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In situ and *in vitro* ruminal degradation of maize grain and untreated or xylose-treated wheat, barley and rye grains

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ABSTRACT

The objective of this study was to estimate the ruminal degradation of dry matter, crude protein (CP) and starch of ground wheat, barley, rye and maize grains as compared to xylose-treated wheat, barley and rye grains. Ruminal degradation was estimated using a standardized *in situ* procedure on three ruminally cannulated mature steers. Data of ruminal degradation of CP and starch was then used to estimate the proportions of ruminally undegraded CP (RUP) and ruminally undegraded starch (RUS) assuming rumen outflow rates of 0.02, 0.05 and 0.08/h. Depending on the assumed rumen outflow rate, treated grains had RUP values (g/kg of CP) which were 204–294 (wheat), 108–231 (barley) and 98–217 (rye) higher than those of the untreated grains. The RUS values (g/kg of starch) of treated wheat were between 110 and 179 higher than the respective values for the wheat. Treatment of barley increased RUS by 48–153 g/kg starch, values which were similar to those observed for RUP. However, the increase in RUS for the treated versus the control rye was small (16–49 g/kg starch) and non-significant. At an assumed rumen outflow rate of 0.08/h, values for RUP (g/kg CP) and RUS (g/kg starch) were 196 and 129 (rye), 413 and 178 (treated rye), 246 and 130 (barley), 477 and 283 (treated barley), 283 and 181 (wheat), 577 and 360 (treated wheat) and 773 and 579 (maize). Our data would indicate that the xylose-treatment was effective in reducing the extent of ruminal degradation of CP for the three grains, thereby augmenting the proportion of RUP. However, only wheat and barley starches but not rye starch responded to the xylose treatment such that RUS was increased for barley and wheat. All treated grains had lower RUP and RUS values than maize grain.

1. Introduction

Lactating ruminants require an adequate supply of absorbable amino acids for the synthesis of milk protein from two sources, i.e., from crude protein (CP) synthesized microbially in the rumen and ruminally undegraded feed CP (RUP) that can be digested in the small intestine. Although the supply with microbial CP makes up the majority of duodenal supply, any deficit in requirement must be met by RUP. Because microbial synthesis requires energy from fermented organic matter and energy intake is often limited in particular during early lactation, supply of extra amino acids to the udder for maintaining

Abbreviations: ADF, acid detergent fibre expressed inclusive of residual ash; aNDF, neutral detergent fibre assayed with a heat stable amylase and expressed inclusive of residual ash; CP, crude protein; DM, dry matter; ED, *in situ* effective degradability; GLM, general linear models; RUP, ruminally undegraded CP; RUS, ruminally undegraded starch; SP, small particles.

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milk protein synthesis can only be achieved by increased dietary concentrations of RUP sources. Several chemical and physical methods have been identified as being effective in increasing the proportion of RUP of total CP of a feedstuff (Petit et al., 2002; Ljøkjel et al., 2003; Wulf and Südekum, 2005; Lund et al., 2008), yet there is a continuing need for developing and establishing methods which allow estimating the degree of protein protection from ruminal degradation with acceptable expenditure of labour and other costs.

Starch is a unique energy source to ruminants because it can be degraded and fermented either in the rumen and large intestine, yielding short-chain fatty acids as primary metabolites, or it can be digested in the small intestine, where glucose is liberated from starch for absorption which is more energy efficient (Owens et al., 1986) and supplies glucose directly to the ruminant animal. The majority of starch in the diet of high-yielding dairy cows is often from cereal grains, which contain between 570 and 770 g/kg (Huntington, 1997) of starch in dry matter (DM). Starch-rich feedstuffs comprise also pulses, such as peas or field beans, and tapioca.

Physical and chemical treatments of starch sources have resulted in varying effects on ruminal degradation of starch (Offner et al., 2003; Dehghan-Banadaky et al., 2007). Utilizing the *in vitro* gas production profile over time as indication of rate and extent of starch degradation of cereal grains, Südekum (2002) reported that hydrothermal treatments covering a wide range of conditions applied on the feeds, increased the rate of gas production and thus carbohydrate degradation of maize grain considerably and in a favourable direction. The increase in rate of degradation was much lower for the other cereal grains. Moreover, a decrease rather than a further increase in rate of carbohydrate degradation of rapidly degraded starch sources like wheat, rye and barley would have been much more desirable to be able to prevent acidosis when large amounts of rapidly degraded starches are consumed by high-yielding dairy cows. The data presented by Südekum (2002) support earlier observations that physical treatments in general tend to increase rather than decrease rate and extent of ruminal starch degradation. Thus it appears that chemical methods may be more promising to protect a certain proportion of otherwise rapidly degraded starch from ruminal degradation, thereby increasing starch flow to the duodenum of ruminants.

The aim of the present study was, therefore, to estimate the ruminal degradation of CP and starch of untreated wheat, barley, rye and maize grains as compared to chemically treated wheat, barley and rye grains in order to compare these feeds in terms of potential RUP and ruminally undegraded starch (RUS) delivery to the small intestine in ruminants.

2. Materials and methods

2.1. Feedstuffs

Wheat, barley, rye and maize grains were obtained commercially from Raifeisen Hauptgenossenschaft Nord AG, Kiel, Germany. All grain commodities were ground through a hammer mill fitted with a sieve with 3-mm pore sizes and, if not being processed further, designated with the grain species name and, where applicable, 'control grain'. Parts of the wheat, rye and barley commodities were further treated with 5% lignin sulphonate (DM basis) and heated by direct addition of steam such that the temperature increased to about 105 °C and moisture content increased to about 200 g/kg. This mixture was held at that temperature for 40 min. The mixture was then returned to ambient temperature by evaporative cooling under a stream of forced air. This cooling process also reduced the moisture content below 150 g/kg (Winowiski et al., 2005). The lignin sulphonate-treated commodities are hereafter designated WeiPass® ('Weizen', German for wheat), GePass ('Gerste', German for barley) and RoPass ('Roggen', German for rye).

2.2. In situ procedure

The *in situ* technique basically followed a proposal for a standardized method for concentrate ingredients (Madsen and Hvelplund, 1994). Three steers received a mixed diet consisting of two-thirds of long mixed grass-legume hay and one-third of mixed concentrates which also contained starch. The diet was supplemented with a commercial mineral and vitamin mix. Ruminal DM, CP and starch degradabilities were determined using polyester bags (R510, Ankom Technology, Macedon, NY, USA) with a pore size of 50 (±15) μm. Quadruplicate samples of each feedstuff were incubated in the rumen of three mature steers. About 1.3 g of feed ground to pass a 2 mm screen was placed in each bag. Each bag was sealed with a commercial cable binder (20 cm length), then bags were clamped to a cylindrical anchor weight (800 g), which was tied to an 80 cm long main line outside the fistula. Prior to incubation, the bags were soaked in warm water (40 °C) for 10 min. All bags for all incubation periods were inserted together into the ventral sac of the rumen at 07:00 h immediately before the morning feeding. Incubation periods were 2, 4, 8, 16, 24, and 72 h.

Immediately after removal from the rumen, bags were immersed in ice-water to stop or minimize microbial activity and then washed with cold water in a washing machine for 20 min. Zero time (0 h) disappearance values were obtained by washing pre-soaked, unincubated bags in a similar fashion. Water-soluble material (WS) was estimated by washing quintuple samples through a folded filter paper. Samples (2 g DM) were first soaked in a beaker in 100 ml warm water (40 °C) for 1 min before washed through the folded filter paper (No. 595½; Schleicher & Schuell, Dassel, Germany) using two times 50 ml warm water (40 °C). All washed bags and filter paper residues were freeze-dried. Contents of washed bags were pooled to give one sample per steer and incubation time. Five replicates of filter-paper residues were analyzed for each