Postprint: Comparison of Nutritional Values of Commonly Used Roughage and Corn Fiber Feed Using the Cornell Net Carbohydrate and Protein System and NRC Model

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Abstract

This experiment aimed to apply the Cornell Net Carbohydrate and Protein System (CNCPS) and NRC model to compare the nutritional value of corn fiber feed (DCGF) with commonly used roughages for dairy cows (alfalfa, corn silage, and Chinese wild rye), and subsequently analyze the feasibility of DCGF as a fiber feed resource for dairy cows. Feed samples were collected from different farms in Northeast China, and following nutritional composition analysis, the CNCPS model was utilized to fractionate the protein and carbohydrate components of each feed and predict the potential nutrient supply to dairy cows, while the NRC model was employed to estimate the digestible nutrients and energy values of the four feeds. The results showed that: 1) The crude protein (CP) content in DCGF was significantly higher than that in corn silage and Chinese wild rye ($P<0.05$), the neutral detergent fiber (NDF) content was significantly higher than that in alfalfa ($P<0.05$), and the acid detergent fiber (ADF) and acid detergent lignin (ADL) contents were significantly lower than those in the other three roughages ($P<0.05$). 2) The contents of rapidly degradable true protein (PB1) and moderately degradable true protein (PB2) in DCGF were significantly lower than those in alfalfa ($P<0.05$); the contents of moderately degradable carbohydrate (CB1) and slowly degradable carbohydrate (CB2) were significantly higher than those in the other three roughages ($P<0.05$). 3) Alfalfa had the highest metabolizable protein (MP) content, followed by DCGF. 4) DCGF had the highest total digestible nutrients (TDNm) and net energy at maintenance level. These results suggest that DCGF has relatively high nutritional value and can be used as a high-protein fiber feed to replace part of the roughage in dairy cow diets, alleviating the shortage of high-quality roughage and protein feed resources in China.

Full Text

Comparison of Nutritional Values of Dry Corn Gluten Feed and Commonly Used Roughages Using Cornell Net Carbohydrate and Protein System and NRC Models

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Abstract

This study aimed to compare the nutritional values of dry corn gluten feed (DCGF) with commonly used dairy cattle roughages (alfalfa hay, corn silage, and wildrye) using the Cornell Net Carbohydrate and Protein System (CNCPS) and NRC models, and to analyze the feasibility of DCGF as a fiber feed resource for dairy cattle. Feed samples were collected from different farms in Northeast China. After nutrient composition analysis, the CNCPS model was used to fractionate proteins and carbohydrates in each feed, and to predict potential nutrient supplies to dairy cattle. Simultaneously, the NRC model was employed to estimate digestible nutrients and energy values of the four feedstuffs. The results showed that: (1) DCGF had significantly higher crude protein (CP) content than corn silage and wildrye ($P<0.05$), significantly higher neutral detergent fiber (NDF) content than alfalfa hay ($P<0.05$), and significantly lower acid detergent fiber (ADF) and acid detergent lignin (ADL) contents than the other three roughages ($P<0.05$). (2) The rapidly degraded true protein (PB1) and intermediately degraded true protein (PB2) contents of DCGF were significantly lower than those of alfalfa hay ($P<0.05$), while its intermediately degraded carbohydrate (CB1) and slowly degraded carbohydrate (CB2) contents were significantly higher than those of the other three roughages ($P<0.05$). (3) Alfalfa hay had the highest metabolizable protein (MP) content, followed by DCGF. (4) DCGF had the highest total digestible nutrients at maintenance level (TDNm) and net energy values. These results indicate that DCGF has relatively high nutritional value and can be used as a high-protein fiber feed to replace part of the roughage in dairy cattle diets, thereby alleviating the shortage of high-quality roughage and protein feed resources in China.

Keywords: dry corn gluten feed; roughage; nutritional value; energy value

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Corn is one of the most important grain resources worldwide, and China is a major corn starch producer. The wet milling process for corn starch production generates approximately 30% by-products, mainly including corn steep liquor, corn bran, corn gluten, and small amounts of corn germ meal. Dry corn gluten feed (DCGF) is a fibrous feed rich in digestible fiber and protein, produced by mixing corn bran with corn steep liquor (concentrated from corn soaking water) at a ratio of approximately 2:1. The starch content of DCGF is about 1/6 or even less than that of corn starch. Adding DCGF to ruminant diets helps stabilize the rumen environment and effectively reduces the incidence of rumen acidosis [1]. Except for starch, the nutrient contents in DCGF are nearly three times those in its raw materials [2]. With the development of China' s dairy industry, the shortage of high-quality roughage resources has become increasingly severe, making the development of new fiber feed resources significant for dairy farming. To scientifically and comprehensively evaluate the nutritional value of DCGF and assess whether it can be developed and utilized as a high-quality fiber feed resource for dairy cattle, this study applied the Cornell Net Carbohydrate and Protein System (CNCPS) and NRC models to compare the nutritional values of DCGF with commonly used dairy cattle roughages (alfalfa hay, corn silage, and wildrye), aiming to provide a scientific basis for the rational application of DCGF in dairy production.

1.1 Experimental Materials

Experimental materials included DCGF, alfalfa hay, corn silage, and wildrye, collected from four farms and Cargill Bio-chemical Co., Ltd. in Northeast China, totaling 11 feed samples representing four raw materials. The two DCGF samples were obtained from Qiqihar Feihe Original Ecological Ranch and Cargill Bio-chemical Co., Ltd. Three samples each of alfalfa hay, corn silage, and wildrye were collected from Shandongtun Holstein Cattle Breeding Farm, Heilongjiang Jiusan Rongjun Australian Cattle Breeding Center, and Nestlé DFI Ranch, respectively. All samples were collected using the quartering method. Corn silage was dried at 65°C for 48 hours, ground through a 1 mm sieve, and stored in sealed bags at 4°C until analysis [3].

1.2.2 CNCPS Fractionation of Feed Protein Components

The CNCPS system provides more valuable reference for feed nutritional value evaluation by fully considering plant cell components and feed digestion characteristics in ruminants. In the CNCPS protein fractionation system, crude protein (CP) is partitioned into non-protein nitrogen (PA), true protein (PB), and unavailable protein (PC). Based on rumen degradation characteristics, PB is further divided into three sub-fractions: rapidly degraded true protein (PB1), intermediately degraded true protein (PB2), and slowly degraded true protein (PB3). The calculation formulas are as follows [8]:

$$PA(\%\ CP) = NPN(\%\ SCP) \times SCP(\%\ CP) \times 0.01$$
$$PB1(\%\ CP) = SCP(\%\ CP) - PA(\%\ CP)$$
$$PC(\%\ CP) = ADICP(\%\ CP)$$
$$PB3(\%\ CP) = NDICP(\%\ CP) - ADICP(\%\ CP)$$
$$PB2(\%\ CP) = 1 - PA(\%\ CP) - PB1(\%\ CP) - PB3(\%\ CP) - PC(\%\ CP)$$

1.2.3 CNCPS Fractionation of Carbohydrate Components

The CNCPS system partitions carbohydrate (CHO) into four fractions based on degradation rate: rapidly degraded carbohydrate (CA, mainly sugars), intermediately degraded carbohydrate (CB1, mainly starch and pectin), slowly degraded carbohydrate (CB2, mainly digestible fiber), and unavailable carbohydrate (CC, mainly plant cell wall). The calculation formulas are as follows [9]:

CHO(% DM) = 1 -CP(% DM) -EE(% DM) -ash(% DM)
CC(% CHO) = 100 × [NDF(% DM) × 0.01 × ADL(% NDF) × 2.4]/CHO(% DM)
CB2(% CHO) = 100 × [NDF(% DM) -NDICP(% CP) × 0.01 × CP(% DM) -NDF(% DM) × 0.01 × ADL(% NDF) × 2.4]/CHO(% DM)
NSC(% CHO) = 1 -CB2(% CHO) -CC(% CHO)
CB1(% CHO) = [1 -starch(% NSC)] × [1 -CB2(% CHO) -CC(% CHO)]

1.2.4 CNCPS Estimation of Potential Nutrient Supply

The CNCPS model was used to estimate the potential nutrient supply from the four experimental feedstuffs, including rumen degraded protein (RDP), rumen-undegraded protein (RUP), microbial protein (MCP), absorbable microbial protein (AMCP), absorbable rumen-undegraded protein (ARUP), absorbable endogenous true protein (AECP), and metabolizable protein (MP). Using each feedstuff as a single-feed diet, rumen energy nitrogen balance (RENB) was estimated according to the CNCPS model as the difference between MCP provided by RDP (MCPRDP) and MCP provided by TDNm at maintenance level (MCPTDNm). The calculation formulas are as follows [10-11]:

RDP = A + B × [Kd/(Kd + Kp)]
RUP = A + B × [Kp/(Kd + Kp)] + C

Where: A is the rapidly degraded CP fraction, B is the degradable CP fraction, and C is the completely undegraded CP fraction; Kd is the degradation rate of B; Kp is the rumen passage rate of the tested feed.

MCP(g/kg DM) = 0.13 × TDNm × eNDFadj

Where: When physically effective neutral detergent fiber (peNDF)/NDF > 20%, eNDFadj = 1.0; when peNDF/NDF < 20%, eNDFadj = 1.0 -[(20 -peNDF) × 0.025].

AMCP(g/kg DM) = 0.80 × 0.80 × MCP

Where: 80% of MCP is PB, and 80% can be absorbed in the small intestine [NRC (2001) [12]].

ARUP = RUP × 0.85
ECP(g/kg DM) = 6.25 × 1.9 × DM
AECP(g/kg DM) = 0.50 × 0.80 × ECP

Where: ECP is endogenous PB, 50% of ECP can reach the duodenum, and 80% is PB [NRC (2001) [12]].

MP(g/kg DM) = ARUP + AMCP + AECP
RENB = MCPTDNm -MCPRDP

Where: MCPTDNm = 0.13 × TDNm, MCPRDP = 0.9 × RDP.

1.2.5 NRC Model Estimation of Truly Digestible Nutrients and Energy Values

The NRC (2001) [12] estimation model was used to predict truly digestible non-fiber carbohydrate (tdNFC), truly digestible crude protein (tdCP), truly digestible neutral detergent fiber (tdNDF), and truly digestible fatty acids (tdFA) for dairy cattle. Subsequently, TDNm, digestible energy at production level (DEP, i.e., when intake is 3 times maintenance level), metabolizable energy at production level (MEP), and net energy for lactation at production level (NELP) were estimated for each feed. Meanwhile, beef cattle estimation model formulas were used to predict net energy for maintenance (NEm) and net energy for gain (NEg). The prediction formulas are as follows [12-13]:

tdNFC = 0.98 × {1 -[(NDF -NDICP) + CP + EE + ash]} × PAF
tdCP = CP × exp[-1.2 × (ADICP/CP)]
tdFA = FA = (EE -1)
tdNDF = 0.75 × (NDF -NDICP -ADL) × {1 -[ADL/(NDF -NDICP)]}^0.667

Where: PAF is the processing adjustment factor; if EE < 1, then FA = 0.

TDNm(%) = tdNFC + tdCP + (tdFA × 2.25) + tdNDF -7
DE1X(MJ/kg) = (tdNFC × 4.2 + tdNDF × 4.2 + tdCP × 5.6 + tdFA × 9.4 -0.3) × 4.18
Discount factor = 4.18 × {[TDNm -(0.18 × TDNm -10.3)] × 2}/TDNm
DEP(MJ/kg) = 4.18 × DE1X × Discount factor
MEP(MJ/kg) = 4.18 × (1.01 × DEP -0.45)
NELP(MJ/kg) = 4.18 × [(0.703 × MEP) -0.19]
NEm(MJ/kg) = 4.18 × [1.37 × (DE1X × 0.82) -0.138 × (DE1X × 0.82)^2 + 0.0105 × (DE1X × 0.82)^3 -1.12]
NEg(MJ/kg) = 4.18 × [1.42 × (DE1X × 0.82) -0.174 × (DE1X × 0.82)^2 + 0.0122 × (DE1X × 0.82)^3 -1.65]

Where: If TDNm < 60%, the digestibility discount is ignored.

1.3 Statistical Analysis

All data were organized using Excel and analyzed statistically using the Mixed model in SAS 9.3. The specific model was:

Yij = + Fi + eij

Where: Yij is the dependent variable from variable i, j; is the overall mean; Fi is the fixed effect of feed source; and eij is the random error.

2.1 Nutrient Composition of DCGF and Three Roughages

As shown in Table 1 , DCGF differed substantially from commonly used dairy cattle roughages in nutrient composition. The dry matter (DM) content of DCGF was similar to that of alfalfa hay and wildrye (P>0.05), while its organic matter content was significantly higher than that of alfalfa hay (P<0.05). Wildrye had the highest NDF and ADF contents, while alfalfa hay had the lowest NDF content. DCGF had significantly lower ADF and ADL contents than the other three roughages (P<0.05). DCGF had the lowest cellulose content but the highest hemicellulose content (371.7 g/kg DM). The starch content of DCGF was comparable to that of corn silage (P>0.05) and significantly higher than that of alfalfa hay and wildrye (P<0.05). Alfalfa hay had the highest CP content (213.4 g/kg DM), followed by DCGF (205.4 g/kg DM), which was significantly higher than corn silage and wildrye (P<0.05). The four roughages showed large differences in soluble crude protein (SCP) and non-protein nitrogen (NPN) contents. DCGF had significantly higher NPN content (in SCP) than the other three roughages. DCGF had the lowest ADICP content (15.2 g/kg CP), significantly lower than other feeds (P<0.05), while wildrye had the highest NDICP content (386.2 g/kg CP).

2.2 CNCPS Fractionation of Protein and CHO Components of DCGF and Three Roughages

As shown in Table 2 , significant differences existed in protein and carbohydrate fractions among DCGF and the other three roughages (P<0.05). After CNCPS protein fractionation, DCGF had high PA content (599.2 g/kg CP) but the lowest PB content (388.6 g/kg CP). Alfalfa hay had significantly higher PB1 and PB2 than the other three feeds (P<0.05). Wildrye had the highest PB3 content, while corn silage had the lowest. DCGF had the lowest PC content (15.2 g/kg DM), whereas corn silage had the highest (135.1 g/kg DM). CNCPS CHO fractionation revealed that DCGF had the lowest CA content but significantly higher CB1 and CB2 fractions than the other three roughages (P<0.05). Wildrye had the highest CC content (412.1 g/kg CHO), followed by alfalfa hay (348.6 g/kg CHO), while DCGF had the lowest CC content (81.4 g/kg CHO).

2.3 Prediction of Potential Nutrient Supply from DCGF and Three Roughages to Dairy Cattle

The predicted potential nutrient supply from DCGF and three commonly used roughages to dairy cattle using the CNCPS model is shown in Table 3 . DCGF had an RDP content of 159.6 g/kg DM, significantly higher than the other three roughages (P<0.05), while its RUP content (41.6 g/kg DM) was lower than alfalfa hay but higher than corn silage and wildrye (P<0.05). The predicted MCP content of DCGF was 89.4 g/kg DM, significantly higher than the other three roughages ($P<0.05$). DCGF had the highest AMCP production, alfalfa hay had the highest ARUP content, and corn silage had significantly lower ECP content than DCGF, alfalfa hay, and wildrye ($P<0.05$), with no significant differences among the other three feeds ($P>0.05$). Alfalfa hay had the highest MP content (106.7 g/kg DM), followed by DCGF (96.8 g/kg DM), both significantly higher than corn silage and wildrye ($P<0.05$). Based on energy and MCP supply, DCGF had the highest MCPRDP and MCPTDNm contents, followed by alfalfa hay, both significantly higher than corn silage and wildrye ($P<0.05$). The rumen energy nitrogen balance (RENB) for DCGF and alfalfa hay were -54.5 and -61.5 g/kg DM, respectively, indicating excess RDP supply but insufficient energy supply, while corn silage and wildrye had insufficient RDP supply.

2.4 Prediction of Digestible Nutrient Contents and Energy Values of DCGF and Three Roughages Using NRC Models

As shown in Table 4, the four feeds showed substantial differences in digestible nutrient contents and energy values. Alfalfa hay had the highest tdNFC content (258.9 g/kg DM), while DCGF and corn silage had tdNFC contents of 212.4 and 211.2 g/kg DM, respectively, significantly higher than wildrye ($P<0.05$). DCGF and alfalfa hay had significantly higher tdCP contents than corn silage and wildrye ($P<0.05$), while alfalfa hay had significantly lower tdNDF content than the other three feeds ($P<0.05$). DCGF had the highest TDNm content, followed by alfalfa hay, both significantly higher than corn silage and wildrye ($P<0.05$). Among the four feeds, DCGF had the highest DEP, MEP, NELP, NEm, and NEg values, followed by alfalfa hay, while wildrye had the lowest energy values.

3.1 Nutrient Composition of DCGF and Three Roughages

This study comprehensively compared and analyzed the differences in nutrient composition between DCGF and commonly used dairy cattle roughages. Conventional nutrient analysis revealed that DCGF contained high levels of NDF, CP, and starch, demonstrating its potential as a good energy and protein source for dairy cattle. Biricik et al. [14] reported that DCGF contains high levels of utilizable NDF and is a high-quality source of digestible fiber. As a by-product of corn wet milling for starch production, DCGF has lower lignification of cell walls than other roughages, resulting in lower ADF and ADL contents. The three roughages showed large variations in CP, NDF, and ADF contents, with values similar to those reported by Coblentz et al. [15]. Compared with the wet corn gluten feed (WCGF) reported by Pan et al. [16], the DCGF samples in this study had slightly higher DM, ADF, SCP, and ADICP contents, but similar contents of other components. The starch content of DCGF samples reached 106.3 g/kg DM in this study, higher than common roughages but significantly lower than its raw material corn (approximately 660 g/kg DM). Numerous reports have documented that the low starch, high pectin, and high fermentable CHO content of DCGF helps maintain rumen health in dairy cows and beef cattle, primarily because adding DCGF to diets can avoid rapid fermentation of starch in the rumen and subsequent rumen acidosis [17]. DCGF and alfalfa hay contained relatively high proportions of CP, resulting in lower total CHO content than corn silage and wildrye. During DCGF production, a certain proportion of corn concentrate steep liquor is added, resulting in high CP content and significantly higher SCP and NPN contents than other roughages [18]. Based on its nutritional characteristics, DCGF possesses dual advantages as both a protein feed and fiber feed. Its inclusion can not only improve the nutritional level of dairy cattle diets but also alleviate the shortage of soybean meal products and high-quality roughage supplies in China, helping to reduce feeding costs and improve economic efficiency.

3.2 CNCPS Fractionation of Protein and CHO Components of DCGF and Three Roughages

The CNCPS system integrates feed nutrient composition, plant cell wall components, and feed degradation characteristics in the rumen, making nutritional value evaluation results more valuable and reflecting new developments in animal nutrition. This study showed that alfalfa hay had significantly higher PB2 fraction content than the other three feeds, indicating its superior protein content advantage. Although DCGF had high CP content, it contained more NPN and lower PB content than alfalfa hay. DCGF is produced by mixing and drying corn bran with corn steep liquor. Unsprayed corn bran has a CP content of approximately 9.50% DM, while corn steep liquor contains high proportions of SCP and NPN in its CP. Therefore, the resulting DCGF contains a high proportion of PA and low PB content [10]. Additionally, DCGF had extremely low PC content, indicating high protein availability. Corn silage also had high PA content and PB content similar to DCGF, consistent with the results of Zhou et al. [19]. However, differences in PB2 and PB3 contents between corn silage and DCGF may be related to different protein molecular structures in the two feeds.

CNCPS CHO fractionation revealed differences in CHO fraction contents among the four feeds. The CHO fractions of the three roughages in this study were generally consistent with the results of Jin et al. [20]. DCGF had low CA content but high CB1 and CB2 contents because DCGF contains high levels of starch, pectin, and hemicellulose, as well as soluble polysaccharides and degradable structural CHO [21]. Alfalfa hay had significantly higher NSC and CA contents than the other three feeds, indicating faster degradation rates of alfalfa CHO in the rumen. Additionally, alfalfa had higher CB1 content than grass wildrye due to its richness in neutral detergent soluble CHO [22]. Wildrye had the highest CC content, indicating slower degradation and lower utilization in the rumen, classifying it as low-quality roughage. In contrast, DCGF had extremely low CC content and high degradable fiber CB2 content, making it a high-quality fiber feed resource.

3.4 Digestible Nutrient Contents and Energy Values of DCGF and Three Roughages

The NRC model divides feed CHO into two parts based on fiber analysis methods: non-fiber carbohydrate (NFC) and fiber carbohydrate (FC) [12]. Both DCGF and alfalfa hay had high tdNFC and tdCP contents, related to their high NFC and CP contents. The tdNFC content is also associated with feed processing, as the processing adjustment factor (PAF) must be considered when calculating tdNFC [24]. The contribution of feed CP to energy supply depends on the proportion of ADICP in CP. According to NRC (2001) [12], tdCP has an exponential relationship with the ADICP/CP ratio. Among the four feeds, alfalfa hay had the lowest NDF content, while DCGF had the lowest NDICP and ADL contents. Therefore, DCGF had the highest tdNDF content, while alfalfa hay had the lowest tdNDF content, indicating that DCGF' s NDF contributed most to energy supply among the four feeds. Biricik et al. [14] and Kelzer et al. [21] also reported that DCGF had high ruminal tdNDF content and a high proportion of fermentable fiber carbohydrates. According to the NRC model, feed TDNm content is the sum of various truly digestible nutrients minus metabolizable TDNm in feces (7% DM) [24]. Consequently, the ranking of TDNm contents among the four feeds was DCGF > alfalfa hay > corn silage > wildrye, showing the same trend for energy values. This indicates that DCGF has the greatest advantage in energy supply, followed by alfalfa hay, while wildrye provides the least energy. However, the digestible nutrient contents and energy values of experimental feeds were based on previous prediction models rather than measured values from in vivo metabolism trials. Model usage assumes that feed characteristics limit energy utilization. Feed composition and DM intake significantly affect digestibility and energy values, and for feeds that cannot maintain optimal rumen fermentation status, estimated energy values may be overestimated.

Conclusions

1. DCGF has high levels of utilizable CP and utilizable NDF. Compared with the other three roughages, DCGF can provide more MCP, MP, and ME for ruminants, but these are all model-derived results requiring further validation in animal trials.

2. Based on the nutrient supply results of the four feeds, DCGF has relatively high nutritional value and can provide high levels of metabolizable energy and protein for dairy cattle. It can be used as a fiber-protein feed to replace part of the roughage in dairy cattle diets, such as alfalfa hay, thereby alleviating the shortage of high-quality roughage resources in China.

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