CORN SILAGE: WHAT'S NEW?

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INTRODUCTION

High quality corn silage contributes greatly to supplying the energy, starch and forage neutral detergent fiber needs of high-producing dairy cows, reducing purchased feed costs from expensive grain and byproduct supplements, and generating milk revenue for dairy producers. The purpose of this paper is to review selected recent developments and considerations for corn silage.

STARCH DIGESTIBILITY

Meta-Analysis

Ferraretto and Shaver (2012) performed a meta-analysis to determine the impact of dry matter (**DM**) content, kernel processing (**PROC**) and theoretical length of cut (**TLOC**) of whole plant corn silage (**WPCS**) on intake, digestion and milk production by dairy cows. The dataset was comprised of 106 treatment means from 24 peer-reviewed journal articles from 2000 to 2011. Categories for DM content at silo removal and PROC and TLOC at harvest were: ≤ 28% (**VLDM**), >28% to 32% (**LDM**), >32% to 36% (**MDM**), >36% to 40% (**HDM**), and >40% (**VHDM**) DM; 1 to 3 or 4 to 8 mm roll clearance or unprocessed; 0.48 to 0.64, 0.93 to 1.11, 1.27 to 1.59, 1.90 to 1.95, 2.54 to 2.86, and ≥ 3.20 cm TLOC. Data were analyzed using Proc Mixed in SAS with WPCS treatments as Fixed effects and trial as a Random effect.

Milk yield was decreased by 2 kg/d per cow for VHDM. Fat-corrected milk (**FCM**) yield decreased as DM content increased. Total-tract digestibility of dietary starch (**TTSD**) was reduced for VHDM compared to HDM and LDM. Processing (1 to 3 mm) increased TTSD compared to 4 to 8 mm PROC and unprocessed WPCS. Milk yield tended to be 1.8 kg/cow/d greater, on average, for PROC (1 to 3 mm) and unprocessed WPCS than 4 to 8 mm PROC. The TLOC of WPCS had minimal impact on any of the parameters evaluated. Starch digestibility and lactation performance were reduced for dairy cows fed diets containing WPCS with >40% DM or WPCS with insufficient kernel processing.

An interaction was observed between DM content and kernel processing for TTSD. Kernel processing increased TTSD for diets containing WPCS with 32% to 40% DM. Also, an interaction was observed between TLOC and kernel processing for TTSD. Kernel processing increased diet TTSD when TLOC was 0.93 to 2.86 cm. Kernel processing WPCS to improve starch digestibility was effective across a wide range of DM contents and TLOC, but did not overcome adverse effects of very high DM content on TTSD and was ineffective at very long TLOC.

Shredlage™

Ferraretto and Shaver (2012b, c) reported on an experiment to determine the effect of feeding Corn Shredlage™ (**SHRD**) versus conventional-processed WPCS (**KPCS**) on lactation performance by dairy cows. The KPCS was harvested using conventional rolls (3-mm gap) and set at a 19-mm TLOC. The SHRD was harvested using novel cross-grooved rolls (2.5-mm gap) and set at a 30-mm TLOC. One hundred and twelve cows stratified by DIM, milk yield, breed and parity were randomly assigned to 14 pens with 8 cows. Pens were randomly assigned to the two TMR treatments in a completely-randomized design. A 2-wk covariate period with cows fed a 50:50 mixture of treatment diets was followed by an 8-wk treatment period with cows fed their assigned treatment diet. The TMR contained (DM basis) KPCS or SHRD (50%), alfalfa silage (10%), concentrate mixture (40%). Data were analyzed using Proc Mixed in SAS with covariate, treatment, week, and treatment x week interaction as Fixed effects and pen within treatment as Random effect. Pen was the experimental unit.

Cows fed SHRD tended to consume 0.7 kg/d more DM. Milk yield and composition was similar between treatments. Yield of 3.5% FCM tended to be 1.0 kg/day greater for cows fed SHRD. A treatment by week interaction was detected for 3.5% FCM yield; similar during wk 2, a tendency for SHRD to be greater during wk 4 and 6, and greater by 2.0 kg/day for SHRD at wk 8. Ruminal in situ digestibility of starch, but not NDF, was greater for SHRD than KPCS. Total tract digestibility of dietary starch was greater for SHRD than KPCS.

Silage Fermentation

Corn kernel vitreousness, the ratio of vitreous to floury endosperm, has been used to assess type of corn endosperm (Ngonyamo-Majee et al., 2008a, b). Highly vitreous corn types generally contain greater concentrations of prolamin proteins than floury corn types (Larson and Hoffman, 2008). Starch granules in the corn endosperm are surrounded by hydrophobic prolamin proteins which are slowly degraded (McAllister et al., 1993). Effects of wide differences in corn grain vitreousness and prolamin content, vitreous corn versus floury corn, on starch digestibility by lactating dairy cows have been demonstrated (Taylor and Allen, 2005; Lopes et al., 2009). Hoffman and Shaver (2009) developed a corn grain evaluation system (UWFGES) for dairy cows where ruminal and total-tract starch digestibility are predicted from equations that include mean particle size (**MPS**), prolamin protein content, and whether or not the corn is dry or high moisture corn (**HMC**; > 22.5% moisture). This system originally did not account for effects of varying corn maturities, moisture contents, or extents of silage fermentation.

Hoffman et al. (2011) reported that ensiling HMC for 240 d reduced zein protein subunits that cross-link starch granules, and suggested that the starch-protein matrix was degraded by proteolytic activity over an extended ensiling period. This could explain reports of greater ruminal in situ starch degradability for HMC with greater moisture contents and extents of silage fermentation (Benton et al., 2005). The Larson and Hoffman (2008) turbidity assay did not detect a reduction in zein protein over the ensiling period for HMC as was measured by high-performance liquid chromatography (Hoffman et al., 2011). Ammonia content increased, however, as HPLC zein protein subunits in HMC decreased (Hoffman et al., 2011), and ammonia was used in combination with MPS for modeling the effects of corn maturity, moisture content and extent of silage fermentation on ruminal and total-tract starch digestibilities for HMC at feed out (Hoffman et al., 2012a). Based on the work by Hoffman et al. (2012a), a revised corn grain evaluation system (v2.0) has been developed (Hoffman et al., 2012b).

Newbold et al. (2006) reported that ruminal in situ starch and crude protein (CP) degradabilities increased for WPCS as length of storage time increased. Increased WPCS in vitro starch digestibility with greater length of storage time was reported by Hallada et al. (2008) and Der Bedrosian et al. (2012). Young et al. (2011) reported that the addition of protease enzymes and greater length of the storage time increased ammonia content and ruminal in vitro starch digestibility of WPCS. The DairyOne (Ithaca, NY) on-line data base (http://www.dairyone.com/) reveals that for over 12,000 corn silage samples analyzed from May-2000 through April-2011, ammonia nitrogen averaged 7.1% of total nitrogen with a normal range from 3.0 to 11.1%. In our analysis of a dataset provided by Dairyland Labs (Arcadia, WI) with over 1,900 corn silage samples, ammonia nitrogen averaged 5.7% of total nitrogen with a normal range from 2.7 to 10.7%. Additionally, in our analysis of a dataset provided by Cumberland Valley Analytical Services (Maugansville, MD) with about 44,000 corn silage samples from May-2007 through February-2012, ammonia nitrogen averaged 9.6% of total nitrogen with a normal range from 7.8 to 11.4%. Corn silage DM content explained almost none of the ammonia nitrogen variation in either dataset, which may not be too surprising since length of silage fermentation prior to on-farm sampling was unknown and could have ranged from less than a few weeks to over a year in storage.

Ferreira and Mertens (2005) reported on a procedure for determining degree of kernel damage in WPCS (**KPS**; % of starch passing through a 4.75 mm screen) which they found was related to ruminal in vitro starch digestibility. Ferreira (2002) reported that KPS was related to total-tract starch digestibility by dairy cows. The ammonia and KPS assays are commonly used by commercial feed testing laboratories in their evaluation of WPCS samples for dairy nutritionists.

Research is needed to determine the effectiveness of ammonia content (Hoffman et al., 2012a, b) in combination with KPS (Ferreira and Mertens, 2005) for predicting WPCS starch digestibility parameters.

HYBRID LACTATION TRIAL

Chase (2010) reported on an experiment that evaluated conventional, brown midrib, and NutriDense hybrids harvested as WPCS and fed to early lactation dairy cows. Greater milk production was observed for the brown midrib WPCS, while greater feed efficiency was observed for the NutriDense WPCS.

Akins and Shaver (2012) reported on an experiment with its primary objective to determine lactation performance by dairy cows fed NutriDense® (**ND;** NutriDense 905823; BASF Plant Science, Raleigh, Durham, NC) corn silage hybrid compared to dual-purpose (**DP;** Pioneer Hi-Bred A DuPont Business, Des Moines, IA) and brown midrib (**BM;**Mycogen Seeds, Dow AgroSciences LLC, Indianapolis, IN) corn silage hybrids at the same concentration of corn silage in the treatment diets. A secondary objective was to determine lactation performance by dairy cows fed ND at two different concentrations of corn silage in the treatment diets.

Corn silage hybrids were planted in a 14 hectare field at the University of Wisconsin-Madison Agricultural Research Station in Arlington, WI on May 4, 2010 with 76 cm row spacing and at 84,000 seeds per hectare. Tillage, fertilizer application and weed control were the same for the three corn silage hybrids which were in field plots separated by buffer strips planted with a corn grain hybrid. Hectares harvested were 4.1, 4.9 and 4.3 for DP, BM and ND, respectively. The field plots were harvested as WPCS using a self-propelled forage harvester equipped with a conventional kernel processor (20-cm cutting height, 19-mm TLOC, and 2 mm roll-gap spacing). Field plots were harvested as soon as possible after kernel maturity progressed to one-half milkline and on Sept. 7, 13 and 20, 2010 for DP, BM and ND, respectively. Total metric tons of DM harvested from the respective field plot hectares provided above were 105, 92 and 121 for DP, BM and ND, respectively. The WPCS treatments were stored in separate 3 m × 76 m silo bags until the feeding trial commenced on July 7, 2011.

One hundred and twenty-eight Holstein (48 multiparous and 64 primiparous) and Holstein × Jersey (16 multiparous) cows were stratified by breed, parity and DIM (105 ± 38 d at trial initiation) and randomly assigned to 16 balanced pens of 8 cows each in the University of Wisconsin-Madison sand-bedded free-stall barn and milking parlor dairy (Emmons Blaine Dairy Research Center; Arlington, WI). The pens were then randomly assigned to 1 of 4 TMR treatments (4 pens per treatment) with DP, BM or ND in a completely-randomized design continuous-lactation feeding trial.

Three treatments (**DP40**, **BM40** and **ND40**) contained 60% forage DM with 2/3rd (40% of TMR DM) from the respective WPCS and 1/3rd alfalfa silage (DM basis). The fourth treatment contained 65% forage DM entirely from ND corn silage (**ND65**). All diets were formulated to be isonitrogenous. A 2-wk covariate period with all pens receiving a TMR containing equal DM proportions of DP40, BM40 and ND40 was followed by an 11-wk treatment period with pens fed their assigned treatment TMR. The TMR treatments were mixed and fed once daily for 5% feed refusals. All cows were injected with bovine somatotropin (Posilac®, Elanco Animal Health, Greenfield, IN) every 14 d commencing on d 1 of the covariate period.

Daily DMI was determined from amounts offered and refused for individual pens throughout the 13-wk experiment. Body weight and condition score were recorded on individual cows at the end of the covariate period and every other week during the treatment period. Body weight change (**BWC**) was determined by regression of the treatment period BW measurements over time. Milk yield was recorded daily on individual cows milked 2x daily in a double-16 parlor throughout the trial and composited by pen prior to statistical analysis. Milk samples were obtained from all cows biweekly on the same two consecutive days from the a.m. and p.m. milkings throughout the trial, composited by pen by week, and composites analyzed for fat, true protein, lactose and MUN concentrations. Samples of TMR, corn silages, alfalfa silage, and concentrate mixes were obtained weekly and then composited for the covariate period and biweekly during the treatment period for analysis.

Data were analyzed as a completely-randomized design with the data from the preliminary period as a covariate using PROC MIXED (SAS Institute, 2004) with week of treatment as repeated measures. Pen was the experimental unit. The model included treatment, week and treatment × week interaction as Fixed effects, and pen within treatment as a Random effect. Contrasts were used to compare ND40 vs. DP40, ND40 vs. BM40, and ND40 vs. ND65. Statistical significance and trends were declared at $P < 0.05$ and $P \geq 0.06$ to $P < 0.10$, respectively.

Although harvest of the three WPCS treatments commenced as soon as possible after being assessed at the one-half kernel milkline stage of maturity, the BM averaged 41.8% DM and was 6.6 and 4.5%-units drier than DP and ND, respectively. For the BM, five days elapsed between the decision to harvest and the actual harvest with weather conditions favoring a rapid dry-down during that time period which resulted in the DM content being greater than desired for that WPCS treatment. The concentrations of NDF and starch in WPCS were similar for DP and BM. The ND WPCS NDF content was 3.4%-units lower and starch content was 4.9%-units greater compared to the average for DP and BM. Overall differences in WPCS nutrient composition resulted in a 3.3% increase in the TDN_{1x} value calculated for ND using the NRC (2001) summative energy equation compared to the average for DP and BM. All three WPCS treatments were well processed with KPS ranging from 68% to 77%.

Ruminal in vitro 30-h NDFD (% of NDF) was 14.3%-units greater for BM than the average of DP and ND which were similar. Greater ruminal NDFD for BM than DP was expected (Gencoglu et al., 2008). Ruminal in vitro 7-h STHD (% of starch) appeared similar with averages ranging from 84% to 89% across the WPCS treatments. It should be noted that the WPCS treatments had been in the silo bags for ten months before commencing with the feeding trial and silage sampling over a subsequent four month period, which would likely have attenuated any inherent differences in starch digestibility that may have existed between the WPCS hybrids (Hoffman et al., 2011).

Dietary CP and ether extract concentrations were similar across the four treatments. Dietary concentrations of forage and total NDF were lower and NFC and starch were greater for ND40 than DP40 and BM40 coincident with the NDF, NFC and starch concentrations of the WPCS treatments. Furthermore the dietary TDN_{1x} values calculated using the NRC (2001) summative energy equation with these dietary nutrient concentrations were greater for ND40 compared to DP40 and BM40 which were similar. The dietary concentration of forage NDF was 2.3%-units greater for ND65 than ND40, while concentrations of NFC, starch and TDN_{1x} were similar for these two TMR treatments. These nutrient concentrations were not unexpected since ND65 contained 65% corn silage while ND40 contained 40% corn silage and 20% alfalfa silage (DM basis).

Ruminal in vitro 30-h NDFD (% of NDF) was 10.4%-units greater for BM40 than the average of DP40 and ND40 TMR treatments which were similar. Greater ruminal NDFD for TMR containing BM40 compared to DP40 was expected (Gencoglu et al., 2008). In vitro measurements for dietary starch digestibility were similar among the DP40, BM40 and ND40 treatments, while ND65 was greater than ND40. For the ND40 and ND65 TMR treatments, 52% and 85% of dietary starch, respectively, was provided by the ND WPCS with an observed ruminal in vitro 7h STHD of 85.5 ± 3.7% of starch. The remainder of the dietary starch in both diets was primarily from dry ground shelled corn with an observed ruminal in vitro 7h STHD of 74.6 ± 3.8% of starch. Together these calculations and data can explain the observations of greater in vitro starch digestibility for ND65 than ND40 TMR treatments.

Actual milk yield tended to be 1.9 kg/d greater ($P = 0.09$) and milk protein and lactose yields were greater ($P < 0.01$ and $P = 0.03$, respectively) for ND40 than DP40. Although DMI was similar ($P = 0.15$) the intakes of fat, NFC, starch and rumen digestible starch were greater ($P < 0.01$) for ND40 than DP40, which could explain the production differences between these two treatments.

There were no lactation performance differences observed ($P > 0.10$) between ND40 and BM40, except for greater MUN and BW ($P = 0.04$ and $P = 0.01$, respectively) for ND40 compared to BM40. The observed difference in BW between these two treatments reflects differences at the time of trial initiation and BWC was unaffected ($P = 0.93$) by treatment, averaging 0.50 and 0.51 kg/d for ND40 and BM40, respectively. We have no explanation for the 8% increase in MUN for ND40 over BM40, since intake of rumen digestible starch was greater ($P < 0.01$) and CP intake was similar ($P = 0.47$) for ND40 compared to BM40. The lack of DMI response ($P = 0.71$) for BM40 with its greater corn silage and TMR 30-h NDFD compared to ND40 was surprising (Gencoglu et al., 2008), but may have been related to the trial being performed on midlactation cows between 100 and 200 DIM where rumen fill may not be limiting energy intake relative to production requirements (Allen, 2000; Mertens, 1997). The trial of Chase (2010) which found greater DMI and milk production for BM WPCS was conducted with early lactation cows. In our study, total and forage NDF intakes across the four treatments were less than or equal to 1.11 and 0.90 % of BW, respectively, and would not be considered fill limiting (Mertens, 1997). Counteracting effects of greater rumen digestible starch intakes for ND40 over BM40 ($P < 0.01$), but greater rumen digestible NDF intakes for BM40 over ND40 ($P < 0.01$), may explain the lack of production differences ($P > 0.01$) between these two treatments.

Dry matter intake and milk yield were reduced by 1.8 ($P < 0.01$) and 2.2 kg/d ($P = 0.02$), respectively, for ND65 compared to ND40. Furthermore, milk fat content and yield were reduced by 0.45%-units ($P = 0.01$) and 0.33 kg/d ($P < 0.01$), respectively, for

ND65 compared to ND40. Reduced DMI and thus nutrient intakes (OM, CP, fat, NFC, and starch; $P < 0.01$) and consequently milk yield along with reduced milk fat could be related to greater ruminal starch digestion (Allen et al., 2009; Allen, 1997) for ND65 compared to ND40. As discussed previously, of the total dietary starch 52% for ND40 and 85% for ND65 was provided by WPCS with greater ruminal digestibility than the dry ground shelled corn which comprised most of the remainder of dietary starch. An alternative explanation for reduced DMI by cows fed ND65 could be rumen-fill limitation of DMI since dietary forage NDF content was 2.3% units greater for ND65 than ND40. However, this explanation seems less likely than the one discussed for ruminal starch digestibility, since total and forage NDF intakes for ND65 were 0.97 and 0.87 % of BW, respectively, which would not be considered fill limiting (Mertens, 1997). Coincident with the milk yield differences, yields of protein ($P < 0.01$) and lactose ($P = 0.01$) were reduced for ND65 compared to ND40. The resultant calculated yields of FCM, ECM and SCM were also reduced ($P < 0.01$) for ND65 compared to ND40. The MUN concentration was 12% greater ($P < 0.01$) for ND65 than ND40. This response may have been related to a reduced ruminal pH from greater starch digestibility, as suggested by milk fat depression, reducing the efficiency of rumen microbial protein synthesis (Russell et al., 1992). Greater BW ($P < 0.01$) for ND40 than ND65 reflects differences at the time of trial initiation and BWC was unaffected ($P = 0.29$) by treatment, averaging 0.50 and 0.32 kg/d for ND40 and ND65, respectively.

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