Commercial ground corn grain samples vary in particle size metrics and in situ rumen starch digestibility

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ABSTRACT

Objective: Commercial dry and ground shelled corn is not a uniform feed. Geometric mean particle size (GMPS; μm) has been related to rumen digestibility, but researchers have specifically sourced or created varied particle size to assess relationships. Researchers have not sourced corn from differing commercial feed manufacturers. The objectives of our work were to assess variation in commercially ground corn sample particle size, prolamin protein content, and in situ rumen starch digestibility. Further, our objective was to relate prolamin protein and particle size measures to in situ rumen starch digestibility for survey samples.

Materials and Methods: Commercial dry and ground shelled corn samples (n = 38) were collected from the eastern and midwestern United States and analyzed for starch (% of DM), prolamin (% of DM), GMPS, surface area (cm²·g⁻¹; SA), and in situ rumen starch digestibility (% of starch) following 0, 7, and 16 h of incubation in 3 cannulated, lactating dairy cows. Survey data were analyzed using multivariate methods to report correlations, and ANOVA was carried out between starch, prolamin protein, and particle size relative to in situ rumen starch digestibility measures using JMP v14.3 (SAS Institute Inc., Cary, NC).

Results and Discussion: Substantial variability was observed for particle size measures; GMPS (μm) = 715 ± 233 and surface area (cm²·g⁻¹) = 92.7 ± 20.8. Further, GMPS and surface area were related to in situ rumen starch digestibility at 16 h (P < 0.01) and 7 h (P < 0.01), respectively.

Implications and Applications: Our survey results for commercially ground dry corn samples suggest that substantial variation exists in geometric mean particle size and surface area for corn supplied by commercial feed mills. This suggests that both the mean and SD of these measures is important when evaluating commercial dry and ground shelled corn.

Key words: grain, processing, energy

INTRODUCTION

Corn grain is an important ingredient within dairy cattle diets worldwide to provide energy for growth and production (Huntington, 1997). Improving corn grain starch rumen digestibility within dairy cattle can improve performance (Ferraretto et al., 2013) and, thus, improve commercial dairy economic sustainability by improving feed conversion. Starch utilization in cereal grains is understood to be limited by physical and chemical factors. A starch–protein matrix, termed “prolamin,” has been found to limit bacterial access to starch (McAllister et al., 1993; Larson and Hoffman, 2008). Genotype, ensiling, and steam flaking have also been shown to influence starch digestibility in ruminants (Philippeau and Michalet-Doreau, 1998; Firkins et al., 2001; Hoffman et al., 2011). Grinding (i.e., rolled or fine ground) and particle size have been extensively studied and related to starch digestibility in dairy cattle (Firkins et al., 2001; Ferraretto et al., 2013). To our knowledge, most published literature varied particle size within the study and did not source commercially dry and ground shelled corn with representative variation for the feed industry. The commercial feed industry has recognized the need to provide finely ground corn for dairy farms and has successfully reduced geometric mean particle size (GMPS) to <400 μm at times. However, substantial variation may exist. For example, at Rock River Laboratory (Watertown, WI) commercial feed corn particle size GMPS measures in 2017 (n = 487) ranged from...
approximately 350 μm to more than 1,400 μm, with a mean of 635 and median of 594 μm (unpublished data). Aside from commercial laboratory population data, it is unclear how much variation currently exists in the field between feed mills. Further, GMPS is often related to rumen starch digestibility (Ferrareto et al., 2013), yet GMPS and SD can be combined into a surface area metric (SA, cm$^2$; Standard ANSI/ASAE S319.4; ASABE, 2008). The relationship between SA and rumen starch digestion is not clearly understood for commercially ground corn. Last, both GMPS and SA are also more easily quantified than rumen starch digestibility. Understanding the relationships between these particle size measures and commercial rumen starch digestibility measures will help commercial nutritionists formulate diets in the event that only GMPS or SA are known. The experimental objective was to determine whether substantial variation existed in commercially sourced samples.

**MATERIALS AND METHODS**

Animal use was in accordance with the University of Wisconsin–Madison Institutional Animal Care and Use Committee (Protocol #A005374). Commercial dry and ground shelled corn (n = 38) samples were collected from feed mills in the eastern and midwestern United States in 2015. Samples were submitted by commercial nutritionists and feed mill managers to Rock River Laboratory Inc., and particle size was determined according to Standard ANSI/ASAE S319.4 (ASABE, 2008). Prior to sieving, corn samples were dried for 12 to 15 h at 55°C in a forced-air oven. Following drying, an approximately 100-g ground corn sample was placed atop a sieve stack. There were 8 sieves within the stack with the following apertures: 2,000, 1,000, 840, 500, 250, 149, and 105 μm and then the pan. The sieve stack was then placed upon a ROTAP shaker (W.S. Tyler, Mentor, OH), latched in place on the shaker, and run for 10 min. Percent weight retained on each sieve was determined by determining sample weight (g) retained on each sieve and relating this to total sample weight. The GMPS and SA were determined using equations described in Standard ANSI/ASAE S319.4 (ASABE, 2008). The GMPS result is nested within the SA calculation as follows:

$$\text{Surface area, cm}^2\cdot\text{g}^{-1} = 6 \div 1.32 \times \exp[0.5 \times \ln(\text{SD, } \mu m)^2 - \ln(\text{GMPS, } \mu m) \times 0.0001].$$

The DM content of the original corn grain sample was determined as weight loss upon drying, following weighing approximately 1 g of corn into an aluminum crucible and drying the sample for 3 h at 105°C. Starch (% DM) was determined using the Hall et al. (2015) AOAC procedure adapted with a YSI 2900D glucose analyzer (YSI Inc., Yellow Springs, OH). Prolamin protein (% of DM) was determined at the University of Wisconsin Soil and Forage Analysis Laboratory (Marshfield, WI) using the Larson and Hoffman (2008) procedure.

For rumen in situ digestion, samples were incubated in lactating dairy cows as received, without further grinding or processing. Approximately 3 g of corn samples was weighed into Ankrom R510 bags (Ankrom Technology, Macedon, NY; 5 × 10 cm bags with 50-μm pores). Seven subsamples were weighed out for each corn sample. A single subsample was used to quantify the wash-out fraction (0 h), and then, a single subsample was incubated in each of 3 rumen-cannulated lactating dairy cows consuming approximately 22 kg·d$^{-1}$ of a 60% forage diet, for 7 and 16 h. Samples were removed simultaneously. All samples were soaked in warm water (between 35 and 40°C) for approximately 20 min before rumen incubation. After digestion, bags were rinsed 3 times with 5-min rinse cycles with cold tap water, in a commercial laundry machine, to remove microbial residue. Residues were then dried at 50°C for 24 h and weighed to determine DM digestion. Residues were composited by time point, and starch concentration was determined as described previously. Corn grain in situ rumen starch digestion at 0 h (isSD0), 7 h (isSD7), and 16 h (isSD16) were determined as starch disappeared from the bag during incubation.

These data were assessed as survey results. A correlation matrix was evaluated using the multivariate methods, multivariate function, with independent pairwise correlations, using JMP v14.3.0 (SAS Institute Inc., Cary, NC). The isSD0, isSD7, and isSD16 observations were then regressed upon starch, prolamin protein, GMPS, or SA. Both GMPS and SA were not allowed within the same relationship, as well as linear interactions, were evaluated. The Akaike information criterion and Bayesian information criterion were used to assess each model fit, with a lesser value deemed best, and independent variables were retained in the model where $P < 0.10$. The residual plots were then visually assessed for normality: A $P < 0.05$ was deemed significant, and $P < 0.10$ was discussed as a trend, and included within the final model. The final models for isSD0, isSD7, and isSD16 were as follows.

**isSD0 Model**

$$Y_i = \mu + S_i + e_i,$$

where $Y_i$ = in situ rumen starch digestion at 0 h, the dependent variable; $\mu$ = population mean; $S_i$ = fixed effect of sample starch content; and $e_i$ = random residual error,
assumed to be normally distributed. The final model for isSD0 exhibited a $P < 0.01$, an $R^2$ value of 0.20, and a root mean squared error of 11.20.

**isSD7 Model**

$$Y_{ij} = \mu + SA_j + S_j + SAS_{ij} + e_{ij},$$

where $Y_{ij} =$ in situ rumen starch digestion at 7 h, the dependent variable; $\mu =$ population mean; $SA_j =$ fixed effect of surface area; $S_j =$ fixed effect of sample starch content; $SAS_{ij} =$ fixed effect of the interaction between SA and starch content; and $e_{ij} =$ random residual error, assumed to be normally distributed. The final model for isSD7 yielded a $P < 0.01$, an adjusted $R^2$ value of 0.32, and a root mean squared error of 9.07.

**isSD16 Model**

$$Y_{ij} = \mu + G_i + P_j + PP_k + e_{ijk},$$

where $Y_{ij} =$ in situ rumen starch digestion at 16 h, the dependent variable; $\mu =$ population mean; $G_i =$ fixed effect of GMPS; $P_j =$ fixed effect of prolamin protein; $PP_k =$ quadratic effect of prolamin protein; and $e_{ijk} =$ random residual error, assumed to be normally distributed. The final model for isSD16 yielded a $P < 0.01$, an adjusted $R^2$ value of 0.35, and a root mean squared error of 7.40.

### RESULTS AND DISCUSSION

The commercial dry and ground shelled corn sample population statistics are presented in Table 1. These survey sample population statistics show that a substantial range in particle size metrics was evident for dry and ground shelled corn sourced from commercial feed mills. To our knowledge, survey results for commercial feed mill dry and ground shelled corn starch, particle size metrics, and prolamin content have not previously been reported. Further, the relationships between these parameters with in situ rumen starch digestibility for commercially sourced samples have also not been reported previously. A correlation matrix for survey parameters is presented in Table 2. Geometric mean particle size and SA were highly correlated. This should be expected with GMPS incorporated in the SA calculation. Starch content was positively correlated with GMPS. This observation is not readily understood. Greater starch content likely implies less protein or fiber content, which are present in the pericarp and endosperm. Thus, larger kernels, and more starch, may need further time grinding or smaller screens based on this observation. Further, this observation contrasts the positive relationship observed between starch and isSD0, recognizing that isSD0 represents the fraction of starch that washes through a 50-μm pore in water. However, GMPS and isSD0 were not correlated; thus, the isSD0 appears to be related to factors other than GMPS. Other parameters were related to one another through ANOVA (Table 3).

Following linear modeling, starch content was determined to be significantly related to isSD0 ($P < 0.01$) and trended toward a positive relationship with isSD7 ($P < 0.06$; Table 3). Surface area (cm$^2$g$^{-1}$) was more highly correlated with isSD7 than GMPS (Table 2; $P < 0.01$); thus, SA was retained in the linear model and was positively related to isSD7 ($P < 0.01$; Table 3). The slope estimate between isSD7 and SA was 0.22 with SE 0.08 around this. This relationship could be used to suggest that for every 1-unit increase in SA, isSD7 may increase by 0.22 units. The relationship also suggests that both GMPS and SD are meaningful relative to this common feed analysis measure (Table 2).

Prolamin protein was not related to either isSD0 or isSD7 but was related to isSD16 in a linear and quadratic fashion. Prolamin has been reported to inhibit bacterial access to starch and negatively affect corn grain starch digestion (Larson and Hoffman, 2008). Our results are in agreement for the 16-h rumen incubation period but contrast for the 7-h rumen incubation time period. Particle size and distribution appear to relate to isSD7; however, prolamin protein content did not. Note that the range in prolamin protein, grams per 100 g of starch, evaluated here was approximately 3.2 to 6.5, whereas Larson and Hoffman (2008) reported ranges of 2.8 to 8.3 g of prolamin protein per 100 g of starch for high-moisture corn samples.

Geometric mean particle size was better related to isSD16 ($P < 0.003$) than SA. Firkins et al. (2001) observed that more finely ground dry corn related to increased total total-tract starch digestibility, and total-tract starch digestibility has been shown to relate to rumen starch dig-

<table>
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<tr>
<th>Parameter</th>
<th>n</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
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<th>Maximum</th>
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<tbody>
<tr>
<td>Starch, % DM</td>
<td>38</td>
<td>70.59</td>
<td>70.35</td>
<td>3.22</td>
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<td>Prolamin, % DM</td>
<td>38</td>
<td>3.06</td>
<td>2.95</td>
<td>0.47</td>
<td>2.40</td>
<td>4.40</td>
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<td>Prolamin, % starch</td>
<td>38</td>
<td>4.35</td>
<td>4.22</td>
<td>0.74</td>
<td>3.22</td>
<td>6.46</td>
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<td>GMPS, μm</td>
<td>38</td>
<td>715.26</td>
<td>640.35</td>
<td>235.56</td>
<td>404.70</td>
<td>1,378.80</td>
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<tr>
<td>SA, cm$^2$g$^{-1}$</td>
<td>38</td>
<td>92.70</td>
<td>94.55</td>
<td>20.95</td>
<td>50.20</td>
<td>138.70</td>
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</tbody>
</table>

| Table 1. Population statistics for starch, prolamin protein, geometric mean particle size (GMPS), and surface area (SA) for a survey of dry and ground corn grain samples (n = 38) collected from multiple locations and commercial feed mills | | | | | | |
gestibility (Ferraretto et al., 2013). Thus, the GMPS relationship with in situ rumen starch digestibility (16 h) observed herein would agree with the literature summary and report by Firkins et al. (2001). Further, our isSD16 results agree with Ramos et al. (2009), who evaluated strategically ground corn samples with 3 GMPS categories, ranging between 526 and 1,360 μm, and observed that in situ rumen starch digestibility decreased with increasing particle size. Our results also agree with Hoffman et al. (2012), who also strategically ground a single lot of corn grain in a laboratory, but with more GMPS categories (n = 11) ranging from 105 to 3,778 μm, and observed a strong negative relationship between GMPS and in vitro rumen gas production parameters. In Table 3, the regression equation parameter estimates for interactions and quadratic effects includes correcting to the arithmetic means for these contributing factors in these effects. This is due to the nature of JMP Pro v14.3.0 linear regression model reporting.

In summary, our observations show that dry and ground shelled corn samples from numerous feed suppliers in the midwestern and eastern United States varied in particle size measures and in situ rumen starch digestibility. Often, based on our experience, consulting nutritionists will use feed library nutritive values for dry and ground shelled corn for diet formulation. However, based on these data and variation recognized, feed library values should be used with caution.

### APPLICATIONS

Our survey results for commercially ground dry corn samples suggest substantial variation exists for corn supplied by commercial feed mills. Our observations also

<table>
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<th>Item</th>
<th>Estimate</th>
<th>SE</th>
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<tr>
<td>isSD0 model parameter estimates</td>
<td></td>
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<tr>
<td>Intercept</td>
<td>−100.68</td>
<td>40.56</td>
<td>0.02</td>
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<tr>
<td>Starch, % DM</td>
<td>0.99</td>
<td>0.51</td>
<td>0.01</td>
</tr>
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<td>isSD7 model parameter estimates</td>
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<tr>
<td>Intercept</td>
<td>−20.20</td>
<td>37.26</td>
<td>0.59</td>
</tr>
<tr>
<td>Surface area, cm²·g⁻¹</td>
<td>0.22</td>
<td>0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>Starch, % DM</td>
<td>0.99</td>
<td>0.51</td>
<td>0.06</td>
</tr>
<tr>
<td>(Surface area − 92.70) × (Starch − 70.59)</td>
<td>0.06</td>
<td>0.03</td>
<td>0.08</td>
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<tr>
<td>isSD16 model parameter estimates</td>
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<tr>
<td>Intercept</td>
<td>119.86</td>
<td>10.49</td>
<td>0.01</td>
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<tr>
<td>Geometric mean particle size, μm</td>
<td>−0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Prolamin protein, % DM</td>
<td>−8.88</td>
<td>3.44</td>
<td>0.02</td>
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<tr>
<td>(Prolamin − 3.06) × (Prolamin − 3.06)</td>
<td>9.79</td>
<td>4.67</td>
<td>0.05</td>
</tr>
</tbody>
</table>
agree with the substantial body of literature documenting that corn grain particle size is negatively related to rumen starch digestibility. Further, the ASABE (2008) surface area (cm²·g⁻¹) measure, incorporating both geometric mean particle size and variance, should be considered in evaluating dry ground corn. If commercial rumen starch digestibility measures are unavailable, SA could be used to predict 7-h in situ rumen starch digestibility, using the regression equation parameters presented here.

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LITERATURE CITED


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