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Relationship between processing score and kernel-fraction particle size in whole-plant corn silage

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ABSTRACT

Kernel processing increases starch digestibility in whole-plant corn silage (WPCS). Corn silage processing score (CSPS), the percentage of starch passing through a 4.75-mm sieve, is widely used to assess degree of kernel breakage in WPCS. However, the geometric mean particle size (GMPS) of the kernel-fraction that passes through the 4.75-mm sieve has not been well described. Therefore, the objectives of this study were (1) to evaluate particle size distribution and digestibility of kernels cut in varied particle sizes; (2) to propose a method to measure GMPS in WPCS kernels; and (3) to evaluate the relationship between CSPS and GMPS of the kernel fraction in WPCS. Composite samples of unfermented, dried kernels from 110 corn hybrids commonly used for silage production were kept whole (WH) or manually cut in 2, 4, 8, 16, 32 or 64 pieces (2P, 4P, 8P, 16P, 32P, and 64P, respectively). Dry sieving to determine GMPS, surface area, and particle size distribution using 9 sieves with nominal square apertures of 9.50, 6.70, 4.75, 3.35, 2.36, 1.70, 1.18, and 0.59 mm and pan, as well as ruminal in situ dry matter (DM) digestibilities were performed for each kernel particle number treatment. Incubation times were 0, 3, 6, 12, and 24 h. The ruminal in situ DM disappearance of unfermented kernels increased with the reduction in particle size of corn kernels. Kernels kept whole had the lowest ruminal DM disappearance for all time points with maximum DM disappearance of 6.9% at 24 h and the greatest disappearance was observed for 64P, followed by 32P and 16P. Samples of WPCS (n = 80) from 3 studies representing varied theoretical length of cut settings and processor types and settings were also evaluated. Each WPCS sample was divided in 2 and then dried at 60°C for 48 h. The CSPS was determined in duplicate on 1 of the split samples, whereas on the other split sample the kernel and stover fractions were separated using a hydrodynamic separation procedure. After separation, the kernel fraction was redried at 60°C for 48 h in a forced-air oven and dry sieved to determine GMPS and surface area. Linear relationships between CSPS from WPCS (n = 80) and kernel fraction GMPS, surface area, and proportion passing through the 4.75-mm screen were poor. Strong quadratic relationships between proportion of kernel fraction passing through the 4.75-mm screen and kernel fraction GMPS and surface area were observed. These findings suggest that hydrodynamic separation and dry sieving of the kernel fraction may provide a better assessment of kernel breakage in WPCS than CSPS.

Key words: corn silage, particle size, corn silage processing score

INTRODUCTION

Whole-plant corn silage (**WPCS**) is a high-energy forage with high DM yield per hectare from kernel and stover fractions, which are high in starch and NDF contents, respectively. The kernel fraction, composed of approximately 72% starch (DM basis; Huntington, 1997), represents nearly 45% of the whole-plant DM (Philippeau and Michalet-Doreau, 1998) and more than 50% of the energy in WPCS (calculated using NRC, 2001). Total-tract starch digestibility of WPCS, however, ranges from about 80 to 98% in lactating dairy cows fed WPCS-based diets (Ferraretto and Shaver, 2012b). Processing WPCS through rollers during harvest reduces the particle size of corn kernels and has been reported to increase total-tract starch digestibility (Bal et al., 2000; Johnson et al., 2002; Cooke and Bernard, 2005). Nevertheless, the efficacy of kernel processing in WPCS is variable and can be influenced by several factors, including maturity or DM content of WPCS at harvest, theoretical length of cut, type of processor, and processor roll-gap clearance (Shinners et al., 2000; Ferraretto and Shaver, 2012a,b). Therefore, methods to evaluate the adequacy of kernel processing in WPCS are critical.

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Ferreira and Mertens (2005) established a methodology to determine degree of kernel breakage in WPCS defined as corn silage processing score (**CSPS**). This methodology is widely used in the dairy industry and measures the proportion of starch passing through a 4.75-mm sieve after vertical shaking separation procedures using dried WPCS samples. However, the use of a single sieve to determine degree of kernel processing leads to the assumption that all particles passing through this sieve are equal. It is unknown, however, if the proportion of different fragments comprising this pool of particles vary widely. Wide variation would suggest that differences in starch digestibility among WPCS samples of similar CSPS exist.

Mean particle size is a mathematical function that describes the degree of reduction of a set of particles and is defined by measuring the relative amounts of particles retained in varied sieves of known dimensions (Liu, 2008). Particle size distribution analysis is desirable in several fields that handle granular or particulate materials. Granulometry is a common method to determine the particle size distribution of feed materials (Clementson and Ileleji, 2012), which can be performed with dry sieving. The material passes through a series of sieves, which are individually weighed and the proportion of material retained on each sieve determined. Geometric mean particle size (**GMPS**) is the most common method used for comparison of particle size distribution in cereal grains (ASABE, 2007). Recently, GMPS has been suggested, in combination with zein protein or ammonia-N, for modeling ruminal and total-tract starch digestibilities and rate of ruminal starch digestion for dry and high-moisture corns (Hoffman et al., 2012a). The GMPS of the kernel fraction in WPCS has not been well described and may provide valuable insights for modeling starch digestibility in WPCS. Thus, the objectives of our study were to evaluate (1) particle size distribution and ruminal in situ DM disappearance of unfermented kernels cut in varied particle sizes; (2) a method to measure GMPS in WPCS kernels; and (3) the relationship between CSPS and hydrodynamically separated kernel fraction GMPS in WPCS.

MATERIALS AND METHODS

Unfermented Kernels

Unfermented kernels from 110 corn hybrids from varied genetic lines commonly used for silage production were obtained from previous experiments in our laboratory. Kernels were collected from middle portions of ears at the maturity stage between one-half and two-thirds of the milk line. All kernels were previously dried at 40°C for 72 h in a forced-air oven. Kernels were kept whole (**WH**) or manually cut in 2, 4, 8, 16, 32, or 64 pieces (**2P**, **4P**, **8P**, **16P**, **32P**, and **64P**, respectively) using scalpel blades (Surgical blade stainless steel n.21, Feather Safety Razor Co., Ltd., Ozaka, Japan). The first cut was done across the kernel, and each subsequent cut halved a previously cut piece. A total of 330 kernels (3 per hybrid) were obtained for each particle number treatment. Throughout the manuscript these treatments will be referred to as a kernel particle number treatment. Each sample (128.2 ± 7.0 g; mean ± SD) was dry-sieved using a Tyler Ro-Tap Shaker (model RX-29, W.S. Tyler, Mentor, OH) using a set of 9 sieves (W.S. Tyler) with nominal square apertures of 9.50, 6.70, 4.75, 3.35, 2.36, 1.70, 1.18, and 0.59 mm and pan (ASABE, 2007) to determine particle size distribution; GMPS (μm) and surface area (cm^2/g) were calculated using a log normal distribution (Baker and Herrman, 2002). Sieves were a combination of sieves used for CSPS (Ferreira and Mertens, 2005; 9.50-, 6.70-, 4.75-, 2.36-, 1.18-, and 0.59-mm sieves) or dry ground corn GMPS (Baker and Herrman, 2002; 3.35- and 1.70-mm sieves). The associated use of these 2 sets of sieves was chosen in an attempt to better characterize and describe the particle size distributions (% of DM retained on each sieve).

Subsequently, in situ measurements of ruminal DM disappearance were performed for each kernel particle number treatment using 2 ruminally cannulated, mid-lactation, multiparous Holstein cows fed a TMR containing (DM basis) alfalfa silage (44.5%), nonexperimental corn silage (26.8%), alfalfa hay (10.7%), wheat straw (6.5%), and concentrate mixture (11.5%). Individual samples of each kernel particle number treatment were recombined from each of the sieves after dry sieving procedures and evaluated for DM disappearance. Dacron polyester cloth bags (R510, 10 × 20 cm and 50-μm pores; Ankom Techonology, Macedon, NY) containing approximately 5 g of DM of each unfermented kernel particle number treatment, yielding a ratio of sample mass per bag area of 25 mg/cm^2, were incubated in duplicate within each cow. The in situ bags for the respective treatments for each time point (3, 6, 12, and 24 h) were placed in a nylon laundry bag (30 × 40 cm) and then positioned in the ventral rumen of each cow. Each laundry bag was attached to the inside of the rumen cannula with a 75-cm long nylon rope and contained a rubber weight to ensure they remained submerged in the ruminal contents. Bags were moistened in warm water for 30 s before incubation. Each laundry bag contained a blank bag to allow correction for infiltration of DM into sample bags. After removal, samples were soaked in cold water for 15 min before washing twice in

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