Effects of Different Processing Methods of Corn Flour on Digestion and Metabolism, Plasma Biochemical Parameters, and Growth and Development of 6-Month-Old Yili Horses: Postprint

Authors: Yang Jingtao, Zhao Fang, Deng Haifeng, Xiaobin Li, Yang Kailun

Date: 2017-10-10T00:00:00+00:00

Abstract

This study aimed to investigate the effects of different processing methods of corn flour on digestion and metabolism, plasma biochemical indices, and growth and development of 6-month-old Yili horses, to provide a reference for the application of steam-flaked corn flour and extruded corn flour in equine diets. Twenty 6-month-old male Yili horses with an average body weight of (105.10±11.83) kg and good health status were selected and randomly divided into 4 groups (n=5 per group) based on similar body weight. Each horse was fed 0.3 kg of powdered concentrate and 3.5 kg of alfalfa hay daily. Additionally, the control group, experimental group I, experimental group II, and experimental group III were fed 0.3 kg of crushed corn flour, 0.3 kg of crushed corn flour + 1 g -amylase, 0.3 kg of steam-flaked corn flour, and 0.3 kg of extruded corn flour per horse per day, respectively. A 20-day digestion and metabolism experiment was conducted, consisting of a 13-day preliminary period and a 7-day formal experimental period. The results showed that group III had significantly higher digestion amounts of dry matter, organic matter, crude protein, neutral detergent fiber, and acid detergent fiber, as well as digestibility of neutral detergent fiber and acid detergent fiber, compared with the control group ($P<0.05$). Group III exhibited significantly higher nitrogen, calcium, and phosphorus retention rates than the control group and group I ($P<0.05$). Group III had significantly higher digestible energy and metabolizable energy than the control group and group I ($P<0.05$), while no significant differences were observed among the control group, group I, and group II ($P>0.05$). During the experimental period, the weight gain and average daily gain of group III were higher than those of the other groups, but the differences among groups were not significant ($P>0.05$). Regarding body length increase, group III was significantly higher than the other groups ($P<0.05$). The chest circumference increase in group II was significantly

higher than that in the other three groups (P<0.05). No significant differences were found in plasma biochemical indices among groups (P>0.05). It is concluded that feeding extruded corn flour can improve the apparent digestibility of dietary nutrients and energy metabolism, and promote the growth and development of horses; whereas feeding crushed corn flour with enzyme preparation or steam-flaked corn flour had no significant promoting effects on the apparent digestibility of nutrients and growth and development of 6-month-old Yili horses.

Full Text

Effects of Corn Meals with Different Processing Methods on Nutrient Digestion and Metabolism, Plasma Biochemical Indexes, and Growth and Development of 6-Month-Old Yili Horses

YANG Jingtao, ZHAO Fang, DENG Haifeng, LI Xiaobin, YANG Kailun*

(Xinjiang Agricultural University, Xinjiang Key Laboratory of Herbivore Nutrition for Meat and Milk Production, Urumqi 830052, China)

Abstract: This experiment aimed to investigate the effects of corn meals processed by different methods on nutrient digestion and metabolism, plasma biochemical indexes, and growth and development of 6-month-old Yili horses, providing a reference for the application of steam-flaked corn meal and extruded corn meal in equine diets. Twenty healthy 6-month-old Yili male horses with an average body weight of (105.10±11.83) kg were randomly divided into 4 groups (n=5) based on similar body weight. Each horse was fed 0.3 kg powdered concentrate and 3.5 kg alfalfa hay daily. Additionally, the control group, trial group I, trial group II, and trial group III received 0.3 kg ground corn meal, 0.3 kg ground corn meal + 1 g -amylase, 0.3 kg steam-flaked corn meal, and 0.3 kg extruded corn meal per horse per day, respectively. A 20-day digestion and metabolism trial was conducted, consisting of a 13-day preliminary period and a 7-day collection period. The results showed that trial group III exhibited significantly higher digestion of dry matter, organic matter, crude protein, neutral detergent fiber, and acid detergent fiber, as well as significantly higher digestibility of neutral detergent fiber and acid detergent fiber compared to the control group (P<0.05). The retention rates of nitrogen, calcium, and phosphorus in trial group III were significantly higher than those in the control group and trial group I (P<0.05). Digestible energy and metabolizable energy in trial group III were significantly higher than in the control group and trial group I (P<0.05), while no significant differences were observed among the control group, trial group I, and trial group II (P>0.05). Body weight gain and average daily gain during the trial period were highest in trial group III, though differences among groups were not significant (P>0.05). For body length increase,

trial group III was significantly higher than other groups (P<0.05). Chest circumference increase in trial group II was significantly higher than in the other three groups (P<0.05). No significant differences were found in plasma biochemical indexes among all groups (P>0.05). In conclusion, feeding extruded corn meal improved apparent digestibility of dietary nutrients, enhanced energy metabolism, and promoted growth and development in 6-month-old Yili horses, whereas feeding ground corn meal with enzyme preparation or steam-flaked corn meal showed no significant promoting effects on nutrient apparent digestibility or growth and development.

Keywords: corn meal; processing method; 6-month-old Yili horses; digestion and metabolism; plasma biochemical indexes; growth and development

Introduction

Corn is the most productive cereal grain crop with high yield potential worldwide and serves as the primary energy source in livestock feed, accounting for over two-thirds of feed formulations. Therefore, improving corn digestibility in diets is key to enhancing feed conversion efficiency. Heating corn starch in the presence of water disrupts its crystalline structure, forming -starch. This configuration breaks hydrogen bonds between starch molecules, making them more susceptible to enzymatic degradation. Additionally, processing alters the spatial structure of corn starch, exposing starch granules and greatly increasing opportunities for enzyme contact. Consequently, steam flaking and extrusion can increase corn utilization and reduce feed waste. Wang et al. [3] added 20%, 40%, and 60% extruded corn meal to weaned piglet diets and found that nutrient digestibility increased with higher extruded corn meal inclusion. Guyton et al. [4] confirmed that feeding steam-flaked corn meal to feedlot cattle reduced fecal and urinary output while increasing fecal and urinary nitrogen concentrations but decreasing total ammonia excretion. Currently, no reports exist on the use of steam-flaked corn meal or extruded corn meal in equine diets. Therefore, this study investigated the effects of steam-flaked corn meal and extruded corn meal on digestion and metabolism, blood biochemical indexes, and growth and development of 6-month-old Yili horses to explore possibilities for improving nutrient digestibility in equine diets.

1.1 Experimental Time and Location

The experiment was conducted from September 25 to October 15, 2014, at the Zhaosu Military Horse Farm in Ili Kazakh Autonomous Prefecture, Xinjiang.

1.2 Experimental Design

Twenty healthy 6-month-old Yili male horses with an average body weight of (105.10±11.83) kg were randomly divided into 4 groups (control group, trial

group I, trial group II, and trial group III; n=5 each) based on similar body weight. All horses received 0.3 kg powdered concentrate and 3.5 kg alfalfa hay daily (local Zhaosu alfalfa hay, chopped to 5 cm length). Additionally, the control group, trial group I, trial group II, and trial group III were fed 0.3 kg ground corn meal (purchased from Xinjiang Yili Tiankang Feed Co., Ltd.), 0.3 kg ground corn meal + 1 g -amylase (purchased from Cangzhou Zhongxin Biotechnology Co., Ltd., activity 4,000 U/g), 0.3 kg steam-flaked corn meal (purchased from Shandong Deling Feed Raw Material Factory), and 0.3 kg extruded corn meal (purchased from Qinhuangdao Jinxu Feed Factory) per horse per day, respectively. The digestion and metabolism trial lasted 20 days, including a 13-day preliminary period and a 7-day collection period. The composition and nutrient levels of the powdered concentrate are shown in Table 1 , and the nutrient levels of alfalfa hay, ground corn meal, steam-flaked corn meal, and extruded corn meal are shown in Table 2 .

1.3 Feeding Management

Horses were individually housed in single stalls and fed at 10:00, 12:00, and 18:00 daily with 0.1 kg powdered concentrate, 0.5 kg alfalfa hay, and 0.1 kg corn meal processed by different methods. At 24:00, an additional 2.0 kg alfalfa hay was provided. During the trial, horses were allowed free access to exercise areas and water after feeding. Body weight and body measurements were taken after overnight fasting on the day before the preliminary period. During the collection period, all urine, feces, powdered concentrate, and alfalfa hay were collected. On day 7 of the collection period, blood plasma was collected, and body weight and measurements were taken after overnight fasting.

1.4.1 Feces Collection and Processing During the collection period, total daily fecal output was weighed and thoroughly mixed, and 10% of the total weight was randomly sampled and placed in labeled bags for natural air-drying and weighing (air-dry weight). The air-dried fecal samples from 7 consecutive days were mixed, and 1 kg was sealed and stored for analysis.

1.4.2 Urine Collection and Processing During the collection period, total daily urine was collected, thoroughly shaken, filtered through gauze to remove impurities, and measured for total volume. Ten percent of the total volume was taken, treated with 5% concentrated sulfuric acid (for nitrogen fixation), stored in plastic bottles at 4°C, and recorded. The 7-day urine samples were mixed, and 1 L was stored for analysis.

1.4.3 Feed Collection and Processing During the trial, samples of powdered concentrate, corn meals processed by different methods, and alfalfa hay were collected, naturally air-dried, and ground for analysis.

1.4.4 Plasma Collection and Processing On day 7 of the collection period, approximately 10 mL of blood was collected from the jugular vein 4 hours after the first feeding into heparinized tubes, centrifuged at 1,500×g for 15 minutes, and plasma was collected in 1.5 mL Eppendorf tubes and stored at -20°C for analysis.

1.4.5 Body Weight and Measurement Body weight and measurements were taken after overnight fasting on the day before the preliminary period and on the morning after the trial ended.

1.5 Sample Analysis Methods

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

1.6 Statistical Analysis

Results are expressed as mean±SD. Data were analyzed using one-way ANOVA with SPSS 18.0 software, and Duncan's multiple range test was used for post-hoc comparisons.

Results

2.1 Effects of Corn Meals with Different Processing Methods on Nutrient Digestibility in 6-Month-Old Yili Horses

The effects of corn meals with different processing methods on nutrient digestibility are shown in Table 3 . No significant differences were observed in nutrient intake among groups ($P>0.05$). Regarding nutrient digestion, the ranking for dry matter and organic matter digestion was trial group III > trial group II > trial group I > control group. Trial group III showed significantly higher digestion of dry matter, organic matter, crude protein, neutral detergent fiber, and acid detergent fiber compared to the control group ($P<0.05$). No significant differences in dry matter, crude protein, neutral detergent fiber, or acid detergent fiber digestion were found among the control group, trial group I, and trial group II ($P>0.05$). For nutrient digestibility, no significant differences were

observed in dry matter, organic matter, or crude protein digestibility among groups (P>0.05). However, trial group III exhibited significantly higher neutral detergent fiber and acid detergent fiber digestibility than the control group (P<0.05).

2.2 Effects of Corn Meals with Different Processing Methods on Energy, Nitrogen, Calcium, and Phosphorus Metabolism in 6-Month-Old Yili Horses

The effects on energy, nitrogen, calcium, and phosphorus metabolism are shown in Table 4 . For energy metabolism, trial group III had significantly higher digestible energy and metabolizable energy than the control group and trial group I (P<0.05), while no significant differences were observed among the control group, trial group I, and trial group II (P>0.05). For nitrogen metabolism, trial group III showed significantly higher nitrogen retention amount and retention rate than the control group, trial group I, and trial group II (P<0.05), with no significant differences among the latter three groups (P>0.05). Calcium and phosphorus retention amounts and rates were highest in trial group III, with calcium retention amount and rate significantly higher than in trial group II (P<0.05), and phosphorus retention amount and rate significantly higher than in the control group and trial group I (P<0.05).

2.3 Effects of Corn Meals with Different Processing Methods on Plasma Biochemical Indexes in 6-Month-Old Yili Horses

The effects on plasma biochemical indexes are shown in Table 5 . No significant effects were observed on any plasma biochemical indexes among groups (P>0.05). However, globulin and urea nitrogen levels were higher in all trial groups compared to the control group, while glucose content was highest in trial group I.

2.4 Effects of Corn Meals with Different Processing Methods on Growth and Development of 6-Month-Old Yili Horses

The effects on growth and development are shown in Table 6 . No significant differences were found in initial body weight among groups (P>0.05). Final body weight increased in all groups, with trial group III showing the highest weight gain and average daily gain, though differences were not significant (P>0.05). Body height, chest circumference, cannon circumference, and body length all increased by the end of the trial. Body height increase differed significantly among groups (P<0.05), with trial group II showing the greatest increase. Body length increase was highest in trial group III, significantly different from other groups (P<0.05), while trial group I was significantly higher than the control group (P<0.05). Chest circumference increase in trial group I was significantly higher than in the other three groups (P<0.05), with no significant difference between the control group and trial group III, though both were significantly higher than trial group II (P<0.05). Cannon circumference increase in trial group III was

significantly lower than in other groups ($P<0.05$), with no significant differences among the remaining groups ($P>0.05$).

Discussion

3.1 Effects of Corn Meals with Different Processing Methods on Nutrient Digestibility in 6-Month-Old Yili Horses

Six-month-old foals are in a rapid growth phase and cannot meet their nutritional needs from forage alone, requiring supplemental feed. The digestive organs of 6-month-old growing foals are still developing and functionally immature, limiting feed utilization efficiency and necessitating feed processing to improve utilization. Steam flaking and extrusion of corn meal cause starch gelatinization, breaking hydrogen bonds between starch molecules to form gelatinized starch, which significantly improves corn starch digestibility. Steam flaking can increase starch digestibility by 10-20% [6]. Zhou et al. [7] reported that steam flaking and extrusion improved corn meal digestibility in animals. Zinn et al. [8] confirmed that steam-flaked corn meal significantly increased apparent digestibility in the animal gut compared to ground corn meal. Hale et al. [9] fed feedlot cattle diets containing different proportions of steam-flaked corn meal and found that increasing steam-flaked corn meal levels significantly improved apparent nutrient digestibility. Wang et al. [3] added 20%, 40%, and 60% extruded corn meal to weaned piglet diets and observed increasing nutrient digestibility with higher extruded corn meal inclusion.

In this study, feeding steam-flaked corn meal and extruded corn meal to 6-month-old Yili horses improved dry matter, organic matter, and crude protein digestion amount and digestibility compared to ground corn meal, with extruded corn meal showing better effects, consistent with previous research. This is because steam flaking and extrusion increase opportunities for enzymatic contact with corn meal in the digestive tract, thereby improving nutrient digestibility. However, feeding ground corn meal with enzyme preparation showed no significant effect on nutrient digestibility, possibly due to insufficient enzyme dosage in this experiment. Although steam-flaked and extruded corn meals improved nutrient digestion amount and digestibility, previous studies reported that horses digest crude protein, calcium, and phosphorus at rates of 80-90%, 51-69%, and 30-55%, respectively [10]. This study found calcium and phosphorus digestibility of 45-60% and 40-55%, consistent with previous results, while crude protein digestibility of 70-80% was slightly lower, likely because the immature gastrointestinal tract and limited digestive enzyme secretion in 6-month-old horses affected crude protein digestibility.

3.2 Effects of Corn Meals with Different Processing Methods on Energy, Nitrogen, Calcium, and Phosphorus Metabolism in 6-Month-Old Yili Horses

Steam flaking and extrusion alter corn protein structure, facilitating digestion and absorption in the animal gastrointestinal tract [11] and improving protein utilization efficiency. Herkelman et al. [12] reported that extruded corn meal increased digestible and metabolizable energy in pig diets. Fan et al. [13] found that feeding extruded corn meal to piglets increased dietary digestible energy by 8.1%. In this study, feeding steam-flaked and extruded corn meals increased digestible and metabolizable energy in 6-month-old Yili horses, but only extruded corn meal showed significant improvement.

Guyton et al. [4] confirmed that feeding steam-flaked corn meal to feedlot cattle reduced fecal and urinary output, increased fecal and urinary nitrogen excretion, but decreased total ammonia excretion and ammonia nitrogen concentration. In this study, feeding ground corn meal with enzyme preparation to 6-month-old Yili horses showed no significant changes in fecal nitrogen, urinary nitrogen, or nitrogen retention rate compared to ground corn meal alone. Steam-flaked corn meal increased fecal and urinary nitrogen excretion but did not significantly affect nitrogen retention rate. Extruded corn meal reduced fecal nitrogen excretion and significantly increased nitrogen retention rate, possibly related to improved nitrogen intake and ammonia utilization.

Glenn et al. [14] reported that replacing ground corn meal with high-moisture corn meal while maintaining consistent phosphorus intake reduced fecal phosphorus excretion. Guyton et al. [4] found that feeding steam-flaked corn meal to dairy cows reduced phosphorus excretion compared to ground corn meal. In this study, feeding ground corn meal with enzyme preparation and extruded corn meal improved calcium retention rate in 6-month-old Yili horses, while steam-flaked corn meal reduced calcium retention rate, possibly related to feed physical properties and the physiological status of the horses. For phosphorus metabolism, steam-flaked and extruded corn meals increased phosphorus retention amount compared to ground corn meal, consistent with Glenn et al. [14], while ground corn meal with enzyme preparation reduced phosphorus retention amount, requiring further investigation.

3.3 Effects of Corn Meals with Different Processing Methods on Plasma Biochemical Indexes in 6-Month-Old Yili Horses

Using steam-flaked and extruded corn meals in animal diets can improve nutrient digestion efficiency and energy-nitrogen balance. Li et al. [15] confirmed that adding different levels of cooked corn starch to beef cattle diets increased plasma glucose content with higher rumen bypass starch content. Wang et al. [16] added ground corn meal, ground steam-corn meal, dry-rolled corn meal, wet-rolled corn meal, and steam-flaked corn meal to Yunnan yellow cattle diets and found that steam-flaked corn meal significantly increased plasma glucose while reducing

urea nitrogen. In this study, feeding ground corn meal with enzyme preparation, steam-flaked corn meal, and extruded corn meal showed no significant effects on plasma total protein, albumin, globulin, glucose, or urea nitrogen in 6-month-old Yili horses, possibly because the low feeding amounts of steam-flaked and extruded corn meals had minimal impact on these plasma indexes.

3.4 Effects of Corn Meals with Different Processing Methods on Growth and Development in 6-Month-Old Yili Horses

Numerous reports exist on the effects of steam-flaked and extruded corn meals on animal growth and development. Ramirez et al. [17] reported that steam-flaked corn meal increased average daily gain and reduced feed-to-gain ratio in beef cattle. Feng et al. [18] found that extruded corn meal increased average daily gain by 8% and average daily feed intake by 6.93% in early-weaned piglets while significantly reducing diarrhea rate. Feeding steam-flaked corn meal and extruded soybean mixed concentrate to calves significantly increased daily gain and eye muscle area compared to the control group [19]. Campbell et al. [20] reported that dietary enzyme supplementation could increase feed protein absorption by 21%. In this study, feeding ground corn meal with enzyme preparation and extruded corn meal increased average daily gain in 6-month-old Yili horses, consistent with nutrient digestibility results, while steam-flaked corn meal showed no significant effect on weight gain.

Body measurements are important indicators of equine growth and development. Meng [21] reported that Yili horses develop body height earliest, followed by body length, and finally chest circumference. In this study, compared to ground corn meal, ground corn meal with enzyme preparation promoted increases in body length and chest circumference, while steam-flaked and extruded corn meals promoted increases in body height, body length, and chest circumference in 6-month-old Yili horses, consistent with improved calcium and phosphorus digestibility and Meng' s [21] findings.

Conclusion

Feeding extruded corn meal improved apparent digestibility of dietary dry matter, organic matter, and crude protein, increased calcium and phosphorus retention rates, and promoted growth and development in 6-month-old Yili horses. In contrast, feeding ground corn meal with enzyme preparation or steam-flaked corn meal showed no significant promoting effects on nutrient apparent digestibility or growth and development in 6-month-old Yili horses.

References

[1] XU Yanxia, LI Xuye, WANG Xiaochun, et al. Development and achievements of corn breeding technology in China since the founding of the People's Republic of China [J]. Heilongjiang Agricultural Sciences, 2009(6): 165–168.

[2] LIU Meiying, XIONG Xian' an, ZONG Li. Study on the effect of feed processing on nutrition [J]. Cereal & Feed Industry, 2000(1): 24-26.

[3] WANG Xiao, HE Ruiguo, ZHANG Wenjing. Effects of different amounts of extruded corn on growth performance and nutrient digestibility in weaned piglets [J]. Feed Industry, 2005, 26(23): 24-26.

[4] GUYTON A D, MCKINNEY J M, KNOWLTON K F. The effect of steam-flaked or dry ground corn and supplemental phytic acid on phosphorus partitioning and ruminal phytase activity in lactating cows [J]. Journal of Dairy Science, 2003, 86(12): 3972-3982.

[5] GLADE M J. Nutrition and performance of racing Thoroughbreds [J]. Equine Veterinary Journal, 1983, 15(1): 31-36.

[6] TANG Zhigao, ZHUO Mei, ZHAO Xiaogang. Effect of dietary extruded corn on growth performance of piglets [J]. China Animal Husbandry & Veterinary Medicine, 2009, 36(2): 39-41.

[7] ZHOU Jiaping, YANG Zaibin. Research and application technology progress on the relationship between feed processing treatment and nutrient utilization [C]//Proceedings of 2007 Shandong Feed Science and Technology Exchange Conference. Tai' an: Animal Husbandry and Veterinary Society, 2007.

[8] ZINN R A, ADAM C F, TAMAYO M S. Interaction of feed intake level on comparative ruminal and total tract digestion of dry-rolled and steam-flaked corn [J]. Journal of Animal Science, 1995, 73(5): 1239-1245.

[9] HALE W H, CUITUN L, SABA W J, et al. Effect of steam processing and flaking milo and barley performance digestion steers [J]. Journal of Animal Science, 1966, 25(2): 392-396.

[10] SCHRYVER H F, PARKER M T, DANILUK P D, et al. Salt consumption and the effect of salt on mineral metabolism in horses [J]. The Cornell Veterinarian, 1987, 77(2): 122-131.

[11] SANTOS J E P, HUBER J T, THEURER C B, et al. Response of lactating dairy cows to steam-flaked sorghum, steam-flaked corn, or steam-rolled corn and protein sources of differing degradability [J]. Journal of Dairy Science, 1999, 82(4): 728-737.

[12] HERKELMAN K L, RODHOUSE S L, VEUM T L, et al. Effect of extrusion on the ileal and fecal digestibilities of lysine in yellow corn in diets for young pigs [J]. Journal of Animal Science, 1990, 68(8): 2414-2424.

[13] FAN M Z, SAUER W C, HARDIN R T, et al. Determination of apparent ileal amino acid digestibility in pigs: effect of dietary amino level [J]. Journal of Animal Science, 1994, 72(11): 2851-2859.

[14] GLENN B P, DAWSON T E, LEFEOURT A M, et al. Effect of level of high moisture corn in alfalfa-based rations on starch digestion by mid lactation cows [J]. Journal of Animal Science, 1998, 76: 336.

[15] LI Fuchang, FENG Yanglian, MO Fang, et al. Digestibility of cooked corn starch and its effect on nitrogen retention and blood glucose concentration in beef cattle [J]. Journal of China Agricultural University, 1998, 3(Suppl.): 167-171.

[16] WANG Guiying, MAO Huaming, WEN Jikun. Effects of different processed corn diets on blood indexes and correlation analysis in Yunnan yellow cattle [J]. Feed Industry, 2010, 31(5): 27-30.

[17] RAMIREZ R G, KIESLING H E, GALYEAN M L, et al. Influence steam-flaked, steamed-whole or whole shelled corn on performance and digestion in beef steers [J]. Journal of Animal Science, 1985, 61(1): 1-8.

[18] FENG Zhanvu, YAN Yijie, ZHANG Tianrong, et al. Effects of different raw material combinations in creep feed on production performance and health status of piglets [J]. China Feed, 2011(3): 7-11.

[19] LIU Ping, MENG Qingxiang, XIE Xiangxue, et al. Effects of steam-flaked corn and extruded soybean on growth and slaughter performance of dairy bull calves [J]. Journal of China Agricultural University, 2013, 18(2): 124-129.

[20] CAMPBELL G L, BEDFORD M R. Enzyme applications for monogastric feeds: a review [J]. Canadian Journal of Animal Science, 1992, 72(3): 449-466.

[21] MENG Jun. Preliminary study on hybrid improvement effect of Yili horses in Zhaosu Horse Farm [D]. Master' s Thesis. Urumqi: Xinjiang Agricultural University, 2010.

Corresponding author, professor, E-mail: yangkailun2002@aliyun.com

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