Northern NY Agricultural Development Program
2021 Project Report

Corn Silage Soluble Starch as Influenced by Kernel Processing Score and Kernel Type

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Background:

Corn silage is the primary forage that is fed on many dairy farms in northern New York. Corn is a high yielding crop and also provides high quality forage that is high in starch content. This starch can be readily used by high-producing dairy cows, but only if the starch is available for digestion in the cow. Research has repeatedly shown that the use of kernel processing equipment on corn harvesters can enhance the availability of starch to rumen microbes which translates into better starch utilization by the cow and higher milk production.

Kernel processors work by crushing the forage between rollers as it passes through the harvester and adjustments can be made to change the aggressiveness of the processing as needed. Inadequate processing leads to lower starch availability and can result in lost milk production potential from the forage. However, overaggressive processing may also have negative consequences. As aggressiveness is increased through processor adjustment, fuel consumption and processor wear increase and the adjustment may only provide marginal nutritional benefit with highly aggressive processing.

Recent corn silage processing research in New York by Cornell University suggests that corn silage processing scores (a laboratory analysis for kernel processing) may be subject to diminishing returns at high levels of kernel processing (Lawrence et al., 2020). The study also showed that, while starch digestibility was improved by kernel processing in fresh forage samples, starch content and starch digestibility were negatively affected in samples that were fermented for 135 days. This is cause for concern since the purpose of kernel processing is to improve the utilization of corn silage starch.

Optimally-processed corn silage is generally considered to have a kernel processing score of 70 or higher, with adequately processed corn having a score greater than 50. To achieve this goal, it has been recommended that the kernel processor roller gap be set between 1 mm and 3 mm (Shinners et al., 2000). The objective of this Northern New York Agricultural Development Program (NNYADP)-commissioned study was to further characterize the impact of kernel processing on corn silage starch by testing two different kernel processor settings on normal (vitreous) and floury type corn hybrids.

Methods:

In the fall of 2021, two corn hybrids were harvested with a self-propelled forage harvester equipped with a kernel processor (Scherer Inc., Tea, SD). One had a vitreous kernel type (VI, B93B09, Brevant Seeds, Johnston, IA), the other a floury kernel type (FL, B93U02, Brevant Seeds, Johnston, IA). Aside from the kernel type, the hybrids had similar characteristics and were grown in adjacent fields. The kernels were in the ½- to ¾-milk line stage of maturity at harvest. During harvest, the kernel processor roller gap was adjusted to create two different processing levels: heavily processed (HP, 1.5 mm gap) and moderately processed (MP, 2.5 mm gap). Bucket mini-silos (2 gal., Uline, Pleasant Prairie, WI) were filled with harvested material from each hybrid/processing level combination and opened at 0, 45-, 90-, and 135-day fermentation time points. The study had four replications.

Mini-silos were weighed at the time of ensiling and again when removed from their temperature-controlled storage location. Upon opening, mini-silo contents were mixed and subsampled. One sample was oven dried (55°C, 48 h) to determine dry matter (DM) content. Fresh and ensiled weights and DMs were used to calculate ensiling losses for each mini-silo. Additional subsamples from each mini-silo were frozen and sent to Cumberland Valley Analytical Services, Inc. (Waynesboro, PA) for 1) wet chemistry determination of starch (Hall, 2009), 2) sugar as water soluble carbohydrates (Dubois et al., 1956), 3) 7-hour starch digestibility, 4) corn silage processing score (dry starch passing through a 4.75 mm screen), and 5) soluble starch (starch washed through a 50-micron screen). Fermentation analysis was also conducted (Cumberland Valley Analytical Services, Inc.) and included 1) lactic acid, 2) acetic acid, 3) propionic acid, 4) butyric acid, and 5) ammonia. A 25 g wet subsample was taken and diluted with 200 mL of deionized water. After soaking overnight, the sample was blended for two minutes and filtered through coarse filter paper (20–25 μm particle retention) to collect extract. A 25 mL extract was mixed with 75 mL of deionized water and analyzed using a Labconco™ Rapidstill II model 65200 analyzer (Labconco, Kansas City, MO) to determine ammonia (titrated with 0.1 N HCl). A 1:1 ratio of extract to deionized water was evaluated using a YSI 2700 Select Biochemistry Analyzer (YSI, Inc. Yellow Springs, OH) to determine L-lactic acid. The result was multiplied by four to obtain total lactic acid. A 3 mL sample of extract was filtered (0.2-micron membrane) and a 1.0 μL subsample was inserted into a PerkinElmer AutoSystem gas chromatograph (PerkinElmer, CT) to test for acetic, propionic, and butyric acid. Minimal propionic and butyric acid were detected in this study.

Results were analyzed using SAS analytical software (JMP Pro 15.0.0, SAS Institute, Cary, NC). The fit model platform was used to conduct a standard least squares analysis of variance (ANOVA) with the fixed effects of hybrid, degree of processing, fermentation time, hybrid*degree of processing, hybrid*fermentation time, degree of processing*fermentation time, and hybrid*degree of processing*fermentation time (Table 1). Replication was specified as a random effect in the model. The Tukey HSD (honest significance difference) test was used for means separation. *P*-values were considered to indicate a significant effect when < 0.05.

Results and Discussion:

In this experiment, adjusting the kernel processor roller gap by one millimeter had little impact on the processed corn silage. A significant degree of processing effect was only observed in the ammonia and soluble starch fractions (Table 1).

Table 1. Fixed effect test results (P – values[1]) from linear model output.

	Hybrid	Degree of Processing (DP)	Fermentation Time (FT)	Hybrid *DP	Hybrid *FT	DP *FT	Hybrid *DP*FT
Dry Matter (DM, % AF)	0.11	0.11	0.40	0.21	0.86	0.97	0.97
Starch Content (% DM)	0.00	0.48	0.00	0.54	0.17	0.64	0.48
Starch Dig. (7 h, % Starch)	0.00	0.29	0.00	0.95	0.03	0.58	0.04
Starch Dig. Rate (kd)	0.00	0.44	0.00	0.84	0.03	0.73	0.06
Processing Score (CSPS)	0.00	0.11	0.90	0.24	0.39	0.68	0.83
Soluble Starch (% Starch)	0.00	0.01	0.00	0.08	0.16	0.00	0.20
Sugar (WSC, % DM)	0.00	0.29	0.00	0.68	0.00	0.33	0.69
Ensiling Loss (% DM)	0.00	0.83	0.95	0.12	1.00	0.70	0.93
Silage pH (acidity)	0.00	0.23	0.00	0.23	0.00	0.97	0.59
Lactic Acid (% DM)	0.21	0.64	0.00	0.05	0.94	0.61	0.68
Acetic Acid (% DM)	0.12	0.17	0.00	0.40	0.45	0.82	0.41
Ammonia (% DM)	0.00	0.04	0.00	0.15	0.01	0.53	0.82
Total VFA (% DM)	0.07	0.31	0.00	0.13	0.75	0.79	0.73

[1] *P*-values generated from ANOVA linear model were considered significant at $P < 0.05$.

In these cases, tightening the roller gap increased the soluble starch fraction but decreased ammonia (Table 2). However, the improvement in soluble starch was primarily the result of differences in unfermented (0 d) samples. Thus, increasing processing agressiveness should not be assumed to increase starch solubility after extended fermentation has taken place. On the other hand, we found that corn with a floury kernel texture was consistently higher in soluble starch at most fermentation time points.

The soluble starch analysis was developed by Cumberland Valley Analytical Services, Inc. with the purpose of quantifying the starch that readily moves into suspension in an aqueous environment (such as the rumen). The analysis is similar to the standard kernel processing analysis for particle size, but uses a wet sieving method and a much smaller screen. While the starch washing through the screen is not “soluble” in the strictest sense, it is still expected to be readily utilized in the rumen. Specific guidelines and animal performance benchmarks for this analysis have not yet been determined.

Table 2. Silage quality results[1] for heavily- and moderately-processed corn silage and floury or vitrious kernel types across fermentation time points.

	Hybrid		HP (heavy processing)				MP (moderate processing)				
	FL	VI	0 d	45 d	90 d	135 d	0 d	45 d	90 d	135 d	SE
Dry Matter (DM, % AF)	37.2	36.3	37.1	35.9	36.0	36.4	38.1	36.9	37.1	36.8	0.9
Starch Content (% DM)	35.3	38.7	36.5	39.2	35.8	35.5	36.1	39.3	36.1	37.3	1.1
Starch Dig. (7 h, % Starch)	66.2	60.0	49.4	62.0	69.3	69.5	51.7	64.8	69.3	68.8	1.4
Starch Dig. Rate (kd)	17.0	14.1	10.3	15.0	18.1	18.1	11.0	16.0	18.2	17.7	0.6
Processing Score (CSPS)	56.7	69.9	63.9	64.5	64.8	64.0	62.3	61.7	61.1	64.2	1.9
Soluble Starch (% Starch)	72	65	51^{d}	72^{c}	77^{abc}	81^{ab}	40^{e}	71^{c}	75^{bc}	83^{a}	2
Sugar (WSC, % DM)	4.55	3.50	9.16	2.45	2.31	2.52	8.49	2.45	2.16	2.65	0.23
Ensiling Loss (% DM)	5.07	1.63	-	3.70	3.51	2.54	-	3.41	3.08	3.87	1.10
Silage pH (acidity)	4.27	4.35	5.63	3.86	3.84	3.86	5.65	3.87	3.89	3.89	0.04
Lactic Acid (% DM)	3.98	4.14	0.04	5.04	5.55	5.49	0.02	5.35	5.40	5.58	0.18
Acetic Acid (% DM)	1.15	1.24	0.17	1.21	1.45	1.80	0.22	1.21	1.58	1.92	0.08
Ammonia (% DM)	0.69	0.55	0.14	0.66	0.76	0.82	0.14	0.74	0.84	0.86	0.03
Total VFA (% DM)	5.13	5.37	0.20	6.25	7.00	7.28	0.24	6.56	6.98	7.49	0.20

[1] Least squares means from linear model output. Connecting letters show hybrid differences by time point in the presence of a significant *P*-value (< 0.05).

Our aim in adjusting the kernel processor in this study was to create two different processing scores for comparison. The actual processing scores that we observed were not statistically different. Processing scores differed numerically when the vitreous hybrid was chopped, but not when the floury hybrid was chopped. This probably resulted from the softness of floury corn kernels as compared to vitreous kernel types. This softness may have allowed the kernels to flatten without breaking apart in the processor. This would also explain why the vitreous hybrid processed to a consistently higher processing score than the floury hybrid in this study. Although the floury kernels did not process to an optimal level (70 or greater) regardless of processor adjustment, their higher starch digestion rate and improved 7 h starch digestibility, particularly during the initial stages of fermentation, may allow larger particles of starch to be fully degraded in the rumen. The rate and extent of starch digestion was not affected by processing aggressiveness overall, but the rate and extent of degradation in the aggressively-processed vitreous corn tended to lag behind the moderately-processed vitreous corn at the 45 d timepoint. Previous research experiments and on-farm observations have found that starch digestibility improves with fermentation time. The present study supports that conclusion. However, our maximum in-vitro starch digestion rate appears to have been achieved by the 90 d timepoint with no improvements resulting from further fermentation. It is important to note that, while in-vitro starch digestion plateaued by 90 days, actual starch digestion in the rumen may still benefit from additional fermentation time since the greatest soluble starch levels were not achieved until the 135 d timepoint. Figure 1 shows how the starch content, digestion rate, soluble starch fraction, processing score, and dry matter loss in vitreous and floury corn types changes across fermentation time points.

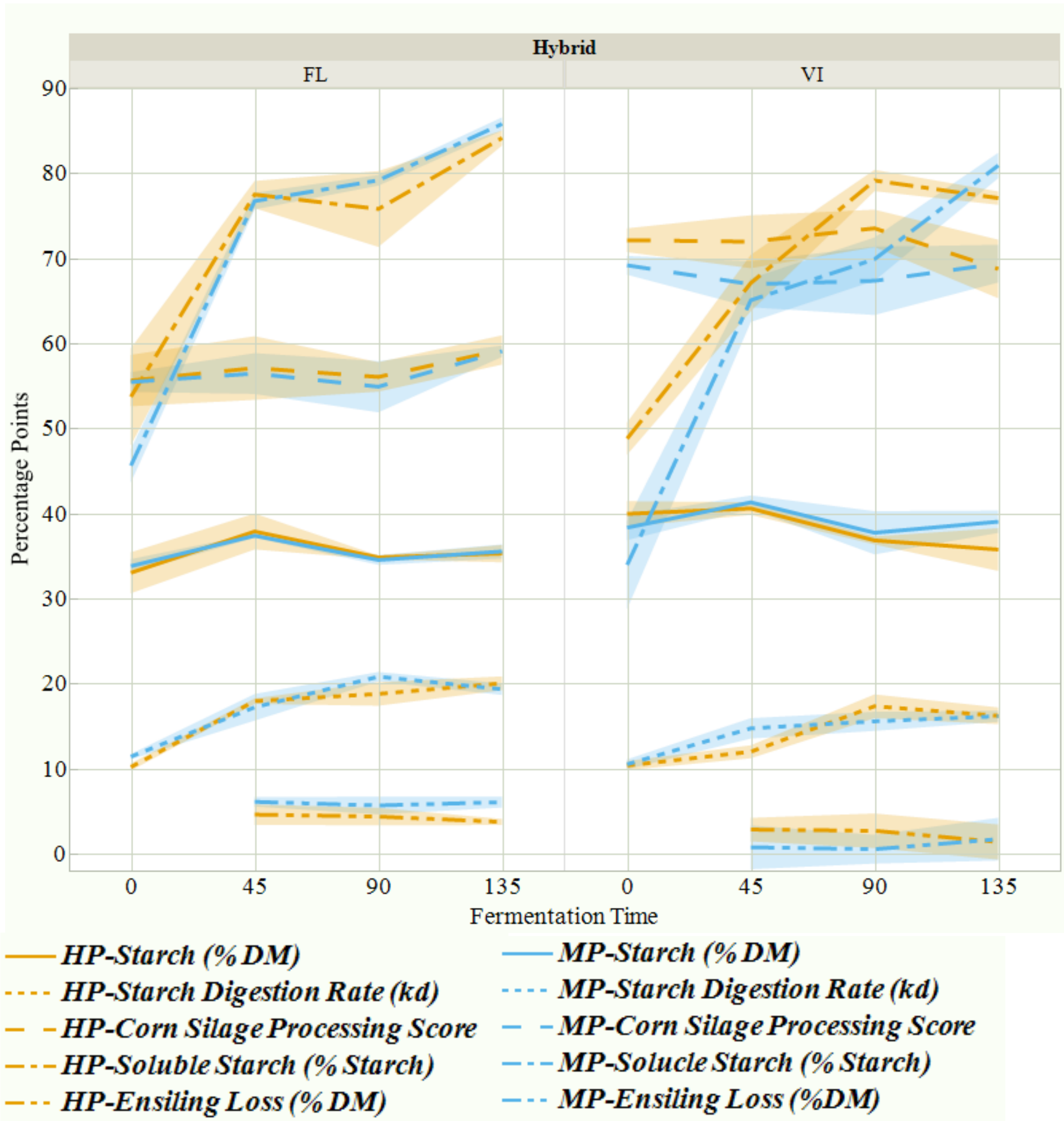

Figure 1. **Heavily- and moderately-processed corn silage starch, starch digestion rate, corn silage processing score, soluble starch, and ensiling loss across fermentation time points. Lines represent treatment average; shaded error band represents the associated standard error.**

The degree of processing did not significantly affect the content of starch or sugar in this experiment. However, the heavily-processed vitreous corn showed a consistent numerical decline in starch content as compared to the moderately-processed vitreous corn during fermentation. If this decline is not the result of random chance, it would indicate that excessive processing might negatively impact starch, as shown in previous studies (Lawrence et al., 2020). The hypothesis that this change in starch content was due to degradation into other pools (soluble starch, sugar) was not observed in this study and the fate of lost starch remains unclear. Starch content in general was highest at the 45 d timepoint of fermentation. This could be explained by the loss of soluble sugars in the initial phases of fermentation resulting in an apparent concentration of starch. The floury hybrid had lower starch overall but had a higher sugar content than the vitreous hybrid. It also had a slightly lower pH than the vitreous corn but a higher ammonia content. Dry matter losses were low for all silages in this experiment, but significantly greater DM losses were observed in silages made from the floury hybrid.

Conclusions:

- Increasing kernel processing aggressiveness by decreasing the roller gap by one millimeter did not improve starch digestibility or rumen accessibility as measured by kernel processing score and soluble starch in fermented samples. While striving for kernel processing scores in the optimum range (kernel processing score of 70 or above) is still recommended, overaggressive kernel processing will increase harvest costs while providing little or no benefit to well fermented corn silage.

- Using a floury corn hybrid increased starch digestibility and the soluble starch pool of corn silage despite resulting in lower processing scores. A different guideline may be needed for kernel processing in floury corn hybrids as current kernel processing score guidelines may not be the best indicator of starch availability for these hybrids.

- Fermenting corn silage for at least 90 days is essential in maximizing both the digestible and soluble starch pools in corn silage regardless of processing aggressiveness. Farms seeking to feed corn silage soon after ensiling would benefit from floury corn genetics, especially if the reduced starch content can be overcome by future corn breeding.

Education and Outreach:

Outcomes of this study will be shared with farmers in the 6 counties in the northern New York region by summarizing data and reporting results in the Miner Institute Farm Report as well as other publications such as those offered by the Cornell Pro-Dairy Program. Additionally, results will be presented at relevant events such as the Miner Institute Crop Congress in 2023.

Next Steps:

Further kernel processing research is needed to continue honing kernel processing guidelines to maximize starch utilization to help farms minimize feed costs and forage losses. The value of soluble starch analysis as an indicator of animal performance is still unproven; more data might allow guidelines to be developed for this fraction in addition to kernel processing score.

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For More Information:

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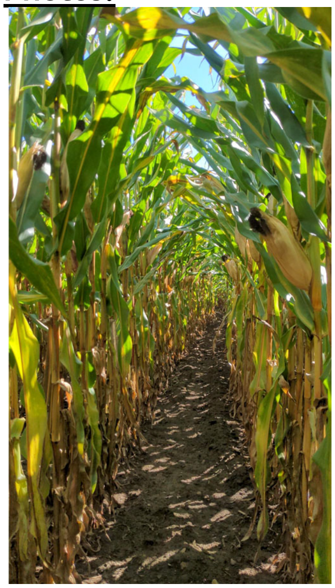
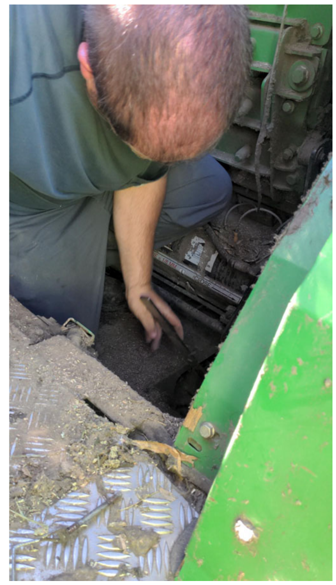
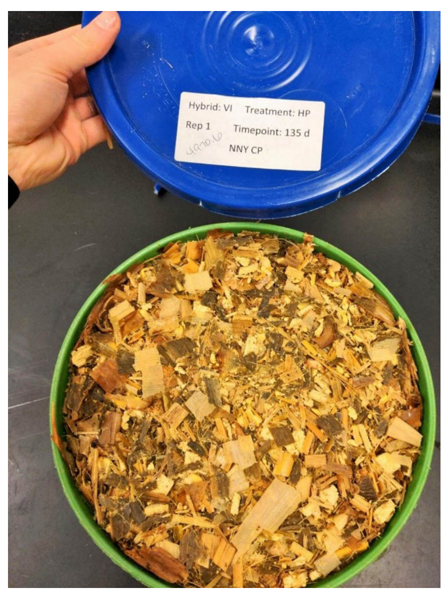
Photos:





Left: Corn prior to harvest, Corn Silage Soluble Starch project, NNYADP, 2021. Photo credit: Allen Wilder.
Center: Corn cob cross sections revealing the milk line which is an indicator of kernel starch fill and maturity. Photo credit: Allen Wilder.
Right: In-field kernel processor adjustment to create a 1 mm difference in the roller gap of the processor, Corn Silage Soluble Starch project, NNYADP, 2021. Photo credit: Allen Wilder.



Left: Visual differences between normal (vitreous) kernel type: 2 ears on the right and floury kernel type: 2 ears on the left from the hybrids used in the Corn Silage Soluble Starch project, NNYADP, 2021, at physiological maturity. Photo credit: Allen Wilder.
Right: Bucket mini-silo at opening, Corn Silage Soluble Starch project, NNYADP, 2021. Photo credit: Allen Wilder.

Left: Moderately-processed corn silage samples, Corn Silage Soluble Starch project, NNYADP, 2021. Photo credit: Allen Wilder.
Right: Heavily-processed corn silage samples, Corn Silage Soluble Starch project, NNYADP, 2021. Photo credit: Allen Wilder.