CROP ECOLOGY, PRODUCTION, & MANAGEMENT

Effect of Seeding Date, Plant Density, Moisture Availability, and Soil Nitrogen Fertility on Maize Kernel Breakage Susceptibility[1]

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ABSTRACT

The objectives of this study were to evaluate seeding date, plant density, moisture availability, and soil N fertility effects on maize (*Zea mays* L.) kernel breakage susceptibility. Three hybrids within each of three relative maturity (RM) groups (90, 100, 110 days by Minnesota Relative Maturity Rating System) were grown in separate seeding date and plant density studies at Arlington, WI [Plano silt loam (fine-silty, mixed, mesic, Typic Argiudoll)], in 1983 and 1984. Maize was seeded four times at 10-day intervals beginning 1 May. Average densities were 1.75, 3.75, 5.75, and 7.75 plants m^{-2}. Hybrids were also evaluated in separate irrigated and dryland trials at Hancock, WI [Plainfield sandy loam (mixed, mesic, Typic Udipsamment)]. In a soil N study, grain samples were collected from an experiment at Arlington in which three N rates (0, 11, and 22 g m^{-2} were applied. Grain was combine-harvested at 25% kernel moisture (except at Hancock where moistures ranged from 21 to 32%) and dried at 82°C in 1983 and 60°C in 1984. Kernel breakage susceptibility, test weight and kernel weight, volume, density, and grain yield were measured. Delayed planting, high plant densities, and low applied N increased kernel breakage susceptibility. At Hancock, higher kernel breakage susceptibility occurred with irrigated- vs. dryland-produced maize. Kernel physical parameters measured were not closely related to kernel breakage susceptibility, except in the soil N study, where the largest range occurred for each variable. The 110-day RM hybrids had lower kernel breakage susceptibility than 90- and 100-day RM hybrids.

Additional index words: Zea mays L., Physical grain quality, Corn yield, Kernel density, Test weight, Kernel size, Kernel damage.

MAIZE (*Zea mays* L.) kernel breakage susceptibility is "the potential for kernel fragmentation or breakage of a load or batch of corn subjected to impact forces when transported mechanically" (American Association of Cereal Chemists, 1983). Modern harvesting, drying, and handling methods have increased the amount of damage in maize that is traded in U.S. markets (Foster, 1975). Hill et al. (1979) found that kernel breakage reduced quality by as many as four grades during shipment from the Midwest to foreign ports. These quality problems threaten the USA's competitive position in world grain markets. Current foreign buyers, foreseeing potential grade changes during transport, offer lower bids that ultimately reduces maize prices at local elevators. In addition to potential market losses and price reductions, broken kernels decrease product yields in domestic wet and dry milling processes and increase storage problems, warehouse cleaning costs, and elevator dust hazards.

Maize produced in the northern USA is especially susceptible to breakage and consequent market quality problems, due to mechanical grain harvest at relatively high moisture levels, followed by rapid artificial drying to safe storage moistures. Harvest moistures of 25% or greater, which are common in northern maize-growing areas, substantially increase breakage potential compared to lower harvest grain moisture percentages (Peplinski et al., 1975).

Agronomic factors are also implicated as having an influence on physical grain quality (Paulsen et al., 1983). Factors such as planting date and plant density influence the environment under which kernel development occurs and may affect breakage susceptibility. The effects of agronomic practices on grain yield of maize have been studied extensively, but little information is available concerning their influence on physical grain quality. Moentono et al. (1984) found that plant density and soil N level significantly affected kernel breakage susceptibility of two maize synthetics.

A range in kernel breakage susceptibility exists among maize genotypes (Mensah et al., 1981; Stroshine et al., 1986; Paulsen et al., 1983; Moentono et al., 1984). Johnson and Russell (1982) reported high heritability estimates (77 to 87%) for kernel breakage susceptibility among 80 inbreds and 40 of their single cross hybrids. Breakage-resistant genotypes usually had small kernels with flinty endosperms. They also found significant interactions between genotype and environment for breakage susceptibility. LeFord and Russell (1985) reported that inbreeding to select for breakage-resistance resulted in earlier-flowering lines with smaller kernels.

These investigations indicate that factors that affect crop productivity also may have an important influence on physical grain quality. Therefore, five separate studies were conducted to investigate the effects of seeding date, plant density, moisture availability, and applied soil N rate on kernel breakage susceptibility of commercially available maize hybrids.

MATERIALS AND METHODS

Preliminary Study

A preliminary screening study was conducted in 1981 and 1982, in which kernel breakage susceptibility determinations were made on 327 commercial corn hybrids entered in the Wisconsin commercial hybrid corn performance trials. Hybrids were grown at Arlington, WI, on a Plano silt loam soil (fine-silty, mixed mesic, Typic Arguidoll). Hybrids were divided into three relative maturity (RM) groups (90, 100, and 110 days based on the Minnesota Relative Maturity Rating System) and were grown in separate kernel breakage susceptibility screening studies each year. The experimental design for each RM group study was a randomized complete block with three replicates. Hybrids were planted in mid-May at a rate to achieve a final density of 6.0 plants m^{-2}

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and hand-harvested in mid-November. Average harvest kernel moisture percentage (on a wet basis) was 18 to 22% (90-day RM), 24 to 28% (100-day RM), and 30 to 35% (110-day RM) as determined by a Steinlite[3] electronic moisture tester. Ears were dried at 32°C, equilibrated to an average kernel moisture content of 11% and hand shelled. Kernel breakage susceptibility was determined using a centrifugal impact device ("Wisconsin Breakage Tester") developed by Singh and Finner (1983). After impacting the grain was placed in a 4.76-mm precision round-hole dockage sieve mounted on a Gamet[3] long-arm shaker, which was run for 15 s (30 strokes). Percentages of kernel breakage susceptibility were defined as 100 times the ratio of the weight of the material passing through the sieve after impact to the weight of the material retained by the sieve before impact.

Nine hybrids (three within each of the three RM groups) were chosen for the 1983 and 1984 studies. Hybrids selected had kernel breakage susceptibility values that ranked either in the upper, middle, or lower third of their respective RM group both years of the preliminary study. An exception was hybrid Stauffer[3] 'S5602' in the 110-day RM group, which was not grown in the trials in 1981, but was chosen for further study because of its ranking in 1982. Selected hybrids within each RM group had similar harvest kernel moisture values both years.

Hybrids chosen from the 90-day RM group and their kernal breakage susceptibilities (1981 and 1982) were: Asgrow[3] 'RX355', 9.7%; Kaltenberg[3] 'KX39', 11.0%; and Lynks[3] 'LX4040', 12.5%. One hundred-day RM hybrids and their average kernel breakage susceptibilities were: Hughes[3] 'H3690', 7.8%; Sokota[3] 'TS-60', 9.1%; and Lemke[3] 'SL40', 10.7%. Among the selected 110-day RM hybrids, Bluetop[3] 'CX10A' and Custom Farm Seed[3] 'CFS1400' had average kernel breakage susceptibilities of 3.4 and 5.7%, respectively, in 1981. The 1982 kernel breakage susceptibility averages for the three 110-day RM hybrids were: CX10A, 10.9%; S5602, 12.9%; and CFS1400, 15.3%.

Seeding Date and Plant Density Studies

The nine hybrids were grown in a seeding date and a plant density study at Arlington in 1983 and 1984. The experimental design for each study was a randomized complete block with treatments in a split-split plot arrangement. The seeding date study had three replicates and main plots were seeding dates of 1, 10, 20, and 30 May; subplots were RM groups; and sub-subplots were hybrids within RM. Plots were overplanted and hand thinned to 5.6 plants m^{-2}. The plant density study had three replicates in 1983 and four replicates in 1984. Main plots were densities (2.0, 4.0, 6.0, and 8.0 plants m^{-2} in 1983; 1.5, 3.5, 5.5, and 7.5 plants m^{-2} in 1984), and RM group and hybrid arrangements were the same as the seeding date study. Hybrid CFS1400 was eliminated from the plant density study in 1984 because of poor emergence. The plant density study was planted on 9 May 1983. In 1984, three replicates were planted on 27 April, and the fourth replicate was planted 23 May. Hybrids in both the seeding date and plant density studies were planted in two rows that were 0.76 m wide and 7.62 m long in 1983 and in four rows, 0.76 m wide by 6.70 m long in 1984.

Moisture Availability Studies

All nine hybrids in 1983 and the three 100-day RM hybrids in 1984 were grown in separate irrigated and dryland trials at Hancock, WI, on a Plainfield sandy loam (mixed, mesic, Typic Udipsamment). In both years, overhead sprinklers applied 12.7 mm of water twice weekly to the irrigated trial during the growing season. Experimental design for each trial in 1983 was a randomized complete block in split-plot arrangement with four replicates. Main plots were RM groups and subplots were hybrids which were planted in two rows, 0.91 m wide by 7.62 m long. In 1984, experimental design for each trial, with only the 100-day RM hybrids, was completely randomized with five replicates. Hybrids were planted in two rows, 0.76 m wide by 6.70 m long. Hybrids at Hancock were planted on 4 May 1983 and 2 May 1984, and were overplanted and hand-thinned to 5.4 plants m^{-2}.

Soil Nitrogen Fertility Study

An investigation of applied soil N effects on kernel breakage susceptibility was made by collecting samples from an ongoing soil fertility study at Arlington, WI, on a Plano silt loam soil in 1983 and 1984. Grain samples were collected from plots receiving annual N applications of 0, 11, and 22 g m^{-2} with 24 replicates of each N rate. A wide range of soil test P (2 to 16 g m^{-2}) and K (11 to 85 g m^{-2}) levels existed on the plots, due to previous experimental objectives and procedures. Regression analysis within and across N rates, showed that neither P or K soil test levels affected kernel breakage susceptibility. Therefore, analyses of applied N rate effects were conducted across P and K soil test levels. A 105-day RM hybrid (Stauffer[3] 'S5602' in 1983; Stauffer[3] 'S5650' in 1984) was planted on 30 Apr. 1983 and 10 May 1984 at rates to achieve a final stand of 7.2 plants m^{-2}. Plot size was four rows, 0.76 m wide by 12.2 m long.

In seeding date, plant density, and moisture availability experiments, high soil test P and K levels were maintained with preplant-incorporated fertilizers. Soil pH levels ranged from 6.1 to 6.6. Nitrogen was applied at a rate of 17 g m^{-2} in the seeding date and plant density studies each year. At Hancock, 13.5 and 27 g m^{-2} N was applied in the dryland and irrigated trials, respectively, each year. Weed control was accomplished in all studies with a combination of herbicides, cultivation, and hand weeding.

Harvest and Kernel Breakage Test Procedure, 1983 and 1984 Studies

Grain moisture was monitored after physiological maturity in the seeding date and plant density studies. Since hybrids within a RM group were chosen for uniformity of harvest kernel moisture content in the preliminary study, hybrids within each RM, and of the same seeding date, were at similar kernel moisture contents during the post-physiological maturity drying period. A randomly chosen sample of interior border-row ears from two replicates of each RM and seeding date combination was collected at two day intervals. These ears were hand-shelled and kernel moisture-tested with a Dickey-John[3] GAC-II moisture tester. When kernel moisture of any composite sample reached 25%, grain was harvested from two rows of all similarly treated plots (RM and seeding date) with an Almaco[3] SPC-20 plot combine. Combine cylinder speed was 650 rev min^{-1}. Harvest dates of the seeding date and plant density studies ranged from 12 Sept. to 4 Nov. 1983 and 4 Oct. to 5 Nov. 1984.

The Hancock irrigated and dryland studies were combine-harvested on 15 Oct. 1983 and 9 Oct. 1984. Harvest kernel moistures in the two studies ranged from 21 to 29% across RM's in 1983 and in 1984 were 28.3 and 32.1% for the irrigated and dryland studies, respectively. The soil N study was combine-harvested when grain reached 25% moisture on 25 Oct. 1983 and 6 Nov. 1984.

[3] Mention of a trade name does not constitute endorsement by the Univ. of Wisconsin and does not imply its approval to the exclusion of other products that may also be suitable.

A 2-kg shelled-grain sample from each plot was brought to 20°C and then dried in a forced-air oven at air temperatures of 82°C (1983) and 60°C (1984) to approximately 14% kernel moisture. Dried samples were stored in sealed plastic bags until all harvests were completed and then placed in a controlled-environment chamber at 25°C and 65% relative humidity for 2 weeks until kernels equilibrated to a moisture content of 13.5 ± 0.5%. Samples were returned to sealed plastic bags and stored at room temperature until laboratory measurements were made.

Fines that would pass through a 4.76-mm precision round-hole dockage sieve were removed by handshaking and kernel weight, kernel volume by liquid displacement, test weight, and oven-dry moisture content (USDA, 1976) were measured. Kernel density was calculated by dividing kernel weight by kernel volume. Kernel breakage susceptibility tests using the Wisconsin Breakage Tester were performed on two, 200-g subsamples, as described previously. Singh (1985) found a close relationship between kernel breakage susceptibility as determined by the Wisconsin Breakage Tester and grain moisture content and developed a correction factor. This correction factor was used to express breakage susceptibility values on a common grain moisture basis of 13.5%.

Statistical Analysis

Seeding dates, plant densities, N rates, RM's and hybrids were considered fixed effects while blocks were considered random in all analyses. Analyses of variance were performed on data collected from all studies. Years were analyzed separately to avoid confounding environmental effects with the different drying temperatures between years.

Since dryland and irrigated trials were grown on different sites at Hancock, there is no valid statistical test of moisture availability (irrigated vs. dryland) or interactions, without including the confounding effect of growing area. The soil type of each study was very similar, however; thus, general observations were made on moisture availability effects each year. Analyses of covariance were performed within irrigated and dryland studies for kernal breakage susceptibility with harvest kernel moisture content as the covariate to isolate RM and hybrid effects from differences in harvest kernel moistures.

Linear, quadriatic, and deviations from quadratic orthogonal polynomial contrasts were performed on the significant main effects and interactions of the seeding date and plant density studies. Linear and deviation from linear orthogonal polynomial contrasts were performed on the N rate effect in the soil N study. Simple correlation coefficients were computed between kernel breakage susceptibility and kernel density, kernel weight, and test weight for seeding date, plant density, and soil N studies.

RESULTS

Seeding date did not affect grain yield in 1983 (Table 1); yields averaged 737 g m^{-2}. In 1984, overall yields were slightly higher (787 g m^{-2}) and a seeding date × RM interaction occurred (Table 1) due to a slight decline in yield with later planting in the 90- and 110-day RM groups, but no differences among seeding dates occurred in the 100-day RM group. Average yield decreases of 4% (1983) and 6% (1984) occurred across all hybrids when comparing the 30 May date to the 1 May date. Data from 6 yr of seeding date studies (1976–1978, 1980–1982) at Arlington showed that average grain yield was reduced 31% for similar RM hybrids when planting was delayed from 1 May to 1 June (Carter, 1984).

Although yield responses to seeding date were relatively small, kernel breakage susceptibility was affected by seeding date both years (Table 1). A seeding date × RM interaction occurred for breakage susceptibility in 1983 (Tables 1 and 2). Kernel breakage susceptibility increased as planting was delayed past 10 May for the 90-day RM hybrids. In the 100- and 110-day RM groups, however, kernel breakage susceptibility of the 10 May date was greatest with only small differences between the remaining dates. A positive linear kernel breakage susceptibility response to seeding date occurred for all RM groups in 1984 (Tables 1 and 2), with an average increase of 1.6% for each 10-day delay in planting. In 1984, the 90-day RM group had higher kernel breakage susceptibility than the 100- and 110-day RM groups. Frost before physiological maturity is thought to make grain brittle and more susceptible to handling damage (Benson, 1984). All

Table 1. Mean squares from the analysis of variance for the seeding date study, Arlington, WI, 1983 and 1984.

Source of variation	df	Breakage susceptibility	Kernel weight × 10^{-2}	Test weight	Kernel density × 10^{3}	Yield × 10^{-3}
		mean squares				
		1983				
Blocks	2	16.6	0.9	33.2	0.3	8.6
Seeding date (SD)	3	3.2	9.5**	2272.8**	1.1	23.3
Error A	6	9.8	0.9	132.7	0.7	13.0
Relative maturity (RM)	2	364.9**	89.2**	2305.9**	3.5**	392.1**
SD × RM	6	22.0**	2.6*	3500.4**	1.0*	8.5
Error B	16	2.6	0.7	116.1	0.3	3.9
Hybrid (H)[RM]	6	43.7**	74.4**	829.5**	1.2*	70.1**
SD × H (RM)	18	3.5	0.9**	182.5**	0.6	9.2
Error C	48	3.4	0.3	49.8	0.5	5.7
		1984				
Blocks	2	1.9	2.4	87.0	3.7	22.4
SD	3	120.3**	45.9**	3919.9**	14.7	21.8*
Error A	6	6.9	1.7	125.0	7.2	4.6
RM	2	76.7**	62.4**	744.5**	3.6	84.1**
SD × RM	6	6.0	0.9	1448.2**	2.6	17.9*
Error B	16	7.2	1.2	97.9	4.4	4.4
H (RM)	6	20.9**	58.9**	3654.5**	2.5	17.5*
SD × H (RM)	18	2.5	1.9	94.9	3.4	4.2
Error C	48	6.1	1.6	82.5	3.6	3.1

*,** Significance at the 0.05 and 0.01 probability level, respectively.

Table 2. Effect of seeding date and relative maturity on maize kernel breakage susceptibility at Arlington, WI, 1983 and 1984.

Seeding date	1983 Relative maturity (days) 90	100	110	Mean	1984 Relative maturity (days) 90	100	110	Mean
	%							
1 May	24.7†	23.2	19.4	22.4	15.3	12.1	10.8	12.7‡
10 May	23.2	25.6	20.5	23.1	14.7	12.9	12.6	13.9
20 May	26.2	23.7	18.8	22.8	17.0	14.8	13.2	15.0
30 May	27.5	23.5	18..6	23.2	18.0	17.4	17.0	17.5
Mean	25.4	24.0	19.3		16.2§	14.3	13.4	

† Significant (P >0.01) seeding date-deviation from quadratic × relative maturity interaction (1983).
‡ Significant (P <0.01) seeding date linear response (1984).
§ LSD (P = 0.05) for comparing relative maturity means over seeding dates is 1.4 (1984).

Table 3. Mean squares from the analysis of variance for the plant density study, Arlington, WI, 1983 and 1984.

Source of variation	df	Breakage suscepti- bility	Kernel weight × 10^{-2}	Test weight	Kernel density × 10^{3}	Yield × 10^{-3}
		mean squares				
		1983				
Blocks	2	3.5	2.0	431.3	1.0	19.0
Plant density (PD)	3	130.3**	26.2**	879.2*	1.3	191.2**
Error A	6	10.4	2.1	182.5	0.7	1.5
Relative maturity (RM)	2	240.8**	82.3**	1576.0**	7.2**	101.9**
PD × RM	6	8.9	6.7**	99.5	0.4	2.4
Error B	16	4.6	1.0	66.4	0.4	3.2
Hybrid (H)[RM]	6	55.0**	81.7**	1045.1**	1.0*	98.1**
PD × H (RM)	18	8.1	1.8*	82.9	0.5	15.6**
Error C	48	5.1	1.0	82.9	0.4	3.3
		1984				
Blocks	3	96.6**	21.3**	3649.7**	20.2**	26.0
PD	3	240.4**	125.0**	763.1*	4.2	1638.0**
Error A	9	6.5	2.6	149.3	2.1	7.7
RM	2	90.4*	165.9**	3069.0**	24.7**	9.3
PD × RM	6	5.2	8.6**	116.1	4.5	10.0*
Error B	24	4.7	1.0	149.3	3.1	3.0
H (RM)	5	11.6*	80.5**	1410.1**	6.7	4.2
PD × H (RM)	15	8.2*	4.3**	182.5*	3.1	2.7
Error C	60	4.1	0.9	82.9	4.8	1.9

*,** Significance at the 0.05 and 0.01 probability level, respectively.

Table 4. Effect of plant density and relative maturity on maize kernel breakage susceptibility at Arlington, WI, 1983 and 1984.

	Year								
	1983					1984			
	Relative maturity (days)					Relative maturity (days)			
Plants m^{-2}	90	100	110	Mean	Plants m^{-2}	90	100	110	Mean
	%					%			
2.0	21.0	23.4	18.8	21.1†	1.5	8.5	7.7	6.6	7.7†
4.0	21.0	24.1	18.1	21.1	3.5	10.2	8.9	7.0	8.7
6.0	24.4	25.3	20.7	23.5	5.5	14.2	10.9	9.7	11.8
8.0	24.0	29.2	23.8	25.6	7.5	14.9	14.0	12.1	13.9
Mean	22.6‡	25.5	20.3			12.0‡	10.4	8.9	

† Significant ($P < 0.01$) plant density-linear response.
‡ LSD's ($P = 0.05$) for comparing relative maturity means are 1.2 (1983) and 1.1 (1984).

hybrids in this study reached physiological maturity [black layer of kernel development (Daynard and Duncan, 1969)] each year before the first killing frost.

A quadratic grain yield response to plant density occurred each year (Table 3). Yields in 1983 increased from 560 g m^{-2} at the lowest density to 747 g m^{-2} at 6.0 plants m^{-2}, with a slight yield decrease when densities were increased to 8.0 plants m^{-2}. In 1984, yields at the lowest density were 321 g m^{-2} and increased to 795 g m^{-2} at 5.5 plants m^{-2}, with a small yield increase with higher plant densities. Kernel breakage susceptibility increased linearly with plant density both years (Tables 3 and 4). For each 2.0 plants m^{-2} increase in density, average kernel breakage susceptibility increased approximately 1.5% (1983) and 2.0% (1984). No interactions between plant density and RM occurred for kernal breakage susceptibility (Tables 3 and 4). In both years, the 110-day RM group had lower kernel breakage susceptibility than the 90- and 100-day RM groups (Table 4). In 1983, the 100-day RM group had higher kernel breakage susceptibility than the 90-day RM group; however, in 1984, the 90-day RM group was highest.

In seeding date and plant density studies, hybrid kernel breakage susceptibility rankings within a RM were not similar to the preliminary study, except within the 110-day RM, where CFS1400 ranked highest (Table 5). Except for CFS1400, hybrid rankings were not consistent across years and studies. A hybrid within RM × plant density interaction occurred for kernel breakage susceptibility in 1984 (Table 3). This interaction was limited to hybrid differences in magnitude, not direction, of response to plant density. No hybrid within RM interactions occurred with seeding date (Table 1).

Grain yield of dryland-grown maize was only 55% of the irrigated-maize yields at Hancock each year. Average yields in 1983 were 483 g m^{-2} (dryland) and 893 g m^{-2} (irrigated). In 1984, yields were 396 and 721 g m^{-2} for dryland and irrigated trials, respectively. Grain produced under dryland conditions had lower kernel breakage susceptibility than the irrigated grain both years (Table 6). Similar to the seeding date and plant density studies, the 110-day RM group had lower kernel breakage susceptibility than the other two RM

Table 5. Maize hybrid kernel breakage susceptibility means in the seeding date and plant density studies at Arlington, WI, 1983 and 1984.

		Study			
		Seeding date		Plant density	
Relative maturity	Hybrid	1983	1984	1983	1984
days		%			
90	RX355	26.2	17.1	24.1	12.8
	KX39	22.5	15.4	19.9	11.8
	LX4040	27.5	16.2	23.8	12.2
100	H3640	23.4	14.7	25.8	10.3
	TS-60	25.0	14.0	24.4	7.8
	SL-40	23.6	14.1	26.3	11.9
110	CX10A	18.2	12.8	18.3	9.5
	S5602	18.4	11.6	19.3	8.2
	CFS1400	21.4	15.7	23.4	--
LSD (0.05)†		0.8	1.0	1.9	1.4

† LSD for comparing hybrids within a relative maturity and year.

Table 6. Maize hybrid kernel breakage susceptibility least square means at Hancock, WI, in 1983 and 1984.

		Dryland		Irrigated	
Relative maturity	Hybrid	1983	1984	1983	1984
days		%			
90	RX355	19.0		26.7	
	KX39	22.6		24.9	
	LX4040	17.4		24.1	
	Mean	19.7		25.2	
100	H3640	21.9	18.0	23.6	17.6
	TS-60	20.6	15.5	24.2	16.9
	SL40	21.9	13.9	25.2	16.4
	Mean	21.5	15.8	24.3	17.0
110	CX10A	13.6		14.9	
	S5602	13.8		18.0	
	CFS1400	18.1		16.4	
	Mean	15.2		16.4	
LSD (0.05),	Hybrids within relative maturity	4.3	3.1	NS	NS
LSD (0.05),	Relative maturities	3.9		NS	

Table 7. Mean seeding date, plant density, and soil N rate effects on kernel weight, test weight, and kernel density at Arlington, WI, 1983 and 1984.

Study	Treatment 1983	Treatment 1984	Kernel weight 1983	Kernel weight 1984	Test weight 1983	Test weight 1984	Kernel density 1983	Kernel density 1984
			mg		kg m^{-3}		g cm^{-3}	
Seeding date	1 May		311	308	707	718	1.15	1.21
	10 May		313	311	729	724	1.16	1.19
	20 May		308	303	724	710	1.16	1.16
	30 May		300	282	721	700	1.15	1.16
	Contrast†		Q*	Q*	D*	D*	NS	NS
Plant density (plants m^{-2})	2.0	1.5	330	330	717	718	1.18	1.20
	4.0	3.5	327	329	727	723	1.17	1.21
	6.0	5.5	319	310	728	721	1.17	1.21
	8.0	7.5	308	289	730	712	1.16	1.18
	Contrast†		L**	Q**	L*	Q*	NS	NS
Soil N (g m^{-2})	0		266	267	686	665	1.09	1.10
	11		313	316	713	687	1.14	1.16
	22		322	328	714	692	1.15	1.19
	Contrast†		D**	D**	D**	D**	D**	D**

*,** Significance at the 0.05 and 0.01 probability level, respectively.
† Highest order significant orthogonal contrast (L = linear, Q = quadratic, D = deviation from linear, NS = nonsignificant).

Table 8. Mean relative maturity effect on kernel weight, test weight, and kernel density for seeding date and plant density studies at Arlington, WI, 1983 and 1984.

Study	Relative maturity	Kernel weight 1983	Kernel weight 1984	Test weight 1983	Test weight 1984	Kernel density 1983	Kernel density 1984
	days	mg		kg m^{-3}		g cm^{-3}	
Seeding date	90	295	299	715	786	1.16	1.19
	100	304	289	718	788	1.14	1.18
	110	325	315	731	780	1.16	1.17
LSD (0.05)		4	6	5	5	0.01	NS
Plant density	90	311	316	734	728	1.19	1.23
	100	313	300	722	727	1.16	1.20
	110	338	344	724	714	1.16	1.19
LSD (0.05)		5	4	4	5	0.01	0.02

groups in both the irrigated and dryland studies (Table 6). Hybrid CFS1400 had higher kernel breakage susceptibility than the other two 110-day RM hybrids in the 1983 Hancock-dryland study. This was the only hybrid to maintain a similar kernel breakage susceptibility ranking within RM across all studies where hybrid differences occurred (preliminary, seeding date, plant density, and Hancock-dryland studies).

Grain yield responses to N rate deviated from linear both years. Averaged over years, yield increased from 336 to 776 g m^{-2} between 0 and 11 g N m^{-2}, and only a 16 g m^{-2} increase occurred between 11 and 22 g N m^{-2}. Kernel breakage susceptibility also exhibited a deviation from linear response to N rate. Values declined from 32.1 to 20.6% (1983) and 25.1 to 14.3% (1984) when N rate was increased from 0 to 11 g m^{-2}. The decrease in kernel breakage susceptibility continued as N rate was increased to 22 g m^{-2}, but at a slower rate. Values were 19.4% (1983) and 11.2% (1984) at the highese N rate.

Kernel physical characteristics (weight, volume, test weight, and density) were measured to assist in explaining breakage susceptibility responses. Singh (1985) and Leford and Russell (1985) reported high correlations between kernel volume and kernel weight. Our results also showed a close relationship between these two kernel characteristics; therefore, only kernel weight is reported. Kernel weight and test weight responses were significant for seeding date, plant density, RM, hybrid within RM (Tables 1 and 3), and soil N rate. Kernel weight increased with early seeding and increased N rates (Table 7). Higher plant densities resulted in decreased kernel weight. The 110-day RM group had greatest kernel weight; 90- and 100-day RM kernel weights were similar (Table 8). Test weight increased with soil N rate (Table 7), but test weight responses to seeding date and plant density (Table 7), RM (Table 8), and hybrid within RM were inconsistent between studies and years. Kernel density was not influenced by seeding date or plant density (Tables 1, 3, and 7), but increased with greater N rates (Table 7). Although kernel density differences due to RM occurred, responses varied (Table 8). In the plant density study, 100- and 110-day RM hybrids had lower kernel densities than 90-day RM hybrids, but no general kernel density trends occurred for RM in the seeding date study.

Table 9. Correlation coefficients between kernel breakage susceptibility and physical characteristics in 1983 and 1984.

Study	1983 Kernel weight	1983 Test weight	1983 Kernel density	1984 Kernel weight	1984 Test weight	1984 Kernel density
Seeding date	−0.33*	−0.19*	−0.04	−0.40*	−0.19*	−0.14
Plant density	−0.46*	0.21*	−0.16	−0.41*	−0.23*	−0.17
Soil N	−0.91**	−0.79**	−0.82**	−0.90**	−0.83**	−0.65**

*,** Significance at the 0.05 and 0.01 probability level, respectively.

The range in treatment differences for kernel characteristics was fairly small, even when significant, in all but the soil N study (Tables 7 and 8). Similarly, correlations between kernel breakage susceptibility and other parameters were small, except for the soil N study, where all relationships were highly significant (Table 9). Kernel density was not correlated with breakage susceptibility in seeding date or plant density studies. In all studies, negative correlations occurred between kernel breakage susceptibility and kernel weight.

DISCUSSION

Increased kernel breakage susceptibility in 1983 compared to 1984 (Tables 2, 4, 5, and 6) was most likely due to higher drying temperatures in 1983. At high drying temperatures, stress cracks (fissures in the kernel endosperm) form, which make kernels more susceptible to breakage (Thompson and Foster, 1963). The high drying temperatures in 1983 appeared to partially mask responses due to treatments, since main effect treatment differences as a percentage were greater in 1984 than 1983, especially for seeding date and plant density.

Increased kernel weight and volume were associated with decreased kernel breakage susceptibility in seeding date, plant density, and soil N studies. This might be an artifact of the sieving procedure following breakage testing; more broken pieces of large kernels would be retained without passing through the sieve than pieces from smaller kernels. However, since correlations between kernel weight and breakage susceptibility were relatively small in seeding date and plant density studies, other factors evidently are involved.

Maize kernels with a high proportion of corneous vs. floury endosperm are thought to be breakage-resistant (Ellis et al., 1983; Paulsen et al., 1983). Corneous endosperm is more dense and contains more zein, a major storage protein, than floury endosperm (Wichser, 1961). Unfortunately, endosperm type ratios were not measured in our study, although we observed in the soil N study that kernel fines passing through the sieve after impacting grain from the 11 and 22 g N m^{-2} treatments contained many hard, flinty pieces, while fines from 0 N m^{-2} treatments had a powdery texture. Hamilton et al., (1951) reported that maize produced under high soil fertility (manure, lime, and P applied) conditions had higher corneous/floury kernel endosperm ratios than that grown under suboptimum soil nutrition (no fertilizer additions). Kernel protein (N) content was increased in the high fertility treatment, and this was attributed to the increased proportion of zein-containing corneous endosperm.

The "floaters test" is an indirect method for estimating the corneous/floury endosperm ratio (Wichser, 1961). Kernels that float in a carbon tetrachloride-kerosene solution tend to be soft due to relatively low amounts of corneous endosperm. We suspected that kernel density and floaters test measurements might be related and anticipated a close relationship between kernel density and breakage susceptibility. However, except for the soil N study, this relationship did not occur. Paulsen et al. (1983) found negative correlations (r=0.89) between percentage of floaters and kernel breakage susceptibility values for high-temperature dried grain from commonly grown central USA maize hybrids. In general, genotypes with low percentages of floaters had thick corneous endosperms (measured directly by visual observation) and high kernel densities. However, with maize hybrids of similar parentage grown the same year at another location, they found no correlation between floaters percentage and kernel breakage susceptibility. These conflicting responses, and our low correlations between kernel density and breakage susceptibility in seeding date and plant density studies, indicate that indirect measures of "kernel hardness" such as percent floaters and kernel density may not adequately reflect kernel corneous vs. floury endosperm status under a wide range of conditions.

Kernel breakage susceptibility differences due to seeding date, plant density, moisture availability, and RM may have been due to altered corneous/floury endosperm ratios, related to different kernel protein or starch metabolism patterns. During grain fill, temperature (Jones et al., 1981; Hunter et al., 1977) and plant moisture status (Harder et al., 1982; Pierre et al., 1977) influence kernel endosperm starch and protein assimilation. Delayed seeding, increased plant density, and reduced soil moisture in our studies are all factors that modified environmental conditions (temperature, nutrient availability, and plant moisture status) during grain-filling.

Delayed planting and increased hybrid RM both caused pollination and grain filling to occur later in the season, but later seeding often increased kernel breakage susceptibility, while increasing RM decreased breakage susceptibility within and across seeding dates. This indicates that decreased kernel breakage susceptibility of later RM hybrids was due to innate kernel characteristics and not to an altered growing environment during later seasonal development. Tsai et al. (1984) found major differences in kernel zein content and N assimilation during grain-fill between an early and a late-maturing maize hybrid. Kernel starch synthesis and endosperm-type ratios might also be influenced by hybrid maturity.

Maize producers will not readily accept cultural changes that improve maize kernel breakage resistance while concurrently decreasing yield potential. In our studies, early planting, optimum soil N fertility, and full-season hybrids (when all hybrid maturities were harvested at 25% kernel moisture) all decreased kernel breakage susceptibility while maintaining or increasing yields. However, increased plant densities resulted in lower kernel breakage resistance. The trend in the northern USA towards greater maize yields with higher plant densities (Carter, 1984) may adversely influence kernel breakage susceptibility.

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