (3) Serum total antioxidant capacity (T-AOC) and superoxide dismutase (SOD) activity increased linearly with increasing sugarcane proportion ($P < 0.05$), with the SC66 and SC100 groups significantly higher than the CON and SC33 groups ($P < 0.05$). Serum malondialdehyde (MDA) content decreased linearly ($P < 0.05$), with the SC66 and SC100 groups significantly lower than the CON and SC33 groups ($P < 0.05$). (4) The SC100 group had significantly lower serum immunoglobulin G (IgG) content than the CON and SC66 groups ($P < 0.05$), while the SC66 group showed significantly lower serum immunoglobulin A (IgA) content than the other three groups ($P < 0.05$). Serum immunoglobulin M (IgM) content in the SC66 and SC100 groups was significantly higher than in the CON and SC33 groups ($P < 0.05$). Serum uric acid content in the CON and SC100 groups was significantly higher than in the SC33 and SC66 groups ($P < 0.05$), and serum creatinine content in the SC100 group was significantly higher than in the other three groups ($P < 0.05$). (5) The CON group had significantly higher total volatile fatty acid (TVFA) concentration in rumen fluid than the SC66 group ($P < 0.05$). The acetic acid proportion in the CON group was significantly higher than in the other three groups ($P < 0.05$), while the propionic acid proportion in the SC100 group was significantly higher than in the other three groups ($P < 0.05$). The acetic acid/propionic acid ratio in the CON group was significantly higher than in the other three groups ($P < 0.05$).

In conclusion, dietary supplementation with whole sugarcane improved feed intake and enhanced antioxidant capacity and immunity in goats. The recommended suitable replacement proportion of whole sugarcane is 33%–66%.

Keywords: whole sugarcane; goats; growth performance; serum indices; rumen fermentation

Introduction

China ranks third globally in sugarcane cultivation area, with production concentrated in southern provinces including Guangxi, Guangdong, Yunnan, Sichuan, and Fujian. According to the China Statistical Yearbook 2016, by the end of 2015, China' s sugarcane planting area reached 1.6 million hectares with a production of 116.968 million tons, representing a substantial resource. Developing sugarcane for feed applications not only addresses the limitations of

single-product processing and poor market risk resistance but also effectively alleviates shortages of forage resources for herbivores, conserves grain, and reduces environmental pressure. Partial replacement of silage corn with sugarcane can reduce production costs without adversely affecting animal growth performance [1]. Compared with conventional energy feeds such as corn and sorghum, fresh sugarcane offers higher production value than nutritional value alone [2]. Sugarcane exhibits good palatability and is rich in antioxidant active substances, but its high crude fiber content and low digestibility limit its dietary inclusion level. Therefore, investigating the optimal proportion of sugarcane in ruminant diets is particularly important.

China' s goat population approaches 150 million, primarily raised in southern regions. With the adjustment of industrial structure in herbivorous livestock farming in these areas, the shortage of roughage resources has become a critical constraint on the sheep industry' s development, making the exploration of new roughage resources urgent. Previous studies have shown that feeding rapeseed straw pellets to growing Hu sheep does not affect growth performance and can reduce farming costs [3], while substituting part of corn with cassava residue has achieved good economic benefits in Hu sheep production [4]. However, research on the nutritional and feeding value of sugarcane and its byproducts as unconventional feed resources for cattle and sheep remains limited [5]. Studies on lactating cows suggest that a 33% sugarcane inclusion level yields good performance [6], but no reports have examined the optimal proportion of whole sugarcane in goat diets or its effects on growing goat performance. This study investigates the appropriate dietary proportion of sugarcane for goats by evaluating growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation parameters, providing technical support for practical application.

Materials and Methods

Experimental Animals and Design

Ninety-six healthy weaned Nubian goats aged 4–5 months with similar body weight were randomly divided into four groups with three replicates per group and eight goats per replicate. The control group (CON) received a basal diet, while the experimental groups (SC33, SC66, and SC100) had 33%, 66%, and 100% of whole silage corn replaced by whole sugarcane, respectively. The pre-experimental period lasted 5 days, during which sugarcane was gradually introduced at one-third and two-thirds of the target proportion before reaching the final experimental levels by day 5. The formal experimental period lasted 30 days.

Experimental Diets

All feed ingredients were sourced locally. The nutrient levels of feed ingredients and diets were determined according to Zhang Liying [7], and dietary metabolizable energy (ME) was calculated following Liu Jie [8]. The nutrient levels of feed ingredients are shown in Table 1 , and the composition and nutrient levels of experimental diets are presented in Table 2 .

Feeding Management

The experiment was conducted from July 18 to September 22, 2017, at Guangxi Fusui Guangyang Agricultural and Animal Husbandry Co., Ltd. in Fusui County, Chongzuo City, Guangxi Province. Each replicate of eight goats was housed in one pen with ear tags. Goats were kept in semi-open sheds with good ventilation. During the formal experimental period, goats were fed twice daily at 08:00 and 16:00 with free access to feed and water. Management followed standard farm practices, with pens kept clean and dry and regular disinfection performed.

Sample Collection and Analysis

Growth Performance At the beginning and on day 25 of the formal period, goats in each replicate were weighed as a group. Daily feed offered and refusals were recorded to calculate average daily gain (ADG), average daily feed intake (ADFI), and feed-to-gain ratio (F/G).

Nutrient Apparent Digestibility During the final 10 days of the experiment, fecal samples were collected using the internal indicator method (acid-insoluble ash) for digestibility determination. After a 5-day pre-collection period, feces were collected continuously for 5 days. One healthy goat with body weight close to the group average was selected from each replicate. Daily fecal collection of 200 g was mixed with 20 mL of 10% sulfuric acid and immediately frozen. After collection, all fecal samples from each goat were thoroughly mixed, and a portion was dried at 65°C to determine initial moisture content, then ground to pass through a 0.45 mm sieve for nutrient digestibility analysis.

Serum Indices On day 25 of the formal period, one hour before morning feeding, one goat was randomly selected from each replicate for jugular blood collection (10 mL) into silica-containing coagulation-promoting tubes. After standing for 30 minutes, samples were centrifuged at 3,000 rpm for 20 minutes, and serum was collected and stored at -20°C for antioxidant and biochemical analysis.

Rumen Fermentation Parameters On the day before the experiment ended, rumen fluid (approximately 50 mL) was collected from two randomly selected goats per replicate via stomach tube three hours after morning feeding.

pH was measured immediately, then the fluid was filtered through four layers of gauze. Two drops of 10% HgCl solution were added to the filtrate to inactivate enzymes and rumen microorganisms. The filtrate was aliquoted into three 15 mL cryovials and frozen at -20°C for ammonia nitrogen (NH -N) and volatile fatty acid (VFA) analysis. After thawing at 4°C, NH -N concentration was determined by the phenol-hypochlorite colorimetric method, and VFA concentration was measured by gas chromatography.

Statistical Analysis

Data were analyzed using one-way ANOVA in SPSS 19.0 to test for significant differences among groups. When significant differences were detected, Duncan' s multiple comparison test was applied. Polynomial contrasts were used to analyze linear and quadratic relationships with increasing sugarcane proportion. Significance was declared at $P < 0.05$.

Results

Effects of Dietary Whole Sugarcane on Growth Performance in Goats

As shown in Table 3 , initial body weight did not differ significantly among groups ($P > 0.05$), meeting experimental requirements. No significant differences were observed in final body weight, ADG, or F/G among groups ($P > 0.05$). However, ADFI increased linearly with increasing sugarcane proportion ($P < 0.05$), with the SC100 group showing significantly higher ADFI than the other three groups ($P < 0.05$).

Effects of Dietary Whole Sugarcane on Nutrient Apparent Digestibility in Goats

Table 4 shows that apparent digestibility of dry matter, organic matter, gross energy, NDF, and ADF decreased linearly with increasing sugarcane proportion ($P < 0.05$), with the CON and SC33 groups significantly higher than the SC66 and SC100 groups ($P < 0.05$). No significant differences were observed in crude protein or ether extract apparent digestibility among groups ($P > 0.05$).

Effects of Dietary Whole Sugarcane on Serum Antioxidant Indices in Goats

As presented in Table 5 , serum T-AOC and SOD activity increased linearly with increasing sugarcane proportion ($P < 0.05$), with the SC66 and SC100 groups significantly higher than the CON and SC33 groups ($P < 0.05$). The SC100 group also showed significantly higher T-AOC than the SC66 group ($P < 0.05$). Serum MDA content decreased linearly ($P < 0.05$), with the SC66 and SC100 groups significantly lower than the CON and SC33 groups ($P < 0.05$).

No significant differences were observed in serum glutathione reductase (GR) activity among groups ($P > 0.05$).

Effects of Dietary Whole Sugarcane on Serum Biochemical Indices in Goats

Table 6 shows that no significant differences were observed in serum total protein, albumin, globulin, growth hormone (GH), insulin-like growth factor 1 (IGF-1), or albumin/globulin ratio among groups ($P > 0.05$). The SC100 group had significantly lower serum IgG content than the CON and SC66 groups ($P < 0.05$), while the SC66 group showed significantly lower serum IgA content than the other three groups ($P < 0.05$). Serum IgM content increased linearly with increasing sugarcane proportion ($P < 0.05$), with the SC66 and SC100 groups significantly higher than the CON and SC33 groups ($P < 0.05$). Serum uric acid (UA) and creatinine (Crea) content showed quadratic changes ($P < 0.01$). The CON and SC100 groups had significantly higher serum UA content than the SC33 and SC66 groups ($P < 0.05$), and the SC100 group showed significantly higher serum Crea content than the other three groups ($P < 0.05$).

Effects of Dietary Whole Sugarcane on Rumen Fermentation Parameters in Goats

Table 7 demonstrates that rumen fluid TVFA concentration decreased linearly with increasing sugarcane proportion ($P < 0.05$), with the CON group significantly higher than the SC66 group ($P < 0.05$). The CON group had significantly higher acetic acid proportion than the other three groups ($P < 0.05$), while the SC100 group showed significantly higher propionic acid proportion than the other three groups ($P < 0.05$). The acetic acid/propionic acid ratio in the CON group was significantly higher than in the other three groups ($P < 0.05$), with the SC33 and SC66 groups significantly higher than the SC100 group ($P < 0.05$). No significant differences were observed in rumen pH or proportions of isobutyric acid, butyric acid, isovaleric acid, valeric acid, or NH -N concentration among groups ($P > 0.05$).

Discussion

Effects of Dietary Whole Sugarcane on Growth Performance in Goats

Green forage is an important feed resource for livestock, and proper combination with concentrate can improve animal growth performance. In this study, ADFI increased with increasing sugarcane proportion, consistent with findings reported by Vieira et al. [9]. Xin et al. [10] also observed increased ADFI in fattening sheep with higher dietary sugarcane tail pellet inclusion. However, some studies have reported different results. Huang et al. [11] found that ADFI did not correlate proportionally with sugarcane straw inclusion when feeding differ-

ent sugarcane straw formulations to goats, and Canizares et al. [12] reported the lowest dry matter intake when sugarcane replaced silage corn at 67%. Several factors may explain these discrepancies. First, dietary NDF content decreased with increasing sugarcane proportion in our study, and NDF content is a primary factor affecting feed intake, thus explaining the increased ADFI. Second, the fresh sugarcane used in our experiment was harvested during the growth period with high non-fibrous carbohydrate (especially sugar) content and adequate moisture, offering good palatability that could enhance intake. Third, sugarcane quality and processing methods affect goat feed intake. No significant differences in final body weight or ADG among groups align with findings from Junior et al. [13] in Holstein dairy cows. Tang et al. [14] reported no significant difference in F/G between water buffalo fed sugarcane tail silage versus corn straw silage, consistent with our results.

Effects of Dietary Whole Sugarcane on Nutrient Apparent Digestibility in Goats

Gao et al. [15] suggested that fiber from different sources affects nutrient apparent digestibility in goats even at similar NDF levels. Sugarcane fiber has low digestibility, increasing chewing and rumination time in ruminants [12]. Zhou et al. [16] reported fluctuating trends in crude protein and ether extract apparent digestibility with increasing proportions of sugarcane tail leaf silage replacing king grass, similar to our findings. In this study, apparent digestibility of dry matter, organic matter, gross energy, NDF, and ADF was highest at 33% sugarcane inclusion, possibly because the rumen and digestive tract require an adaptation period to sugarcane. The 33% inclusion level may represent an optimal adaptation stage. Reduced digestibility at higher inclusion levels may result from sugarcane fiber being less utilizable by rumen microbes, with excessive fiber accumulation in the digestive tract burdening the rumen. Rotta et al. [17] investigated different proportions of corn silage and fresh sugarcane as roughage for cattle and found that appropriate sugarcane inclusion improved dry matter and organic matter digestibility, though NDF digestibility was higher in the corn silage group. Teixeira et al. [18] reported that adding sugarcane to elephant grass silage reduced ADF apparent digestibility. These findings align with our results. Overall, appropriate replacement of corn silage with fresh sugarcane improved nutrient apparent digestibility in weaned goats, indicating that dietary sugarcane supplementation is feasible.

Effects of Dietary Whole Sugarcane on Serum Antioxidant Indices in Goats

The body maintains redox balance through an oxidative defense system, in which enzymes such as SOD and GR are widely distributed and constitute the primary enzymatic antioxidant system, acting as effective free radical scavengers. SOD reflects cellular aging 程度 by scavenging superoxide anions and dismutating oxygen radicals to prevent hydrogen peroxide damage. GR, primar-

ily located in mitochondrial and cytosolic compartments, clears both hydrogen peroxide and lipid peroxides [19]. MDA, a metabolite of lipid peroxidation from polyunsaturated fatty acids attacked by free radicals, serves as an indirect indicator of cellular oxidation since free radicals are unstable and difficult to detect directly. Excessive MDA disrupts cellular metabolism and causes functional impairment. T-AOC reflects overall antioxidant capacity as a comprehensive indicator closely related to health status. Clinical manifestations of bodily injury typically include reduced serum SOD and GR activities and decreased T-AOC. In this study, increasing sugarcane proportion linearly decreased serum MDA content while linearly increasing SOD activity and T-AOC, with no significant change in GR activity. These changes in bioactive substance levels demonstrate that dietary sugarcane supplementation enhances antioxidant capacity. Sun et al. [20] and Sartori et al. [21] extracted various phenolic compounds from sugarcane tops and leaves. Phenolic compounds effectively scavenge free radicals and chelate metal ions, achieving antioxidant effects [22]. Therefore, sugarcane as a green forage offers not only good palatability but also strong antioxidant properties, serving as a natural antioxidant source.

Effects of Dietary Whole Sugarcane on Serum Biochemical Indices in Goats

Serum total protein and albumin primarily reflect liver synthetic function and protein metabolism, closely related to immune function. Decreased serum total protein indicates abnormal liver function and suppressed protein metabolism pathways. Most serum uric acid (UA) is excreted through urine after renal metabolism of nitrogenous substances, and serum UA normally remains within a relatively constant range [23]. In this study, lower serum UA in treatment groups may be attributed to lower protein content in whole sugarcane compared to whole corn silage, resulting in slower protein catabolism and accelerated nitrogenous compound synthesis. Although serum UA differed among groups, all values remained within normal ranges. Min et al. [24] reported that serum UA decreased with reduced dietary energy levels, consistent with our findings. Serum UA and creatinine (Crea) are associated with protein metabolism [25] and kidney function, with abnormal levels linked to various diseases [26]. In this study, compared with the CON group, treatment groups showed decreased serum UA, while the SC66 and SC100 groups exhibited increased serum Crea, suggesting that appropriate sugarcane inclusion may alleviate kidney burden. Serum IgA, IgM, and IgG are antibodies produced during immune responses, while IGF-1 is a growth-promoting factor and active protein peptide. Our data showed that the SC66 group had lower serum IgA than other groups, while the SC66 and SC100 groups had higher serum IgM than the CON group, and the SC66 group had higher serum IgG than the CON group. No significant differences were observed in serum IGF-1 or GH levels, indicating that appropriate sugarcane supplementation enhances immune capacity. Tatsumi et al. [27] reported that feeding piglets a mixture of sugarcane extract and rice bran cake significantly enhanced neutrophil and monocyte phagocytic capacity and im-

proved immune function, showing similarities with our results.

Effects of Dietary Whole Sugarcane on Rumen Fermentation Parameters in Goats

Rumen pH is a crucial fermentation parameter, with the normal range considered to be 5.5–7.5. In this study, rumen pH ranged from 6.31 to 6.48, within the normal range, consistent with Magalhães et al. [6] in lactating dairy cows. Rumen NH -N is an important degradation product of protein and urea, which rumen microbes can utilize to synthesize microbial protein. The effective range for microbial protein synthesis is 5.0–30.0 mg/dL [28]. All treatment groups in this study had similar rumen NH -N concentrations within the normal range, indicating that sugarcane supplementation does not affect normal microbial growth and can meet microbial protein requirements, consistent with Gandra et al. [1] comparing corn silage and sugarcane silage diets. VFA metabolism provides most of the energy for rumen digestion and absorption, playing a vital role in maintaining the rumen environment. Acetic and propionic acids supply nutrients and energy to rumen microbes through different metabolic pathways, and the acetic acid/propionic acid ratio influences microbial structure, fermentation patterns, and energy utilization. Propionic acid is the primary precursor for hepatic gluconeogenesis in ruminants, and increased propionic acid proportion indicates improved energy utilization efficiency [29]. In this study, the CON group had the highest acetic acid proportion, lowest propionic acid proportion, and highest TVFA concentration and acetic acid/propionic acid ratio. With increasing sugarcane proportion, acetic acid proportion decreased significantly while propionic acid proportion increased, reducing the acetic acid/propionic acid ratio. Da Andrade et al. [30] found that dairy cows fed fresh sugarcane diets had lower rumen acetic acid/propionic acid ratios than those fed corn silage, similar to our results. The shift from acetic acid-dominant to propionic acid-dominant fermentation indicates that sugarcane supplementation improved dietary energy utilization efficiency. Although no significant changes in body weight or ADG were observed, changes in body composition, particularly energy deposition, may have occurred and warrant further investigation.

Conclusion

Under the conditions of this experiment, dietary supplementation with whole sugarcane increased ADFI in goats, with the highest nutrient apparent digestibility observed at 33% inclusion. Feeding appropriate proportions of whole sugarcane also enhanced antioxidant capacity and immunity. Considering growth performance, nutrient apparent digestibility, serum indices, and rumen fermentation parameters, the recommended suitable inclusion proportion of whole sugarcane is 33%–66%.

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