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Gas production and starch degradability of corn and barley meals differing in mean particle size

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ABSTRACT

The objective of this study was to verify the effect of mean particle size (mPS) on both gas production and in vitro rumen starch degradability (IVSD) of corn and barley meals (Cm and Bm, respectively). Batches of the same Cm or Bm were separately processed through 2 different mills (i.e., a cutter mill or a rotor speed mill) equipped with or without different screens to achieve different mPS for each tested meal. Samples were analyzed accordingly to a completely randomized design and the main tested effect of model was mPS (n = 11, from 0.46 to 3.50 mm mPS for Cm or n = 10, from 0.11 to 2.98 mm mPS for Bm). For both in vitro assays, the rumen inocula were collected from 2 rumen-fistulated Holstein lactating dairy cows fed a total mixed ration with 16.2% crude protein, 28.5% starch, and 35.0% neutral detergent fiber on a dry matter basis. To fit gas production data, 1-pool exponential model and 1-pool or 2-pool Gompertz models were adopted. The rate of gas production decreased and lag increased by increasing mPS of both Cm and Bm, irrespective of adopted 1-pool models. When the 2-pool Gompertz model was used to fit gas production data, a shift of particles from fast to slow fermentable pools was measured by increasing mPS. In particular, the ratio between fast and slow final volumes ranged from 0.90 at 0.11 mm mPS to 0.10 at 2.98 mm mPS for Bm. For Cm, the ratio between fast and slow final volumes decreased quadratically by increasing mPS, with the highest value (i.e., 0.58) measured at the lowest tested mPS. Values lower than 0.10 were measured for mPS greater than 1.93 mm for Cm. Concerning IVSD data, linear decreases in rate of starch degradation equal to −0.049 or −0.092 h^{-1} for each 1-mm increase in mPS were achieved for Cm and Bm, respectively. The 7-h IVSD decreased by 6.3 or 6.5% starch for each 1-mm increase in mPS of Cm or Bm, respectively. Present findings supported the hypothesis that different particle sizes within the same starch source represent an important factor influencing both fermentation kinetic parameters and IVSD.
Key words: cereal, particle size, gas production, starch degradation

INTRODUCTION

Cereals represent the primary energy source in ruminant diets, being a cost-effective source of digestible energy (Gozho and Mutsvangwa, 2008), and relatively high levels are commonly used in high-producing lactating dairy cow diets to meet their energy requirements (Giuberti et al., 2014). However, endosperm of cereal grains is enclosed by the pericarp, which is extremely resistant to rumen microbial degradation (Huntington, 1997; Dehghan-banadaky et al., 2007). Kernel mechanical processing, such as breaking, cracking, milling, or rolling, makes the starch of grains more accessible to amylolytic digestion by both microorganisms and pancreatic enzyme action (Offner et al., 2003; Hoffman et al., 2012), thus enhancing both rate and extent of starch digestibility in the rumen and in the different tracts of the intestine (Nocek and Tamminga, 1991; Beauchemin et al., 1994; Mathison, 1996). Although processing is essential to maximize the total-tract utilization of starch from grains (Nocek and Tamminga, 1991), kernel over-processing could cause an excessive amount of digested starch in the rumen-reticulum compartment, thus producing great amounts of VFA, a severe pH drop, rumen hypertonicity, lactate production, an excessive flux of propionate to the liver, and rumen disorders (Hindle et al., 2005; Rémond et al., 2004; Gozho and Mutsvangwa, 2008).

Recently, Moharrery et al. (2014) evaluated effects of source, intake, or escape of starch on its digestibility in the 3 major compartments of the digestive tract of lactating dairy cows (i.e., rumen, small intestine, and hind gut) through a meta-analytic approach. As a result, rumen starch digestion was reduced by 1.4% per each kilogram increase in starch intake. Furthermore, rumen starch digestibility lower than 62% starch intake

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for corn and sorghum or greater than 87% starch intake for wheat, barley, oat, or starch from corn silage was reported. However, these authors did not consider the effects of various processing methods as well as variation in mean particle sizes (**mPS**) obtained with different kernel mechanical processing, with these effects being pooled within starch source. Nevertheless, the authors recommended introducing specific corrective coefficients to better model starch digestibility as a function of different mPS, this aspect being recognized as an important factor to predict both site and extent of starch digestion and consequently the nature of the available energy (VFA or glucose) substrates (Firkins et al., 2001; Offner and Sauvant, 2004; Larsen et al., 2009).

Unfortunately, although several in vivo studies evaluated lactation performance and starch digestibility for different grain types or various heat processing methods (Joy et al., 1997; Crocker et al., 1998; Tothi et al., 2003), few studies investigated the site and extent of starch digestion as a function of mechanical processing methods. In particular, when these studies were conducted to compare the effect of mechanical processing on performance and nutrient digestibility in lactating dairy cows, only 2 (Yu et al., 1998; Knowlton et al., 1998; San Emeterio et al., 2000) or at most 3 (Callison et al., 2001; Rémond et al., 2004) different mPS levels were tested. To better model the effect of mPS on starch degradation dynamics, a greater number of mPS levels from the same starch source should be used. Such an approach can be favorably carried out by adopting in situ or in vitro evaluations simulating monogastric (Al-Rabadi et al., 2009, 2012; Bao et al., 2016) or ruminant (Lykos and Varga, 1995; Offner and Sauvant, 2004; Ramos et al., 2009) digestive tracts. Despite in vivo studies being the best method to define the dynamics of rumen starch digestion for ruminants (Hindle et al., 2005; Giuberti et al., 2014), the adoption of in situ or in vitro approaches could represent a good alternative because these methods are characterized by a satisfactory ranking ability (Nocek and Tamminga, 1991; Offner and Sauvant, 2004; Sveinbjörnsson et al., 2007). Furthermore, in vitro data provided a good prediction of kinetic dynamics of starch digestion, as declared by Huntington (1997), and this evaluation has also the possibility to be routinely employed in research as well as commercial laboratories. Among in vitro methods, a direct measurement of potential rumen starch degradability can be obtained by performing an in vitro rumen starch degradability (**IVSD**) test. Usually, the evaluation of IVSD is commonly analyzed after 6 to 8 h of rumen incubations (Cone, 1991; Sveinbjörnsson et al., 2007; Gallo et al., 2014), with 7 h being the most adopted one. This was chosen because it was considered a reasonable mean retention time of concentrate into the rumen compartment of lactating dairy cows when the method was developed (Allen, 2012). Furthermore, evidence (Krause et al., 2002; Krause and Combs, 2003) indicated the postfeeding times at which the probability of incidence of rumen acidosis increases are close to 7 h. Shorter incubation times (i.e., from 2 to 5 h) have been proposed to improve the ranking ability of IVSD for the evaluation of potential extent of rumen grain degradation (Chai et al., 2004; Giuberti et al., 2014). However, the adoption of shorter incubation times worsened the intra-laboratory method repeatability (Gallo et al., 2016).

The objective of the current study was to model the effect of mPS on gas production kinetic parameters and IVSD of 2 different starch feeds, corn and barley meals (**Cm** and **Bm**, respectively), adopting well-established rumen-based in vitro methods. Furthermore, the opportunity to fit gas production data by using 1 or 2 (i.e., fast and slow) digestible pools was evaluated by using different mathematical models.

MATERIALS AND METHODS

Feed Preparation and Chemical Analysis

Three 15-kg batches of dry whole kernel corn (Cm) and dry hulless whole kernel barley (Bm) were respectively collected over 3 wk (one batch each week) by the same feedstock grains stored in 2 silos located in CERZOO research and experimental dairy farm (San Bonico, PC, Italy) as previously detailed by Gallo et al. (2016). For each sampled batch, subsamples of both Cm and Bm were separately processed following the procedure adopted by Hoffman et al. (2012) through 2 different mills (cutter mill Pulviresette 19; rotor speed mill Pulverisette 14; Fritsch, Idar-Oberstein, Germany) equipped without or with different screens to achieve Cm and Bm with different mPS as reported on Table 1. Then, a representative charge (100 g) of the obtained grounds was run for 10 min through a sieve shaker (Multidimensional Sieveshaker IG/1/S, Giuliani Tecnologie s.r.l., Torino, Italy) equipped with a series of 8 screen sieves with nominal aperture sizes of 4.00, 3.50, 2.50, 1.50, 0.75, 0.50, 0.25, and 0.125 mm, followed by a pan. For each resulting ground, mPS was measured using the ASAE (2003) method S319.3. For both Cm and Bm, a portion of each subsample grounded through a screen above 0.50 mm was re-ground using the rotor speed mill equipped with a 0.5-mm screen and analyzed for total starch content (Megazyme assay kit K-TSTA 07/11; Megazyme International Ireland, Bray, Ireland). Chemical composition of unprocessed Cm and Bm was previously reported (Gallo et al., 2016).