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Shrunken2 Sweet Corn Yield and the Chemical Components of Quality

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Abstract. **Extensive variability was found among 24 currently available commercial *sh2* hybrids of sweet corn (Zea *mays* L.) for yield and yield components, and for the chemical components of eating quality. The primary source of variation was explained by genotypic differences, with the environmental effects due to planting locations having a minor influence. Kernel sugar concentrations, however, had a highly significant level of genotype by environment interaction. The extensive genotypic variability among the *sh2* hybrids indicated that allelic variation at other loci is profoundly influencing sucrose and total sugar levels in freshly harvested sweet corn. In each case, the kernel chemical components of quality decreased from 20 to 29 days after pollination (DAP). Mean performance of *sh2* hybrids for yield, yield components, and kernel quality parameters was in all cases equal or better than the hybrids homozygous for the *su1* endosperm mutation. In addition, there were no strong negative relationships between yield and some of the important chemical components of kernel quality, suggesting that it may be feasible to develop superior *sh2* hybrids with acceptable yield potential and improved eating quality targeted for the different sweet corn markets.**

The primary components of sweet corn eating quality associated with consumer preference are kernel flavor, texture, and aroma (Flora and Wiley, 1974). Sweetness in sweet corn constitutes most of what the average consumer perceives as flavor (Culpepper and Magoon, 1927), and it is closely related to kernel sucrose content (Reyes et al., 1982), the primary sugar in developing kernels (Cobb and Hannah, 1981). Textural eating quality of sweet corn consists of several factors, including pericarp tenderness (Bailey and Bailey, 1938), level of water soluble polysaccharides or phytoglycogen (Culpepper and Magoon, 1927), and moisture content (Wann et al., 1971). Aroma, which has not been as easily defined as either sweetness or texture, is most often associated with dimethyl sulfide (DMS), a volatile compound described by taste panelists as lending a pleasing and "corn-like" character (Wiley, 1985). Several studies have reported significant differences in DMS levels among sweet corn genotypes and harvest maturities, with DMS content decreasing with increasing kernel age (Dignan and Wiley, 1976; Williams and Nelson, 1973). Traditional sweet corn hybrids homozygous for the *sugary1 (su1)* mutation are characterized by rapid moisture loss and the conversion of endosperm sugars to starch. This decline in quality places a time constraint on the shipment of fresh sweet corn to major urban markets and also creates a very narrow harvest window for the sweet corn processing industry (Marshall, 1987). Consequently, there has been a dramatic shift away from the traditional *su1* hybrids to hybrids with the *shrunken2 (sh2)* mutation. Compared to *su1,* the *sh2* phenotype is characterized by kernels that have two to three times more sucrose at harvest maturity (Creech, 1965), can retain higher sugar and moisture content for longer postharvest periods (Garwood et al., 1976), and is preferred by consumers in taste tests (Evensen and Boyer, 1986; Showalter and Miller, 1962).

While the long-distance shipping market of fresh sweet corn has largely converted to the use of *sh2* hybrids, acceptance and use in the processing sector of the industry has lagged behind because there has been a perception that these hybrids display poor stand establishment and yield potential. Some of the first *sh2* hybrids released in the 1960s and 1970s suffered from these problems, but numerous extension publications suggest that more recent hybrids have improved yield and enhanced quality. Comparison of *sh2* hybrids with widely used *su1* hybrids for yield, yield components, and kernel quality is needed to determine any improvements. The following experiments were designed to provide information on the phenotypic variability among commercial *sh2* hybrids for yield and yield components, and for the chemical composition of eating quality. Additional objectives were to determine the effect of harvest maturity on the chemical composition of eating quality, examine the relationships between yield, yield components, and quality attributes, and provide sweet corn breeders with the information needed to develop superior *sh2* hybrids.

Materials and Methods

Field design. In 1989, 31 commercial hybrids, consisting of 24 *sh2,* five *su1,* and two *sugary enhancer (se1)* types, were grown in a randomized complete-block design with four replications on a Flanagan silt loam (fine, montmorillonitic, mesic Aquic Argiudoll), characterized by high (5%) organic matter content and high nutrient holding capacity (a CEC of 24.0 meq·l00g^{-1} soil), at the South Urbana Research Farm of the University of Illinois. The 24 *sh2* hybrids were chosen for their potential use by the processing industry, while the five *su1* types were selected as standards currently used in commercial sweet corn production. Each plot consisted of four rows spaced 90 cm apart, with each row containing 30 hills at 25-cm intervals. Plots were established by hand planting to result in an approximate stand of 50,000 plants/ha. Plants in the two outer rows were self-pollinated.

The following year, six *sh2* hybrids, which varied in yield and kernel chemical composition in the 1989 study, were planted on a Plainfield sand (mixed, mesic Typic Udipsamment) at the Illinois River Valley Sand Field (IRVSF) in Kilbourne, Illinois. This site, with soil organic matter content of 0.7% and a CEC of 2.5 meq·l00 g^{-1}, was selected to determine the effect of environment on yield and chemical composition of quality in *sh2* sweet corn. Four replicates of the six genotypes were planted in a randomized

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complete-block design at a planting density equivalent to the 1989 field experiment. Supplemental sprinkler irrigation was provided as needed throughout the growing season.

Yield and yield component evaluations. Pollination of the central row(s) was permitted to occur via open pollination. From 20 to 25 ears in the outer rows were manually self-pollinated at plot mid-silk for subsequent sample harvest. Husked ears from the central row(s) were used for comparison of ear uniformity, the components of yield (i.e., ear weight, ear length, and kernel depth), and estimates of yield (i.e., potential ear yield and kernel yield). Open-pollinated ears were harvested 23 days after the plot mid-silk date and evaluated within 24 h.

A rating scale of 0 to 4 was used to rate husked ear uniformity. Genotypes were assigned a uniformity rating of 0 when less than 10% of the ears harvested in a plot had good marketable quality, up to a rating of 4 when more than 90% of the ears harvested were identical in size, shape, and overall appearance. Ten of the ears harvested from each plot were then selected randomly and measured to determine average ear weight (g) and average ear length (cm). Mean kernel depth (cm) was estimated from averaged measurements from three of these ears. Ears were broken in half and kernel depth was measured with a ruler.

Potential yield was the estimated weight in $MT \cdot ha^{-1}$ of husked ears, assuming a stand density of 45,000 plants/ha. Kernel yield was estimated by using the following formula: kernel yield $=[\pi(r_{ear})^2 l_{ear}]-[\pi(r_{cob})^2 l_{ear}]/\pi(r_{ear})^2 l_{ear} \times$ potential yield, where ^{r}ear = ear radius in cm, ^{l}ear = ear length in centimeters, and r_{cob} = ear radius – kernel depth in centimeters. The first part of the formula is essentially the proportion of kernel volume in an average ear. Multiplying this proportion by the potential yield would give an estimate of kernel yield in $MT \cdot ha^{-1}$ that the various genotypes would provide the processors after separation of the kernels from the husks by commercial cutting machines.

Chemical analysis. All ears harvested for chemical analyses were hand-pollinated to ensure uniform maturity and genetic purity. As many plants as possible within a plot were pollinated on the same day with a minimum of about ten plants in each of the outer rows. Harvests of self-pollinated ears in each plot were made at 3-day intervals from 20 to 29 days after pollination (DAP) in 1989, and from 20 to 26 DAP in 1990. These stages were chosen because sugars reach maximum levels at ≈21 DAP and sweet corn typically is harvested at this stage of maturity (Carey et al., 1984). No ears were harvested within 1 m of the beginning and end of each row to avoid edge effects on yield and chemical analyses.

At each harvest date, four self-pollinated ears were picked at random for each genotype in each of the four replicates. Directly after harvest, ears were husked and silk was removed. To reduce sample storage volume, a portion of the tip and butt of each ear was discarded. The remaining portion was immediately frozen in liquid nitrogen to stop all metabolic activity. Frozen ears were placed in labeled plastic bags, placed on dry ice, and transported to cold storage at about –20C. The time from harvest to freezing in liquid nitrogen was generally <15 min. By resuspension of the frozen ears in liquid nitrogen, a central band of kernels (≈2.5 cm) was later removed from individual ears with a screwdriver. Kernels from each of the four ear samples were bulked. Subsamples were then weighed, freeze-dried, weighed again for moisture content determination, ground into powder with a coffee grinder, and stored in the freezer at –20C for subsequent sugar and DMS analyses.

Sugars and DMS levels were analyzed using a gas chromatograph (model 5790A; Hewlett-Packard, Palo Alto, Calif.) with an autosampler (model 7671A; Hewlett-Packard), a 12-m capillary column (model Ultra-l; Hewlett-Packard), a flame-ionization detector, and an integrator (model 3390A; Hewlett-Packard). Helium was used as the carrier gas.

Determination of fructose, glucose, and sucrose concentrations ($mg \cdot g^{-1}$ dry weight of seed) was conducted as described by Juvik and LaBonte (1988), who reported this procedure effective in extracting >98% of the sugars in ground kernel samples. Total sugars were obtained by adding the amounts of fructose, glucose, and sucrose. Dimethyl sulfide level was analyzed using the procedure of Breeden and Juvik (1992), and expressed as $\mu g \cdot g^{-1}$ dry weight of seed. This method avoids the problems of headspace gas analysis by keeping the DMS in solution, and is compatible with automated multiple-sample gas chromatographic analysis.

Data evaluation. Analysis of variance (ANOVA) was performed on yield and yield components for each location. A factorial design was used to analyze for kernel moisture content, sugar concentration, and DMS level, with genotype and kernel maturity as main factors. Least significant difference (LSD) values calculated at $P = 0.05$ (Steel and Torrie, 1960) were used to compare hybrid means within kernel maturity, and kernel maturities within hybrids. Based on the ANOVA procedure, the percentage of variability explained by each source of variation was computed for yield and yield components at 23 DAP, and for kernel chemical composition at 20 DAP for the six *sh2* hybrids used in both locations. These were calculated by dividing the sum of squares of the factor involved by the total sum of squares and expressed as percentages.

To address the issue of *sh2* yield, yield components, and kernel quality performance, replicate means averaged over the 24 *sh2* hybrids in the Urbana planting were compared with replicate means averaged over the five widely used *su1* hybrids using Student's *t* test as described by Steel and Torrie (1960). Yield and yield component evaluations were tested from the 23 DAP harvest, while kernel chemical compositions were computed from the 20 DAP harvest. The two *se1* hybrids were not included in this evaluation, since the sample size was insufficient. In addition, simple phenotypic correlations over all the *sh2* hybrids grown at the South Urbana Research Farm were determined between yield, yield component evaluations, and kernel chemical compositions at 23 DAP, and between chemical factors of quality at 20 and 23 DAP.

Results and Discussion

Yield and yield component evaluations. In 1989, significant differences among genotypes were observed for all of the yield and yield component parameters measured (Table 1). Ear uniformity, an important characteristic for the fresh market industry, ranged from a low of 1.0 in 'Style Sweet' and 'Sweetie 70' to a high of 3.5 in 'Sweetie 82'. Kernel depth and kernel yield, two closely related parameters important to the processing industry, were generally highest in 'Florida Staysweet' and 'Sweetie 82', and lowest in 'Sweetie 70'. Ear weight also varied significantly, with highest values in 'FMX 261' and 'Summer Sweet 7210'. Among the *sh2* hybrids, potential yields showed an almost 2-fold difference, ranging from 6.6 $MT \cdot ha^{-1}$ in 'Sweetie 70' and 7.2 $MT \cdot ha^{-1}$ in 'Crisp-N-Sweet 620' to 12.5 $MT \cdot ha^{-1}$ in 'Summer Sweet 7210'.

Similar to the response in 1989, significant differences were observed in 1990 among the six *sh2* hybrids for each of the yield variables evaluated (Table 1). Ear weight and ear length at the IRVSF site were generally highest in 'Crisp-N-Sweet 710' and 'FMX 263', and along with good kernel depth provided for high potential yields and kernel yields. 'Summer Sweet 7210' produced a generally smaller ear in 1990, with lower potential yield and kernel yield. 'Sweetie 70' at the IRVSF station produced small ears

Table 1. Yield and yield component evaluations of hybrids harvested at 23 DAP at South Urbana Research Farm (1989) and the Illinois River Valley Sand Field (1990).

Hybrid[z]	Ear uniformity (0 to 4)[x]	Ear wt (g)	Ear length (cm)	Kernel depth (cm)	Potential yield ($MT \cdot ha^{-1}$)	Kernel yield ($MT \cdot ha^{-1}$)
			1989			
Bunker Hill	2.1	210.2	18.9	0.75	9.3	5.2
Crisp-N-Sweet 620	1.5	163.2	17.4	0.77	7.2	4.3
Crisp-N-Sweet 710	2.5	231.8	20.6	0.72	10.3	5.4
Excel GSS3724	2.4	191.7	20.6	0.72	8.5	4.8
Florida Staysweet	2.6	238.6	20.4	0.94	10.6	6.8
FMX 263	2.6	235.2	21.0	0.82	10.5	6.1
Illini Gold	3.1	238.6	21.0	0.79	10.6	6.1
Landmark	2.2	254.5	20.9	0.86	11.3	6.7
Northern Extrasweet	1.4	171.2	18.5	0.66	7.6	4.0
Pinnacle	2.6	223.9	20.8	0.79	10.0	5.7
SCH 4006	1.9	239.8	20.9	0.79	10.7	6.1
SCH 4415	3.2	250.0	19.2	0.84	11.1	6.4
Style Sweet	1.0	198.7	17.3	0.78	8.8	5.2
Sucro	2.9	250.0	20.8	0.84	11.1	6.5
Summer Sweet 7210	2.6	280.3	21.0	0.77	12.5	6.6
Summer Sweet 8000	3.1	246.6	19.9	0.85	11.0	6.4
Supersweet Jubilee	2.5	200.8	19.6	0.80	8.9	5.1
Sweet Belle	2.8	242.0	21.0	0.81	10.8	5.6
Sweetie 70	1.0	149.5	18.8	0.56	6.6	3.2
Sweetie 76	2.4	234.1	18.4	0.86	10.4	5.6
Sweetie 82	3.5	260.2	20.0	0.90	11.6	6.9
Upmost	1.9	210.2	19.1	0.79	9.4	5.4
Wisc. Natl. Sweet 9000	2.5	228.3	20.4	0.82	10.2	5.9
Xtra Sweet 82	1.6	244.2	20.0	0.83	10.9	6.2
Bellringer *su1*	2.8	212.5	19.6	0.86	9.4	5.9
FMX 261 *su1*	2.5	284.1	21.6	0.80	12.6	6.7
Jubilee *su1*	3.0	234.1	20.8	0.83	10.4	6.2
Seneca Horizon *su1*	1.9	230.7	16.3	0.78	10.3	5.4
Style Pack *su1*	2.4	269.3	20.3	0.80	12.0	6.6
Maple Sweet *se1*	1.5	143.2	16.3	0.72	6.4	3.6
Merlin Supersweet *se1*	1.2	156.8	17.8	0.69	7.0	3.8
LSD ($P = 0.05$)[y]	1.1	39.3	1.6	0.1	1.8	1.2
			1990			
Crisp-N-Sweet 710	3.1	235.6	20.4	1.20	10.5	7.6
FMX 263	2.7	232.4	21.1	1.18	10.3	7.5
Summer Sweet 7210	3.0	211.0	20.0	1.17	9.4	6.8
Supersweet Jubilee	3.0	199.0	19.6	1.22	8.8	6.7
Sweetie 70	2.1	190.5	19.0	0.92	8.5	5.3
Sweetie 82	3.5	218.8	18.7	1.23	9.7	7.2
LSD ($P = 0.05$)[y]	0.4	28.6	0.8	0.1	1.3	1.0

[z]*sh2* endosperm mutation unless otheruise indicated.
[y]LSD between hybrid means at $P = 0.05$.
[x]Rating of 0 was assigned when <10% of the ears harvested in a plot had good marketable quality up to a rating of 4 when >90% of the ears harvested were identical in size, shape, and overall appearance.

and low yield, while 'Sweetie 82' maintained a uniform ear with large kernels, resulting in high kernel yield. With the exception of 'Sweetie 70', which performed marginally at both sites, differences in the relative ranking of genotypes between locations for ear weight, potential yield, and kernel yield indicated that there was significant genotype × environment interaction influencing hybrid yield and yield component parameters.

Chemical components of kernel quality. Significant differences among hybrids and over harvest dates were observed in each of the kernel chemical variables for the 31 hybrids grown in Urbana (Table 2). At 20 DAP, kernel moisture content in *sh2* hybrids ranged from 73.1% in 'Crisp-N-Sweet 620' to 76.8% in 'Florida Staysweet', suggesting that the hybrids varied in their rates of ear maturation. As anticipated, kernel moisture content decreased with increasing harvest maturity, dropping 5.2% from 20 to 29 DAP, or 0.6%/day among the *sh2* hybrids.

Variation in the concentrations of individual and total sugars was significant among the *sh2* hybrids during the 1989 season (Table 2, refer to the bottom of table for LSDs). Except in three of the *sh2* hybrids, sucrose was the primary sugar, accounting for 76.7% of the mean total sugar content. Of the 24 *sh2* hybrids evaluated, 'Upmost', 'Wisconsin Natural Sweet 9000', and 'Xtra

Table 2. Kernel composition for hybrids grown at South Urbana Research Farm.

Hybrid[z]	DAP[y]	Moisture (%)	Fructose	Glucose	Sucrose	Total sugars	DMS
			($mg \cdot g^{-1}$)				($\mu g \cdot g^{-1}$)
Bunker Hill	20	74.8	22.8	25.8	261.5	310.1	77.5
	23	73.2	21.6	26.8	258.6	306.9	41.8
	26	71.8	18.9	22.3	206.1	247.4	35.0
		1.7	6.8	7.6	19.7	22.0	14.8
Crisp-N-Sweet 620	20	73.1	40.7	43.6	371.0	455.2	67.4
	23	71.3	40.1	42.8	320.7	403.6	50.2
	26	69.2	26.8	29.7	260.7	317.3	28.8
		0.8	7.7	7.6	43.9	40.7	14.8
Crisp-N-Sweet 710	20	75.8	41.5	48.6	317.5	407.6	184.6
	23	73.3	36.3	42.5	286.9	365.7	107.3
	26	72.0	29.6	35.2	228.3	293.1	59.4
		0.5	8.1	6.9	40.2	44.9	33.3
Excel GSS3724	20	73.2	15.3	16.4	115.3	147.1	72.2
	23	72.7	14.4	15.8	109.6	139.9	39.3
	26	71.8	13.3	14.5	106.1	133.9	24.3
		1.3	3.4	3.1	19.0	23.1	11.5
Florida Staysweet	20	76.8	18.7	16.6	121.6	156.8	92.8
	23	73.7	12.4	14.4	110.4	137.2	51.7
	26	73.1	8.1	9.8	96.8	114.7	24.4
		1.4	7.0	3.5	13.5	14.8	18.3
FMX 263	20	75.5	22.9	25.8	266.3	315.0	76.4
	23	72.6	13.7	17.7	222.0	253.4	41.7
	26	73.6	14.0	17.6	204.4	236.0	16.6
		1.5	3.3	4.3	45.8	47.9	10.9
Illini Gold	20	74.5	17.2	21.4	282.4	321.0	54.9
	23	72.6	10.8	14.2	235.9	261.0	46.7
	26	71.6	10.3	14.0	183.0	207.3	16.2
		1.2	4.1	4.4	32.4	36.5	20.6
Landmark	20	74.5	13.8	16.0	184.8	214.6	97.0
	23	72.4	18.3	22.3	237.2	277.8	40.0
	26	70.9	14.1	17.6	193.6	225.3	22.8
		0.9	3.7	3.1	39.8	36.3	16.0
Northern Extrasweet	20	75.0	32.7	38.1	221.4	292.2	117.9
	23	72.3	33.7	36.7	210.1	280.5	82.6
	26	70.3	30.6	33.9	208.4	272.9	32.5
		1.1	3.4	2.6	32.8	28.7	16.1
Pinnacle	20	75.6	35.3	37.8	237.2	310.3	154.3
	23	73.8	28.0	31.0	188.2	247.2	64.4
	26	72.6	24.1	26.5	166.7	217.3	41.3
		1.1	5.6	4.6	62.4	60.4	36.4
SCH 4006	20	74.6	25.2	33.3	268.1	326.6	92.1
	23	73.3	23.0	26.2	242.7	291.9	62.7
	26	72.0	19.9	23.5	201.2	244.6	29.3
		1.2	10.0	7.0	42.4	50.3	17.4

Sweet 82' were genetically unique in that the dominant sugar fraction was in the form of hexose (i.e., fructose and glucose) instead of sucrose. At 20 DAP, sucrose concentrations in *sh2* hybrids varied from 33 to 371 $mg \cdot g^{-1}$ dry weight, while total sugar content ranged from 133 to 455 $mg \cdot g^{-1}$ dry weight. This range of variability among the *sh2* hybrids suggests that allelic variation at other loci is profoundly influencing sucrose and total sugar levels in freshly harvested sweet corn.

Ears from the 20 DAP harvest had the highest kernel sucrose and total sugar concentrations (Table 2). Total sugar levels averaged over the *sh2* hybrids dropped from 289 $mg \cdot g^{-1}$ dry weight at 20 DAP to 186 $mg \cdot g^{-1}$ dry weight at 29 DAP, a total loss of 36% over a 9-day period, or 4%/day. Substantial variation among the hybrids was observed in the rates of sugar loss with increasing kernel maturity. For example, of two hybrids with comparable sugar concentrations at 20 DAP, the average sugar loss per day was only 2.8% for 'Northern Extrasweet', but was 5.7% for 'Illini Gold'. Soberalske and Andrew (1978) have emphasized the importance of considering both the amount of sugar and its rate of change in varietal selection and breeding programs, since both factors influence sweet corn quality.

In 1990, the general response in the various kernel chemical quality components for the six *sh2* hybrids at the IRVSF (Table 3) was comparable to results in the 1989 field trial at Urbana, with

Table 2. Kernel composition for hybrids grown at South Urbana Research Farm (cont.).

Hybrid	DAP	Moisture (%)	Fructose	Glucose	Sucrose	Total sugars	DMS
			($mg \cdot g^{-1}$)				($\mu g \cdot g^{-1}$)
SCH 4415	20	73.7	34.4	37.4	282.0	353.8	54.6
	23	72.1	29.7	32.9	290.5	353.1	27.4
	26	69.1	28.0	30.7	226.3	285.0	25.8
		1.2	7.5	8.2	68.4	74.0	16.9
Style Sweet	20	75.4	41.3	42.3	308.3	391.9	80.8
	23	74.8	48.9	50.9	289.7	389.5	58.4
	26	75.3	24.9	30.1	324.9	379.9	36.8
		1.6	15.7	13.4	72.0	65.0	14.5
Sucro	20	73.2	26.0	36.1	210.5	272.6	98.4
	23	72.0	39.4	47.7	209.3	296.4	50.4
	26	71.5	22.8	29.2	164.6	216.6	39.1
		1.0	14.2	14.4	49.9	66.9	15.5
Summer Sweet 7210	20	75.1	42.9	46.5	185.2	274.6	206.6
	23	72.1	23.6	32.8	170.8	227.2	109.6
	26	69.5	27.0	33.6	158.1	218.8	59.9
		1.9	15.2	12.8	35.5	47.0	44.3
Summer Sweet 8000	20	74.6	37.6	36.0	228.7	302.3	112.0
	23	74.1	29.1	29.4	195.0	253.4	72.8
	26	73.6	22.4	22.4	192.7	237.6	39.4
		1.6	9.0	7.6	41.0	34.8	16.8
Supersweet Jubilee	20	74.6	26.8	30.2	223.8	280.8	56.1
	23	73.7	23.0	27.0	207.4	257.4	33.4
	26	73.6	16.7	20.4	171.8	208.9	10.6
		2.0	6.1	6.7	36.8	46.8	10.7
Sweet Belle	20	74.8	32.9	32.9	267.3	333.2	81.8
	23	73.0	30.1	30.2	218.4	278.8	47.3
	26	73.0	19.8	20.0	206.3	246.2	69.8
		0.7	6.8	5.8	41.4	44.9	21.3
Sweetie 70	20	72.8	42.3	38.6	194.8	275.7	95.9
	23	71.1	35.6	33.7	174.9	244.2	66.6
	26	68.2	27.5	26.3	153.9	207.6	31.0
		2.0	9.9	8.1	37.8	47.2	22.2
Sweetie 76	20	73.7	29.6	28.1	156.6	214.2	79.3
	23	73.7	19.9	19.0	151.8	190.6	66.9
	26	73.3	19.3	21.1	137.2	177.7	28.4
		0.9	6.7	3.8	16.7	15.0	14.0
Sweetie 82	20	75.7	33.0	29.8	174.7	237.6	110.5
	23	74.4	28.6	27.1	151.0	206.8	77.3
	26	74.1	22.5	22.3	120.9	165.7	33.0
		0.7	9.6	8.0	29.3	40.3	18.0
Upmost	20	74.3	59.0	55.6	35.5	150.2	130.9
	23	71.9	63.6	62.0	29.8	155.4	70.6
	26	70.0	49.6	46.1	37.8	133.5	26.2
		0.9	18.8	17.8	26.6	42.2	28.8

kernel moisture content and sugar levels decreasing with increasing harvest maturity. Averaged over the six genotypes, kernel total sugar concentration at 20 DAP was approximately equivalent between the two locations (325 $mg \cdot g^{-1}$ at IRVSF vs. 298 $mg \cdot g^{-1}$ at Urbana). As was observed with yield, several of the hybrids displayed substantial differences in kernel sugar levels, depending on environmental variability. In 'Crisp-N-Sweet 710', kernel total sugar concentrations at 20 and 23 DAP averaged ≈32% higher at Urbana than at the IRVSF, whereas the opposite effect occurred in 'Supersweet Jubilee' and 'Sweetie 82', with 25% and 72% more sugars in kernels from the sandy soil site at the IRVSF than at Urbana, respectively.

Significant differences were also found in the amounts of DMS generated from kernel samples among the *sh2* hybrids at a given harvest date and over harvest dates for individual hybrids at both locations (Tables 2 and 3). At Urbana, DMS levels at 20 DAP varied from 54.6 $\mu g \cdot g^{-1}$ dry weight in 'SCH 4415' to 206.6 $\mu g \cdot g^{-1}$ dry weight in 'Summer Sweet 7210', with an average concentration of 94.9 $\mu g \cdot g^{-1}$ for the 31 hybrids. At the IRVSF, kernel DMS levels at 20 DAP averaged 89.4 $\mu g \cdot g^{-1}$, ranging from 50.5 $\mu g \cdot g^{-1}$ in 'FMX 263' to 125.6 $\mu g \cdot g^{-1}$ in 'Crisp-N-Sweet 710'.

Dimethyl sulfide concentrations in all genotypes decreased with increasing kernel maturity. Mean DMS levels in the 24 *sh2* hybrids at Urbana dropped 40% from 20 to 23 DAP, 47% from 23

Table 2. Kernel composition for hybrids grown at South Urbana Research Farm (cont.).

Hybrid	DAP	Moisture (%)	Fructose	Glucose	Sucrose	Total Sugars	DHS
			($mg \cdot g^{-1}$)				($\mu g \cdot g^{-1}$)
Wisc. Natl. Sweet 9000	20	75.5	51.8	48.3	33.1	133.2	93.0
	23	74.1	48.8	40.6	15.4	104.8	24.0
	26	73.8	37.4	30.7	40.5	108.7	28.4
		1.4	17.9	16.0	37.6	44.4	24.8
Xtra Sweet 82	20	74.5	79.4	74.1	93.3	246.8	92.6
	23	72.7	70.6	61.2	46.3	178.1	56.2
	26	70.4	57.5	49.0	43.5	150.0	35.1
		1.2	20.4	14.5	42.6	51.7	12.8
Bellringer su1	20	69.8	29.7	30.1	41.9	101.2	82.8
	23	65.9	25.9	28.7	41.4	96.0	62.2
	26	63.1	22.8	26.7	37.4	86.9	23.4
		1.6	2.0	1.4	8.7	7.3	18.7
FMX 261 su1	20	72.2	26.9	25.2	66.7	118.8	72.4
	23	68.2	28.7	28.2	67.5	114.4	43.8
	26	65.4	18.2	19.6	67.8	105.6	29.9
		1.8	5.8	5.5	10.7	12.4	16.2
Jubilee su1	20	71.1	34.6	32.4	57.9	124.9	57.5
	23	67.3	26.9	26.8	45.8	99.4	28.7
	26	64.2	24.1	23.8	33.6	81.5	15.4
		2.5	5.4	5.0	16.4	19.0	9.9
Seneca Horizon su1	20	71.9	43.6	42.1	80.1	165.7	106.8
	23	69.1	33.9	33.8	49.0	116.8	71.3
	26	65.5	24.4	25.9	56.4	106.8	42.5
		1.1	13.2	12.2	22.8	39.9	37.7
Style Pack su1	20	71.6	25.2	25.2	56.9	107.3	88.4
	23	68.9	19.5	20.7	55.3	95.4	54.3
	26	67.0	15.5	15.8	43.2	74.4	19.4
		2.1	4.6	4.9	11.2	11.9	15.0
Maple Sweet se1	20	70.0	38.6	33.4	171.2	243.3	78.0
	23	68.5	32.0	31.8	133.2	196.9	42.9
	26	66.7	23.6	26.6	109.3	159.5	8.6
		1.1	8.0	7.2	20.8	36.7	18.6
Merlin Supersweet se1	20	72.2	45.2	38.7	70.3	154.1	75.6
	23	69.6	37.5	34.6	81.3	153.4	50.0
	26	67.2	35.6	34.8	68.4	138.7	29.1
		1.5	7.1	5.3	23.5	23.2	15.7
	20	1.3	11.7	10.3	40.1	45.8	28.2
	23	1.1	9.9	8.7	39.2	44.2	18.6
	26	1.2	8.4	7.6	29.6	33.7	12.7

[z]*sh2* endosperm mutation unless otherwise indicated.
[y]To reduce table size, data at 29 DAP were not presented since concentrations of kernel chemical composition mostly leveled off by this harvest date. LSD between harvest maturities for each hybrid at $P = 0.5$ is presented on the fourth line of each entry.
[x]LSD between hybrid means at each harvest maturity at $P = 0.05$.

to 26 DAP, and another 40% from 26 to 29 DAP. Dimethyl sulfide levels at 29 DAP were only 19% of those assayed at 20 DAP kernel samples, an average reduction of 9%/day.

Comparison of DMS concentrations between the two locations revealed that, on the average, 20 DAP kernels from Urbana generated 37% more of the compound than samples from IRVSF. This difference could be attributed to differences in rates of kernel maturation and/or soil environment associated with different locations. In contrast to kernel sugar content, the relative ranking of genotypes for DMS content over planting locations did not vary dramatically.

Sources of variation in yield and yield component evaluations and the chemical composition of quality. Following ANOVA, the total variability (based on the sum of squares) for each trait was partitioned into component sources of variation due to genotype, environment, genotype by environment interaction, and an error term. The relative contribution of each source of variation to the total variability of a trait is presented in Table 4 as percentages.

With the exception of kernel depth, main effects for genotype contributed to the major portion of the total variation in the various yield and yield component parameters. Significant amounts of variation in ear weight, potential yield, and kernel yield was attributable to genotype by environmental interactions. Kernel maturity, as measured by moisture content, was also primarily under the control of genotypic variation. With nearly 80% of the variability associated with genotypic differences, the genes con-

Table 3. Kernel composition for hybrids grown at the Illinois River Valley Sand Field.

Hybrid[z]	DAP[y]	Moisture (%)	Fructose	Glucose	Sucrose	Total sugars	DMS
			(mg·g^{-1})				(µg·g^{-1})
Crisp-N-Sweet 710	20	75.9	35.1	36.4	217.7	289.3	125.6
	23	74.0	28.5	29.3	238.1	296.0	91.4
	26	73.7	27.6	28.9	215.8	272.3	66.8
		1.5	5.1	4.5	15.8	12.6	18.6
FMX 263	20	76.4	29.4	31.5	274.2	335.0	50.5
	23	74.8	25.0	25.5	279.5	329.9	42.0
	26	74.7	20.3	21.7	253.3	295.3	37.0
		0.8	2.8	3.0	15.8	18.5	12.0
Summer Sweet 7210	20	76.9	23.0	25.4	216.3	264.6	122.1
	23	75.3	20.3	22.4	218.3	261.0	79.5
	26	74.4	16.7	18.7	196.2	231.6	50.4
		0.6	3.4	3.2	14.6	17.9	21.8
Supersweet Jubilee	20	74.9	30.6	30.5	297.3	358.5	55.5
	23	73.1	21.2	24.8	270.4	316.3	29.4
	26	74.3	17.2	21.2	269.5	307.9	27.5
		1.4	4.8	4.1	13.9	20.6	8.6
Sweetie 70	20	74.6	28.5	28.0	251.8	308.2	65.0
	23	73.0	26.0	24.6	229.6	280.1	44.4
	26	71.6	17.7	18.6	225.0	261.3	31.4
		1.3	2.4	2.2	12.8	12.5	11.2
Sweetie 82	20	76.1	36.1	34.1	319.6	389.8	117.4
	23	76.0	21.6	23.9	327.5	373.0	74.4
	26	75.7	18.0	22.1	315.5	355.6	55.6
		0.6	5.1	5.1	41.4	42.6	14.3
	20	1.0	5.0	4.6	20.1	22.0	17.6
	23	1.1	3.5	3.2	16.7	18.8	13.2
	26	1.2	3.4	3.3	25.7	26.7	13.2

[z]*sh2* endosperm mutation unless otherwise indicated.
[y]LSD between harvest maturities for each hybrid at $P = 0.05$ is presented on the fourth line of each hybrid entry.
[x]LSD between hybrid means at each harvest maturity at $P = 0.05$ is presented in the bottom three lines of the table.

trolling kernel DMS variation in the hybrids appear to have similar phenotypic expression in both planting locations. In contrast, fructose, glucose, sucrose, and total sugar concentrations, which determine kernel sweetness, were primarily influenced by the interaction between the genotype and the environment.

Comparative performance of sh2 and su1 hybrids. Mean performance of *sh2* hybrids for yield and yield component parameters and kernel quality characteristics was in all cases equal or better than that of hybrids homozygous for the *su1* mutation (Table 5). Ear uniformity of *sh2* hybrids was very close to being significantly superior ($P = 0.052$) to the *su1* hybrids. On the basis of yield and yield component evaluations in this study, the perception that *sh2* hybrids give lower yields than *su1 is* unfounded, since ear and cut kernel yield were about equal in both endosperm types.

As expected from the action of *sh2* gene (Laughnan, 1953), kernel moisture content, sucrose level, and total sugar concentration were significantly greater in *sh2* than in *su1* hybrids. With mean DMS levels of 99.1 and 81.6 µg·g^{-1} for *sh2* and *su1* hybrids, respectively, the type of endosperm mutation did not significantly influence the concentration of kernel DMS.

Correlation of yield, yield components, and kernel quality characteristics. To ascertain if key traits display positive or negative associations, correlation coefficients were computed among yield and yield component variables at 23 DAP, and between kernel chemical components at 20 and 23 DAP for the 24 *sh2* hybrids harvested at South Urbana Research Farm (Table 6). All of the yield and yield component parameters were correlated ($P < 0.01$). This response was expected since ear weight, ear length, and kernel depth were used to calculate potential and kernel yield. Similarly, the association between kernel moisture and yield also was expected, since water is the largest single component determining kernel weight and consequently contributes to increased yield. Ear uniformity and potential yield of the ear did not correlate with kernel sucrose, total sugar, and DMS concentrations, suggesting that these traits are controlled by genes operating independently. Kernel yield, while unrelated to sucrose level and DMS concentration, was negatively correlated with total sugar concentration in the kernel, although the value of r was low ($r = –0.22$). A negative correlation was observed between fructose and sucrose, but no relationship between glucose and sucrose was found.

The selection of hybrids for commercial production or for sources of favorable alleles in a breeding program for sweet corn improvement will depend on the consistency of a cultivar's performance over environments. Our replicated study at two locations with six of the *sh2* hybrids was conducted to provide information concerning the effect of environmental factors on the performance of these hybrids. Not only do the two planting sites have distinctly different soil types, but they were used in separate years to maximize the environmental effects on yield-related traits and on kernel chemical composition. Partitioning the variability in yield and kernel chemical components showed that genetic differences among the hybrids generally are the primary source of variation affecting yield, yield component characteristics, and kernel quality, although there were significant environmental effects, particu-

Table 4. Percentage of variability explained by the model and by each source of variation in the model for yield and yield component evaluations at 23 DAP and kernel chemical composition at 20 DAP for six *sh2* hybrids harvested at South Urbana Research Farm and the Illinois River Valley Sand Field station.[z]

Variable	Model[y]	Genotype[x]	Environment	Genotype × environment	Error term[w]
		Yield and yield components at 23 DAP			
Ear uniformity	62.3	70.0 (0.0002)	11.4 (0.0455)	8.2 (0.5518)	10.3
Ear weight	78.6	60.7 (<0.0001)	2.9 (0.2048)	26.0 (0.0008)	10.3
Ear length	62.2	71.2 (0.0002)	4.2 (0.2562)	11.1 (0.3869)	13.5
Kernel depth	94.3	20.4 (<0.0001)	77.1 (<0.0001)	1.3 (0.2891)	1.3
Potential yield	78.6	60.8 (<0.0001)	2.9 (0.2053)	26.0 (0.0008)	10.3
Kernel yield	84.9	54.4 (<0.0001)	26.7 (0.0091)	10.4 (0.0134)	8.5
		Kernel chemical composition at 20 DAP			
Moisture content	70.1	55.9 (<0.0001)	12.8 (0.1461)	13.0 (0.1369)	18.1
Fructose	67.2	33.8 (0.0056)	10.0 (0.0595)	47.9 (0.0007)	8.3
Glucose	76.6	37.5 (<0.0001)	14.5 (0.0170)	43.6 (<0.0001)	4.4
Sucrose	85.0	26.7 (<0.0001)	13.4 (0.0034)	57.4 (<0.0001)	2.6
Total sugar	83.0	24.0 (0.0002)	6.4 (0.0178)	65.3 (<0.0001)	4.3
DMS	89.2	77.0 (<0.0001)	13.4 (0.0034)	8.6 (0.0045)	0.9

[z]Values were calculated by dividing the sum of squares of the factor involved by the total sum of squares in the model expressed as percentages.
[y]Consisted of genotype, environment, and genotype × environment variability.
[x]Numbers in parenthesis are *P* values.
[w]Composed of rep and rep × environment variability.

Table 5. Mean comparisons between *sh2* and *su1* hybrids for yield and yield component evaluations harvested at 23 DAP and kernel chemical composition harvested at 20 DAP at South Urbana Research Farm.

Variable	Mean performance		*P* value[z]
	sh2 hybrid	*su1* hybrid	
	Yield and yield components at 23 DAP		
Ear uniformity, 0 to 4	2.30	2.20	0.0520
Ear weight, g	225	206	0.3420
Ear length, cm	19.9	19.2	0.2711
Kernel depth, cm	0.79	0.78	0.2923
Potential yield, MT·ha^{-1}	9.99	9.15	0.3022
Kernel yield, MT·ha^{-1}	5.72	4.99	0.5688
	Kernel chemical composition at 20 DAP		
Moisture content, %	74.6	71.3	0.0025
Fructose, mg·g^{-1}	34.3	31.9	0.3292
Glucose, mg·g^{-1}	35.8	31.0	0.1069
Sucrose, mg·g^{-1}	210	60.7	<0.0001
Total sugar, mg·g^{-1}	280	124	<0.0001
DMS, µg·g^{-1}	99.1	81.6	0.0540

[z]Computed using Student's *t* test.

larly on kernel sugar concentrations.

Of all the chemical parameters of sweet corn eating quality measured in this study, DMS displayed the greatest reduction with kernel age. This rapid loss of aromatic quality is of particular concern for the sweet corn processing industry. Apparently, S-methylmethionine, which is a precursor of DMS (Bills and Keenan, 1968; Wong et al., 1991), is undergoing active conversion to other metabolic products during this period. This stage of kernel development also corresponds to a period when kernel protein metabolism is shifting from the synthesis of water soluble enzymes to the accumulation of zein storage proteins (Bjarnason and Vasal, 1992).

Under conditions of similar emergence and stand uniformity, these data showed that *sh2* hybrids display superior quality with yields comparable to traditional *su1* cultivars. The *sh2* hybrids were in all cases equal, or better than that of the *su1* hybrids for yield, yield component, and kernel quality parameters. Since both ear and kernel yields were not significantly different for both endosperm types, the perception that *sh2* hybrids give lower yield than *su1* is unfounded. The substantial variability among the *sh2* hybrids, with a major proportion of the variation attributable to genotypic differences and the lack of strong negative associations between yield and important chemical components of kernel quality, suggests that it should be feasible to develop *sh2* hybrids with satisfactory yield potential and improved eating quality for specialized sweet corn markets.

Table 6. Pearson's correlation coefficients for yield and yield component evaluations at 23 DAP and kernel chemical composition at 20 and 23 DAP for the 24 *sh2* hybrids harvested at South Urbana Research Farm.

Variable	DAP	EW	EL	KD	PY	KY	MC	FR	GL	SU	TS	DMS
						Yield and yield components						
Ear uniformity	23	0.60 (<0.0001)	0.32 (0.0017)	0.43 (<0.0001)	0.60 (<0.0001)	0.53 (<0.0001)	NS	–0.27 (0.0086)	–0.28 (0.0049)	NS	NS	NS
Ear weight (EW)	23		0.47 (<0.0001)	0.63 (<0.0001)	0.99 (<0.0001)	0.85 (<0.0001)	0.23 (0.0242)	NS	NS	NS	NS	NS
Ear length (EL)	23			0.21 (0.0441)	0.47 (<0.0001)	0.36 (0.0004)	NS	NS	NS	NS	NS	NS
Kernel depth (KD)	23				0.63 (<0.0001)	0.70 (<0.0001)	NS	NS	NS	NS	NS	NS
Potential yield (PY)	23					0.85 (<0.0001)	0.23 (0.0236)	NS	NS	NS	NS	NS
Kernel Yield (KY)	23						0.24 (0.0176)	NS	NS	NS	–0.22 0.0332	NS
						Kernel chemical composition						
Moisture content (MC)	20							NS	NS	NS	NS	0.32 (0.0014)
	23							NS	NS	NS	NS	NS
Fructose (FR)	20								0.96 (<0.0001)	–0.28 (0.0052)	NS	0.25 (0.0155)
	23								0.96 (<0.0001)	–0.30 (0.0026)	NS	NS
Glucose (GL)	20									NS	NS	0.30 (0.0032)
	23									NS	NS	NS
Sucrose (SU)	20										0.94 (<0.0001)	NS
	23										0.93 (<0.0001)	NS
Total sugar (TS)	20											NS
	23											NS

[z]Numbers in parentheses are *P* values.
[NS]Nonsignificant at $P = 0.05$.

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