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Effect of starch content and processing method on in situ ruminal and in vitro intestinal digestion of barley grain in beef heifers☆

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ABSTRACT

Rate of barley starch digestion in the rumen is critical issue in high-grain fed beef cattle because it is associated with growth performance and health. The digestion rate of starch varies with variety, grain processing or starch content. The objectives of this study were to evaluate the effect of starch content and processing method of barley grain on in situ ruminal dry matter (DM) and starch digestion kinetics, and to develop a model to predict the rate of DM digestion of barley grain. The study was a 2×2 factorial arrangement of treatments: starch content (low vs. high) and processing method (PM; grinding vs. dry rolling). Ten barley samples with 5 low (571 ± 17 g/kg) and 5 high (660 ± 7 g/kg DM) starch were either ground 2 mm or dry-rolled with processing index (PI) of 0.75 (PI = bulk density processed/bulk density whole). Three beef heifers (650 kg body weight) fitted with rumen cannulas and fed diet consisting (g/kg DM) of 700 barley silage and 300 barley grain were used for in situ incubation. In situ degradation kinetics of DM, starch, neutral detergent fibre (NDF) and crude protein (CP) were estimated after 0, 2, 4, 8, 12, 24, and 48 h of ruminal incubation. Data from DM, starch, NDF and CP degradation at different times of incubation were fitted to a model $y = a + b(1 - e^{-c(t-L)})$. In vitro intestinal disappearances of DM, starch, NDF and CP of ruminal residue after 12 h of incubation were determined using a modified three-step procedure. Interactions between starch content and PM on the degradation kinetic parameters of DM, starch, NDF and CP were seldom observed. High starch barley had greater ($P < 0.01$) *a* and effective degradability (ED) of DM and starch, but it had less ($P = 0.03$) b of starch versus low starch barley. Ground barley had greater ($P < 0.01$) a, c and ED of DM and starch, and lower ($P < 0.01$) b compared with dry-rolled barley. Intestinal disappearance DM and starch of rumen residues were affected by both starch content and PM. Starch content of barley grain and manipulating processing method could effectively alter rumen digestion of barley grain.

Abbreviation: ADF, acid detergent fibre; BD, bulk density; CP, crude protein; DM, dry matter; DMD, dry matter disappearance; ED, effective degradability; aNDF, neutral detergent fibre using heat-stable α-amylase and sodium sulfite; PI, processing index; PM, processing method.

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1. Introduction

Barley grain is the major energy source used in the diets of dairy and beef cattle in western Canada. As much as 0.80 of all barley grain grown in Alberta enters the feed chain for cattle and swine Alberta Agriculture and Rural Development (2010). Barley grains from different sources are diverse in their chemical composition and estimated metabolizable energy contents due to geographical, environmental and genetic variations as well as their interactions (Dehghan-banadaky et al., 2007). This inherent variability in barley chemical composition leads to differences in animal performance (Yang et al., 2013). The rate of barley starch digestion in the rumen is critical in high-grain fed cattle since it is associated with growth performance and animal health (Mathison et al., 1991; Ramsey et al., 2002). The degradation of starch varies with variety, processing method (PM) or starch content (Ramsey et al., 2002; Yang et al., 2014). Because of rapid digestion of barley starch in the rumen, we hypothesized that starch content of barley grain can influence both rates of dry matter (DM) and starch digestion.

Digestibility of whole barley in cattle is much less than its potential because of its fibrous hull and intact pericarp which are resistant to bacterial attachment and digestion in the rumen (McAllister et al., 1994). Hence, barley grain needs to be processed prior to feeding to expose the endosperm, encased within indigestible pericarp and hull layers, to the microbial population in the rumen (Wang and McAllister, 2000). Physical processing techniques such as grinding or rolling increase digestibility of grain (Hironaka et al., 1992) and the advantages and disadvantages of these PM are well documented (Mathison, 1996). Dry rolling is widely used in barley processing by the western Canadian feedlots. Beauchemin et al. (2001) reported that the optimal degree of dry rolling is around 0.75 of processing index (PI) for barley fed to finishing beef cattle. The PI is widely used by feed industry or feedlot operators to quantify the degree of barley processing; it is expressed as fraction of bulk density after processing to the bulk density before processing (Yang et al., 2000). However, Yang et al. (2014) recently found some advantages of grinding processing over dry-rolling to evaluate digestion characteristics of barley in batch culture. For instance, ground barley had similar starch disappearances after 24 h of incubation to in vivo values, low variability in DM digestibility, better correlation between chemical composition and in vitro digestibility, and no concern on processing quality associated with kernel uniformity compared with dry-rolled barley.

In addition, commercially, feed barley is often marketed as a blend from different varieties or locations during handling and transport. Yang et al. (2014) reported large variability of physical and chemical constituents, and in vitro gas production and DM digestibility of commercial feed barley collected from different locations and year. This finding emphasizes the challenge in precision feeding of commercial feed barley, and suggests a need to develop a simple way to rapidly and concisely determine the feed value of blend barley. The objective of this study was to evaluate the effect of starch content and PM of commercial blend barley on the in situ ruminal digestion kinetics and in vitro intestinal digestibility.

2. Materials and methods

2.1. Barley sample collection and processing

Barley samples (n = 120) were collected monthly from ten commercial feedlots in southern Alberta for one year from November 2012 to October 2013. All 120 samples were analyzed for starch content, ranked them, and then used the samples with lowest and highest concentration for the experiment. Ten barley samples with 5 low ($571 \pm 17.5\ g\ kg^{-1}$) and 5 high ($660 \pm 7.3\ g\ kg^{-1}$ of DM) starch were selected. Subsequently, each sample was divided into two equal parts: one part was ground through 2 mm sieve (Arthur Thomas Co., Philadelphia, PA, USA) and the other part was dry-rolled using a laboratory scale roller (Kal Rob Machining, Picture Butte, AB, Canada) with extent of processing expressed as PI of 0.75. Thus, total 20 samples: 10 samples (5 low and 5 high starch) × 2 PM (ground and dry-rolled) were evaluated in in situ study; the experiment was designed as a 2 × 2 factorial arrangement. Particle size distribution of processed barley samples was measured using a series of sieves at 3.35, 2.36, 1.18, 0.85 mm, and a pan using a Ro-Tap machine (RX-29, W.S. Tyler, Mentor, OH, USA).

2.2. In situ procedures

All animal procedures were in accordance with the guidelines of the Canadian Council on Animal Care (2009). Three Angus beef heifers (650 ± 25.5 kg of body weight) fitted with rumen cannulas (Bar Diamond Inc., Parma, ID, USA) with internal diameter of 10 cm were used for this study. The heifers were fed twice daily at 08:00 and 16:00 h a total mixed ration consisting of $700\ g\ kg^{-1}$ barley silage and $300\ g\ kg^{-1}$ concentrate containing dry-rolled barley grain, molasses, canola oil, minerals and vitamins (DM basis). The heifers were adapted to the diet for two weeks before starting the in situ incubation.

Rumen digestion kinetics of different processed barley was determined using the in situ method. Briefly, 5 g DM of barley samples were weighted into bags (10 × 20 cm) made of monofilament PeCAP polyester screen (pore size of $50 \pm 3\ \mu m$). Bags were heat sealed and placed in large (20 × 30 cm) mesh retaining sacs with 3- × 5-mm pores that permit ruminal fluid to percolate freely. Duplicate bags were incubated in the rumen of each heifer for each incubation time of 0, 2, 4, 8, 12, 24 and 48 h in reverse order of incubation time so that all bags were removed simultaneously. Two consecutive in situ ruminal incubation runs were conducted. Zero hour bags were not placed in the rumen but were treated to the same rinsing procedures described for the other bags. Upon removal, bags were washed under running tap water until the effluent was clear and then dried at 55 °C for 48 h. Bags and contents were weighed to estimate DM disappearance (DMD). Residues from bags belonging to the same sample were pooled by animal and by incubation time.

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