

Effects of Different Processing Methods on the Nutritional Value of Corn Fiber Feed (Postprint)

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Abstract

This experiment utilized dry corn gluten feed (DCGF) and wet corn gluten feed (WCGF) as raw materials to analyze the effects of processing technology on the nutritional value of corn gluten feed. Three dry-period Holstein dairy cows fitted with permanent rumen fistulas were selected as experimental animals. Conventional methods were employed to determine the nutrient composition of DCGF and WCGF, the nylon bag method was used to determine rumen degradation characteristics, a three-step in vitro method was applied to determine the intestinal digestibility of rumen undegraded protein (RUP), and the NRC model was utilized to predict metabolizable protein and essential amino acid supply. The results showed: 1) Among the conventional nutrients of DCGF, except for neutral detergent fiber (NDF), neutral detergent insoluble crude protein (NDICP), and acid detergent insoluble crude protein (ADICP) contents, which were significantly higher than those of WCGF ($P < 0.05$), the contents of other nutrients showed no significant differences ($P > 0.05$); 2) The ruminal NDF degradation rate showed no significant difference between DCGF and WCGF ($P > 0.05$), whereas the ruminal dry matter (4, 24, 48 h) and crude protein (CP) degradation rates (12, 24, 48, and 72 h) and effective degradation rate of DCGF were significantly lower than those of WCGF ($P < 0.05$); 3) The RUP content of DCGF was significantly higher than that of WCGF ($P < 0.05$), while total digestible nutrients, microbial protein, and metabolizable protein contents showed no significant differences from DCGF ($P > 0.05$); 4) The intestinal digestibility of RUP of DCGF was significantly lower than that of WCGF ($P < 0.05$), but total digestible protein content showed no significant difference ($P > 0.05$); 5) Among the essential amino acids provided by feed RUP, the contents of histidine (His), phenylalanine (Phe), isoleucine (Ile), and total essential amino acids provided by RUP of DCGF were significantly higher than those of WCGF ($P < 0.05$). In conclusion, both DCGF and WCGF contain high levels of utilizable fiber and protein, and can serve as good sources of fiber and protein for dairy cows; how-

ever, the lower ruminal CP degradation rate and intestinal digestibility of RUP of DCGF may affect its protein and amino acid nutritional value.

Full Text

Effects of Different Processing Techniques on Nutritional Value of Corn Gluten Feed

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Abstract

This trial was conducted to evaluate the effects of processing technology on the nutritional value of corn gluten feed using wet corn gluten feed (WCGF) and dry corn gluten feed (DCGF) as ingredients. Three ruminally cannulated Holstein cows in dry period were selected as experimental animals. Nutrient composition contents of DCGF and WCGF were determined by conventional methods, nylon-bag technique was used to evaluate rumen degradation characteristics, intestinal digestibility of rumen undegraded protein (RUP) was determined using an in vitro three-step method, and the NRC model was used to determine supplemental amounts of metabolizable protein and essential amino acids. The results showed as follows: 1) Except for contents of neutral detergent fiber (NDF), neutral detergent insoluble crude protein (NDICP), and acid detergent insoluble crude protein (ADICP), nutrient contents of DCGF and WCGF were not significantly different ($P>0.05$). 2) Compared with WCGF, dry matter (DM) (at 4, 24, and 48 h) and crude protein (CP) degradability (at 12, 24, 48, and 72 h) of DCGF were significantly lower ($P<0.05$), but NDF degradability was not significantly different between the two feeds ($P>0.05$). 3) RUP content of DCGF was significantly higher than that of WCGF ($P<0.05$), and there were no significant differences in contents of total digestible nutrients, microbial protein, and metabolizable protein between the two feeds ($P>0.05$). 4) Compared with WCGF, intestinal digestion of RUP of DCGF was significantly lower ($P<0.05$), but total digestible protein was not significantly different ($P>0.05$). 5) Among essential amino acids provided by RUP, contents of histidine, phenylalanine, isoleucine, and total essential amino acids provided by RUP of DCGF were significantly higher than those of WCGF ($P<0.05$). In conclusion, DCGF and WCGF contain high contents of available fiber and protein, which can be used as fiber and protein feed for dairy cows, but low degradability of CP and small intestinal digestibility of RUP of DCGF may affect their nutritional values of protein and amino acids.

Keywords: corn gluten feed; rumen degradability; intestinal digestibility; amino acid

Introduction

The processing flow for corn starch production using wet milling can be broadly divided into three basic stages: soaking, grinding, and separation. Corn soaking involves immersing cleaned corn in a 0.2% sulfurous acid solution at approximately 50°C for 60-70 hours. The primary purposes are to soften the corn and reduce its mechanical strength for grinding, and to disrupt protein structures in the endosperm cells to release free starch for easier separation. The resulting soaking liquid, known as dilute corn steep liquor, contains 7-9% dry matter (DM) with a pH of 3.9-4.1. This dilute corn steep liquor is concentrated through a three-effect falling film evaporation system to produce concentrated corn steep liquor with approximately 40% DM content. After soaking, corn moisture content is about 45%. Following three grinding steps, germ, starch, and seed coat are separated. The starch milk undergoes sedimentation, washing, fiber removal, and drying to produce starch products. The germ is processed through washing, dehydration, and drying for corn oil and corn germ meal production. The separated corn fiber (corn seed coat, germ root, and root cap) is washed countercurrently and dehydrated to approximately 40% DM content. Corn fiber is then mixed with concentrated corn steep liquor at a specific ratio (related to final crude protein content) in a large mixer to produce wet corn gluten feed (WCGF) with about 40% DM content for direct use as animal feed. Alternatively, WCGF is dried in a tube-bundle dryer to approximately 12% moisture content to produce dry corn gluten feed (DCGF). In foreign countries, most corn gluten feed is utilized by dairy farms in WCGF form with good feeding results, but due to storage and transportation limitations, many domestic manufacturers produce DCGF instead.

Different processing techniques may affect feed nutritional value, yet comparative studies on the nutritional value of WCGF and DCGF are lacking. Therefore, this trial compared WCGF and DCGF nutritional value differences in terms of nutrient composition, rumen degradation characteristics, and metabolizable protein and amino acid supply to explore the effects of heat drying on corn gluten feed nutritional value and provide a theoretical basis for scientific and rational utilization.

Materials and Methods

Experimental Animals and Materials

Three healthy Holstein cows in dry period weighing approximately 600 kg and fitted with permanent rumen cannulas were selected as experimental animals. DCGF and WCGF were collected from two batches each at Cargill Biochemical Co., Ltd. and Feihe Original Ecology Ranch in Songyuan City, Jilin Province, totaling four feed samples. WCGF was dried at 65°C for 48 hours, and air-dried samples were ground through a 1 mm sieve for analysis.

Basal Diet and Management

The basal diet for experimental cows was formulated according to NRC (2001) dairy cattle nutrient requirements, with composition and nutrient levels shown in Table 1. Cows were fed twice daily (06:00 and 18:00) with free access to water.

Experimental Methods

Nutrient Composition Analysis Conventional nutrient contents including DM, crude ash, CP, and ether extract (EE) of DCGF and WCGF were determined according to AOAC (1997) methods. Starch content was measured using the enzymatic method of Zhang et al. with reagent kits purchased from Shanghai Rongsheng Biopharmaceutical Company. Contents of neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), neutral detergent insoluble crude protein (NDICP), and acid detergent insoluble crude protein (ADICP) were determined according to Van Soest et al. Non-protein nitrogen (NPN) and soluble protein (SP) contents were measured using the Cornell Net Carbohydrate-Protein System (CNCPS) method. Each sample was analyzed in triplicate for each index.

Rumen Degradability Determination by Nylon Bag Technique The nylon bag procedure followed the steps described by Nuez-Ortín and Yu. Approximately 7 g of sample (precise to 0.0001 g) was placed in nylon bags measuring 10 cm × 20 cm with 50 μm pore size, resulting in a sample weight to surface area ratio of 17.5 mg/cm². Bags were incubated in the rumen of three experimental cows for 0, 4, 8, 12, 24, 36, 48, and 72 hours. Upon removal, bags were immediately rinsed with cold tap water to remove surface chyme and residues and terminate microbial fermentation. Bags were further washed with cold tap water until the rinse water was clear and odorless, then dried at 65°C for 48 hours without wringing. Residues were ground for nutrient content analysis. Three replicate bags were used for each time point from 0-12 hours, and four replicate bags for 16-48 hours, with no more than 30 bags in the rumen simultaneously. Rumen dynamic degradation parameters were calculated using the non-linear model of Ørskov and McDonald:

$$P = a + b[1 - \exp(-ct)]$$

Where: P is nutrient degradability at each time point (%); a is rapidly degradable fraction (soluble fraction) content (%); b is slowly degradable fraction content (%); c is degradation rate of slowly degradable fraction (%/h) (c > 0); and a+b is potentially degradable fraction (%).

Effective degradability was calculated as: $ED = a + bc/(c + Kp)$, where ED is effective degradability (%) and Kp is rumen outflow rate of feed, taken as 4.6%/h.

Intestinal Digestibility of Rumen Undegraded Protein (RUP) by Three-Step In Vitro Method Intestinal digestibility of RUP was determined using a modified three-step in vitro method. Residues from nylon bags after 16 hours of rumen incubation (5 g) were placed in 50 mL centrifuge tubes with 10 mL pepsin solution (Sigma p-7012, Sigma-Aldrich, USA) at pH 1.9, and incubated in a 37°C water bath shaker for 60 minutes. Then, 13.5 mL trypsin solution (Sigma p-7545, Sigma-Aldrich, USA) and 0.5 mL of 1 mol/L NaOH solution were added to adjust pH to 7.9. Tubes were incubated in a 38°C water bath shaker for an additional 24 hours with vortexing every 8 hours. After incubation, 3 mL of 100% trichloroacetic acid (TCA) was added, vortexed, and centrifuged at 10,000×g for 15 minutes. CP content in the supernatant was determined by Kjeldahl method. The ratio of CP content in the supernatant to CP content in the 16-hour rumen degradation residue represented intestinal digestibility of RUP.

$$\text{IDP} = \text{RUP} \times \text{dIDP}$$

$$\text{TDP} = \text{IDP} + \text{RDP}$$

Where: IDP is intestinally digestible protein; dIDP is intestinal digestibility of RUP (%); TDP is total digestible protein; and RDP is rumen degradable protein.

NRC Model Prediction of Metabolizable Protein Supply The NRC (2001) model was used to estimate potential nutrient supplies of both feeds, including total digestible nutrients, microbial protein, intestinally absorbable microbial protein, intestinally absorbable RUP, endogenous true protein, intestinally absorbable endogenous true protein, and metabolizable protein. According to the NRC model, feed nutrient supply formulas are:

$$\text{TDN} = \text{dNFC} + \text{dCP} + (\text{dFA} \times 2.25) + \text{dNDF} - 7$$

$$\text{MCP} = 0.13 \times \text{TDN}$$

$$\text{AMCP} = 0.80 \times 0.80 \times \text{MCP}$$

$$\text{ARUP} = \text{RUP} \times \text{dIDP}$$

$$\text{ECP} = 6.25 \times 1.9 \times \text{DM}$$

$$\text{AECP} = 0.50 \times 0.80 \times \text{ECP}$$

$$\text{MP} = \text{ARUP} + \text{AMCP} + \text{AECP}$$

Where: TDN is total digestible nutrients (g/kg DM); dNFC is digestible non-fiber carbohydrate (%); dCP is digestible CP (%); dFA is digestible fatty acid (%); dNDF is digestible NDF (%); MCP is microbial protein (g/kg DM); AMCP is intestinally absorbable microbial protein (g/kg DM); ARUP is intestinally absorbable RUP (g/kg DM); ECP is endogenous true protein (g/kg DM); AECP is intestinally absorbable endogenous true protein (g/kg DM); and MP is metabolizable protein (g/kg DM).

NRC Model Prediction of Amino Acid Supply Amino acid contents were determined by acid hydrolysis method and analyzed using a Hitachi L-

8800 automatic amino acid analyzer. Detection wavelengths were 440 and 570 nm; column temperature was 57°C; reaction column temperature was 135°C; flow rate was 0.400 mL/min; post-column derivatization reagent flow rate was 0.350 mL/min; and injection volume was 20 µL.

According to the NRC (2001) prediction model, essential amino acid contents provided by RUP were calculated as:

$$\begin{aligned} \text{EAAiRUP} &= \text{CP} \times \text{RUP} \times \text{EAAi} \times 0.001 \\ \text{TEAARUP} &= \sum \text{EAAiRUP} \end{aligned}$$

Where: EAAiRUP is content of a specific essential amino acid provided by feed RUP (g/kg DM); EAAi is content of a specific essential amino acid (% CP); and TEAARUP is total essential amino acid content provided by feed RUP (g/kg DM).

Statistical Analysis Data were processed using SAS 9.2 NLIN procedure to calculate rumen dynamic degradation parameters, and MIXED model was used for statistical analysis.

Results

Nutrient Composition of WCGF and DCGF

Nutrient composition contents of DCGF and WCGF are shown in Table 2. Crude ash and EE contents were not significantly different between the two feeds ($P>0.05$). Regarding carbohydrates, DCGF contained higher NDF content, significantly greater than WCGF ($P<0.05$, 520.9 vs. 490.8 g/kg DM), while starch, ADF, and ADL contents were not significantly different ($P>0.05$). For protein components, CP contents were not significantly different ($P>0.05$), but NDICP, ADICP, and NPN contents of DCGF were significantly higher than those of WCGF ($P<0.05$).

Rumen Degradation Characteristics of DM, CP, and NDF in WCGF and DCGF

Degradability of DM, CP, and NDF of DCGF and WCGF in the rumen at different time points is shown in Table 3. As rumen degradation time increased, degradability of DM, CP, and NDF gradually increased. DM degradability of DCGF was significantly lower than WCGF at 4, 24, and 48 h ($P<0.05$), with no significant differences at other time points ($P>0.05$). CP degradability was not significantly different between the two feeds before 8 h ($P>0.05$), but WCGF showed higher CP degradability after 12 h, significantly greater than DCGF ($P<0.05$), reaching 91.51% at 72 h. NDF degradability was not significantly different between the two feeds at any time point ($P>0.05$), indicating similar NDF degradation characteristics in the rumen.

Rumen dynamic degradation parameters of DM, CP, and NDF for DCGF and

WCGF were analyzed using non-linear fitting in SAS 9.2 software and are presented in Table 4. Rapidly degraded fraction of DM was not significantly different between the two feeds ($P>0.05$), while slowly degraded fraction of DM in DCGF was significantly higher than in WCGF ($P<0.05$), but its degradation rate and effective degradability were significantly lower ($P<0.05$). WCGF showed significantly higher slowly degraded fraction and potentially degradable fraction of CP ($P<0.05$), with no significant difference in rapidly degraded fraction ($P>0.05$). Effective degradability of CP in WCGF was significantly higher than in DCGF (67.01% vs. 64.08% CP, $P<0.05$). All rumen degradation parameters of NDF were not significantly different between the two feeds ($P>0.05$).

Comparison of Intestinal Digestion Characteristics of Protein in DCGF and WCGF

Comparison of intestinal digestion characteristics is shown in Table 5. Intestinal digestibility of RUP in DCGF was significantly lower than in WCGF ($P<0.05$, 65.31% vs. 71.49%). Contents of intestinally digestible protein and total digestible protein were not significantly different between the two feeds ($P>0.05$).

NRC Model Prediction of Metabolizable Protein Supply in DCGF and WCGF

Predicted metabolizable protein supply from DCGF and WCGF using the NRC model is shown in Table 6. Total digestible nutrients content was not significantly different between the two feeds ($P>0.05$), and correspondingly, microbial protein and intestinally absorbable microbial protein contents were also not significantly different ($P>0.05$). The two feeds showed different protein degradation characteristics in the rumen, with RUP content of DCGF significantly higher than WCGF ($P<0.05$, 75.30 g/kg DM vs. 66.80 g/kg DM). Due to differences in intestinal digestibility of RUP, intestinally absorbable RUP content was not significantly different ($P>0.05$). Consequently, metabolizable protein contents of DCGF and WCGF were not significantly different ($P>0.05$), at 110.90 and 108.42 g/kg DM, respectively.

Essential Amino Acid Nutritional Value of DCGF and WCGF

Essential amino acid nutritional values are shown in Table 7. Among feed essential amino acids, except for isoleucine (Ile), threonine (Thr), and total essential amino acids (TEAA), other essential amino acid contents were not significantly different ($P>0.05$). However, among essential amino acids provided by RUP, histidine (His), phenylalanine (Phe), and Ile contents provided by RUP of DCGF were significantly higher than those of WCGF ($P<0.05$), while other essential amino acids provided by RUP were not significantly different ($P>0.05$). TEAA content provided by RUP of DCGF was significantly higher than WCGF (26.33 g/kg DM vs. 24.43 g/kg DM). Lysine and methionine contents provided by RUP in DCGF were 2.72 and 1.06 g/kg DM, respectively, compared to 2.57 and 1.01 g/kg DM in WCGF. Lys:Met ratios were 2.56 and 2.54, respectively,

indicating lysine as the first limiting amino acid with relatively balanced amino acid profiles.

Discussion

Nutrient Composition of WCGF and DCGF

This trial comprehensively analyzed and compared nutrient composition differences between WCGF and DCGF. Both feeds contained high levels of NDF, CP, and starch, making them good sources of fiber and protein for dairy cows. DCGF had significantly higher NDF content than WCGF, while ADF, ADL, and starch contents were not significantly different, potentially giving DCGF an advantage in energy supply. Measured nutrient contents of WCGF in this trial were basically consistent with results reported by Pan (2014), except for slightly lower NDICP content, but differed from values reported by foreign researchers, possibly due to differences in corn varieties and quality used for starch processing. DM, CP, NDF, and ADF contents of DCGF were comparable to results from Lin et al. (2013), but EE and crude ash contents were higher, likely due to differences in origin and processing procedures. Significantly higher NDICP and ADICP contents in DCGF indicated lower protein degradability compared to WCGF, likely resulting from increased heat-denatured proteins (Maillard reaction products) during the corn fiber steeping and drying process. Different feed protein processing methods cause differences in three-dimensional structures and chemical bonds (such as cross-linking bonds) within and between protein molecules and between proteins and carbohydrates.

Rumen Degradation Characteristics of DM, CP, and NDF in WCGF and DCGF

Currently, limited research data are available on rumen degradation patterns of corn gluten feed, providing few comparable references. Rumen degradation characteristics of WCGF in this trial were similar to results from Li et al. (2015). Feed degradation in the rumen 主要取决于其发酵的难易程度和在瘤胃内的滞留时间, with passage rate primarily determined by feed specific gravity and particle size. Small particles allow full contact with rumen contents, enabling adequate fermentation and promoting degradation. Within 72 hours of rumen incubation, DM degradability of DCGF was lower than WCGF at 4, 24, and 48 h, with no significant differences at other time points, indicating WCGF was more easily degraded than DCGF. Both feeds showed high initial DM degradability (at 4 h) that plateaued after 24 h, suggesting DM degradation occurred mainly within 24 h. DCGF had higher slowly degraded DM fraction but significantly lower degradation rate and effective degradability than WCGF. WCGF showed faster CP degradation with significantly higher slowly degraded fraction and degradation rate, likely due to protein structural changes during heat drying. NRC (2001) reported that heat treatment reduces CP availability, explaining RUP content differences. Both feeds showed slow NDF degradation within 24 h, with extensive degradation after 24 h, and no significant difference in effective

NDF degradability, indicating drying does not affect fiber availability. Hristov et al. (2003) reported that high specific gravity of WCGF results in short rumen retention time and higher diet passage rate. Because it provides non-forage short fiber with relatively high specific gravity and short rumen retention time, Allen and Grant (2000) suggested adding appropriate alfalfa hay to diets containing corn gluten feed to increase diet rumen retention time and NDF degradability.

Intestinal Digestion Characteristics of Protein in DCGF and WCGF

After entering the small intestine, RUP and microbial protein undergo digestion similar to monogastric animals, being hydrolyzed by pancreatic proteases into free amino acids absorbed by small intestinal epithelial cells, together constituting total digestible protein. In this trial, intestinal digestibility of RUP in DCGF was significantly lower than in WCGF, possibly due to protein structural changes during processing altering protein bound to cellulose and affecting digestibility. Lower protein digestibility resulted in similar intestinally absorbable RUP and metabolizable protein contents between DCGF and WCGF. Feed protein nutritional value depends on metabolizable protein content.

Prediction of Truly Absorbable Protein Supply from DCGF and WCGF

According to the NRC model, total digestible nutrients are determined by digestible CP, digestible NDF, digestible NFC, and digestible FA contents. DCGF had higher NDF content while WCGF contained more NFC, resulting in no significant difference in total digestible nutrients content between the two feeds, indicating similar energy supply values. Although RUP contents differed, differences in intestinal digestibility of RUP led to no significant difference in intestinally absorbable RUP content. In the NRC model, microbial protein content positively correlates with total digestible nutrients content, and no significant difference was observed between DCGF and WCGF. Microbial protein contains 80% true protein with approximately 80% intestinal absorption rate; rumen endogenous nitrogen (containing 80% true protein) content positively correlates with feed DM content, with 50% of endogenous true protein reaching the duodenum for absorption. Therefore, endogenous true protein and intestinally absorbable endogenous true protein contents of WCGF were significantly lower than DCGF. Metabolizable protein entering the small intestine consists of intestinally absorbable RUP, intestinally absorbable microbial protein, and intestinally absorbable endogenous true protein. No significant difference in metabolizable protein content was observed between WCGF and DCGF, indicating similar nutritional values from a metabolizable protein perspective.

Essential Amino Acid Nutritional Value of DCGF and WCGF

Amino acids provided by feed RUP, rumen microbial protein, and endogenous true protein are essential raw materials for body tissue and milk protein synthesis, with small amounts also serving as precursors for other metabolites. This

trial measured 10 essential amino acids in DCGF and WCGF. Essential amino acid contents of WCGF were similar to results from Pan (2014), and those of DCGF were similar to Lin et al. (2013). Significant differences in RUP content between the two feeds resulted in significantly higher TEAA content provided by RUP in DCGF. Research indicates that efficiency of metabolizable protein for protein synthesis depends on the match between essential amino acid ratios in metabolizable protein and animal requirements, as well as TEAA content in metabolizable protein. Most studies identify Lys and Met as the first-limiting essential amino acids in dairy cow metabolizable protein, though the limiting order depends on their relative contents in RUP. When corn or its by-products provide most or all dietary RUP, Lys is the first-limiting amino acid. Estimating feed digestible amino acid supply must consider two “amino acid pools” : the first is essential amino acids provided by RUP, and the second is essential amino acids from microbial protein and endogenous true protein. This trial only considered essential amino acids provided by RUP. Due to lower rumen CP degradability, DCGF provided more essential amino acids through RUP, but its significantly lower intestinal digestibility of RUP may affect essential amino acid nutritional value.

Conclusions

1. Both DCGF and WCGF contain high contents of available fiber and degradable protein, serving as good fiber and protein sources for dairy cows.
2. Rumen NDF degradability was not significantly different between DCGF and WCGF, but DCGF showed reduced rumen CP degradability and intestinal digestibility of RUP, affecting its protein nutritional value.
3. DCGF and WCGF provided similar total digestible nutrients and microbial protein, with comparable nutritional values in metabolizable protein supply.
4. DCGF provided higher TEAA content through RUP than WCGF, but its lower intestinal digestibility of RUP may reduce amino acid nutritional value.

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