

Wet-Milling Characteristics of Selected Yellow Dent Corn Hybrids as Influenced by Storage Conditions

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ABSTRACT

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Three yellow dent corn hybrids (FR1064×LH59, FR600×FR1087, and FR618×LH123HT) from the 1994 crop, one hybrid (FR1064×LH59) from the 1995 crop, and two hybrids (FR1064×LH59 and FR618×LH123HT) from the 1996 crop were used to study the effect of storage time and storage temperature on starch yields. Samples of all of the corn hybrids were stored under one of two conditions: in a 4°C cold room or under a shed exposed to ambient conditions. The hybrids from the 1994, 1995,

and 1996 crops were stored for up to 24, 12, and 3 months, respectively. No significant differences were found between starch yields of the hybrids with respect to storage time. However, there was a significant difference in starch yields of two of the three corn hybrids (from the 1994 crop) stored in the 4°C cold room were higher when compared to the starch yields of the same hybrids stored at ambient conditions.

After harvesting and drying, corn is generally stored for two to 12 months (sometimes longer) in concrete or metal bins before it is delivered for processing or shipment. The harvesting and drying of corn are done in a relatively short time, and storage is required to provide a continuous supply to processors throughout the year (Leath and Hill 1987). The typical storage time of corn (after the harvest) used in wet-milling ranges from two to three days (if procured right from the field) to up to one year (if purchased through marketing channels). During periods when corn had been in surplus (1973–1982, USDA 1997) and under Commodity Credit Corporation (CCC) loan programs during the early 1960's, corn was stored for extended periods of two to five years (Leath and Hill 1987). During storage, corn is exposed to variable conditions of humidity and temperature, due to either natural convective ventilation or forced ventilation.

Wet-millers have communicated two phenomena related to corn storage. The first is that freshly harvested corn is generally more difficult to process than two- to three-month-old corn. They experience an increase in foaming during steeping and a need to readjust the mill to accommodate the new corn. A similar problem with freshly harvested wheat has been reported (Posner and Deyoe 1986, Shelke et al 1992) and is commonly known as the “new crop phenomenon”. Corn wet-millers believe that starch yields from freshly harvested corn are lower than yields from corn stored for two to three months (*personal communication*). The second phenomenon expressed by wet-millers is that the corn milling quality decreases with storage time due to intrinsic structural, chemical, or biological changes in the corn kernel.

Roushdi et al (1979) reported a 2.5% decrease in starch yields of corn samples stored at room temperature for nine months. However, they did not report any quality control for their corn samples or for their wet-milling procedure. Lasseran (1973) studied the storage of wet corn and the associated loss in starch yield resulting from microbial damage. Other than these two studies, there is a lack of scientific data on the effect of storage on the wet-millability of corn. The objective of this study was to determine whether there is a change in starch yields during corn storage.

MATERIALS AND METHODS

Three sets of hybrids, representing the range of endosperm hardness, were grown on the Agricultural Engineering farm at the

University of Illinois at Urbana-Champaign during the 1994, 1995, and 1996 crop seasons. Three yellow dent corn hybrids: FR1064×LH59, FR600×FR1087, and FR618×LH123HT of soft, medium, and hard endosperm, respectively, were grown during 1994, field-dried to ≈14% moisture content and combine-harvested. Corn hybrid FR1064×LH59 from the 1995 crop was also harvested at ≈14% moisture content. Corn hybrids FR1064×LH59 and FR618×LH123HT from the 1996 crop were harvested at 16–18% moisture content and ambient-dried using a forced-air thin layer dryer to ≈14% moisture content. Although the hybrids in 1996 were harvested at a 2–4% higher moisture content and ambient-dried to 14% moisture content rather than field-dried like the hybrids harvested in 1994 and 1995, based on the previous work done on wet-milling characteristics of artificially dried corn (MacMasters et al 1951, Watson and Yoshiro 1961, Vojnovich et al 1975, Weller et al 1988), we assume that harvesting corn at up to 16–18% moisture content and drying it with low flow rate ambient air does not significantly affect the corn wet-millability. Hybrids and growing seasons were selected so that one hybrid (FR1064×LH59) was tested for three growing seasons (1994, 1995, and 1996) and one hybrid (FR618×LH123HT) was tested for two growing seasons. Samples of all of the corn hybrids were stored at one of two conditions: in a cold room maintained at 4°C or under a shed, without walls, exposed to ambient environmental conditions (Fig. 1). The samples stored at 4°C were hand-cleaned to remove the broken corn and foreign material (BCFM) and packaged in plastic bags until they were wet-milled. The samples stored outside were stored loose in 5-gal plastic buckets with airtight lids until they were wet-milled. Samples were hand-cleaned for BCFM before milling. All of the samples were routinely monitored visually for microbial damage or insect activity.

Wet-milling was performed in duplicate using the procedure of Eckhoff et al (1996). Three duplicate full-factorial experiments were performed (one for each crop year) to determine the effect of storage condition and storage time on the wet-milling fractions of the hybrids. In the first experiment, the three hybrids from 1994 were wet-milled after 0, 1, 2, 3, 4, 6, 9, 12, 18, and 24 months of storage. In the second experiment, one hybrid from 1995 was wet-milled after 0, 1, 2, 3, 4, 6, 9, and 12 months of storage. And in the third experiment, two hybrids from 1996 were wet-milled after 0, 1, 2, and 3 months of storage.

Analysis of the hybrids' oil, fiber, starch, and protein content (Table I) was performed using near-infrared spectroscopy by the Identity Preserved Grain Laboratory of Illinois Crop Improvement Association, Champaign, IL. The NIR instrument used was GrainSpec (Foos Electric Inc.), a fixed-filter whole-grain analyzer that operates on a transmittance mode and a wavelength range of 800–1,100 nm. Five readings of a 250-g sample for each hybrid were taken for the analysis. The calibration of the NIR instrument

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was based on the wet-chemistry standard methods of the Corn Refiners Association (CRA). The oil, crude fiber, protein, and starch calibrations for the NIR instrument were based on methods A-6, A-8, A-18, and A-20, respectively (CRA 1980). The whole-kernel moisture content of the samples was measured using the 103°C forced-air oven method (AACC 1995).

The average starch yields were plotted against storage time with ± 2 standard deviations. An experimental standard deviation value of 0.55% starch yield has been observed as the experimental error occurring in the wet-milling procedure and was determined by wet-milling 30 samples of a single hybrid within one week and then milling one sample per week which had been stored at 4°C (Eckhoff et al 1996 and unpublished data). The range (average ± 2 standard deviations) represents the experimental error of the wet-

milling procedure. Duncan's multiple range test (SAS Institute, Cary, NC) was used to determine the significant differences between storage conditions within a hybrid. The significance level was $P < 0.05$.

RESULTS AND DISCUSSION

Starch yields within a hybrid (Figs. 2–4) at a fixed storage condition (4°C or ambient) were higher (greater than average + two standard deviations) at zero storage time when compared to the starch yields at other storage times for all hybrids except FR600×FR1087 (from the 1994 crop) stored at 4°C. Starch yields at other storage times ranging from one to 24 months were within the experimental error.

The significant drop in starch yields from zero to one month of storage (Figs. 2–4) was due to the replacement of grinding plates on the Quaker City mill before the one-month storage test. Worn plates have a much larger contact surface area and tended to grind the fine fiber so hard that it released additional starch, more than normally occurs in wet-milling. This problem, as reported by Eckhoff et al (1996), was identified after the zero-time samples were run. For all subsequent milling (from one month of storage onward), plate replacement was conducted as described by Eckhoff et al (1996).

Figures 2–4 do not show any trend of increase or decrease in starch yields with storage time (after the zero-time sample), with all of the starch yields within the experimental error. No trend of increase or decrease was seen in the other fractions, i.e., steep-water solids, germ, fiber, and gluten (Tables II–IV).

Comparing the starch yields of hybrid FR1064×LH59 from the 1995 crop at either storage condition, no significant differences between storage time from zero to 12 months (Fig. 5) were observed. Also, no significant differences were observed between zero and three months of storage time in hybrids FR1064×LH59 and FR618×LH123HT from the 1996 crop at either storage condition (data not shown). All of the starch yields again were within the experimental error, and there was no trend of increase or decrease in starch yields. No trend was observed in other fractions for the hybrids from 1995 and 1996 (Tables V–VII, respectively). The results from 1995 and 1996 support the previous conclusion that the drop in starch yield from zero to one month in the 1994 samples was due to the replacement of the grinding plates in the Quaker City mill.

When comparing the average starch yields at different storage conditions (across storage time), the average starch yields of two of the three hybrids (FR600×FR1087 and FR618×LH123HT) from the 1994 crop were statistically higher when stored at 4°C (Table VIII). Hybrid FR1064×LH59 from the 1995 crop and hybrids FR1064×LH59 and FR618×LH123HT from the 1996 crop did not show any significant differences in starch yields with respect to storage condition (Table VIII).

These results suggest that there is a negligible effect of storage time on starch yield at a particular storage condition (4°C or ambient). However, the results suggest a hybrid- and growing season-dependent effect when comparing starch yields of the same hybrids stored at different conditions. One of the three hybrids (FR600×FR1087) showed lower starch yields at ambient conditions, one hybrid

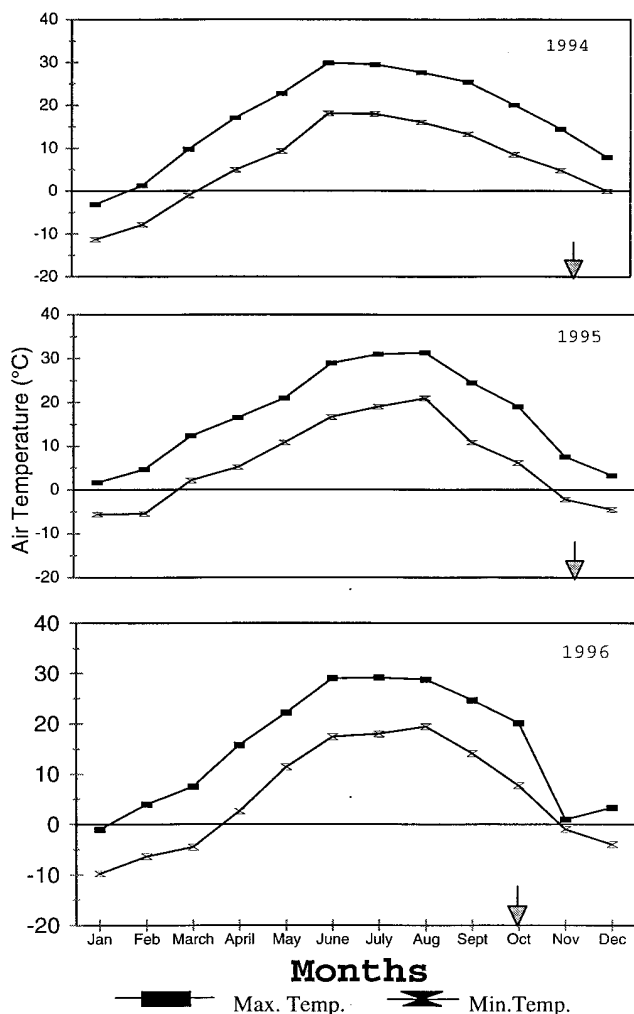


Fig. 1. Maximum and minimum air temperature data of Champaign County for 1994, 1995, and 1996. Arrows indicate when the corn samples were put into storage.

TABLE I
Analysis of Corn Hybrids Using Near-Infrared Transmittance^a

Hybrid (Year)	Oil	Fiber	Starch	Protein
FR1064×LH59 (1994)	4.39	2.27	71.86	9.25
FR600×FR1087 (1994)	4.48	2.57	68.47	10.30
FR618×LH123HT (1994)	3.38	1.88	71.80	10.28
FR1064×LH59 (1995)	4.32	1.94	71.83	9.70
FR1064×LH59 (1996)	4.84	2.36	69.41	9.52
FR618×LH123HT (1996)	3.65	1.96	71.81	9.72

^a All yields are expressed as a percentage of dry solids and are the mean of five observations.

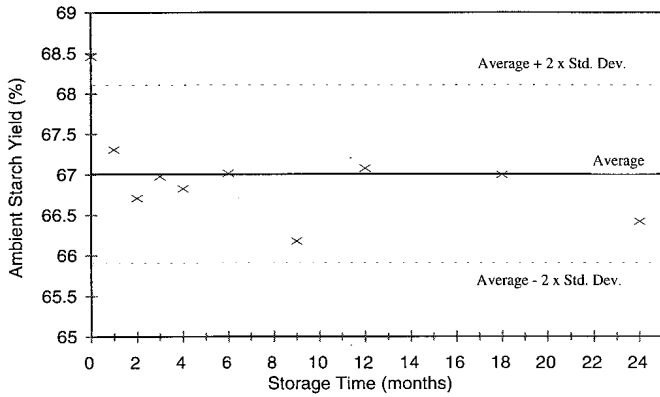
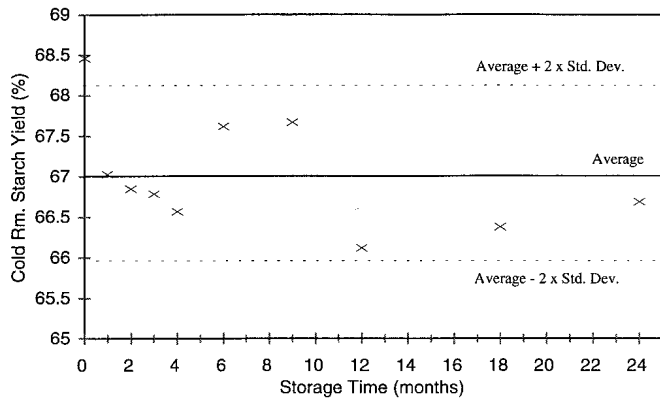


Fig. 2. Storage time vs. starch yield of corn hybrid FR1064xLH59 (1994 crop) stored at ambient conditions and 4°C (cold room).

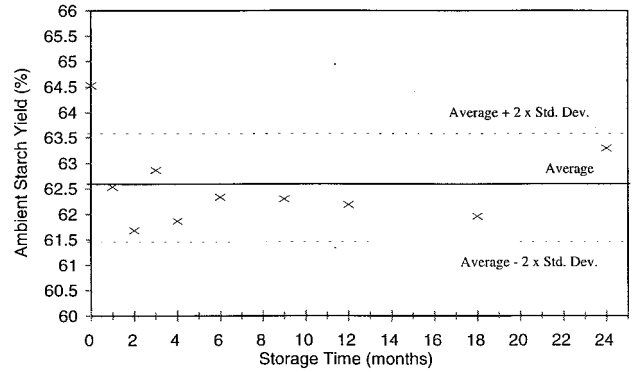
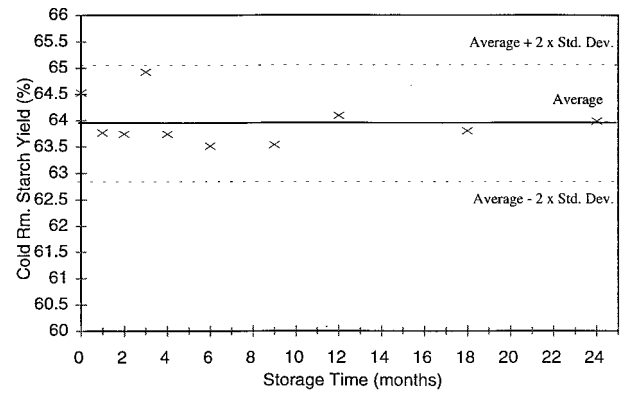


Fig. 4. Storage time vs. starch yield of corn hybrid FR618xLH123HT (1994 crop) stored at ambient conditions and 4°C (cold room).

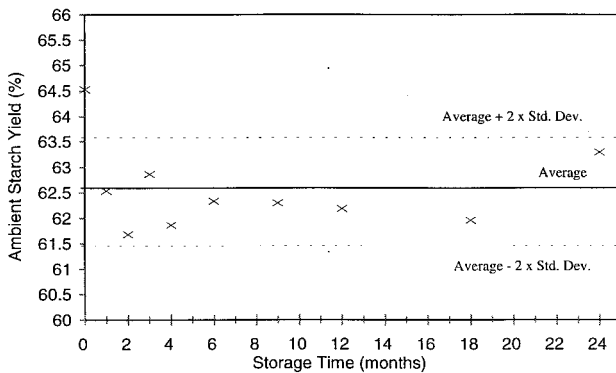
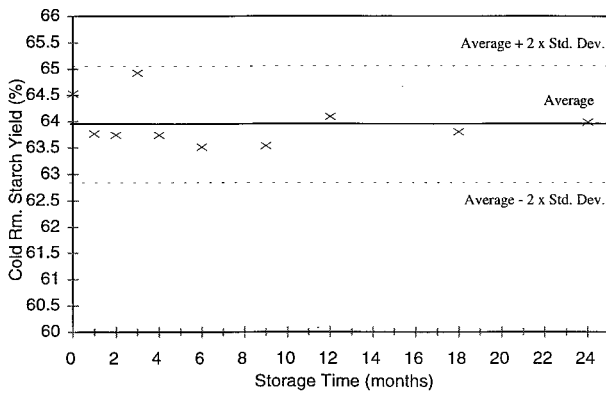


Fig. 3. Storage time vs. starch yield of corn hybrid FR600xFR1087 (1994 crop) stored at ambient conditions and 4°C (cold room).

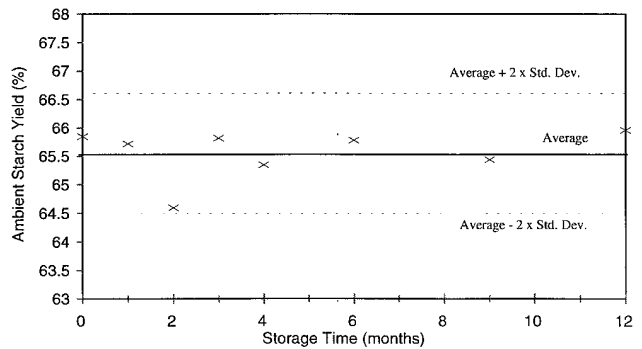
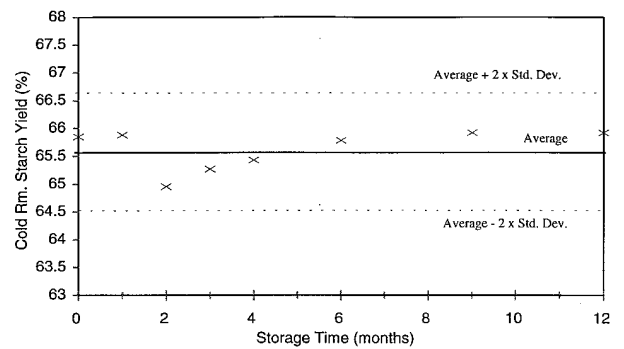


Fig. 5. Storage time vs. starch yield of corn hybrid FR1064xLH59 (1995 crop) stored at ambient conditions and 4°C (cold room).

TABLE II
Wet-Milling Fraction Yields^a of Corn Hybrid FR1064×LH59 (1994 Crop) Stored Under Two Different Conditions for Up to Two Years

Storage Condition	Time (months)	Steepwater Solids	Fiber	Germ	Starch	Gluten	Total Recovery	
4°C cold room	0	3.49	10.85	6.30	68.46	9.68	98.78	
	1	3.57	13.51	6.08	67.03	9.05	99.24	
	2	3.54	14.03	6.25	66.85	9.10	99.78	
	3	3.50	12.62	6.28	66.79	9.62	98.81	
	4	3.56	13.05	6.31	66.57	9.60	99.09	
	6	3.66	13.18	6.00	67.62	9.03	99.49	
	9	3.49	13.74	6.18	67.67	8.65	99.73	
	12	3.57	14.25	6.34	66.12	9.03	99.31	
	18	3.59	14.16	6.68	66.38	8.57	99.37	
	24	3.61	13.35	6.64	66.69	9.44	99.73	
	Ambient temperature	0	3.49	10.85	6.30	68.46	9.68	98.78
		1	3.60	13.68	6.30	67.31	8.82	99.71
2		3.53	14.83	6.35	66.71	8.55	99.97	
3		3.57	12.88	6.11	66.98	9.69	99.23	
4		3.62	13.26	6.17	66.83	9.01	98.89	
6		3.52	14.02	6.23	67.02	8.82	99.61	
9		3.58	15.38	6.19	66.18	8.44	99.76	
12		3.55	14.15	6.11	67.08	8.79	99.68	
18		3.56	14.10	6.04	67.00	8.83	99.53	
24		3.61	13.35	6.64	66.69	9.44	99.73	

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

TABLE III
Wet-Milling Fraction Yields^a of Corn Hybrid FR600×FR1087 (1994 Crop) Stored Under Two Different Conditions for Up to Two Years

Storage Condition	Time (months)	Steepwater Solids	Fiber	Germ	Starch	Gluten	Total Recovery	
4°C cold room	0	3.44	12.27	7.18	64.53	11.65	99.08	
	1	3.44	17.29	5.58	63.77	9.55	99.62	
	2	3.35	16.99	5.54	63.75	9.49	99.12	
	3	3.47	15.19	5.62	64.93	10.13	99.34	
	4	3.47	15.93	5.65	63.75	10.17	98.97	
	6	3.59	16.70	5.46	63.52	10.21	99.47	
	9	3.52	17.35	5.57	63.54	9.61	99.59	
	12	3.46	17.12	5.61	64.10	9.31	99.59	
	18	3.42	17.70	5.51	63.81	9.29	99.74	
	24	3.47	17.38	5.87	63.99	9.13	99.84	
	Ambient temperature	0	3.44	12.27	7.18	64.53	11.65	99.08
		1	3.41	15.32	7.38	62.54	11.20	99.85
2		3.43	16.13	7.37	61.69	10.52	99.13	
3		3.46	14.08	7.07	62.87	11.30	98.77	
4		3.45	15.17	7.29	61.87	10.74	98.52	
6		3.44	15.36	7.13	62.34	10.91	99.19	
9		3.51	14.87	7.18	62.30	11.87	99.72	
12		3.56	15.71	7.05	62.19	10.46	98.96	
18		3.55	15.43	7.19	61.97	10.86	99.00	
24		3.56	14.76	7.14	63.30	10.57	99.33	

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

TABLE IV
Wet-Milling Fraction Yields^a of Corn Hybrid FR618×LH123HT (1994 Crop) Stored Under Two Different Conditions for Up to Two Years

Storage Condition	Time (months)	Steepwater Solids	Fiber	Germ	Starch	Gluten	Total Recovery	
4°C cold room	0	3.35	13.63	5.82	65.75	10.79	99.34	
	1	3.42	18.51	5.70	63.13	8.82	99.58	
	2	3.38	17.80	5.64	63.48	9.53	99.82	
	3	3.39	16.43	5.48	62.94	10.71	98.96	
	4	3.47	16.70	5.69	63.96	9.46	99.28	
	6	3.46	16.75	5.71	63.17	10.36	99.45	
	9	3.47	17.08	5.72	64.60	9.11	99.99	
	12	3.42	17.37	5.80	63.86	8.80	99.25	
	18	3.38	17.96	5.67	63.83	8.45	99.29	
	24	3.45	16.36	5.86	64.19	9.76	99.63	
	Ambient temperature	0	3.35	13.63	5.82	65.75	10.79	99.34
		1	3.39	17.36	5.97	62.06	10.60	99.38
2		3.30	17.85	6.10	62.52	9.64	99.42	
3		3.42	15.50	5.77	63.63	10.48	98.81	
4		3.36	16.55	6.15	62.82	10.08	98.96	
6		3.53	16.50	5.89	63.64	9.95	99.50	
9		3.45	17.52	5.90	62.47	10.26	99.61	
12		3.49	17.13	5.81	62.73	10.11	99.26	
18		3.44	17.74	5.72	62.77	9.54	99.20	
24		3.48	17.49	5.99	63.24	9.20	99.39	

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

TABLE V
Wet-Milling Fraction Yields^a of Corn Hybrid FR1064×LH59 (1995 Crop) Stored Under Two Different Conditions for Up to One Year

Storage Condition	Time (months)	Steepwater Solids	Fiber	Germ	Starch	Gluten	Total Recovery	
4°C cold room	0	3.58	13.84	6.42	65.85	9.43	99.12	
	1	3.58	13.51	6.43	65.88	10.07	99.48	
	2	3.56	13.99	6.62	64.96	9.62	98.75	
	3	3.51	13.05	6.76	65.27	10.69	99.28	
	4	3.51	13.47	6.51	65.43	10.27	99.18	
	6	3.53	13.47	6.62	65.78	9.49	98.89	
	9	3.57	12.57	6.89	65.92	11.45	100.39	
	12	3.60	13.00	6.45	65.92	10.93	99.89	
	Ambient temperature	0	3.58	13.84	6.42	65.85	9.43	99.12
		1	3.57	13.64	6.57	65.72	9.66	99.16
		2	3.51	14.04	6.73	64.60	9.78	98.65
		3	3.53	13.49	6.86	65.82	10.01	99.72
4		3.55	13.71	6.37	65.35	10.06	99.04	
6		3.53	14.02	6.24	65.78	10.03	99.60	
9		3.55	12.82	6.38	65.44	11.41	99.59	
12		3.58	12.54	6.66	65.96	10.78	99.52	

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

TABLE VI
Wet-Milling Fraction Yields^a of Corn Hybrid FR1064×LH59 (1996 Crop) Stored Under Two Different Conditions for Up to Three Months

Storage Condition	Time (months)	Steepwater Solids	Fiber	Germ	Starch	Gluten	Total Recovery
4°C cold room	0	3.28	13.34	6.11	67.81	9.18	99.72
	1	3.24	12.76	5.64	68.18	9.70	99.52
	2	3.38	13.48	6.00	67.99	8.69	99.55
	3	3.25	13.89	5.88	67.57	8.52	99.10
Ambient temperature	0	3.28	13.34	6.11	67.81	9.18	99.72
	1	3.25	13.04	5.97	68.54	8.92	99.72
	2	3.31	13.95	6.04	67.47	8.38	99.14
	3	3.17	13.86	5.99	67.01	9.03	99.06

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

TABLE VII
Wet-Milling Fraction Yields^a of Corn Hybrid FR618×LH123HT (1996 Crop) Stored Under Two Different Conditions for Up to Three Months

Storage Condition	Time (months)	Steepwater Solids	Fiber	Germ	Starch	Gluten	Total Recovery
4°C cold room	0	3.08	15.56	5.78	65.57	6.67	99.66
	1	2.98	14.97	5.56	66.49	9.92	99.92
	2	2.97	16.56	5.80	65.09	9.27	99.69
	3	2.97	16.16	5.77	65.02	9.20	99.11
Ambient temperature	0	3.08	15.56	5.78	65.57	9.67	99.66
	1	2.96	15.05	5.65	66.34	9.72	99.73
	2	2.96	16.27	5.76	65.35	9.44	99.79
	3	3.01	16.21	6.10	64.95	8.84	99.10

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

(FR1064×LH59) from three different crop years (1994, 1995, and 1996) showed no significant differences between storage conditions (4°C or ambient), and one hybrid (FR618×LH123HT) from the 1994 crop showed a lower starch yield at ambient conditions, but the same hybrid from the 1996 crop showed no significant difference between 4°C or ambient storage conditions.

The lack of an effect of storage time on starch yield at a particular storage condition (4°C or ambient) is not in agreement with the results reported by Roushdi et al (1979) which showed a drop of 1.1, 1.9, and 2.5% in starch yield as storage time (at room temperature) increased from zero to three, six, and nine months, respectively. It is not possible to ascertain why this study does not agree with the Roushdi et al (1979) results. Roushdi et al (1979) did not report or indicate any quality control of their wet-milling procedure. Our experience with laboratory wet-milling shows that wet-milling results (prime product yields) can change with time due to changes in the test procedure as run by the laboratory personnel and by changes in the test equipment. Reference samples have to be milled periodically to assure that no changes have occurred (Eckhoff et al 1996). Also, Roushdi et al (1979) reported no information regarding microbial deterioration (which could also lead to lower starch yields).

TABLE VIII
Average Starch Yield of Corn Hybrids (Across Storage Time) at Cold Room (4°C) and Ambient Storage Conditions

Hybrid	Average Starch Yield (%)	
	Cold Room	Ambient
FR1064×LH59 (1994)	67.0a ^a	67.0a
FR600×FR1087 (1994)	64.0a	62.6b
FR618×LH123HT (1994)	63.9a	63.2b
FR1064×LH59 (1995)	65.6a	65.6a
FR1064×LH59 (1996)	67.9a	67.7a
FR618×LH123HT (1996)	65.5a	65.5a

^a Starch yields followed by the same letter in a row are not significantly different at a 95% confidence level.

CONCLUSIONS

The effect of storage time (up to two years) is not statistically significant on corn starch yields. However, the effect of storage condition is statistically significant in some cases. The results of this study indicate that there is no naturally occurring long-term degradation process occurring during storage resulting in decreased starch yield. The long-term loss in starch yield observed

by the industry is probably due to microbial deterioration and market channel blending of lower quality corn with good corn.

This study suggests that there may be a set of storage conditions or parameters that will optimize starch yield. Starch yields were affected by storage condition, but not in every case. We do not know whether this was an anomalous effect because it occurred in only two hybrids of one growing season. More detailed study is warranted based on this work to study the effect of storage conditions on starch yields of different hybrids from different growing seasons.

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