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THE EFFECT OF BYPRODUCTS FROM THE CORN GRAIN PROCESSING ON THE POSTPRANDIAL DYNAMICS OF RUMEN pH

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Invited paper

Abstract: The effects of two fiber-rich byproducts of the corn grain processing on the postprandial dynamics of rumen pH were studied on three rumen cannulated non-lactating cows, within a 3x3 Latin square experimental design. The two byproducts, dried corn gluten feed (dCGF) and dried corn distillers grains (dCDG) replaced corn grains (C) in high concentrate diets, which suddenly replaced a standard diet (designed to ensure appropriate rumen activity) and were feed once a day. Rumen content was sampled every two hours, two days after the diet changes, during first 14 postprandial hours and pH was measured immediately. Average, pH_{min} and pH_{max} as well as duration and intensity of pH decrease were calculated for each series of pH measurements. Diets containing dCGF and dCDG led to higher average pH comparing to the corn-based diet: 6.26 ± 0.03 and 6.12 ± 0.12 versus 6.02 ± 0.2, respectively (P<0.05). Differences were more marked when duration and intensity of pH decrease were considered: corn diet led to a pH decrease below 6.0 of 8.02±2.58 hours, whereas for dCDG and dCGF diets the decreases were of 6.71±3.59 and 3.02±2.17 hours only. Relative differences were even higher when a lower pH threshold (5.8) was considered: observed values were 5.33±4.02, 3.14±3.64 and 0.83±1.24 for C, dCDG and dCGF diets, respectively. Of the two by-products, dCGF was more efficient against pH decrease after the sudden change from a low concentrate to a high concentrate diets. It is concluded that both by-products are feasible solutions to help limiting the pH decrease while allowing formulation of high energy and highly digestible diets for ruminants.

Key words: corn by-products, rumen, SARA

Introduction

Massive corn grain production specific to some countries and the development of food and non-food processing of corn lead to the availability of large quantities of corn by-products on the feed market. The diversity of these by-products is also large, determined by the purpose of processing (alcohol, bio-fuels, starch, gluten, etc.), particularities of processing technologies and variation of the quality of the raw material. This diversity is a good opportunity for animal nutritionists to customize the diets for ruminants according to specific needs, depending on animal category requirements and feeding strategy.

One of the side effects of the nowadays intensive production systems for ruminants is the subacute rumen acidosis (SARA), a digestive disorder with high incidence and important negative effects on animal performances and ruminant farms profitability *(Oetzel, 2000)*. The mechanism of SARA onset and development is complex but basically it is provoked by the ingestion in a short period of large quantities of feeds containing high proportion of rapidly digestible energy substrates. There are many influencing factors, among which change of diets, dynamics of feed digestion in rumen, presence of certain feed additives, etc *(Sauvant, 1999)*.

The starch from corn is fermented slower that soluble sugars or starch from other cereals *(Sauvant, 1997)*; however it represents about 70% of the corn grain weight and, when corn is fed in large quantities, can be a determining factor for an exaggerate pH decrease and SARA onset, leading to unfavorable effects such as impairing the fiber digestibility or microbial protein synthesis *(Shriver, 1986; Martin and Michalet-Doreau, 1995; Russel, 1996)*.

An important way to minimize SARA occurrence or intensity is to decrease the overall rate of carbohydrates fermentation in rumen, which can de achieved by shifting the main dietary source of energy from nonstructural to structural carbohydrates. However, feeding fiber-rich feeds on the expense of starchy ones is not always a convenient solution, especially when intake capacity of animals is limitative (e.g. case of early lactating cows). The two studied by-products could be a good alternative to corn: although their particle size is rather small (making them less effective in favoring pH stability), they both have high content of NDF (40-45%), which is also digestible *(Ham, 1994, 1995; Larson 1993)*.

Therefore, their energy content is close to that of corn and other cereals, which opens the opportunity to use them in energy-dense diets, thus ensuring high animal performances, but with a smaller risk to trigger SARA.

While the studied by-products are similar from the point of view of fiber content, both resulting from the extraction of starch from the corn grains, the processing technologies (dry versus wet milling) and other particularities (protein degradability, fat content) raise the question of their comparability in terms of effects on rumen pH. Literature is scarce in direct comparisons between these two feeds and available studies were mainly targeted on animal performances, rather than rumen energy metabolism. The objective of the present paper is to asses the effects of the two by-products on rumen pH dynamics versus whole corn grains, when a rumen-friendly diet is sudden changed with a high concentrate diet.

Materials and Methods

The experiment was performed on three ruminally cannulated dry cows, housed in individual digestibility stands and organized in a 3x3 Latin Square design: 3 cows, 3 diets, 3 periods (Table 1).

Table 1. Experimental design

	Fistulated cow no. 1	Fistulated cow no. 2	Fistulated cow no. 3
Experimental period 1	C	dCGF	dCDG
Experimental period 2	dCGF	dCDG	C
Experimental period 3	dCDG	C	dCGF

C= corn grains diet, DCGF = dried corn gluten feed diet, DCDG = dried corn distillers grains diet

During each of the experimental periods, animals were fed one of the experimental diets (Table 2) in the first two days and a standard diet in the remaining 14 days. Experimental diets, consisting of 20% barley hay and 80% compound feeds based on corn, dCDG and dCGF respectively, suddenly replaced the standard diet and were fed once a day in order to maximize their possible effects on rumen pH. The standard diet, formulated as to ensure appropriate rumen fermentation and commonly used for *in situ* trials *(Michalet-Doreau and Ould-Bah, 1992)* was fed before and between the experimental periods in order to allow rumen pH to recover after the pH challenges and to eliminate the influence of the previous experimental diet. The nutritive values of the feed ingredients and the feeding requirements of the animals were calculated on the basis of equations recommended by *Burlacu (2002)*.

Rumen content samples were taken in both first and second day of each experimental period, during the first 14 hours after the single meal of the day, every two hours. The samples were collected using a high volume syringe, always from the same area of the rumen; the sampled ruminal content (about 100 ml) was filtered through four layers of gauze and the pH was read with a Beckman pH meter, immediately after sampling (2 readings/sample). Samples were taken in two consecutive days; therefore 4 observations were available for each diet & period & animal.

Table 2. Experimental diets

	Standard diet	Corn diet	dCGF diet	dCDG diet
Barley hay, kg	4.0	1.0	1.0	1.0
Molasses, kg	0.1	-	-	-
Specific compound feed, kg	2.0	4.0	4.0	4.0
Compound feeds structure (%)				
Barley	38.5	-	-	-
Sugar beet pulp	38.5	-	-	-
Whole corn grains	-	82.4	27.1	27.1
Dried corn gluten feed	-	-	63.6	-
Dried corn distillers grains	-	-	-	63.6
Sunflower meal	18.0	12.6	4.3	4.3
Mono-calcium phosphate	2.0	2.0	2.0	2.0
Salt	1.5	1.5	1.5	1.5
Mineral-vitamin premix	1.5	1.5	1.5	1.5

Following parameters were identified or calculated: minimum pH (pH min), maximum pH (pH max), average pH, duration of pH decrease below threshold (t<threshold), intensity of pH decrease below threshold (a<threshold), area under pH curve (a.u.c). Duration and intensity of pH decrease were calculated using a Visual Basic script, by assuming linear evolution of pH between sampling times. Following thresholds, assessed on literature basis as having biological significance *(Dragomir, 2008b)* were considered for analysis: 5.5, 5.8, 6.0 and 6.2.

Statistical analyses were performed by GLM procedure followed by Tuckey test. Rumen pH parameters were compared using diet, animal, period, repetition (day of sampling) and interaction diet & animal as factors.

Results and Discussion

The three experimental diets, as well as the standard diet, had similar energy values (4.98-5.24 milk feeding units), therefore their influence on pH dynamics is to be attributed to the nature, not to the amount of energy supply (Table 3).

Table 3. Nutritive value of the experimental diets

	Standard diet	Corn diet	dCDG diet	dCGF diet
DM, g	5730	4355	4470	4393
MFU, kg DM	5,23	5,24	4,98	5,16
IDPA, g/kg DMI	115,1	219,7	332,5	149,7
IDPN, g/kg DMI	341,9	443,4	657,6	510,5
IDPE, g/kg DMI	420,3	447,8	535,4	367,7
Ca, g/kg DMI	35,2	25,2	25,6	27,8
P, g/kg DMI	27,5	28,9	38,7	42,7

MFU=milk feeding units; PDIA=intestinal digestible protein of dietary origin; PDIN = intestinal digestible protein allowed by nitrogen; PDIE = intestinal digestible protein allowed by energy

The pH curves drawn from pH measurements exhibited the usual postprandial behavior of rumen pH, when ingested diet contains high amounts of digestible carbohydrates: an initial decrease, an inflexion point at several hours after the feeding and a recovery tendency. In the current study, the pH didn't reach its initial level, even at 14 hours after the feeding. On the other hand, the usual variability between animals was observed (Figure 1), one of the cows constantly having a lower pH, comparing with the two others, disregarding the ingested diet. The influence of animal, expressed by the variability of the rumen ecosystem resilience to pH decrease, was minimized by using a Latin Square design. In this study, the average pH was 6.2±0.05, 6.2±0.08 and 6.0±0.22 for the cow 1, 2 and 3, respectively. The differences among cows were even more visible when threshold related parameters were considered: 4.6±2.69; 3.83±1.99 and 9.31±2.93 hours below pH 6.0, respectively (Table 3).

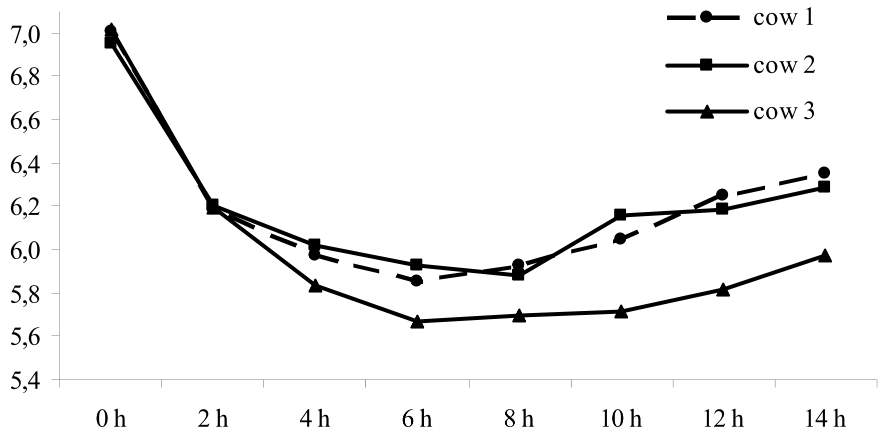

Figure 1. Expression of the influence of animal on pH postprandial evolution in moderate acidosis conditions (*curves represents averages across three diets*)

An interesting evolution was the decrease of pH from the first to the second day, when its values were slightly lower at the most of the measurement periods (Figure 2). This difference of 0.04 pH units (from 6.15 ± 0.15 to 6.11 ± 0.15) may be an indication of the pH spiral onset *(Oetzel, 2007)*, commonly observed when the acidosis is installing. However, in the present study the pH measurements were performed for only two days, therefore there's no indication of further possible evolution.

Figure 3 shows the influence of the experimental diets on the shape of curves representing the postprandial evolution of rumen pH. While all experimental diets led to similar decrease of pH in the first two hours, the remaining parts of the curves expressed diet-specific behavior. Thus, corn-based diet was associated with a long decrease of rumen pH below the safety level of 6.0 and the rate of pH recovery was also very low. The dCDG-based diet was also associated with a long period pf pH decrease below 6.0, but the rate of pH recovery was faster.

As for the dCGF-based diet, the pH curve barely descends below 6.0 and it increases fast toward safety levels, therefore the shape of the curve is more flat. The graphical representation of pH evolution has the disadvantage of not allowing quantitative interpretation of the pH evolution except when all measurement points are taken into account. Several parameters that quantitatively synthesize the pH evolution corresponding to the experimental diets are presented in Table 3.

The same tendency expressed by curves is highlighted by all the integrative parameters. It is worthy to note that differences between diets, although significant ($P<0.05$) are rather small when average pH is considered: 6.02 ± 0.2, 6.12 ± 0.12, 6.26 ± 0.03. However, according to *Kolver and deVeth (2002)*, average pH has low value as rumen pH descriptor when referring to SARA and its influence on rumen processes.

Although their descriptive power is limited by truncation and nonlinearity *(Dragomir, 2008a)*, the threshold-related pH parameters better express the relevant differences between diets and the overall rumen status when SARA is involved.

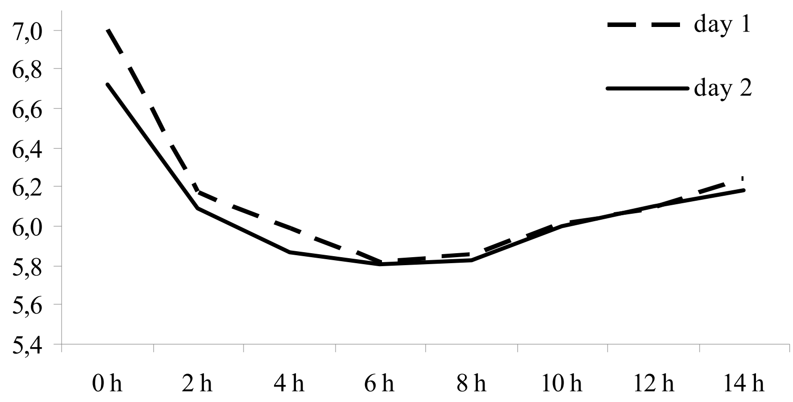

Figure 2. Expression of the day to day variation of pH postprandial evolution (*curves represents averages across three diets and three experimental periods*)

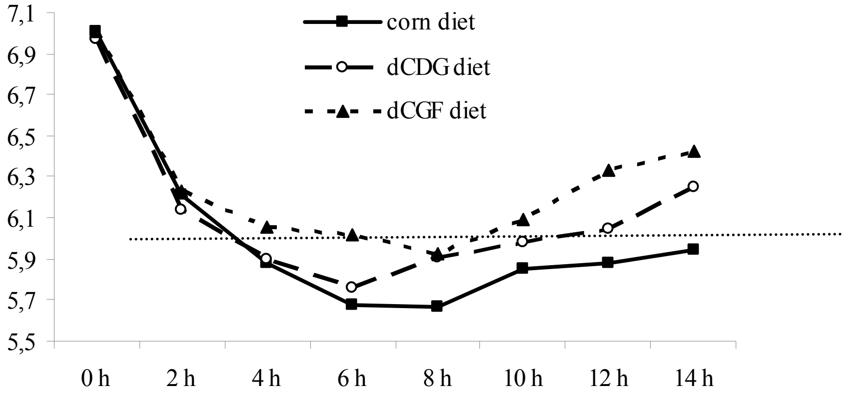

Figure 3. The influence of the dietary energy nature on the postprandial pH evolution, when the concentrate rich diets suddenly replace a high forage diet ***(dCGF = dried corn gluten feed; dCDG = dried corn distillers grains)***

In the current study, the high pH_{max} contributed to a high overall average pH and to the hindering of differences among diets. On the other hand, duration and intensity of pH decrease better showed the differences between diets from the point of view of acidosis. Thus, pH decreased below the safety level of 6.0 for 8.02 ± 2.58; 6.71 ± 3.59 and 3.02 ± 2.17 hours in case of corn, dCDG and dCGF diets, respectively. The relative differences are getting larger when lower pH thresholds are considered, e.g. 5.33, 3.14 and .0.83 when 5.8 was used as threshold or 1.53, 0 and 0 when 5.5 was set as threshold, for C, dCDG and dCGF diets, respectively.

Table 3. Integrative parameters describing postprandial evolution of rumen pH associated to the experimental diets

	C diet		dDDG diet		dCGF diet	
average pH	6.02 [a]	± 0.2	6.12 [b]	± 0.12	6.26 [c]	± 0.03
pH min	5.61 [a]	± 0.2	5.73 [b]	± 0.14	5.87 [c]	± 0.11
pH max	7.0	± 0.17	6.97	± 0.15	7.0	± 0.21
t<5.5	1.53	± 3.0	0	-	0	-
a<5.5	0.14	± 0.31	0	-	0	-
t<5.8	5.33 [a]	± 4.02	3.14 [b]	± 3.64	0.83 [c]	± 1.24
a<5.8	1.13 [a]	± 1.52	0.28 [b]	± 0.33	0.04 [b]	± 0.06
t<6	8.02 [a]	± 2.58	6.71 [a]	± 3.59	3.02 [c]	± 2.17
a<6	2.5 [a]	± 2.12	1.28 [b]	± 1.16	0.36 [c]	± 0.42
t<6.2	11.09 [a]	± 1.25	10.79 [a]	± 1.68	8.17 [c]	± 0.94
a<6.2	4.41 [a]	± 2.45	3.07 [b]	± 1.58	1.48 [c]	± 0.64
a.u.c	83.3 [a]	± 2.72	84.67 [b]	± 1.71	86.73 [c]	± 0.47

dCGF = dried corn gluten feed; dCDG = dried corn distillers grains; t< = duration of pH decrease below the specified threshold (hours), a< = intensity of pH decrease below the specified threshold (hours), a.u.c. = area under pH curve

In many countries, most of the ruminants' diets contain high proportions of whole corn grains, in various forms. Although its starch is not as fermentable as the starch of other cereals or as the soluble sugars and although the intake level in the current study was rather moderate, the inclusion level of more than half of the diet and the sudden change of the diets led to a negative effect on all pH parameters. Thus, corn diet was associated with an average pH of 6.02 and a decrease of pH under 6.0, 5.8 and 5.5 safety levels of 8.02, 5.33 and 1.53 hours respectively, which is equivalent to a moderate SARA, and according to several authors would impair important rumen functions such as cellulolysis or microbial protein synthesis *(Shriver, 1986; Martin and Michalet-Doreau, 1995; Russel, 1996)*.

Total replacement of corn with its by-products, while maintaining the high inclusion level in the diet and the other feeding conditions, led to a significant improvement of all parameters describing the pH postprandial evolution. The improvement was moderate for dCDG but more important for dCGF. Taken into account a frequently used pH parameter, t<6.0 (Owens & Goetsch, 1988), dCDG led to an improvement of 17% whereas dCGF has diminished the decrease of pH below 6.0 with 62%. The improvements were more marked when the intensity of pH decrease below 6.0 was considered: 49% for dCDG and 86% for dCGF.

The improvement was higher than the level obtained by Khrebiel, 1995: 11.3 hours of decrease below 6.0 when dry-rolled corn was fed and 8.3 hours of decrease below 6.0 when wet corn gluten feed was used. However, the results from the current study, although obtained in different feeding situation, are consistent with the tendencies observed by *Sindt (2003)* – a 0.1 units increase of average pH, from 5.89 to 5.97 when wet corn gluten feed dietary proportion was increased from 25% to 45% and *Dragomir (2008b)*, who obtained a pH increase from 6.31 to 6.63 when barley grains were replaced by corn gluten feed. Improvement of pH parameters when corn gluten feed replaced corn were also observed by *Firkins (1991) and Montgomery (2004)*.

No literature references were found for the effects of dried or wet CDG on rumen pH. Although this by-product have also a high content of NDF, its effect against pH decrease was less marked than in the case of dCGF, but still significant for most of the pH parameters. There are few particularities that might explain this difference: it has a higher fat content than dCGF, known for its depressing effect on rumen pH and its protein is less degradable, thus releasing less ammonia in the rumen (ammonia is contributing, although moderately, to pH increase).

Conclusion

Dried corn distillers grains and dried corn gluten feed were associated with significant better rumen pH parameters (P<0.05) comparing to corn, in the context of high inclusion levels and sudden change of diets and from the point of view of acidosis traits. Of the two by-products, the effects of dried corn gluten feed were more important, presumably due to its lower fat content and potential to release ammonia from a more degradable protein. Use of the two by-products, especially the corn gluten feed, is an efficient tool to help preventing subacute rumen acidosis, while allowing formulation of energy dense diets, suitable with the intensive feeding of ruminants.

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Uticaj sporednih proizvoda u preradi kukuruza na postpranidjalnu dinamiku pH u buragu

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Rezime

Ispitivan je uticaj dva vlaknima bogata nusproizvoda kukuruznog zrna na postprandijalnu dinamiku pH rumena na uzorku od tri zasušene krave sa buragom pod kateterom, putem eksperimentalnog modela 3x3 Latinskog kvadrata. Dva nusproizvoda, suvo kukuruzno gluteinsko hranivo (dCGF) i suvo kukuruzno destilovano zrno (dCDG) zamenila su kukuruzno zrno (C) u visoko koncentratnim obrocima što je naglo zamenilo standarni obrok (formulisan da omogući odgovarajuću aktivnost buraga) i davani su jednom dnevno. Sadržaj buraga uzorkovan je svaka dva sata, dva dana nakon izmene obroka, tokom prvih 14 postprandijalnih sati i pH je izmeren odmah. Prosečna, pH_{min} i pH_{max} kao i trajanje i intenzitet smanjenja pH obračunati su za svaku seriju pH merenja. Obroci koji su sadržali dCGF i dCDG vodili su većim prosečnim pH vrednostima u poređenju sa obrocima zasnovanim na kukuruznom zrnu: 6,26 ± 0,03 i 6,12 ± 0,12 versus 6,02 ± 0,2, respektivno (P<0,05). Razlike su bile izraženije kada je u obzir uzeto trajanje i intenzitet smanjenja pH: kukuruzni obroci vodili su smanjenju pH ispod 6,0 za 8,02±2,58 sati, dok je za dCDG i dCGF obroke smanjenje bilo samo 6,71±3,59 i 3,02±2,17 sati. Relativne razlike bile su čak i veće kada je u obzir uzeta donja granična vrednost pH (5,8): ispitivane vrednosti iznosile su 5,33±4,02, 3,14±3,64 i

0.83±1,24 za C, dCDG i dCGF obroke, respektivno. Od dva nusproizvoda, dCGF je bio mnogo efikasniji protiv opadanja pH nakon nagle promene od niskokoncentratne na visokokoncentrovanu ishranu. Zaključeno je da su oba nusproizvoda pogodna rešenja za limitiranje smanjenja pH tokom primene visoko energetskih i visoko svarljivih formulacija obroka kod preživara.

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