Comparison of *in situ* nutrient disappearance of alternative maize milling by-product feeds in lactating dairy cows

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Abstract

Two maize milling by-products (maize gluten feed; MGF and maize by-product feed; MBPF) were compared with shelled maize (SM) and soyabean meal (SBM) for their *in situ* nutrient disappearance. *In situ* experiments were conducted in two rumen fistulated Holstein cows to evaluate dry matter (DM), crude protein (CP), neutral detergent fibre (NDF) and starch disappearance of the products. Zero-hour washout (*in situ* Fraction A) of DM was higher for MBPF (56.9%) than SM (45.0%). The disappearing rate (k_d) of DM was higher for MGF (0.054/h) than for SM (0.046/h). Fraction A for CP was higher for MBPF (69.6%) than MGF (55.9%) and lower for SBM (7.8%). Similarly, ruminal CP disappearance was higher for MBPF (83.4%) and MGF (80.1%) than SBM (52.1%). Neither NDF disappearance rate nor ruminal NDF disappearance was different between MGF and MBPF. The disappearance rate of starch was higher for MGF (0.203/h) and MBPF (0.116/h) than for SM (0.051/h). Similarly, ruminal starch disappearance was higher for MGF (82.7%) than for SM (54.2%). Results indicate that the tested maize by-product feeds had greater ruminal CP disappearance when compared to SBM. Both MGF and MBPF may be useful feedstuffs in lactating dairy cows ration due to their higher ruminal starch disappearances.

Keywords: Maize gluten feed, maize, maize by-product feed, *in situ*, ruminal disappearance
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Introduction

In most countries maize by-products usually are priced lower than shelled maize (SM), and provide an alternative protein source. Using traditional concentrate energy sources may result in digestive problems due to rapid carbohydrate fermentation in the rumen. However, Coppock (1987) indicated that by-product feeds tend to have lower concentrations of fermentable starch and sugar. In addition, some by-product feeds contain highly digestible fibre that can serve as partial replacement for forage fibre. Maize gluten feed (MGF) is a by-product of the SM wet milling process, and comprised primarily of maize bran and steep liquor (Boddugari *et al*., 2001). It is the remaining portion after the extraction of a larger portion of the starch, gluten and germ (Blasi *et al*., 2001). In addition, it is a readily available non-forage source of fibre. Based on the processing method, maize by-product feed (MBPF) may contain fermented maize extractive (steep liquor), maize germ meal and maize bran (Blasi *et al*., 2001).

It has been suggested that MGF can effectively replace up to 100% of SM in rations containing greater than 50% forage, without compromising the performance of growing cattle (Ham *et al*., 1995). Research has demonstrated that MGF possesses a rumen degradable protein fraction similar to that of SBM (Firkins *et al*., 1984). In addition, others (Bowman *et al*., 1988 & Richards *et al*., 1998) showed that MGF alone could meet the increased requirements for degradable intake protein of cattle when it replaces SM. Although maize by-products have been fed at up to 60% of the diet, it is recommended to be limited at 10-20% in lactating dairy cattle rations for optimal milk production (Bernard *et al*., 1991). This recommendation is probably due to a significant variation in nutrient composition of maize by-products as a consequence of variation in processing methods. Boddugari *et al*. (2001) tested the replacement effect of wet MBPF at 50, 75, and 100% level of inclusion in the concentrate portion of lactating dairy cattle diets, where SM and soyabean meal (SBM) constituted 45.7% of diet dry matter (DM). The diets containing MBPF resulted in equivalent milk production (28.5 kg/d) and 13.6% greater efficiency of 4% fat-corrected milk (FCM) production than the control diet. These studies were conducted with a particular nutrient composition of MGF and MBPF.

Therefore, nutrient composition of specific maize by-products needs to be evaluated before formulating proper dairy cattle diets.

The objective of this experiment was to compare the nutrient disappearance of selected maize by-products (MGF and MBPF) with commonly used concentrate sources (SM and SBM) and to determine whether or not they can substitute these sources in lactating dairy cattle diets.

Materials and Methods

The selected by-products were MGF (IFN 5-28-243) and MBPF (IFN 5-28-236). Dry SM (IFN 4-02-854) and SBM (IFN 5-20-637) were included in the study for comparative purposes. The maize by-products as well as the SM and SBM were collected from five different feed mills. The MBPF consisted of a mixture of maize bran-germ meal (50%) and steep liquor (50%). The *in situ* ruminal disappearances of the DM, crude protein (CP), neutral detergent fibre (NDF) and starch were compared between MGF, MBPF, SBM and SM; between MGF, MBPF and SBM; between MGF and MBPF, and between MGF, MBPF and SM, respectively.

Two rumen fistulated multiparous lactating Holstein cows were used for the *in situ* study. The cows were 130 ± 12 days in milk, and with body weights of 585 ± 25 kg. Feeds were offered as total mixed rations, containing 175 g CP and 300 g NDF/kg, and consisting of a 50:50 forage to concentrate mix (DM basis). The forage portion of the diet consisted of 35% maize silage (300 g DM, 82 g CP and 438 g NDF/kg) and 15% lucerne silage (580 g DM, 203 g CP and 451 g NDF/kg). The concentrate portion of the diet (232 g CP and 156 g NDF/kg) contained a dry maize (28%) and soyabean meal (17.9%) mixture along with 4.1% of a mineral-vitamin pre-mix. Cows were fed to meet or exceed NRC (2001) requirements for minerals and vitamins. Feeds were offered twice daily at 09:00 and 18:00.

The *in situ* bag material was dacron polyester with a pore size of 50 ± 5 µm (R102 Marvelaine White, N. Erlanger, Blumgardt and Co. Inc. Broadway, NY). *In situ* bags were 20 x 10 cm in size and glued at the sewed edges to reduce feed escape (Batajoo & Shaver, 1998). All test feeds were ground to pass a 1-mm cutter mill screen (Ika-Werke, Gmbh and Co., Germany). Each experimental feed (6 g as fed) was weighed in triplicate for each time point for each cow (six measurements for each feed at each time point) into the dacron bags. The bags were placed in a nylon laundry bag (30 x 40 cm), which was positioned in the ventral rumen, and a reverse order for incubation times of 3, 6, 9, 12, 24, 48, and 72 h was followed. Empty dacron bags were also placed in the laundry bag to estimate possible DM influx into them. The laundry bag was removed after the completion of 72 h incubation, soaked in cold water and then washed twice with cold water in a commercial washing machine (Cherney *et al*., 1990). Triplicate zero-hour bags prepared for each product were also soaked in cold water for 30 min before washing to estimate the zero-hour washout from the dacron bags (Fraction A). Bags were dried at 60 °C for 48 h in a forced-air oven. Residual DM of each bag was corrected for DM entry into their corresponding blank bags. Microbial nitrogen correction was not performed in this study. The dried residues in the triplicate bags for each cow at each incubation time point were mixed for nutrient analyses. Residues were ground through a 1-mm cutter mill screen (Ika-Werke, Gmbh and Co., Germany) before chemical analysis. Residues from each time point within each cow were analysed for DM, CP (AOAC, 1990), NDF (with amylase and sulphite; Van Soest *et al*., 1991) and starch (Bal *et al*., 2000).

Rate and extent of DM, CP, NDF and starch disappearance were estimated using the non-linear procedure of SAS (1985) as described by Sievert & Shaver (1993). The model is described as follows:

$$R = B * e^{-kt} + C$$

$$\text{and } R = B + C \text{ when } 0 < t$$

Where:

R = DM, CP, NDF or starch remaining at time = t;
B = potentially disappearing fraction; 100 -(A+C) at fractional rate k;
C = fraction undigested at 72 h;
t = incubation time (h);

The predicted ruminal disappearance of DM, CP, NDF and starch was calculated as $[A+B*k_d/(k_d+k_p)]$ where A is the rapidly disappearing fraction, B the slowly disappearing fraction, k_d the disappearing rate of fraction B and k_p the passage rate. The variable, k_p, was assumed to be 0.07/h (Batajoo & Shaver, 1998).

The DM and NDF levels in the residues were determined in all samples up to the 72 h incubation time, the CP levels in the residues up to the 48 h incubation time and starch concentrations in the residues up to the 24 h incubation time. This was necessary, because after the CP analyses there were not enough residue samples left at 48 h for the starch analysis.

A contrast statement was used to evaluate treatment by-products for each nutrient and ruminal *in situ* parameter. These contrasts were as follows; SM *vs*. MGF and MBPF, and SBM *vs*. MGF and MBPF for DM; SBM *vs*. MGF and MBPF for CP; MGF *vs*. MBPF for NDF; and SM *vs*. MGF and MBPF for starch. The variance of cow by feedstuff was used to test these contrasts. Differences between feeds were determined using the least significant difference method after a significant F-test ($P < 0.05$).

Results

Table 1 Mean (± s.d.) chemical composition of shelled maize (SM), soyabean meal (SBM), maize gluten feed (MGF) and maize by-product feed; MBPF) (dry matter basis)

Nutrients (g/kg)	Treatments			
	SM (n = 5)	SBM (n = 5)	MGF (n = 5)	MBPF (n = 5)
Organic matter	963 (6)	931 (7)	938 (11)	949 (19)
Crude protein	108 (5)	494 (9)	252 (14)	183 (17)
Neutral detergent fibre	123 (8)	167 (5)	381 (10)	266 (15)
Starch and free glucose	675 (9)	116 (10)	293 (14)	211 (20)

s.d. – standard deviation; n = number of samples

Table 2 Mean *in situ* dry matter (DM) and crude protein (CP) disappearances of shelled maize (SM; n = 5), soyabean meal (SBM; n = 5), maize gluten feed (MGF; n = 5) and maize by-product feed (MBPF; n = 5) in dairy cows

Treatments	Ruminal disappearance parameters (%, DM basis)				
	A fraction (%)	B fraction (%)	C fraction (%)	Rate of disappearance (/h)	Ruminal disappearance (%)
Dry matter					
SM	45.0	53.9	1.1	0.046	66.4
SBM	31.2	68.3	0.5	0.087	69.0
MGF	44.8	51.9	3.3	0.054	67.4
MBPF	56.9	41.0	2.1	0.045	73.0
s.e.m.	0.2	0.3	0.2	0.003	0.9
Contrast (P-value)					
SM *vs*. MGF and MBPF	< 0.01	< 0.01	0.06	< 0.01	0.69
SBM *vs*. MGF and MBPF	< 0.01	< 0.01	0.02	0.25	0.23
Crude protein					
SBM	7.8	79.5	12.7	0.090	52.1
MGF	55.9	37.5	6.6	0.136	80.1
MBPF	69.6	22.5	7.9	0.110	83.4
s.e.m.	0.4	0.3	0.3	0.005	1.2
Contrast (P-value)					
SBM *vs*. MGF and MBPF	< 0.01	< 0.01	0.01	0.37	0.03

s.e.m. - standard error of mean

The nutrient composition of the test feeds is presented in Table 1. Crude protein of SM was within the spectrum of NRC (2001) values. Similarly, CP of SBM was similar to solvent extracted SBM values (NRC, 2001). Higher NDF and starch concentrations were observed for MGF than for MBPF. However, the higher starch value in SBM was somewhat surprising and was possibly due to the starch assay that hydrolyzed other carbohydrates to release glucose.

In situ DM and CP disappearances of the test feeds are presented in Tables 2 and that of NDF and starch in Table 3. The DM A fraction of MBPF was higher than that of SM and MGF. The lowest DM A fraction was observed for SBM. Shelled maize contained a higher proportion of the B fraction than MGF and MBPF. However, the disappearing rate (k_d) of the B fraction of MGF was faster than that of SM and MBPF. Compared to MGF and MBPF, SBM contained the lowest A fraction of CP. The k_d of the B fraction of the tested feeds did not differ. However, the ruminal CP disappearances were higher in MGF and MBPF than in SBM, though no difference was observed for NDF disappearance parameters between MGF and MBPF (Table 3). However, the A fraction of NDF in MBPF was higher than in MGF.

The starch A fraction of MGF was larger than those in SM and MBPF. The larger C fraction of starch in MBPF was also confirmed by lower ruminal disappearance of this by-product feed. This pattern indicates that the starch of MBPF may be more resistant to ruminal disappearance than that in MGF. The highest k_d of the B fraction was observed for MGF. Additionally, MGF had a higher ruminal disappearance.

Table 3 Mean i*n situ* neutral detergent fibre (NDF) and starch disappearances of shelled maize (SM), soyabean meal (SBM), maize gluten feed (MGF) and maize by-product feed (MBPF) in dairy cows

Treatment	Ruminal disappearance parameters (% DM basis)				
	A fraction (%)	B fraction (%)	C fraction (%)	Rate of disappearance (/h)	Ruminal disappearance (%)
Neutral detergent fibre					
MGF	0.7	92.3	7.0	0.046	37.0
MBPF	9.1	84.1	6.8	0.036	37.4
s.e.m.	0.2	0.5	0.3	0.003	0.7
Contrast (P-value)					
MGF *vs*. MBPF	< 0.01	0.13	0.51	0.93	0.95
Starch and free glucose					
SM	31.8	53.0	15.2	0.051	54.2
MGF	41.0	56.1	2.9	0.203	82.7
MBPF	26.1	50.7	23.2	0.116	57.8
s.e.m.	0.6	0.6	0.1	0.008	1.1
Contrast (P-value)					
SM *vs*. MGF and MBPF	< 0.01	< 0.01	< 0.01	0.29	< 0.01

s.e.m. - standard error of mean

Discussion

The CP concentration of MGF is usually dependent on the wet milling process. The ratios of maize bran to steep liquor blends are usually different for each manufacturer. Blasi *et al*. (2001) indicated that, in the final MGF, the ratio of bran to steep liquor is normally between 2/3 and 1/3. Although MBPF is obtained by a fermentation of maize milling process, bran inclusion may dilute the CP concentration of the feed in some cases. The higher starch level for MGF compared to the tabulated values of the Corn Refiners Association Inc. (1989) might be due to variation in processing methods of the feeds quoted.

A higher DM A fraction of MBPF could be related to a greater nutrient escape of this product compared to SM and SBM. However, the DM A fraction of SM was higher than values reported in the literature (Herrera-Saldana *et al*., 1990; Batajoo & Shaver, 1998). This could be related to the loss of finer particles from the bags in this treatment, rather than a higher solubility. Higher ruminal DM disappearance of MBPF was also in agreement with the results of Boddugari *et al*. (2001). They found 8% higher total tract

DM digestibility in MBPF when MBPF was replaced with a SM and SBM mixture as the concentrate source (71 *vs*. 63%).

A higher CP A fraction of MGF in comparison with SBM was also observed by Batajoo & Shaver (1998). Likewise, lower residual CP values of MGF and MBPF at 3 and 6 h incubations have been reported by Firkins *et al*. (1984). They found less CP remaining in the dacron bags after 4 and 6 h incubations of MGF compared to SBM. During the maize wet milling process, a steeping effect may cause some hydrolysis of CP in MGF and MBPF. Therefore these maize by-products may have lower CP concentrations which may be highly soluble, resulting in rapid disappearance rates. The high rumen CP disappearance of MGF found in our study, was also observed by Batajoo & Shaver (1998). In addition, the lower ruminal CP disappearance of SBM observed in our study was in agreement results from a study by Susmel *et al*. (1993). This type of CP disappearance pattern for MGF and MBPF could be due to extensively degraded CP fractions of these feeds as a result of the highly soluble N source (steep liquor) that is added during the milling process.

Firkins *et al*. (1985) found a similar *in situ* NDF disappearance pattern for MGF to that in our study. Based on the remaining portions of NDF at various incubation times, they found 79.0, 60.9 and 43.1% residual NDF after 9, 18 and 27 h incubations, respectively. Similarly, we found 75.1, 60.1 and 43.1% residual NDF after 9, 12 and 24 h of incubation, respectively (data not presented).

By virtue of the starch analysis used, the fraction A of starch contains mostly soluble sugars along with some soluble starch molecules. Therefore, the MBPF used in our study might have contained more crystalline starch for bacterial digestion, due to method of processing. The starch A fraction value of SM was somewhat higher than values reported in the literature (Cerneau & Michalet-Doreau, 1991). Maize hybrid type could be one reason for variation in disappearance results. In addition, Batajoo & Shaver (1998) concluded that variation in fraction A of starch among feeds could also be due to the variation in feed particle size. Small feed particles could be lost from the bags during soaking prior to incubation and would overestimate the amount that was truly soluble and degradable. Therefore, Noziere & Michalet-Doreau (2000) suggested that sample particle sizes should be described rather than their grinding screen size, because ground particles contain an array of particle sizes that differ in chemical composition and in rate and extent of degradability. The faster rate of starch disappearance of MGF and MBPF was possibly due to the differences in processing method. Since both maize by-product feeds contained various concentrations of soluble starch and steep liquor, the rapid rate of starch and free glucose disappearance can be explained. A slower starch disappearance rate of SM could be related to hybrid type and association of the protein matrix with starch granules (McAllister *et al*., 1993). In this respect, Philippeau & Michalet-Doreau (1997) and Correa *et al*. (2002) found a negative correlation between vitreousness and ruminal starch disappearance of SM (-0.86 and -0.93, respectively). In addition, Correa *et al*. (2002) concluded that vitreousness of SM is correlated with the starch A fraction as well as the fractional rate of starch disappearance. These results suggest that differences in maize wet milling processing methods may account for differences in ruminal and postruminal starch disappearance of MGF and MBPF.

Conclusions

Although the tested maize by-products (MGF and MBPF) differed in CP due to the variation in their processes of production, they can be used as rapid degradable protein sources in dairy cattle diets. In addition, MGF would be favoured to SM in dairy cattle diets because of its ruminal starch and free glucose disappearance. Higher starch and free glucose disappearance of this maize by-product can provide a readily available energy source for ruminal fermentation. This may increase microbial growth and protein synthesis, though care must be taken to limit the risk of rumen acidosis. The higher indigestible starch fraction of MBPF has the potential to enhance the intestinal starch supply for this maize by-product. Both MGF and MBPF have the potential to be used in dairy cattle diets that are economical, especially in situations in which grains or other protein meals are expensive. Variation between our estimates and others for ruminal disappearance kinetics of these feeds could be due to inherent differences between the tested feeds, particularly for maize by-products (i.e. method of processing, particle size), and differences in analytical procedures.

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