Yield, Protein Content, and Viscosity of Starch from Wet-Milled Corn Hybrids as Influenced by Environmentally Induced Changes in Test Weight

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ABSTRACT

Forty-three yellow dent corn samples of five different hybrids varying in test weight and moisture content were obtained from 14 different locations in 1993. The locations for acquired samples were selected randomly to cover a wide range of test weights based on preliminary data from eight states of the corn belt where 94% of the U.S. corn crop was produced in 1993. Samples were wet-milled using a 100-g standard laboratory-scale wet-milling procedure. Protein content in starch and starch viscosity were determined. Starch yield, protein content in starch, and starch viscosity were not affected significantly by test weight.

Test weight of corn routinely is used for grade designation and quality assessment. Test weight is an indirect measure of density (Pomeranz et al 1986) and results from a combination of true density of the grain and its packing characteristics (Freeman 1973). Many factors have an impact on test weight, including grain maturity, size and shape of the grain, uniformity, surface characteristics, moisture content, type and amount of impurities, mechanical or heat treatment, and percentage and type of broken kernels and foreign material (Freeman 1973, Pomeranz et al 1986). Among these factors, grain size and shape, surface characteristics, and uniformity of the grain do not negatively affect the grain grade and processing characteristics. However, other factors such as mechanical and heat treatment and percentage of broken kernels and foreign material can affect the grade and processing characteristics.

Corn hybrid, moisture content at harvest, drying temperature, and mechanical damage can affect the test weight. Hall (1972) studied the effects of drying temperature, moisture content at harvest, cultivar, and mechanical damage on test weight. Test samples were shelled by hand or by combine, with the former considered to have no mechanical damage and the latter to have some. Hand-shelled corn test weight was 1.2–2 lb/bu higher than that of combined corn at a harvest moisture content of ≈22%. For both hand-shelled and combined corn, test weight decreased with an increase in drying temperature. Test weights with lower harvest moisture contents for both hand-shelled and combined samples were higher than those with higher harvest moisture contents. Hall and Hill (1974) discussed the test weight adjustment based on moisture content and mechanical damage of corn kernels. They found that differences in harvest damage level caused differences in the beginning and final test weights. Brown et al (1979) studied the effect of drying method on corn quality of five hybrids with harvest moisture contents of 20, 21, 26, 28, and 30% and drying temperatures of 45, 60, and 80°C. Corn hybrid had a significant effect on final test weight, and test weight tended to decrease as drying temperature increased, particularly for corn harvested at 28 and 30% moisture content (Brown et al 1979). Peplinski et al (1975) studied the characteristics of five corn hybrids; four were harvested at 24% moisture content and dried at 82°C, and the other was harvested at moisture contents of 16, 20, 25, and 32% and dried at temperatures ranging from ambient to 149°C. They reported that the test weight of corn harvested at 32% moisture content and artificially dried at 149°C was 6 lb/bu less than that of field-dried corn. When the drying temperature was raised from 82 to 149°C, test weight could be lowered by 0–2 lb/bu. This decrease in test weight can lower the quality by one grade level (USDA 1988).

Low test weight not only affects the grade but also is associated with problems during the wet-milling process. This is particularly true when low test weight is caused by high drying temperature. Numerous problems can occur such as difficulty in grinding, difficulty in drying the gluten fraction, poor separation of starch and protein, poor germ separation, and low yield of oil (MacMasters et al 1959). It also can result in a reduction in production capacity, poor dewatering of coarse fiber, and low starch viscosity (Freeman 1973).

Weller et al (1988) studied the correlation of starch recovery with assorted quality factors of four corn hybrids with low (17.2–20.2%), medium (21.9–24.0%), and high (29.6–33.9%) harvest moisture contents and drying temperatures of ambient, 49, 71, and 93°C. Test weights were in the range of 752–835 kg/m^3 (Weller 1986). The differences in test weight were caused by the combination of different harvest moisture contents and different drying temperatures. A 40-hr steep, 53°C steep temperature, and a steep medium containing 0.1% (w/w) sulfur dioxide and 1.5% (w/w) lactic acid were used for wet-milling. Weller et al (1988) reported that starch recovery of yellow dent corn was a function of starch content, test weight, and ethanol-soluble protein. Vojnovich et al (1975) studied the wet-milling properties of corn after field-shelling and artificial drying. One corn hybrid was harvested at different moisture contents (17, 20, 25, and 32%) and dried at different temperatures (49, 82, and 149°C) which caused different test weights of the samples ranging from 53–59 lb/bu. A 48-hr steep, 52°C steep temperature, and 0.25% sulfur dioxide were used. There was no significant correlation between starch recovery and test weight. Based on visual examination of steeped corn sections, Brown et al (1979) derived a steeping index that was significantly correlated to starch recovery (r = 0.97). They used the steeping index as a standard measure of starch recovery against quality factors such as stress cracks, test weight, and viability. Stress cracks, test weight, and viability of dried corn were correlated to the steeping index, which was significantly correlated to starch recovery during wet-milling. Test weight range was 53.1–58.3 lb/bu. Steeping was performed at 52°C for 32 hr.

The different test weights for previous studies were caused by high harvest moisture contents and high drying temperatures. High harvest moisture and high drying temperature can affect wet-milling characteristics of corn. Watson and Hirata (1962) reported that corn dried at ≥82°C was less suitable for wet-milling than corn dried at lower temperatures because of a lower prime starch yield and a higher fiber yield. Freeman (1973) reported a 25% reduction in production capacity of a plant, poor separation of starch and protein, and low starch viscosity as a result of processing corn dried from 30 to 15% moisture in a single pass using excessive heat.

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Singh et al (1998) reported that eight of nine hybrids harvested at a high moisture content (33–35%) and dried at 110°C showed a large decrease in starch yields compared with those of the same hybrids harvested at a low moisture content (21–22%) dried at 110°C.

The objective of this study was to determine the effect of changes in corn test weight caused only by environmental differences for low temperature and high precipitation during the growing season and growing location, on starch yield, protein content, and starch viscosity.

MATERIALS AND METHODS

A total of 43 corn samples of five different, popular high-yielding commercial hybrids were used in this study. Hybrids were grown at 14 locations in Iowa, Michigan, Minnesota, Nebraska, North Dakota, Pennsylvania, South Dakota, and Wisconsin in 1993. Locations for acquiring samples were randomly selected based on preliminary determination of test weights to ensure a wide range of test weights. At none of the locations were data available regarding wet-milling characteristics of the hybrids. There was no frost damage or artificial drying of any of the samples. Weather information for each state was obtained from the weather station closest to the location of the acquired samples. For those states in which multiple locations were used, average weather conditions were used.

Whole kernels were analyzed for moisture content using the 103°C convection oven method (Approved Method 44-15A, AACC 1995). Test weight data was provided by a commercial seed corn company. Wet-milling was performed using the procedure described by Eckhoff et al (1996), and starch yield was calculated as the ratio of the total dry weight of recovered starch to total dry weight of corn. Protein content (N × 6.25) in starch was determined by Silliker Laboratories Group, Inc. (Cedar Rapids, IA) using Kjeldahl nitrogen content (Method B-48, CRA 1984). Viscosity of starch was determined by Cerestar U.S.A. (Hammond, IN) at a starch slurry concentration of 8%. A Brabender Visco-Amylograph was used for rapid heating of the starch slurry from room temperature to 65°C and then heating at 1.5°C/min from 65 to 95°C. It was maintained at 95°C for 15 min.

Wet-milling of samples from different locations and hybrids was performed randomly in duplicate. Because starch yield is significantly affected by corn hybrid (Singh et al 1997), starch yield was compared within the same corn hybrid from different locations so that the variability of hybrid would be removed. Statistical software (User's Guide, 4th ed., SAS Institute, Cary, NC.) was used to run a one-way analysis of variance (ANOVA) with the general linear model procedure (Proc GLM) and followed by Duncan's multiple range test. Statistical significance level was $P \leq 0.05$. The range of protein content in starch, and the range of peak, final, and breakdown viscosity (average ±2 standard deviations) represent the experimental error of the measurements.

RESULTS AND DISCUSSION

Corn growers experienced a unique crop year in 1993. For each of the states where samples were acquired, the temperature was generally lower than or close to normal during the corn growing season. Exceptions were Minnesota, North Dakota, and Pennsylvania in July, and Wisconsin in August (Fig. 1). Total precipitation was generally higher than or close to normal. Exceptions

TABLE I
Observed and Average Percentages for Different Development Stages of Corn Grown in Different Locations in 1993[a]

	Iowa		Michigan		Minnesota		Nebraska		South Dakota		Wisconsin		Pennsylvania	
Week Ending	**Obs**	**Avg**	**Obs**	**Avg**	**Obs**	**Avg**	**Obs**	**Avg**	**Obs**	**Avg**	**Obs**	**Avg**	**Obs**	**Avg**
Silking stage														
July 4	0	1	0	2	0	0	0	3	0	0	0	0	0	0
July 11	0	15	3	5	0	1	0	17	0	4	0	5	3	3
July 18	1	31	5	15	0	13	9	41	0	16	0	16	7	8
July 25	6	62	10	35	1	38	29	69	0	36	3	35	19	21
Aug 1	24	85	45	60	20	64	61	87	16	60	10	58	44	42
Aug 8	55	95	80	80	45	82	84	96	36	79	40	77	71	60
Aug 15	78	99	95	95	75	96	94	99	61	92	68	87	84	76
Aug 22	92	100	100	99	94	99	98	100	84	98	79	96	93	87
Dough stage														
July 25	0	9	0	0	0	0	0	6	0	0	0	0	0	0
Aug 1	0	10	0	1	0	3	4	15	0	11	0	8	0	3
Aug 8	0	24	0	4	0	13	13	35	1	32	3	20	11	11
Aug 15	8	43	2	15	5	40	28	60	8	57	7	33	24	24
Aug 22	15	62	15	30	7	67	51	79	17	74	23	49	40	40
Aug 29	35	77	30	50	16	83	72	92	39	86	45	63	65	53
Sep 12	64	99	95	80	71	97	97	100	76	99	68	86	78	68
Sep 19	85	99	100	90	86	98	100	100	86	100	71	90	91	81
Sep 26	92	100	100	96	90	99	100	100	91	100	86	95	95	88
Dent stage														
Aug 15	0	17	0	2	0	12	0	15	0	15	1	9	1	4
Aug 22	0	32	1	6	0	24	7	31	1	28	5	17	8	8
Aug 29	10	50	3	15	4	38	22	54	9	45	15	28	19	15
Sep 5	20	90	15	30	8	60	37	75	21	63	17	42	29	27
Sep 12	32	92	40	50	25	79	65	88	41	78	34	59	58	40
Sep 19	64	93	70	65	40	91	91	95	52	89	42	73	68	52
Sep 26	78	99	100	80	61	97	95	98	62	96	68	85	87	77
Oct 3	85	100	100	95	85	99	98	100	82	100	72	91	97	94
Mature stage														
Sep 5	0	31	0	3	0	15	0	20	1	25	2	11	1	4
Sep 12	4	49	3	10	2	32	4	37	4	40	7	24	7	8
Sep 19	20	69	7	20	3	45	16	57	11	58	9	35	9	13
Sep 26	34	85	25	30	6	64	34	76	20	74	16	50	16	18
Oct 3	50	96	35	50	15	82	79	91	36	86	33	67	35	31
Oct 10	75	99	60	65	20	93	84	97	50	92	42	77	55	48
Oct 17	95	100	70	80	35	96	95	99	68	99	59	84	74	65
Oct 24	100	100	100	90	55	100	98	100	79	100	70	92	85	78

[a] Data obtained from the United States Departments of Commerce and Agriculture (USDA 1993).

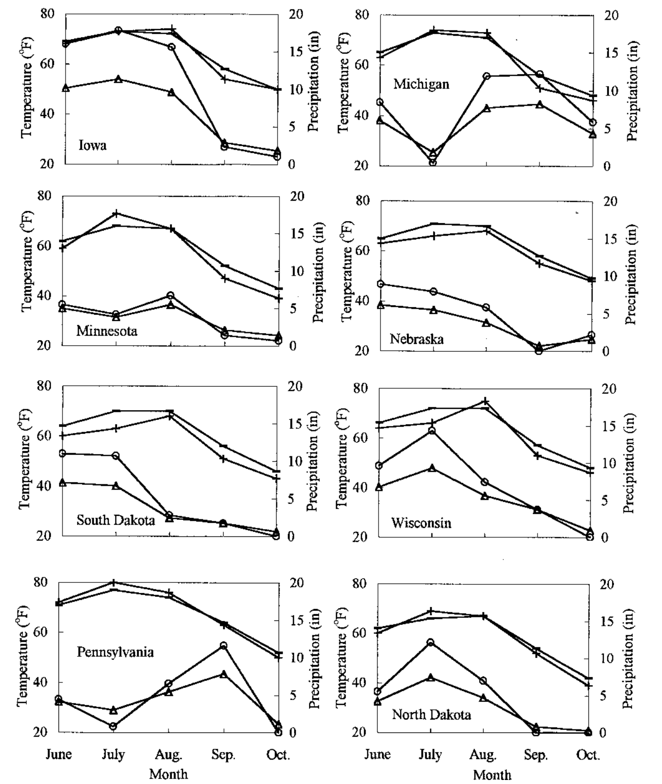

Fig. 1. Average temperature, average precipitation, and 1993 temperature and precipitation during the corn growing season for states where corn samples were acquired. Data were obtained from the United States Departments of Commerce and Agriculture for (USDA 1993). + = Temperature in 1993, – = average temperature, ○ = precipitation in 1993, Δ = average precipitation.

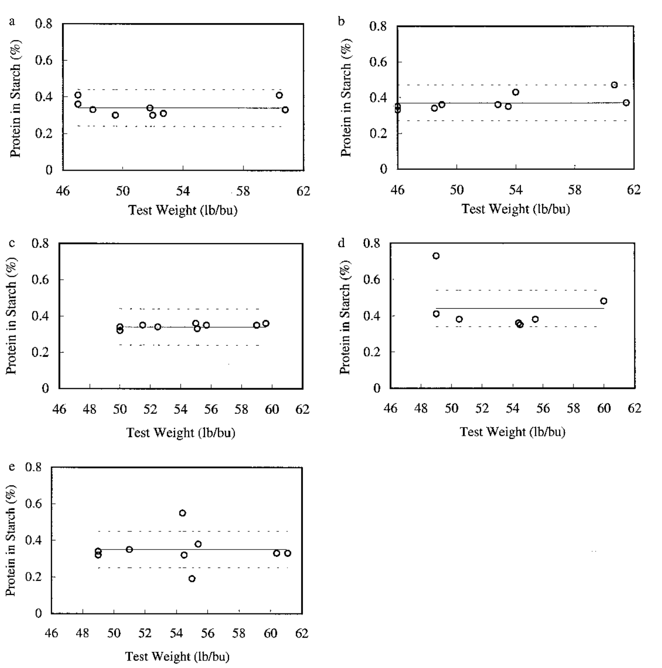

Fig. 2. Protein content in starch vs. test weight for different 1993 corn hybrids: 1006, 1510, 1015, 1109, 1107 (a–e, respectively). Solid lines = average; dashed lines = average ± 2× standard deviation.

were Pennsylvania in July and Nebraska in September. Iowa had ≈5 in. above normal precipitation during June, July, and August. The cooler and wetter weather conditions delayed corn growing through silking, dough, dent, and mature stages (Table I). Only in Michigan and Pennsylvania, corn exceeded average levels later. Data for corn growth in North Dakota were not available. For the week ending July 18, 1993, in Iowa, only 1% of corn plants were silking, which was far behind average (31%). However, during the same period in Pennsylvania, the percentage of corn plants silking (7%) was close to the average (8%). For the week ending August 15, 1993, in Iowa, 78% of corn was silking, 8% was in the dough stage, and 0% was in the dent stage, while the average silking, dough, and dent values were 99, 43, and 17%, respectively. Again, during the same period in Pennsylvania, percentages of silking, dough, and dent were 84, 24, and 1%, respectively, compared with the average level of 76, 24, and 4%, respectively. For the week ending October 10, 1993, 75% of the corn was mature in Iowa, while 55% of the corn was mature in Pennsylvania, compared with average values of 99 and 48%, respectively.

Both rainfall and temperature affect the percentage of dry matter in grain (Aldrich 1943). Iowa had the highest precipitation in 1993, and the samples from Iowa had a relatively low test weight, ranging from 46 to 55.5 lb/bu regardless of the hybrid. Pennsylvania had relatively low precipitation, and the sample had a test weight of 60.4 lb/bu (Table II).

TABLE II
Test Weight, Moisture Content, and Wet-Milling Yields of Five Corn Hybrids Grown in Different Locations in 1993[a]

Hybrid Code	Location Code	State	Test Weight (lb/bu)	Moisture Content (%)	Starch Yield (%)
1006	BR	IA	47.0	12.1	65.4 ± 0.2c[b]
	RU	IA	47.0	11.9	64.9 ± 0.2c
	SC	IA	48.0	11.9	67.1 ± 0.5ab
	VL	IA	49.5	12.3	67.2 ± 0.9ab
	GF	ND	51.8	11.2	64.9 ± 0.7c
	LU	IA	52.0	11.6	65.9 ± 1.3bc
	GL	MN	52.7	11.0	61.4 ± 0.8e
	NH	PA	60.4	10.4	63.4d
	EA	WI	60.8	11.2	68.3 ± 0.8a
1510	BR	IA	46.0	12.3	62.8 ± 2.9ab
	RU	IA	46.0	12.0	65.2 ± 1.0a
	SC	IA	48.5	12.0	64.6 ± 1.8a
	VL	IA	49.0	11.9	65.7 ± 0.5a
	GL	MN	52.8	10.8	59.9 ± 0.6b
	GF	ND	53.5	10.8	62.3 ± 0.1ab
	LU	IA	54.0	11.9	64.9 ± 0.3a
	JV	WI	60.7	11.0	62.9 ± 0.6ab
	NP	NE	61.5	10.5	63.6 ± 0.8a
1015	BR	IA	50.0	11.5	66.2 ± 0.3b
	SC	IA	51.5	11.4	68.1 ± 0.1a
	VL	IA	52.5	11.8	66.9 ± 0.2b
	LU	IA	55.0	11.4	65.8 ± 0.5bc
	GF	ND	55.1	11.0	65.8 ± 0.4bc
	GL	MN	55.7	10.8	60.7 ± 0.7e
	HU	SD	59.0	10.4	64.8 ± 0.6cd
	WL	MN	59.6	10.5	64.1 ± 0.7d
1109	BR	IA	49.0	11.8	63.7 ± 1.8a
	RU	IA	49.0	11.8	64.9 ± 1.4a
	SC	IA	50.5	11.5	65.9 ± 0.4a
	GL	IA	54.4	11.0	61.0 ± 0.2b
	VL	IA	54.5	11.7	64.0 ± 0.1a
	LU	IA	55.5	11.5	65.0 ± 0.6a
	EA	WI	60.0	10.5	65.3 ± 0.6a
1107	BR	IA	49.0	11.8	64.9 ± 0.6bc
	RU	IA	49.0	12.0	66.2 ± 0.6ab
	SC	IA	51.0	11.7	67.5 ± 1.0a
	GF	ND	54.4	11.1	64.9 ± 2.4bc
	VL	IA	54.5	11.7	66.3 ± 0.1ab
	LU	IA	55.0	11.7	66.1 ± 0.1ab
	GL	MN	55.4	11.1	63.0 ± 0.4c
	MI	MI	60.4	10.7	66.6 ± 1.3ab
	JV	WI	61.1	10.7	66.4 ± 0.4ab

[a] Values are the means of two replicates.
[b] Numbers followed by the same letter within the same corn hybrid were not significantly different at $P < 0.05$.

TABLE III
Analysis of Variance for the Effect of Location on Starch Yield of Five Corn Hybrids Grown in 1993

Hybrid Code	Source	df	Sum of Squares	*F* Value
1006	Model	7	69.1	19.8 ***[a]
	Error	10	5.0	
1510	Model	7	46.2	3.25
	Error	10	20.3	
1015	Model	7	67.6	31.1***
	Error	10	3.15	
1109	Model	5	37.3	8.1***
	Error	8	7.3	
1107	Model	7	26.1	3.3
	Error	10	11.3	

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

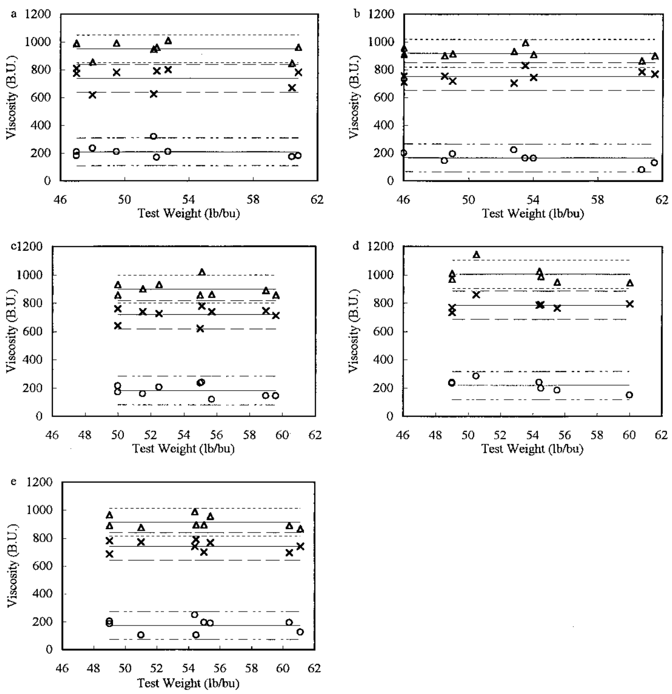

Fig. 3. Peak, final, and breakdown viscosity vs. test weight for different 1993 corn hybrids: 1006, 1510, 1015, 1109, 1107 (a–e, respectively). Δ = Peak viscosity, × = final viscosity, and ○ = breakdown viscosity. Solid lines = average; dashed lines = average ± 2× standard deviation.

The differences in test weights were caused by environmental factors including temperature, rainfall, and plant locations. The effect of test weight on starch yield was not significant (Table II). For the hybrid samples coded as 1006, test weights were 47.0–60.8 lb/bu, and starch yields were 61.4–68.3%. The highest starch yield (68.3%) was obtained from 1006EA with a test weight of 60.8 lb/bu, while 1006NH with a similar test weight of 60.4 lb/bu gave only a 63.4% starch yield. The hybrid samples coded as 1015 had test weights of 50.0–59.6 lb/bu and starch yields of 60.7–68.1%. Although 1015GF hand 1015GL had similar test weights, their starch yields were significantly different. Also, 1015RU and 1015HU had very different test weights but still had similar starch yields.

The differences in starch yield were caused by planting location (Table II), which is in agreement with Singh et al (1996). The effect of planting location on starch yield was hybrid-dependent. For corn hybrids coded as 1510 and 1107, the effect of location on starch yield was not significant. For hybrids coded as 1006, 1109, and 1015, the effect of location on starch yield was significant (Table III). There was no increasing or decreasing trend in protein content in starch with test weight. All of the protein in starch data, except for that from the hybrid coded as 1109 planted at location RU and the hybrid coded as 1107GF and 1107LU, were within the experimental error (Fig. 2). No relationship was found between viscosity (peak, final, breakdown) and test weight. All of the viscosity data, except for 1109SC were in the range of experimental error (Fig. 3).

CONCLUSIONS

High precipitation and low temperature during the growing season caused delays in the development of corn and resulted in low test weights. In such cases, test weight had no significant effect on starch yield. Starch yield was significantly affected by planting location and was hybrid-dependent. No relationship between starch protein content or starch viscosity and test weight was found.

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