Hybrid-Dependent Effect of Lactic Acid on Corn Starch Yields

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ABSTRACT

The effect of lactic acid on starch yields of different corn hybrids was determined by wet-milling 18 commercial corn hybrids at three levels of lactic acid. All 18 hybrid samples tested had higher starch yields when lactic acid was added to the steep solution, although the magnitude of the increased starch yields varied between 2.9 and 12.0%. The optimal lactic acid concentration for maximum starch recovery was found to be between 0.55 and 1.67% lactic acid, by wet-milling nine of the same 18 corn hybrids with seven levels of added lactic acid. Between 0.83 and 1.67% lactic acid, the starch yields of eight of the nine hybrids were constant (within ±0.5%). Results showed that the average starch yield across all hybrids decreased with a lactic acid concentration <0.55% and a lactic acid concentration >1.67%.

Lactic acid is produced to a level of 0.6 to 2.0% during conventional counter-current steeping (Watson et al 1955). Some of lactic acid's beneficial effects observed in corn milling are: increased starch yields (Watson et al 1951, Roushdi et al 1981a, Eckhoff and Tso 1991), increased gluten filtration rate (Watson 1984), decreased evaporator fouling (Watson 1984), increased kernel softening (Cox et al 1944, Roushdi et al 1981a, Earp et al 1985, Shandera et al 1995), increased rate of water uptake (Cox et al 1944, Roushdi et al 1981a, Ruan et al 1992), and increased rate of SO_2 absorption (Shandera et al 1995).

Other researchers noticed no beneficial effect of lactic acid on starch yields. Cox et al (1944) reported that starch release was mainly due to SO_2 and that lactic acid had no effect. Watson and Sanders (1961) reported that more than just adding lactic acid is needed to increase starch yields. Roushdi et al (1979a) reported that a high level of lactic acid reduces the starch yield and increases protein in starch. Shandera et al (1995) studied interactions between lactic acid, SO_2 and temperature in steep solutions and reported that excessive use of lactic acid decreases the overall millability of the steeped corn kernel. Roushdi et al (1979b and 1981b) reported that a high level of SO_2 in steepwater inhibits lactic acid formation and gives the highest yield of starch. While it is possible that the varied results reported on the effect of lactic acid on starch yield are due to different steeping and milling parameters (steep time, SO_2 level, steep temperature, or different mill settings) used in the different studies, preliminary tests in our laboratory indicate that the effect is related to differences in the corn hybrids.

The level of lactic acid needed to induce a change in starch yield has also not been determined. Watson et al (1951) and Yahl et al (1971) used 1.6% lactic acid in their laboratory procedure to recover starch from corn and sorghum. Watson and Yahl (1967) used two-phase steeping that used 1.5% lactic acid for 36 hr and then used 0.5% lactic acid for 16 hr. Rousdhi et al (1981a) first used a 0.55% lactic acid concentration to study its effect on corn wet-milling. Subsequently, some researchers have continued to use 0.55% lactic acid in their procedures (Ling and Jackson 1991, Eckhoff et al 1993, Singh and Eckhoff 1995, Eckhoff et al 1996), while others have used 0.47% lactic acid in their laboratory procedures (Wehling et al 1993). However, no reason for using these lactic acid concentrations has been reported.

The objectives of this study were: 1) to determine whether the effect of lactic acid on starch yields is hybrid-dependent, and 2) to determine the optimum level of lactic acid in batch steeping for maximum starch recovery.

MATERIALS AND METHODS

Three yellow dent corn varieties (FR1064×LH59, FR1064×FR450, FR618×LH123) grown during the 1995 crop season at the Agricultural Engineering farm, University of Illinois at Urbana-Champaign, were field-dried to 14% mc and combine harvested. Six corn hybrids (S55, S68, S713, S717, S59_94, S59_95) were obtained from a commercial seed corn company, and nine hybrids (FR1041×LH185, FR1064×FR400, FR1041×FR448, FR1064×FR616, FR1041×LH617, FR1141×FR621, FR701× FR697, FR3037×FR697, FR4326×FR701) were obtained from Illinois Foundation Seeds, Champaign, IL. Hybrids S59_94 and S59_95 were the same hybrid from the 1994 and 1995 crop year, respectively. All other hybrids were from the 1995 crop. All hybrids were hand-cleaned to remove the broken corn and foreign material, packaged in plastic bags, and stored at 4°C until wet-milling. The whole kernel moisture content of the samples was measured using the 103°C forced-air oven method (AACC 1995).

Wet-milling of samples was done using the 100-g laboratory wet-milling procedure of Eckhoff et al (1996). Two full-factorial experiments were performed with duplicate measurements in order to assess the effect of hybrid and lactic acid level on the wet-milling fractions. The first experiment determined whether the effect of lactic acid on starch yield was hybrid-dependent. Samples (100 g each) of the 18 hybrids were steeped in 180 mL of filtered water (to remove organic matter and chlorine) containing 2,000 ppm of SO_2 and either 0, 0.55, or 2.22% lactic acid.

In the second experiment, the optimum lactic acid level for maximum starch recovery was determined using nine hybrids (FR1064×LH59, FR1064×FR450, FR618×LH123, S55, S68, S713, S717, S59_94, S59_95), steeped with 2,000 ppm of SO_2 and either 0.28, 0.83, 1.11, or 1.67% lactic acid. Lactic acid percentages were based on the volume of steep solution.

Analysis of hybrid oil, fiber, starch, and protein content (Table I) was performed using near-infrared transmittance (GrainSpec, Foos Electric, Inc.) by the Identity Preserved Grain Laboratory, Champaign, IL. Transmittance readings of 250 g were taken over a wavelength range of 800–1,100 nm.

Analysis of variance (ANOVA) and Duncan's multiple range test were used (SAS 1985) for data analysis. The level selected to show statistical significance was 5% ($P < 0.05$).

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TABLE I
Analysis of 18 Corn Hybrids Using Near-Infrared Transmittance[a]

Hybrid	Oil	Fiber	Starch	Protein
FR1041×LH185	3.18	2.21	72.86	11.54
FR1064×FR400	4.21	2.11	73.21	10.69
FR1041×FR448	4.21	2.40	71.08	10.26
FR1064×FR616	2.96	2.26	74.57	9.20
FR1041×LH617	3.57	2.36	73.01	10.47
FR1141×FR621	3.58	2.25	71.58	10.57
FR701×FR697	3.31	2.53	71.48	12.62
FR3037×FR697	2.92	2.20	70.22	11.80
FR4326×FR701	3.37	2.18	70.82	12.50
FR1064×LH59	3.23	2.33	72.47	10.60
FR1064×FR450	4.99	2.40	70.39	9.92
FR618×LH123	4.43	2.34	70.18	10.39
S55	3.66	2.48	73.46	7.51
S68	4.23	2.29	70.20	8.09
S713	2.85	2.30	73.46	9.50
S717	3.96	2.63	71.89	8.47
S59_94	3.77	2.14	72.30	10.75
S59_95	3.24	2.32	73.87	8.78

[a] All yields are expressed as a percentage of dry solids and are the mean of two observations.

TABLE II
Analysis of Variance for Starch Yields of 18 Corn Hybrids at Lactic Acid Concentrations of 0, 0.55, and 2.22%

Source	df	Sum of Squares	Mean Squares	*F* Value
Block	1	0.009	0.009	0.04
Hybrid	17	1,772.852	104.285	470.64***[a]
Lactic	2	1,046.775	523.387	2362.05***
Hyb×Lactic	34	161.442	4.748	21.43***
Error	53	11.744	0.221	. . .

[a] *** = Significant at $P < 0.05$.

RESULTS AND DISCUSSION

Effect of Hybrid and Lactic Acid Level on Starch Yield

The main effects of hybrid and lactic acid concentration were statistically significant ($P < 0.05$) (Table II). The interaction term between the hybrid and lactic acid was also significant, suggesting that lactic acid affected the starch yields of different hybrids differently. However, a closer look at the ANOVA (Table II) showed that the sum of squares associated with the interaction term accounted for very little (5.4%) of the total variation. The effect of the hybrid was more pronounced than the lactic acid concentration effect. Similar results were reported by Shandera et al (1995), who showed that the hybrid effect on the wet-milling yields was more pronounced than the effects of the steep solution.

Total recoveries of initial solids >100% (Table III) are due to the addition of lactic acid. The more lactic acid that is added, the higher the total dry solids recovered because the percentage is based on the dry solids of corn. A lactic acid concentration of 2.22% will contribute an increase of ≈4.0 g of dry solids per sample (for a 180-mL steep solution). Most of this lactic acid remains in the steepwater and gluten fraction. In the laboratory wet-milling procedure used, gluten filtrate solids are not separated from the gluten meal fraction, so that all of the washwater ends up in the gluten fraction.

Increasing lactic acid from 0 to 0.55% significantly increased starch yields by ≈3–12%, depending upon the hybrid (Table III). This variation in magnitude of the starch yields of hybrids was due to the significant interaction between the hybrid and lactic acid concentration effects.

The increase in starch yield due to the addition of lactic acid came from the fiber fraction of the hybrids. The fiber fraction dropped from 3.1 to 13.1%, depending upon the hybrid, with the addition of 0.55% lactic acid. This increase in starch yield with decrease in the fiber fraction is in agreement with other studies (Roushdi et al 1981a, Eckhoff and Tso 1991, Du et al 1996).

Increasing lactic acid from 0.55 to 2.22% decreased the starch yields for 5 of the 18 hybrids by levels ranging from 1.08 to 2.35% (Table III). One of the hybrids (FR4326×FR701) increased in starch yield by 1.6%, and 12 of the 18 hybrids showed no statistically significant effect with an increase in lactic acid concentration from 0.55 to 2.22%. Also, the effect of lactic acid (from 0 to 0.55%) on increasing starch yields was more pronounced (6–12%) on the Foundation Seed hybrids compared to the commercial seed company hybrids (3–8.5%) or the hybrids grown at the University of Illinois (4–7.5%). The reason for this difference in starch yields is again due to different effects of lactic acid on different hybrids.

Although the starch content of all 18 hybrids were in the same range 70–74% (Table I), the starch recoveries of Foundation Seed hybrids with no lactic acid were low (47–60%) compared to the starch recoveries of commercial seed company hybrids (57.5–64%) and the hybrids grown at the University of Illinois (56–62%). No reason for this difference was determined. However, planting location, agronomic practices (planting date, fertilizer rate, etc.) or genetics may explain these differences.

Optimization of Lactic Acid Level:

To determine the optimal concentration of lactic acid for maximum starch recovery, nine corn hybrids were tested at 0.28, 0.83, 1.11, and 1.67% lactic acid concentrations. Starch yields for 4 of the 9 hybrids significantly increased by 0.77 to 1.29% with an increase in lactic acid concentration from 0.28 to 0.83% (Table IV). Starch yields of all of the nine hybrids were statistically similar at 0.83, 1.11, and 1.67% lactic acid concentrations, except for hybrid FR618×LH123, which showed a significantly higher starch yield (by 0.82 and 1.43%) at 1.11% lactic acid concentration when compared to 0.83 and 1.67% lactic acid concentration, respectively.

If we average starch yields across all nine hybrids for 0, 0.55, and 2.22% lactic acid concentration (Fig. 1), we find that starch yields at 0.55% lactic acid concentration are statistically higher (by 5.32 and 1.07%) when compared to starch yields at 0 and 2.22% lactic acid concentration, respectively. When averaging starch yields across all nine hybrids for 0.28, 0.83, 1.11, and 1.67% lactic acid concentration (Fig. 2), we see that hybrids at 1.67% lactic acid concentration have a statistically higher starch yield (by 0.95 and 0.38%) when compared to starch yields at 0.28 and 0.83% lactic acid concentration, respectively. Starch yields at 1.67% lactic acid concentration were statistically similar to starch yields at 1.11% lactic acid concentration. Starch yields at 0.83% lactic acid were statistically higher (by 0.57%) when compared to

TABLE III
Wet-Milling Fraction Yields[a] of 18 Corn Hybrids at Lactic Acid Concentrations of 0, 0.55, and 2.22%

Hybrid	Lactic Acid (%)	Steepwater	Germ	Fiber	Starch	Gluten	Total Recovery
FR1041×LH185	0.0	2.58	6.98	22.36	54.77b[b]	10.58	97.26
	0.55	3.56	6.70	12.50	63.73a	12.17	98.67
	2.22	4.94	6.98	12.43	63.61a	13.66	101.62
FR1064×FR400	0.00	2.75	5.34	29.48	50.18c	8.94	97.30
	0.55	3.91	5.42	16.36	62.19a	9.65	98.24
	2.22	5.30	6.00	17.32	60.53b	12.02	101.17
FR1041×FR448	0.0	2.34	6.24	19.92	60.36b	8.86	97.72
	0.55	3.30	6.06	12.71	66.49a	10.63	99.19
	2.22	4.55	6.66	13.38	65.81a	11.36	101.76
FR1064×FR616	0.00	3.38	6.41	24.50	55.55b	7.42	97.26
	0.55	4.52	6.14	14.39	64.54a	8.48	98.08
	2.22	6.09	6.55	15.27	63.95a	9.24	101.10
FR1041×LH617	0.0	2.15	5.88	20.09	60.17b	9.44	97.73
	0.55	3.17	5.66	12.41	66.20a	11.51	98.94
	2.22	4.21	5.87	12.63	66.23a	12.74	101.68
FR1141×FR621	0.00	3.02	3.21	29.59	52.87b	9.46	98.12
	0.55	4.30	3.66	17.62	61.75a	11.12	98.46
	2.22	5.56	4.29	18.50	60.77a	12.16	101.28
FR701×FR697	0.0	3.03	4.26	30.27	49.48b	10.18	97.23
	0.55	4.25	4.04	19.51	58.27a	12.76	98.84
	2.22	5.49	4.50	20.51	58.43a	12.49	101.42
FR3037×FR697	0.00	2.93	6.49	27.44	50.89b	9.61	97.36
	0.55	4.09	5.51	18.90	57.79a	12.24	98.54
	2.22	5.27	5.93	19.74	58.07a	12.13	101.14
FR4326×FR701	0.0	2.67	5.49	32.90	46.88c	8.95	96.89
	0.55	4.13	5.46	20.97	55.61b	12.05	98.21
	2.22	5.52	5.76	21.06	57.21a	11.60	101.16
FR1064×LH59	0.00	2.62	5.49	18.54	61.94c	9.30	97.90
	0.55	3.51	6.10	14.50	65.92a	9.55	99.60
	2.22	4.90	6.54	14.50	64.61b	11.56	102.11
FR1064×FR450	0.00	2.40	5.71	22.90	56.37c	10.47	97.84
	0.55	3.45	5.79	14.52	63.85a	11.43	99.04
	2.22	4.76	6.10	15.72	62.77b	12.57	101.93
FR618×LH123	0.0	2.47	6.40	23.94	56.09b	8.77	97.66
	0.55	3.48	6.15	17.10	62.32a	9.93	98.97
	2.22	4.73	6.28	17.99	62.21a	10.66	101.88
S55	0.0	2.43	3.34	18.42	64.72b	8.72	97.63
	0.55	3.40	3.47	14.17	69.53a	8.65	99.22
	2.22	4.59	4.08	14.26	68.79a	10.23	101.95
S68	0.0	2.76	4.11	15.78	66.17b	8.77	97.59
	0.55	3.76	4.53	12.65	69.06a	8.96	98.95
	2.22	4.95	5.30	13.28	68.18a	10.01	101.72
S713	0.0	3.06	4.01	19.92	61.35c	8.82	97.16
	0.55	4.24	3.82	14.74	66.36a	9.41	98.57
	2.22	5.60	4.57	16.18	64.38b	10.58	101.31
S717	0.0	2.94	5.25	17.86	61.69b	9.64	97.38
	0.55	3.81	4.92	14.44	66.57a	10.07	98.81
	2.22	5.08	4.80	14.90	65.38a	11.40	101.56
S59_94	0.0	3.10	4.01	24.13	57.60c	9.08	97.91
	0.55	4.25	4.31	15.04	66.02a	9.19	98.82
	2.22	5.73	5.18	15.59	63.67b	11.17	101.34
S59_95	0.0	2.77	2.94	19.33	62.76b	9.95	97.75
	0.55	3.79	2.99	15.13	66.96a	10.18	99.06
	2.22	5.10	3.44	14.79	66.45a	11.99	101.76

[a] All yields are expressed as a percentage of dry solids and are the mean of two observations.
[b] Average starch yields followed by the same letter within a hybrid are not significantly different at a 95% confidence level.

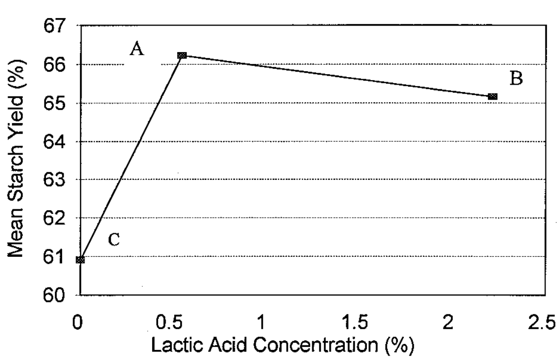

Fig. 1. Average starch yield of nine corn hybrids versus lactic acid concentration of 0.00, 0.55, and 2.22%. Means with the same letter are not significantly different at a 95% confidence level.

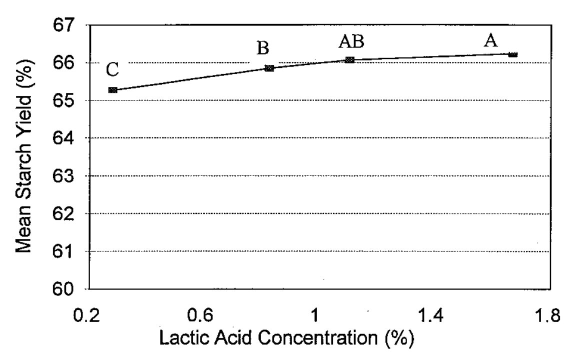

Fig. 2. Average starch yield of nine corn hybrids versus lactic acid concentration of 0.28, 0.83, 1.11, and 1.67%. Means with the same letter are not significantly different at a 95% confidence level.

TABLE IV
Wet-Milling Fraction Yields[a] of Nine Corn Hybrids at Lactic Acid Concentrations of 0.28, 0.83, 1.11, and 1.67%

Hybrid	Lactic Acid (%)	Steepwater	Germ	Fiber	Starch	Gluten	Total Recovery
FR1064×LH59	0.28	3.19	6.52	14.38	64.93a[b]	10.92	99.93
	0.83	3.88	6.33	13.38	65.01a	11.46	100.06
	1.11	4.15	6.61	13.53	65.48a	10.87	100.65
	1.67	4.49	6.50	13.84	65.63a	11.32	101.78
FR1064×FR450	0.28	3.14	6.16	15.83	61.73b	11.66	98.52
	0.83	3.86	5.80	14.65	63.02a	12.53	99.86
	1.11	4.07	5.67	15.02	63.47a	12.13	100.36
	1.67	4.37	5.72	14.84	63.67a	12.96	101.56
FR618×LH123	0.28	3.17	6.47	17.89	60.86c	9.87	98.26
	0.83	3.86	5.99	17.36	61.67b	10.76	99.65
	1.11	4.12	6.24	17.58	62.49a	9.70	100.13
	1.67	4.40	6.29	18.26	61.06bc	11.16	101.18
S55	0.28	3.22	3.89	13.81	68.89a	8.62	98.44
	0.83	3.74	3.82	14.34	68.84a	9.42	100.14
	1.11	3.92	3.63	14.53	69.07a	9.23	100.38
	1.67	4.27	3.56	14.71	69.54a	9.52	101.60
S68	0.28	3.49	5.16	12.30	69.46a	8.54	98.95
	0.83	4.12	4.75	12.60	69.39a	9.44	100.31
	1.11	4.28	4.70	12.71	69.51a	9.56	100.77
	1.67	4.73	4.80	12.90	69.70a	9.56	101.69
S713	0.28	3.90	4.11	15.39	65.60b	9.53	98.52
	0.83	4.68	3.62	15.27	65.84ab	10.42	99.82
	1.11	4.85	3.70	15.67	65.73ab	10.33	100.28
	1.67	5.22	3.76	14.89	66.60a	10.76	101.22
S717	0.28	3.58	5.32	14.59	64.89b	10.17	98.54
	0.83	4.24	4.86	14.52	65.59ab	10.94	100.14
	1.11	4.42	5.27	14.83	65.87ab	10.28	100.67
	1.67	4.88	4.79	14.52	66.21a	11.18	101.59
S59_94	0.28	3.94	4.55	15.91	64.59b	9.62	98.61
	0.83	4.71	4.17	15.17	65.36a	10.77	100.18
	1.11	4.85	4.23	15.46	65.19ab	10.57	100.30
	1.67	5.18	4.49	15.37	65.81a	10.41	101.26
S59_95	0.28	3.53	3.45	15.07	66.53b	10.29	98.87
	0.83	4.03	3.19	14.76	67.41a	10.61	100.00
	1.11	4.29	2.99	14.88	67.78a	10.60	100.53
	1.67	4.67	3.42	14.25	67.87a	10.64	100.84

[a] All yields are expressed as a percentage of dry solids and are the mean of two observations.
[b] Average starch yields followed by the same letter within a hybrid are not significantly different at a 95% confidence level.

starch yields at 0.28% lactic acid concentration (Fig. 2). Between 0.83 and 1.67% lactic acid concentration starch yields of 8 of the 9 hybrids varied within 1% (Table IV).

If we look at Figs. 1 and 2, we find that the average starch yield at 2.22% lactic acid concentration is lower than the average starch yield at 1.67% lactic acid concentration. Also, starch yields at 0 and 0.28% lactic acid concentration are lower than at 0.55, 0.83, 1.11, and 1.67% lactic acid levels. Therefore, the optimal range of lactic acid concentration for maximum starch recovery would be between 0.55 to 1.67% lactic acid concentration. Beyond 1.67% lactic acid concentration the starch yields will decrease.

CONCLUSIONS

Lactic acid and corn hybrid have statistically significant effects on starch yield. The effect of lactic acid on starch yield is significantly hybrid-dependent. Starch yield of all hybrids can be improved by adding 0.55–1.67% lactic acid to the batch steep solution. Lactic acid levels >1.67% will reduce the starch yield. These test results indicate that a tighter control over the steeping process may be required to maintain lactic acid levels in the optimal range (i.e., between 0.55 and 1.67%). Short steep times or new technologies that reduce the steep time, such as gaseous SO_2 processes (Eckhoff and Okos 1990, McKinney 1996) or the intermittent milling and dynamic steeping process (Lopes-Filho 1995), might require the addition of externally produced lactic acid to the steeping system. Therefore, when considering the cost of adding lactic acid as well as maximizing starch yield, a lactic acid level of 0.55% would appear to be the most economical. However, if relying on natural fermentation, lactic acid levels up to 1.67% will not be detrimental to starch yields. To determine more accurately the most economical level of lactic acid, a more detailed and comprehensive study will be required. Verification of these results in a counter-current steeping system is needed.

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