Effects of Differently Processed Corn Flour on Digestive Metabolism, Plasma Biochemical Parameters, and Body Weight Gain in 12-Month-Old Yili Horses (Postprint)

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Abstract

This experiment aimed to investigate the effects of steam-flaked corn meal and extruded corn meal on digestion and metabolism, plasma biochemical indices, and body weight gain in 12-month-old Yili horses, so as to provide a reference for the application of steam-flaked corn meal and extruded corn meal in equine feeding practice. Twenty-four male Yili horses with similar body weight [(261.95$±$14.73) kg] and similar age (around 12 months) were selected and randomly divided into 3 groups with 8 horses each, namely the control group, experimental group I, and experimental group II. Each horse in all groups was fed 1.5 kg of concentrate and 8 kg of alfalfa hay daily. On this basis, horses in the control group, experimental group I, and experimental group II were additionally fed 1.5 kg of ground corn meal, steam-flaked corn meal, and extruded corn meal per horse per day, respectively. A 26-day digestion and metabolism trial was conducted, including a 19-day preliminary period and a 7-day formal collection period. The results showed that the apparent digestibility of dry matter, organic matter, crude protein, neutral detergent fiber, and acid detergent fiber in experimental group II was 4.93% (P>0.05), 5.84% (P>0.05), 7.10% (P>0.05), 14.78% (P<0.05), and 17.45% (P<0.05) higher than that in the control group, respectively, while the apparent digestibility of dry matter, organic matter, crude protein, and neutral detergent fiber in experimental group I showed no significant difference compared with the control group (P>0.05). The nitrogen retention and nitrogen retention rate in experimental group II were significantly higher than those in the control group and experimental group I (P<0.05), being 81.19% and 79.86% higher than the control group, and 104.78% and 97.50% higher than experimental group I, respectively, while there was no significant difference between the control group and experimental group I (P>0.05). The calcium and phosphorus retention amounts and retention rates in experimental

group II were higher than those in the control group and experimental group I (P>0.05). The glucose content in plasma of experimental group II was 10.04% and 20.79% higher than that of the control group and experimental group I, respectively (P<0.05). Feeding steam-flaked corn meal and extruded corn meal had no significant effect on body weight gain and average daily gain in 12-month-old Yili horses (P>0.05); however, the body weight gain and average daily gain during the trial period in experimental group II increased by 18.88% and 20.37% compared with the control group, and were 20.43% and 20.37% higher than those in experimental group I, respectively. Therefore, feeding extruded corn meal can improve the apparent digestibility of dietary nutrients and energy metabolism in 12-month-old Yili horses and promote horse growth, while feeding steam-flaked corn meal had no significant effect on nutrient metabolism, plasma biochemical indices, or body weight gain in 12-month-old Yili horses.

Full Text

Effects of Different Processing Methods of Corn Meal on Digestion and Metabolism, Plasma Biochemical Indices, and Body Weight Gain in 12-Month-Old Yili Horses

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Abstract

This experiment investigated the effects of steam-flaked corn meal and extruded corn meal on nutrient digestion and metabolism, plasma biochemical indices, and body weight gain in 12-month-old Yili horses to provide a reference for the application of processed corn meals in equine feeding practices. Twenty-four 12-month-old male Yili horses with similar body weight [(261.95$±$14.73) kg] were randomly divided into three groups (n=8 per group): control group, trial group I, and trial group II. All horses received 1.5 kg of concentrate and 8 kg of alfalfa hay daily. Additionally, each horse in the control group, trial group I, and trial group II received 1.5 kg of ground corn meal, steam-flaked corn meal, and extruded corn meal, respectively. A 26-day digestion and metabolism trial was conducted, comprising a 19-day preliminary period and a 7-day collection period. The results showed that trial group II exhibited higher apparent digestibility of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) compared to the control group, with increases of 4.93% (P>0.05), 5.84% (P>0.05), 7.10% (P>0.05), 14.78% (P<0.05), and 17.45% (P<0.05), respectively. However, trial group I showed no significant differences in DM, OM, CP, and NDF digestibility compared to the

control group (P>0.05). Nitrogen retention and nitrogen retention rate in trial group II were significantly higher than those in the control and trial group I (P<0.05), increasing by 81.19% and 79.86%, and 104.78% and 97.50%, respectively, while no significant differences were observed between the control and trial group I (P>0.05). Calcium and phosphorus retention and retention rates in trial group II were higher than those in the other groups (P>0.05). Plasma glucose concentration in trial group II was significantly elevated by 10.04% and 20.79% compared to the control and trial group I, respectively (P<0.05). Although feeding steam-flaked or extruded corn meal had no significant effects on body weight gain or average daily gain (ADG) (P>0.05), trial group II showed improvements of 18.88% and 20.37% in body weight gain and ADG compared to the control group, and 20.43% and 20.37% compared to trial group I. Therefore, feeding extruded corn meal can enhance nutrient apparent digestibility and energy metabolism while promoting growth in 12-month-old Yili horses, whereas steam-flaked corn meal had no significant effects on nutrient metabolism, plasma biochemical indices, or body weight gain.

Keywords: corn meal; processing method; 12-month-old Yili horses; digestion and metabolism; plasma biochemical indices; body weight gain

Introduction

Horses have limited capacity for starch digestion, producing only 8%–10% of the amylase activity observed in pigs [1]. Consequently, most dietary starch remains undigested in the equine intestine, particularly when high-grain diets are fed [2]. Starch that escapes small intestinal digestion enters the hindgut, where microbial fermentation produces lactic acid, altering intestinal pH, causing microbial death, releasing endotoxins, and potentially triggering laminitis and other health issues. Additionally, low pH environments reduce cellulose hydrolysis and disrupt the acetate-to-propionate ratio, affecting volatile fatty acid production and absorption [3]. Corn starch represents the primary energy source in equine diets, making its improved digestibility crucial for preventing disease and enhancing feed conversion efficiency. Research indicates that extrusion or steam-flaking of corn not only irreversibly gelatinizes starch and inactivates antinutritional factors but also increases susceptibility to gastrointestinal digestive enzymes, enhances digestible fiber content, improves nutrient utilization, and reduces feeding costs [4]. Wang et al. [5] reported that increasing extruded corn meal supplementation from 20% to 60% in weaned piglet diets linearly improved nutrient digestibility. Zinn et al. [6] demonstrated that steam-flaking increased both the net energy value of corn meal and the digestibility of other nutrients such as protein. Based on these findings in piglets and lactating dairy cows, this study investigated the effects of steam-flaked and extruded corn meal on digestion and metabolism, body weight gain, and plasma biochemical indices in 12-month-old Yili horses to identify optimal corn processing methods for equine feeding.

1. Materials and Methods

1.1 Experimental Period and Location

The experiment was conducted from July 28 to August 27, 2014, at the Zhaosu Military Horse Farm in Ili Kazakh Autonomous Prefecture, Xinjiang.

1.2 Experimental Design

Twenty-four 12-month-old male Yili horses with similar body weight [(261.95$±$14.73) kg] were randomly allocated to three groups (n=8): control, trial I, and trial II. All horses received 1.5 kg concentrate and 8.0 kg alfalfa hay daily (local Zhaosu alfalfa hay chopped to 5 cm length). Additionally, the control, trial I, and trial II groups received 1.5 kg of ground corn meal (purchased from Xinjiang Yili Tiankang Feed Co., Ltd.), steam-flaked corn meal (Shandong Deling Feed Raw Material Factory), and extruded corn meal (Qinhuangdao Jinxu Feed Factory), respectively. The digestion and metabolism trial lasted 26 days, including a 19-day preliminary period and a 7-day collection period. During the collection period, total daily urine and fecal samples were collected, along with samples of the powdered concentrate and alfalfa hay. Blood samples were collected on day 7 of the collection period. The composition and nutrient levels of the concentrate are shown in Table 1 , while nutrient levels of alfalfa hay, ground corn meal, steam-flaked corn meal, and extruded corn meal are presented in Table 2 .

1.3 Management and Diet Composition

All horses were individually housed in stalls (2.5 m × 1.2 m × 2.0 m) and fed at 10:00, 12:00, and 18:00 with 0.5 kg corn meal, 0.5 kg concentrate, and 2 kg alfalfa hay per meal, followed by an additional 2 kg alfalfa hay at 24:00. The feeding regimen followed a concentrate-first, forage-second principle with small, frequent meals to ensure complete consumption of all feedstuffs, with ad libitum access to water. During the preliminary period, horses were released to exercise after feeding but prevented from consuming any additional feed. During the collection period, all horses were individually stalled with custom-designed fecal and urine collection apparatus, maintained in a standing position, with samples collected every 2 hours. Stalls were cleaned daily throughout the trial to maintain optimal experimental conditions.

Table 1 Composition and nutrient levels of concentrated feed (DM basis, %)

Ingredients	Content	Nutrient levels	Content
Corn	60.00	Dry matter	88.00
Wheat bran	10.00	Organic matter	85.00
Wheat middling	10.00	Crude protein	18.00
Soybean meal	15.00	Neutral detergent fiber	15.00
CaHPO4	1.50	Acid detergent fiber	8.00

Ingredients	Content	Nutrient levels	Content
NaCl	1.00	Calcium	0.80
Limestone	1.00	Total phosphorus	0.60
Premix	1.50		

Premix provided per kg of concentrate: VA 20 IU, VB1 0.34 g, VB2 0.27 mg, VD 60 IU, VE 8.33 IU, Cu (as copper sulfate) 4.3 g, Fe (as ferrous sulfate) 17.89 g, Mn (as manganese sulfate) 13.47 g, Zn (as zinc sulfate) 12.65 g, I (as potassium iodide) 1.10 g, Se (as sodium selenite) 2.37 g, Co (as cobalt chloride) 0.42 g, bentonite 138.45 g.

Table 2 Nutrient levels of alfalfa hay, ground corn meal, steam-flaked corn meal, and extruded corn meal (DM basis, %)

Item	Alfalfa hay	Ground corn meal	Steam-flaked corn meal	Extruded corn meal
Dry matter	91.23	87.65	87.12	88.34
Organic matter	88.45	85.32	85.69	86.45
Crude protein	18.23	8.56	8.45	8.67
Neutral detergent fiber	45.67	12.34	11.98	11.45
Acid detergent fiber	32.15	4.56	4.32	4.23
Calcium	1.45	0.03	0.03	0.03
Total phosphorus	0.34	0.28	0.27	0.29

1.4 Sample Collection and Processing

1.4.1 Weighing Horses were weighed on an empty stomach before the preliminary period and on the morning after the collection period concluded.

1.4.2 Feed Collection and Processing Concentrate and alfalfa hay samples were collected throughout the trial, naturally air-dried, and ground for subsequent analysis.

1.4.3 Fecal Sample Collection and Processing During the collection period, horses were maintained in a standing position using custom-designed fecal collection apparatus. Feces were collected and weighed every 2 hours throughout the day. Daily fecal collections were thoroughly mixed, and 10% of the total weight was randomly sampled into labeled bags, naturally air-dried, and weighed. The 7-day air-dried fecal samples from each horse were combined, mixed, and 1 kg was retained for analysis.

1.4.4 Urine Sample Collection and Processing Urine was collected every 2 hours during the collection period using custom-designed urine collection apparatus while horses remained standing. Daily urine volume was measured, and 10% of the total volume was preserved with 5% concentrated sulfuric acid in plastic bottles. The 7-day urine collections from each horse were combined, mixed, and 1 L was retained for analysis.

1.4.5 Blood Collection and Processing On day 7 of the collection period, approximately 5 mL of blood was collected via jugular venipuncture 4 hours after the first feeding into heparinized tubes, centrifuged at 1,500×g for 15 minutes, and plasma was harvested into 1.5 mL Eppendorf tubes and stored at -20°C for analysis.

1.5 Sample Analysis Methods

Dry matter and organic matter contents in concentrate, alfalfa hay, feces, and urine were determined using conventional feed analysis methods. Calcium and phosphorus concentrations were measured by o-cresolphthalein colorimetry and ammonium vanadomolybdate colorimetry, respectively. Energy content was determined using an HR-15 oxygen bomb calorimeter. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed using an ANKOM fiber analyzer. Crude protein (CP) was determined using an Elementar Analysen Systeme rapid nitrogen analyzer. Plasma total protein (TP), albumin (ALB), urea nitrogen (UN), and glucose (GLU) concentrations were measured using commercial kits (Zhongsheng Beikong Biotechnology Co., Ltd.; catalog numbers: 2090-2003, 2074-2003, 2102-2003, 2085-2003).

1.6 Statistical Analysis

Data are expressed as mean±SD. Statistical analysis was performed using one-way ANOVA in SPSS 18.0. Duncan' s multiple range test was used for pairwise comparisons among group means.

2. Results

2.1 Effects of Different Corn Processing Methods on Nutrient Digestibility in 12-Month-Old Yili Horses

As shown in Table 3 , feeding extruded corn meal increased apparent nutrient digestibility. The apparent digestible amounts of NDF and ADF were significantly higher than in the control group (P<0.05), while DM, OM, and CP digestible amounts were significantly higher than in trial group I (P<0.05). Trial group II showed the highest apparent digestibility coefficients for all nutrients, with NDF and ADF digestibility significantly exceeding the control group by 14.78% and 17.45%, respectively (P<0.05). In contrast, trial group I showed no significant differences in DM, OM, CP, or NDF digestibility compared to the control group (P>0.05).

Table 3 Effects of different corn processing methods on nutrient digestibility in 12-month-old Yili horses (DM basis, n=8)

Item	Control group	Trial group I	Trial group II
DM intake (kg/d)	9.77$±0.36	9.70±0.39	9.85±0.34
$DM apparent digestion (kg/d)$	5.39±0.20ab	5.18±0.28b	5.59±0.17a

In the same row, values with no or the same letter superscripts indicate no significant difference (P>0.05), different lowercase letters indicate significant difference (P<0.05), and different uppercase letters indicate extremely significant difference (P<0.01). The same notation applies to subsequent tables.

2.2 Effects of Different Corn Processing Methods on Energy, Nitrogen, Calcium, and Phosphorus Metabolism

As shown in Table 4 , no significant differences were observed among groups in gross energy intake or digestible energy (P>0.05). However, metabolizable energy in trial group II was significantly higher than in the control and trial group I (P<0.05). For nitrogen metabolism, trial group II exhibited lower fecal nitrogen (P>0.05) and urinary nitrogen (P<0.05) compared to the other groups, while nitrogen retention and retention rate were significantly higher (P<0.05), increasing by 81.19% and 79.86%, and 104.78% and 97.50% compared to the control and trial group I, respectively. No significant differences were found

between the control and trial group I (P>0.05). Calcium and phosphorus retention and retention rates in trial group II were higher than those in the other groups (P>0.05), while trial group I showed lower values than the control group (P>0.05).

Table 4 Effects of different corn processing methods on energy, nitrogen, calcium, and phosphorus metabolism in 12-month-old Yili horses (DM basis, n=8)

Item	Control group	Trial group I	Trial group II
Energy metabolism			
Intake GE (MJ/d)	245.24$±8.22\|238.21±7.15\|248.36±5.12\|\|$DE(MJ/d)$\|127.40±4.73\|122.26±8.59\|131.11±6.58\|\|$ME(M $*Nitrogenmetabolism*$ $*|||||IntakeN(g/d)|173.94±5.17|168.99±4.09|174.54±5.72||FecesN(g/d)|68.41±3.24a|69.87±3.84a|$5 $*Calciummetabolism*$ $*\|\|\|\|\|IntakeCa(mg/d)\|64.98±2.59\|63.52±1.59\|66.14±1.23\|\|FecesCa(g/d)\|33.95±4.29\|37.53±7.09\|34.$ $*Phosphorusmetabolism*$ $*\|\|\|\|\|IntakeP(mg/d)\|29.10±0.37\|28.68±0.34\|29.73±0.16\|\|FecesP(g/d)\|22.27±3.21\|22.83±4.43\|21.89$	

2.3 Effects of Different Corn Processing Methods on Plasma Biochemical Indices

As shown in Table 5 , feeding steam-flaked or extruded corn meal had no significant effects on plasma total protein or albumin concentrations (P>0.05). However, plasma urea nitrogen in trial group I was significantly higher than in the control and trial group II (P<0.05), increasing by 12.05% and 13.97%, respectively. Plasma glucose concentration in trial group II was significantly higher than in the other groups (P<0.05), showing increases of 10.04% and 20.79% compared to the control and trial group I, respectively.

Table 5 Effects of different corn processing methods on plasma biochemical indices in 12-month-old Yili horses (n=8)

Item	Control group	Trial group I	Trial group II
Total protein (TP) (g/L)	60.47$±6.36\|62.96±3.36\|59.77±4.99\|\|$*Albumin*$(ALB)(g/L)\|15.24±3.16\|17.15±4.30\|17.31±2.84\|\|Ure$		

2.4 Effects of Different Corn Processing Methods on Body Weight Gain

As shown in Table 6 , feeding steam-flaked or extruded corn meal had no significant effects on body weight gain or average daily gain (ADG) in 12-month-old Yili horses (P>0.05). However, trial group II exhibited improvements in body

weight gain and ADG of 18.88% and 20.37% compared to the control group, and 20.43% and 20.37% compared to trial group I, respectively.

Table 6 Effects of different corn processing methods on body weight gain in 12-month-old Yili horses (n=8)

Item	Control group	Trial group I	Trial group II
Interval days (d)	26	26	26
Initial weight (kg)	260.00$±21.23\|262.75±15.68\|262.71±19.94\|\|$Finalweight(kg)$|274.25±20.39|276.83±12.40|289.64±18		

3. Discussion

3.1 Effects on Nutrient Digestibility

Corn contains over 70% starch, with amylose and amylopectin ratios of 27% and 73%, respectively. Starch granules are tightly packed in the endosperm, encapsulated by protein and linked by hydrogen bonds, which limit microbial and enzymatic digestion. Steam-flaking and extrusion release starch from protein matrices and disrupt starch chain structures, thereby improving corn digestibility, with steam-flaking increasing starch digestibility by 10%–20%. Zinn et al. [6] reported that steam-flaking enhanced both net energy and crude protein digestibility. Plascencia et al. [7] found that steam-flaked corn increased rumen microbial protein and nitrogen digestibility in the small intestine and total tract. Burkholder et al. [8] observed that steam-flaked corn reduced fecal and urinary nitrogen excretion while increasing nitrogen retention by 4.21% in feedlot cattle. Qi [9] reported that extruded corn meal significantly increased rumen degradability of DM and starch in lactating dairy cows, though excessive extrusion temperatures reduced degradability. Chen et al. [10] demonstrated that diets containing 40% steam-flaked corn increased NDF and ADF apparent digestibility by 21.96% and 23.35%, respectively, in lactating cows.

In this study, extruded corn meal improved apparent digestible amounts and digestibility coefficients of DM, OM, CP, NDF, and ADF in 12-month-old Yili horses, consistent with previous research. Extrusion increases enzyme access to corn substrates, enhancing dietary nutrient digestibility. However, steam-flaked corn meal showed no significant effects on nutrient digestibility compared to the control, possibly due to processing parameters. Notably, reported crude protein digestibility in mature horses ranges from 80%–90% [11], whereas our 12-month-old horses exhibited 60%–66% digestibility, likely reflecting incomplete gastrointestinal development in younger animals.

3.2 Effects on Energy, Nitrogen, Calcium, and Phosphorus Metabolism

Extrusion and steam-flaking irreversibly gelatinize corn starch, inactivate antinutritional factors, and increase enzyme sensitivity while enhancing digestible fiber content [4]. The NRC (2007) reported that steam-flaked corn has a net energy value of 6.48 MJ/kg, 11.5% higher than dry-processed corn [12]. Knowlton et al. [13] found that high-moisture corn reduced nitrogen excretion by 13.10% despite increased nitrogen intake in lactating cows. Glenn et al. [14] reported 11.26% lower phosphorus excretion with high-moisture corn. Hu [4] demonstrated that extruded corn improved protein digestibility, nitrogen retention, and energy utilization in growing piglets. Chen [15] observed significant reductions in nitrogen and phosphorus excretion when feeding 20% steam-flaked corn to lactating cows.

In this study, extruded corn meal increased digestible and metabolizable energy in 12-month-old Yili horses, likely due to enhanced starch hydrolysis by intestinal enzymes, providing more glucose for energy supply and increasing blood glucose concentrations. Improved energy availability increased glucose uptake by intestinal mucosal cells [16], where glucose oxidation via the tricarboxylic acid cycle generates ATP to support nucleic acid and protein metabolism, promoting mucosal cell proliferation and expanding absorptive surface area [17], thereby enhancing nutrient digestibility. Steam-flaked corn tended to reduce nutrient metabolism, possibly due to suboptimal processing temperature and moisture conditions.

3.3 Effects on Plasma Biochemical Indices

Processed corn improves nutrient digestibility and energy-nitrogen balance. Li et al. [18] reported that increasing bypass starch content in beef cattle diets elevated plasma glucose. Wang et al. [19] demonstrated that steam-flaked corn significantly increased plasma glucose while reducing urea nitrogen in Yunnan yellow cattle. Chu [20] reported plasma total protein and albumin concentrations of 54–65 g/L and 18–25 g/L, respectively, in 8–11-month-old Yili horses, similar to our findings in 12-month-old horses. While processed corn meals did not significantly affect total protein or albumin, trial group I showed significantly higher plasma urea nitrogen, likely due to lower crude protein digestibility and nitrogen retention, indicating enhanced protein catabolism. Extruded corn meal significantly increased plasma glucose compared to ground and steam-flaked corn, probably because extrusion breaks hydrogen bonds between starch molecules, transforming compact structures into loose, disordered configurations [21] that are rapidly hydrolyzed by small intestinal amylase, increasing glucose absorption.

3.4 Effects on Body Weight Gain

Numerous studies have reported growth responses to processed corn. Liu et al. [22] found that feeding steam-flaked corn with extruded soy protein increased body weight gain by 4.32% in 3-day-old calves. Lv et al. [23] reported that extruded corn improved ADG and feed efficiency in post-weaning piglets. Li [24] demonstrated that 90% steam-flaked corn supplementation significantly increased ADG in Simmental crossbred cattle.

In this study, extruded corn meal improved body weight gain and ADG in 12-month-old Yili horses by enhancing starch hydrolysis, nutrient utilization, and plasma glucose availability, providing precursors for fat synthesis. Abundant glucose in adipocytes generates α-glycerophosphate and acetyl-CoA via glycolysis, while glucose through the pentose phosphate pathway provides NADPH for fatty acid synthesis [25], thereby increasing fat deposition and body weight gain. The lack of significant effect from steam-flaked corn may relate to animal physiological status, feeding regimen, or incomplete starch gelatinization.

4. Conclusion

Feeding extruded corn meal improves apparent nutrient digestibility, energy metabolism, and growth performance in 12-month-old Yili horses, whereas steam-flaked corn meal shows no significant effects on nutrient metabolism, plasma biochemical indices, or body weight gain in horses of this age.

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