

Effects of Dietary Replacement of Corn with Sorghum from Different Sources on Growth Performance, Intestinal Mucosal Morphology, and Serum Indices in Yellow-Feathered Broilers: Postprint

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Abstract

This experiment aimed to investigate the effects of replacing corn with sorghum from different sources on production performance, immune organ indices, intestinal mucosal morphology, and serum biochemical and antioxidant indices in yellow-feathered broilers. A total of 350 healthy 1-day-old male yellow-feathered broilers with similar body weight were randomly allocated into 7 groups with 5 replicates per group and 10 birds per replicate. Each group was fed one of seven different diets: a basal diet (control), and diets in which 30% of corn in the basal diet was replaced by American sorghum, Hunan sorghum, or Inner Mongolia sorghum, and diets in which 50% of corn was replaced by American sorghum, Hunan sorghum, or Inner Mongolia sorghum. The experiment lasted for 56 days and was conducted in two phases: early phase (1-28 days of age) and late phase (29-56 days of age). The results showed that: 1) Compared with the control group, replacing corn with 30% or 50% of the three different sorghum sources had no adverse effects on growth performance of yellow-feathered broilers. 2) The abdominal fat rate was significantly higher in the group with 50% Hunan sorghum replacement compared with the control group ($P < 0.05$), while no significant differences were observed among groups in other slaughter performance indicators ($P > 0.05$). 3) During the early phase, no significant differences were found among groups in duodenal villus height, crypt depth, and villus height/crypt depth (V/C) ratio, jejunal villus height and V/C ratio, or ileal villus height and crypt depth ($P > 0.05$); compared with the control group, 50% replacement with American sorghum significantly increased ileal V/C ratio ($P < 0.05$). 4) During the early phase, serum glutathione peroxidase (GSH-Px) activity showed a slight decreasing trend with increasing replacement ratios of

Inner Mongolia and Hunan sorghum ($P>0.05$); during the late phase, serum total antioxidant capacity (T-AOC) increased with increasing replacement ratios of Inner Mongolia and Hunan sorghum, and was significantly higher at 50% replacement ($P<0.01$). In conclusion, different types of sorghum replacing corn had no adverse effects on production performance of yellow-feathered broilers in this experiment, and based on intestinal mucosal morphology and serum antioxidant indices, 50% replacement with Inner Mongolia sorghum was considered optimal.

Full Text

Abstract

This study investigated the effects of replacing corn with different sources of sorghum on growth performance, immune organ indices, intestinal mucosal morphology, and serum biochemical and antioxidant indices in yellow-feathered broilers. A total of 350 healthy 1-day-old yellow-feathered roosters with similar body weight were randomly allocated to 7 groups with 5 replicates per group and 10 birds per replicate. Each group received one of seven dietary treatments: a basal diet (control), diets with 30% corn replacement by American, Hunan, or Inner Mongolia sorghum, and diets with 50% corn replacement by American, Hunan, or Inner Mongolia sorghum. The 56-day feeding trial was divided into two phases: early stage (1-28 days) and late stage (29-56 days). The results showed: (1) Replacing corn with three different sorghum sources at 30% and 50% levels had no adverse effects on growth performance compared to the control group. (2) The abdominal fat percentage was significantly higher in the group fed Hunan sorghum at 50% replacement ($P<0.05$), while other slaughter performance indices showed no significant differences among groups ($P>0.05$). (3) During the early stage, no significant differences were observed among groups in duodenal villus height, crypt depth, and villus height/crypt depth (V/C) ratio, jejunal villus height and V/C ratio, or ileal villus height and crypt depth ($P>0.05$). However, American sorghum at 50% replacement significantly increased ileal V/C ratio compared to the control ($P<0.05$). (4) During the early stage, serum glutathione peroxidase (GSH-Px) activity showed a slight decreasing trend as the replacement proportion of Inner Mongolia and Hunan sorghum increased ($P>0.05$). During the late stage, serum total antioxidant capacity (T-AOC) increased with higher replacement proportions of Inner Mongolia and Hunan sorghum, showing a highly significant improvement at 50% replacement ($P<0.01$). In conclusion, different sorghum types replacing corn had no detrimental effects on yellow-feathered broiler performance. Based on intestinal mucosal morphology and serum antioxidant indices, Inner Mongolia sorghum at 50% replacement yielded the best overall results.

Keywords: yellow-feathered broilers; sorghum; growth performance; slaughter performance; intestinal mucosal morphology; serum indices

Introduction

Sorghum exhibits strong tolerance to poor soil, drought, salinity, and waterlogging, making it suitable for cultivation in arid, semi-arid, and low-lying flood-prone regions [1]. In China, sorghum is widely cultivated with high yields and serves as an energy feed ingredient at a lower cost than corn [2-4]. Given the relative shortage of bulk energy feed resources in China, rational utilization of sorghum could substantially alleviate the insufficient supply of feed corn. Sorghum has been widely applied in livestock and poultry production with numerous related studies. Truong et al. [5] investigated the effects of #3 and #5 sorghum varieties on broiler performance and nutrient utilization, finding that broilers fed #3 sorghum showed improvements in body weight gain, feed conversion ratio, apparent metabolizable energy (AME), ME:GE ratio, and true apparent metabolizable energy (AMEn) compared to those fed #5 sorghum. Issa et al. [6] examined sorghum replacement of corn in broiler diets and found no significant effects on average daily gain (ADG), average daily feed intake (ADFI), feed-to-gain ratio (F/G), or dressing percentage. However, nutritional content varies among sorghum varieties, and different replacement levels produce differential effects on animal growth. Therefore, this experiment utilized American, Hunan, and Inner Mongolia sorghum to replace corn at equal proportions in yellow-feathered broiler diets to explore the effects on production performance, immune organ indices, intestinal mucosal morphology, and serum biochemical and antioxidant indices. The findings provide theoretical reference and practical basis for the extensive application of sorghum in feed industry, while also offering insights for reducing feed and rearing costs and mitigating the shortage of feed raw materials, particularly feed corn.

1.1 Experimental Animals and Materials

Experimental animals consisted of 350 yellow-feathered roosters purchased from Hunan Dadi Poultry Company. The American sorghum was procured from Yueyang Port, Hunan sorghum from local farmers in Hunan Province, and Inner Mongolia sorghum from Inner Mongolia.

1.2 Experimental Design and Grouping

Three hundred fifty 1-day-old healthy yellow-feathered roosters with identical genetic background, from the same batch and normal development were randomly divided into 7 groups (Groups I-VII) with 5 replicates per group and 10 birds per replicate. Initial body weight showed no significant differences among groups ($P > 0.05$). The 56-day trial was divided into two phases: early stage (1-28 days) and late stage (29-56 days). A single-factor randomized design was employed: Group I (control) received the basal diet; Groups II, III, and IV received diets with 30% corn replacement by American, Hunan, and Inner Mongolia sorghum, respectively; Groups V, VI, and VII received diets with 50% corn replacement by American, Hunan, and Inner Mongolia sorghum, respectively. All diets were provided in mash form.

1.3 Experimental Diets

The basal diet was formulated using corn, soybean meal, wheat bran, and other ingredients according to NRC (1994) and the Chinese Chicken Feeding Standard (NY/T 33-2004). Dietary composition and nutrient levels are presented in Table 1, while the gross energy and major nutrient contents of the three sorghum varieties are shown in Table 2.

1.4 Feeding Management

Broilers were raised in multi-tier cages under continuous artificial lighting with normal temperature control. Infrared lamps provided heat during the brooding period: 35–36°C at 1–7 days, 28–31°C at 8–14 days, and adjusted according to conditions at 15–56 days. The chicken house used natural ventilation with regular cleaning to maintain relative humidity at 55–65%. Birds had free access to water and feed, and received routine vaccinations.

1.5 Measurement Indicators

1.5.1 Growth Performance Throughout the trial, growth and health status were monitored, and feed consumption was recorded by replicate. Birds were weighed after 8-hour fasting at 29 and 57 days to determine final body weight (FBW), which was used to calculate ADFI, ADG, and F/G for each group.

1.5.2 Slaughter Performance At 57 days, one bird per replicate with body weight close to the group average was selected for slaughter to determine slaughter performance indices according to the Chinese Agricultural Industry Standard NY/T823-2004 “Poultry Production Performance Terminology and Measurement Statistical Methods.”

1.5.3 Intestinal Morphology At 29 days, one bird per replicate near the group average was selected for sampling. After slaughter, the intestine was immediately removed to isolate the duodenum, jejunum, and ileum. Approximately 2 cm segments from the middle portion of each section were gently washed with saline, blotted dry with filter paper, and fixed in 10% formalin phosphate buffer. Fixed specimens underwent dehydration, clearing, paraffin infiltration, embedding, trimming, sectioning, mounting, and routine hematoxylin-eosin (HE) staining to prepare paraffin sections. Microscopic examination at 40× and 100× magnification was used to randomly select multiple non-consecutive fields, with typical fields photographed for measurement using the IMAGEEX software integrated with the YLE-21DY microscopic imaging system. Villus height and crypt depth were measured to calculate the villus height/crypt depth (V/C) ratio.

1.5.4 Serum Biochemical and Antioxidant Indices At 29 and 57 days (after 8-hour fasting), one bird per replicate near the group average was se-

lected for blood collection via neck bleeding. Six milliliters of blood were placed in 10 mL centrifuge tubes, allowed to naturally coagulate for 0.5 hours, then centrifuged at 3,000 r/min for 15 minutes to separate serum. The supernatant was collected, aliquoted, and stored at -20°C for subsequent biochemical and antioxidant analysis. Serum alkaline phosphatase (ALP) activity and uric acid (UA) content were determined using a Mindray BS-200 automatic biochemical analyzer, strictly following kit instructions. Serum total antioxidant capacity (T-AOC) and glutathione peroxidase (GSH-Px) activity were measured using a Thermo Fisher microplate reader, also following kit protocols precisely.

1.5.5 Economic Analysis Theoretical economic benefits were analyzed for each group based on production performance data combined with current feed and market prices.

1.6 Data Processing and Statistical Analysis

Experimental data were preliminarily processed using Excel 2007, then analyzed using one-way ANOVA in SPSS 17.0. If significant differences were detected among groups, Duncan's multiple comparison test was applied. Significance was set at $P < 0.05$. Results are expressed as "mean \pm standard deviation."

Results

2.1 Effects of Different Sorghum Sources and Replacement Levels on Growth Performance

As shown in Table 3, during the early stage (1-28 days), all treatment groups exhibited higher ADG and ADFI than the control group. Compared with the control, ADG was significantly improved by Hunan sorghum (Group III), Inner Mongolia sorghum at 30% replacement (Group IV), and American sorghum at 50% replacement (Group V) ($P < 0.05$). ADFI was highly significantly increased by Hunan sorghum (Group III), Inner Mongolia sorghum at 30% replacement (Group IV), and Inner Mongolia sorghum at 50% replacement (Group VII) ($P < 0.01$). Furthermore, ADFI in Groups III and IV was significantly higher than in Group II (American sorghum at 30% replacement) by 7.23% and 6.27%, respectively ($P < 0.05$). No significant differences in F/G were observed among groups ($P > 0.05$).

During the late stage (29-56 days), ADG increased in groups receiving American sorghum at 30% (Group II) and 50% (Group V) replacement and Inner Mongolia sorghum at 30% (Group IV) and 50% (Group VII) replacement compared to the control, while ADG decreased in groups receiving Hunan sorghum at 30% (Group III) and 50% (Group VI) replacement. However, no significant differences were detected among groups ($P > 0.05$). All treatment groups showed highly significant increases in ADFI compared to the control ($P < 0.01$). The F/G ratio increased in all treatment groups relative to the control, but differences were not significant ($P > 0.05$).

Throughout the entire trial (1-56 days), ADG was slightly higher in all treatment groups compared to the control, though differences were not significant ($P>0.05$). ADFI was highly significantly increased in all treatment groups ($P<0.01$). The F/G ratio was significantly higher only in the group receiving Hunan sorghum at 50% replacement ($P<0.05$), while other treatment groups showed non-significant increases ($P>0.05$).

2.2 Slaughter Performance

As presented in Table 4, dressing percentage remained consistent across all groups. Eviscerated carcass percentage increased in all treatment groups compared to the control, but differences were not significant ($P>0.05$). No significant differences were observed in breast muscle percentage among groups ($P>0.05$). Leg muscle percentage decreased slightly in all treatment groups, but differences were not significant ($P>0.05$). Abdominal fat percentage was significantly higher in the group receiving Hunan sorghum at 50% replacement compared to the control ($P<0.05$), while other groups showed non-significant increases ($P>0.05$).

2.3 Intestinal Mucosal Morphology

Table 5 shows that during the early stage, no significant differences were observed among groups in duodenal villus height, crypt depth, and V/C ratio; jejunal villus height and V/C ratio; or ileal villus height and crypt depth ($P>0.05$). However, American sorghum at 50% replacement significantly increased ileal V/C ratio compared to the control ($P<0.05$), with no other significant differences among groups ($P>0.05$).

2.4 Serum Biochemical and Antioxidant Indices

As shown in Table 6, during the early stage (1-28 days), serum GSH-Px activity in the group receiving American sorghum at 50% replacement (Group V) was significantly higher than in groups receiving Hunan sorghum (Group VI) and Inner Mongolia sorghum at 50% replacement (Group VII) ($P<0.05$), with increases of 70.12% and 66.21%, respectively. Additionally, Group IV (Inner Mongolia sorghum at 30% replacement) showed significantly higher GSH-Px activity than Group VI ($P<0.05$), representing a 48.99% increase. During the late stage (29-56 days), serum T-AOC in Groups VI and VII was highly significantly increased compared to the control by 46.87% and 41.22%, respectively ($P<0.01$), and highly significantly increased compared to Group II (American sorghum at 30% replacement) by 48.55% and 42.37%, respectively ($P<0.01$). Group VI also showed significantly higher T-AOC than Groups IV and V ($P<0.05$). No significant differences were detected among groups in serum ALP activity or UA content ($P>0.05$).

2.5 Economic Analysis

Table 7 demonstrates that all treatment groups achieved varying degrees of profit improvement compared to the control, with the greatest increases observed in Group V (American sorghum at 50% replacement) and Group VII (Inner Mongolia sorghum at 50% replacement) at 27.29% and 26.66%, respectively.

Discussion

3.1 Effects of Different Sorghum Sources on Growth Performance

Corn serves as a high-quality energy feed with excellent palatability and digestibility. However, increasing demand from the feed industry has created supply constraints. Sorghum offers nutritional value comparable to corn and demonstrates potential as an alternative energy feed ingredient [7]. Ahmed et al. [8] reported that high-level sorghum replacement significantly increased ADG and ADFI in broilers without affecting F/G. Similarly, Bulus et al. [9] found that complete corn replacement with sorghum had no detrimental effects on ADG, ADFI, nutrient utilization, or F/G in Marshall broilers. Conversely, Sharif et al. [10] observed negative effects on broiler performance when replacing corn with sorghum at equal proportions, likely attributable to tannin content. Our results indicate that 30% and 50% replacement of corn with three different sorghum sources produced no adverse effects and even showed some improvements in yellow-feathered broiler performance. Across the entire trial period, the three sorghum varieties at 30% replacement increased ADG by 3.38-4.92% and ADFI by 7.91-8.67%, while at 50% replacement, ADG increased by 1.23-7.38% and ADFI by 7.16-10.05%. All treatment groups showed increased F/G compared to the control. These findings suggest that under our experimental conditions, replacing corn with up to 50% of any of the three sorghum sources promoted feed intake and growth in yellow-feathered broilers, thereby reducing production costs.

3.2 Effects on Slaughter Performance

Slaughter performance is a crucial indicator of meat production capacity in livestock and poultry. Numerous studies have demonstrated that carcass traits are directly related to live animal quality, with slaughter performance being incorporated into chicken meat standards and considered equally important as nutritional value in most developed countries [11]. Our results showed dressing percentages above 80% and eviscerated carcass percentages above 60% across all groups, indicating good meat production performance. Replacement of corn with sorghum at levels below 50% did not significantly alter dressing percentage, eviscerated carcass percentage, breast muscle percentage, or leg muscle percentage compared to the control. Only the group receiving Hunan sorghum at 50% replacement showed significantly increased abdominal fat percentage, while other groups remained non-significant. These findings align with those of Stringhini et al. [12] and Garcia et al. [13].

3.3 Effects on Intestinal Mucosal Morphology

Increased villus height expands the contact area between the small intestine and nutrients, facilitating absorption. Shallower crypt depth indicates reduced epithelial cell generation rate, increased maturation rate, and enhanced secretory function. The V/C ratio comprehensively reflects intestinal functional status; an increased ratio indicates improved mucosal structure, higher villus cell density per unit area, and enhanced digestive absorption capacity, while a decreased ratio suggests diminished intestinal absorption [14]. Our results showed that during the early stage, sorghum replacement did not impair small intestinal villus growth in yellow-feathered broilers, and the American sorghum group at 50% replacement exhibited significantly higher ileal V/C ratio than the control. These findings are consistent with reports by Thomas et al. [15] and Torres et al. [16]. However, Torres et al. [16] also found that 50% sorghum replacement significantly increased crypt cell proliferation index in the jejunum and ileum, while 100% replacement negatively affected intestinal mucosa and performance by 42 days. Nyamambi et al. [17] similarly reported reduced small intestinal villus height with increasing dietary tannin levels. These results suggest that sorghum replacement exceeding certain thresholds may exert detrimental effects on the intestine due to tannin content. Our findings demonstrate that replacement up to 50% did not inhibit small intestinal villus growth in yellow-feathered broilers.

3.4 Effects on Serum Biochemical and Antioxidant Indices

GSH-Px is a crucial antioxidant enzyme that scavenges peroxides and plays a vital role in the antioxidant defense system. T-AOC is a comprehensive indicator of antioxidant capacity, with serum T-AOC levels reflecting the compensatory capacity of enzymatic and non-enzymatic antioxidant systems and free radical metabolism status [18]. ALP, primarily derived from liver and bone, is commonly used to assess liver and bone metabolic status. UA, the end product of protein metabolism in poultry, reflects protein metabolism, amino acid balance, and kidney health. During the early stage, no significant differences in serum GSH-Px activity were observed among groups compared to the control. However, at 50% replacement, the American sorghum group showed significantly higher GSH-Px activity than the Hunan and Inner Mongolia sorghum groups. This may be attributed to incomplete development of broilers during the early stage, combined with lower tannin content in American sorghum, which enhanced serum GSH-Px activity at equivalent replacement levels. Higher tannin levels in Hunan and Inner Mongolia sorghum likely exerted inhibitory effects. During the late stage, no significant differences were detected in serum ALP activity or UA content among groups, consistent with the report by Manwar et al. [19]. Serum T-AOC increased with higher replacement proportions of Inner Mongolia and Hunan sorghum, likely due to the complex tannin phenolic compounds in sorghum that are partially water-soluble and possess strong antioxidant properties [20].

3.5 Economic Analysis

Our results demonstrate that replacing corn with three sorghum sources at 30% and 50% levels improved yellow-feathered broiler production performance, increased market weight, reduced time to market, and maintained bird health without adverse effects. All treatment groups showed improved economic benefits compared to the control, with the highest improvements in the American sorghum 50% replacement group and Inner Mongolia sorghum 50% replacement group. According to the National Grain and Oil Information Center, sorghum demand has increased annually [3], and market prices are lower than corn [4]. These findings indicate that sorghum replacement of corn in diets can reduce feed costs and improve economic efficiency.

Conclusions

1. Replacing corn with different sorghum sources at 30% and 50% levels achieved growth and slaughter performance comparable to or better than corn, demonstrating the feasibility of partial sorghum replacement in yellow-feathered broiler diets. Under our experimental conditions, Inner Mongolia sorghum at 50% replacement produced the best comprehensive performance.
2. Different sorghum sources and replacement proportions did not substantially affect immune organ indices or intestinal mucosal morphology development, and birds remained healthy while achieving cost savings.

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