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Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting[1]

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ABSTRACT

Over the last 25 years, whole-plant corn silage has become an important and popular feedstuff for dairy production. Copious research has been dedicated to the development and evaluation of alternatives to enhance the nutritive value of whole-plant corn silage. These efforts have been aimed at manipulating the physical and chemical characteristics of whole-plant corn silage in an effort to maximize dairy profitability. Results from this review indicate that optimization of harvest maturity, kernel processing, theoretical length of cut, and cutting height improve or maintain the nutritive value and milk production of lactating dairy cows. Technological advancements have been developed and made available to dairy producers and corn growers desiring to enhance fiber and starch digestibility of whole-plant corn silage. Future research should be directed toward further assessment of new processors available in the market and the development of assessment methods for optimization of crop processor settings, harvest efficiency, and nutritional modeling.
Key words: corn silage, kernel processing, fractionated silage, silage harvest, forage analysis

INTRODUCTION

Whole-plant corn silage (**WPCS**) has become the predominant forage used in dairy cattle diets worldwide. Annually, 105 million Mg of fresh corn forage was harvested in the United States, on average, over the last 10 years (Table 1; USDA-NASS, 2017). Many factors contribute to the high adoption of WPCS by dairy farmers, including lower harvesting costs, minimized risks of production, elevated yield per area, and flexibility to harvest corn for forage or grain (Allen et al., 2003). Moreover, uniquely in comparison with other forages, WPCS offers dairy nutritionists the opportunity to provide high energy (mainly from starch in the kernel fraction) along with physically effective NDF (**peNDF**; provided by the stover fraction) concurrently.

Dairy farmers and corn growers are challenged to produce greater amounts of higher quality WPCS to meet the nutrient requirements of high-producing dairy cows (NRC, 2001). Despite continual improvements in total DM and kernel productivity of corn hybrids, advancements in nutritional quality of WPCS through hybrid selection programs were marginal in the last century (Lauer et al., 2001; Ferraretto and Shaver, 2015). Therefore, development of alternatives for enhancing the nutritive value of WPCS by manipulating its physical and chemical characteristics is crucial.

Harvest practices, such as proper maturity at harvest, kernel processing, theoretical length of cut (**TLOC**), and cutting height are well-established management tools for improving physical and chemical characteristics and hence nutrient digestibility of WPCS (Johnson et al., 1999; Allen et al., 2003; Buxton and O'Kiely, 2003; Ferraretto and Shaver, 2012b). However, nutritionists strive for greater consistency in the nutritive value of feedstuffs in the new era of precision feeding. Greater consistency allows for more optimal dietary formulation and feed bunk management. Thus, a greater understanding of how these various harvest practices interact with each other in combination with the development of new technologies are warranted to enhance the decision-making process for forage harvesting.

Recently, several technological advancements have been made available to dairy producers and corn growers desiring to enhance the nutritional value of forages. These advancements vary from data collection of spatial yield and nutrient characteristics at the time of harvest to processors and equipment modifications that allow for the production of silage of various whole- or fractionated-corn plant materials (i.e., shredlage,

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Table 1. Area harvested, yield, and production of corn for silage in the United States[1]

Year	Area harvested (1,000 ha)	Yield (Mg of fresh crop/ha)	Production (1,000 Mg of fresh crop)
2007	2,452	39.2	96,936
2008	2,414	41.9	101,259
2009	2,268	43.3	98,166
2010	2,253	43.3	97,354
2011	2,402	41.2	98,968
2012	2,986	34.5	102,920
2013	2,542	42.1	107,316
2014	2,578	45.1	116,163
2015	2,518	45.7	115,116
2016	2,503	45.5	114,006

[1]Adapted from USDA-NASS (2017).

snaplage, toplage). Although these developments have garnered a lot of interest by dairy farmers and corn growers, a review of research trials describing and summarizing these findings is unavailable.

Finally, continual improvements in on-farm methods to evaluate physical and chemical characteristics of forages enhance the likelihood of achieving greater consistency at harvest. Enhancement of these methods of analysis at the laboratory level would allow for potential improvements to the current models of diet formulation.

The objectives of this review are to (1) evaluate effects of selected practices and recent technological advancements for silage harvesting on physical and chemical characteristics of WPCS and their corresponding effects on lactation performance by dairy cows; and (2) discuss current procedures used for WPCS physical characterization and highlight areas where improvements are needed.

HARVEST PRACTICES

Kernel Processing

Although the use of self-propelled forage harvesters (**SPFH**) equipped with 2 counter-rotating rolls for corn processing was a common practice in Europe for many years, its US implementation came only in the 1990s (Johnson et al., 1999; Shinners, 2003). Adoption in the United States was possibly related to increasing grain prices, a trend toward longer TLOC, and rapid dry down of kernels due to climatic changes (Johnson et al., 1999).

The starch endosperm in corn kernels is protected by the pericarp, which, if intact, is highly resistant to microbial attachment and enzymatic digestion (McAllister et al., 1994); therefore, breakage of the seed coat is required for improved digestibility. Processing rolls are intended to break corn kernels down to a smaller particle size to ensure the starch endosperm is exposed, and thus, starch digestion and utilization by ruminant animals is enhanced. However, until the 1990s, the use of short TLOC settings (<10 mm) without processing rollers was a common harvest practice in the United States. Short TLOC settings allow for more kernel breakage by the cutting knives, and thus, the importance of kernel processing using a roller mill is tempered (Johnson et al., 1999; Ferraretto and Shaver, 2012b). With the establishment of peNDF as an index of chewing activity, ruminal pH, and milk fat content (Mertens, 1997), harvesting WPCS with longer TLOC settings became of greater interest, and thus, the importance of mechanical processing of kernels was established in the United States (Johnson et al., 1999; Allen et al., 2003). Shinners et al. (2000) reported that increasing TLOC settings from 9.5 to 19 mm without the addition of processing rolls reduced the proportion of broken and cracked kernels by 10 percentage units (61 vs. 51% of total kernel mass, respectively), on average, in whole-plant corn samples harvested between one-third and three-quarters kernel milk line. Conversely, when whole-plant corn was harvested with a harvester set for a 19-mm TLOC and equipped with processing rolls (roll gap set at 1 to 3 mm), broken and cracked kernels were >90% of total kernel mass (Shinners et al., 2000). Similar results were reported by others (Schurig and Rodel, 1993; Roberge et al., 1998). Ferraretto and Shaver (2012b), from a meta-analysis of WPCS trials with lactating dairy cows, reported 5.9- and 2.8-percentage-units greater total-tract starch digestibility (**TTSD**) when WPCS was processed using 1- to 3-mm roll gap settings compared with 4- to 8-mm processed or unprocessed WPCS. This was likely related to the extent of kernel breakage. Shinners et al. (2000) reported the fraction of broken and cracked kernels to be approximately 99, 96, and 88% of total kernel mass when roll gap settings were 1, 3, and 5 mm, respectively.

Degree of kernel processing in WPCS, however, may be inhibited by other factors. The review by Allen et