Seed Maturity Influences Germination and Vigor of Two *Shrunken-2* Sweet Corn Hybrids

Alicia M. Borowski¹, Vincent A. Fritz², and Luther Waters, Jr.³

Department of Horticultural Science, University of Minnesota, St. Paul, MN 55108

Additional index words. seed moisture, *Zea mays*, seed weight

Abstract. The objective of this study was to examine seed maturity at harvest as it relates to seed vigor in two commercial *shrunken-2* (*sh₂*) sweet corn hybrids (*Zea mays* L. var *rugosa* Bonaf., cvs. Florida Staysweet, Crisp N[®] 'Sweet 710'). Seed harvest began at 0.76 g H₂O/g fresh weight in 1987 and at 0.70 g H₂O/g fresh weight in 1988 and 1989, and was continued at gradually declining moisture levels until frost. In five different tests of seed performance, seed of 'Florida Staysweet' (FLASS) harvested between 0.23 to 0.57 g H₂O/g fresh weight in 1987 possessed the highest seedling vigor. In 1988 and 1989, maximum vigor was achieved by FLASS seed harvested from 0.40 to 0.60 g H₂O/g fresh weight and 'Crisp N[®] Sweet 710' (CNS) seed harvested from 0.45 to 0.65 g H₂O/g fresh weight. Standard germination test, seedling growth cold test (SGCT), and seed leachate conductivity provided the most consistent results to 'determine optimum seed maturity. Seed weight was not as reliable an indicator of seed vigor in 1988 and 1989 as it was in 1987, and endosperm and embryo weights did not correlate with seedling vigor in any year.

High sugar sweet corn hybrids continue to increase in popularity with fresh market consumers. The *sugary enhanced* (*se*) and *shrunken-2* (*sh₂*) genotypes have dominated the market because of their extra sweetness and extended postharvest kernel quality (Boyer and Shannon, 1983).

Problems related to stand establishment with these hybrids, especially the *sh₂* genotype, are numerous and have been well-documented (Styer and Cantliffe, 1983a, 1984a; Warm, 1986). Poor seed quality in *sh₂* hybrids contributes to erratic emergence and low seedling vigor, especially in cold soils (< 10C) (Andrew, 1982).

Genetics, conditions at time of seed formation, date of harvest, maturity at harvest, mechanical handling, drying, storage temperature, relative humidity, length of storage, insects, and diseases all can affect seed vigor (Amaral, 1981). Seedling vigor in field corn has been found to be highly dependent on date of harvest or stage of kernel maturity, and poor seed quality could result from an untimely harvest (Knittle and Burris, 1976). Ideally, seeds should be harvested at physiological maturity; i.e., when a seed possesses maximum viability and vigor (Harrington, 1972). However, it is difficult to measure physiological maturity precisely. Black layer formation in the placental region of the kernel is a visual and subjective rating often used by dent corn producers to denote physiological maturity (Daynard and Duncan, 1969). This is not a reliable index for sweet corn since some cultivars do not form a black layer.

Drawing conclusions about the optimal maturity date for sweet corn seed harvest from previous studies is difficult since different hybrids, locations, and maturity indices were used (Bennett et al., 1988; Churchill and Andrew, 1984; Styer and Cantliffe, 1983a). Styer and Cantliffe (1983a) used days after pollination as the maturity index for *sh₂* hybrids while Churchill and Andrew (1984) used percent seed moisture (dry weight basis). The interval between pollination and maturity depends on location and seasonal weather conditions, but the use of percent seed

moisture as the maturity index is a more finite and objective criterion. Bennett et al. (1988) used percent seed moisture to determine the optimal seed maturity of a *sugary* (*su*) sweet corn inbred. However, their results may not be applicable to harvest maturity of *sh₂* hybrid seed due to the difference in the endosperm composition between *su* and *sh₂*.

Styer and Cantliffe (1983a) harvested *sh₂* hybrid seed between 18 and 46 days after pollination and found between 62% and 91% germination for standard germination tests, and between 45% and 79% germination for cold rolled-towel tests. Hybrid *sh₂* seed harvested between 0.26 to 0.74 g H₂O/g fresh weight by Churchill and Andrew (1984) obtained germination of ≥90% in standard germination tests. However, 90% to 95% germination was achieved in the cold test only by seeds harvested between 0.37 to 0.51 g H₂O/g fresh weight. Bennett et al. (1988) found that seed of a sweet corn inbred harvested from 0.29 to 0.59 g H₂O/g fresh weight had germinated at ≥95% in the standard test, and from 77% to 96% in the cold test.

The seed industry currently harvests seed at 0.35 to 0.45 g H₂O/g fresh weight. While this moisture level maybe optimal for mechanical harvesting, seed may not be at a stage of maximum viability. Using seed moisture as the maturity index, the objective of this study was to examine seed maturity at harvest as it relates to improved seed vigor in two commercial *sh₂* hybrids.

Materials and Methods

The parental inbreds of two commercial *sh₂* hybrids, FLASS and CNS (Crookham Co., Caldwell, Idaho), were planted in May 1987 at appropriate intervals on a Nicollet clay loam (Aquic Hapludoll, fine loamy, mixed mesic) at the Southern Experiment Station, Waseca, Minn., to ensure pollen shed and silking would coincide to allow hand pollinations to be conducted over 5 days. Urea was broadcast at 54 kg N/ha and incorporated with a spring tooth cultivator before planting. The herbicides 2-chloro-2,6-diethyl-N-(methoxymethyl)acetanilide (alachlor) and 2[(4-chloro-6-(ethylamino)-s-triazin-2-yl)amino]-2-methylpropionitrile (cyanazine) were broadcast preemergence at rates of 2.8 and 2.3 kg·ha⁻¹, respectively. An insecticide, 1-naphthyl-N-methylcarbamate (carbaryl), and a fungicide, ethylene bistiocarb-

Received for publication 27 Apr. 1990. Minnesota Agr. Expt. Sta. Journal Series no. 18,123. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

¹Graduate Research Assistant. Current address: Asgrow Seed Co., 500 Lucy Brown Lane, Box L, San Juan Bautista, CA 95045.

²Assistant Professor. Southern Expt. Sta., Waseca, MN 56093.

³Professor. Current address: Dept. of Horticulture, Ohio State Univ., Columbus, 43210.

Abbreviations: CNS, 'Crisp N[®] Sweet 710'; FLASS, 'Florida Stayawee'; SGCT, seedling cold growth test.

mate ion plus manganese and zinc (mancozeb), were sprayed as needed at rates of 1.4 and 2.3 kg·ha⁻¹. The CNS parental inbreds did not produce any seed in 1987 because severe winds caused extensive lodging of the plants before pollen shed.

Seed moisture levels, all on a fresh-weight basis, were monitored regularly in the field by use of an Automatic Volatility Computer (Borowski and Fritz, 1990). Eight harvests of FLASS, each within a single pollination date, were made at ≈ 0.08 g H₂O/g fresh weight intervals, beginning at 0.76 g H₂O/g fresh weight and continuing until frost.

The study was repeated in 1988 and 1989 and seed was harvested at four maturity levels with moisture ranges (g H₂O/g fresh weight) as follows: 1) 0.67 to 0.75, 2) 0.58 to 0.66, 3) 0.49 to 0.57, and 4) 0.40 to 0.48. In 1989, a frost preceded the fourth harvest of both hybrids.

At each harvest, ≈ 200 ears were hand-picked, husked, and dried in a closed-system forced-air dryer (32C) (Fritz et al., 1990) until seed moisture reached 0.10 to 0.12 g H₂O/g fresh weight. Seeds were hand-shelled and stored at 4C and 45% RH until evaluated for germination and seedling vigor.

Composite samples of seed were used for all tests. Standard germination tests (International Seed Testing Assn., 1976) and a modified SGCT (Waters and Blanchette, 1983) were conducted using four replications of 50 seeds each. Seeds in both germination tests were placed on two sheets of moistened 25.4 x 38.1-cm standard weight germination paper (Anchor Paper, St. Paul, Minn.), with pedicels oriented in the same direction, and then covered with another moistened sheet. The sheets were rolled up as "rag dolls", covered with black plastic, and placed on end (pedicels facing downward) in a germination chamber to maintain normal geotropic response during germination. This technique minimizes abnormal seedling growth. Seedling dry weight in the SGCT was determined by weighing the severed roots and shoots from all seeds that germinated normally and calculating the average seedling dry weight.

Seed weight was determined from a 100-seed sample dried at 80C for 24 h. Endosperm and embryo weights were determined as described by Bennett et al. (1988). Leachate conductivity of individual seeds "was measured with an ASA-610 Electronic Seed Analyzer (Agro Sciences, Ann Arbor, Mich.). Samples of 100 seeds, replicated three times, were soaked in distilled water in imbibing trays and stored 24 h in a germination chamber set at 25C. Conductivity readings in microamps were recorded for each seed.

All data were subjected to analysis of variance (ANOVA). Means were compared between harvests in 1987 by least significant differences at $P = 0.05$. Data for each hybrid in 1988 and 1989 were initially combined, but an ANOVA revealed a significant year-harvest interaction. Therefore, the 2 years were analyzed independently. A severe frost in 1989 before harvest of both hybrids at maturity level 4 greatly reduced germination percentages; thus, the data were excluded from the analysis. Means were separated in 1988 and 1989 by single-degree-of-freedom orthogonal comparisons for maturity levels 4 and 3, respectively.

Results and Discussion

Germination tests. FLASS seed harvested in 1987 between 0.31 to 0.63 g H₂O/g fresh weight had higher germination in the standard germination test than seeds harvested at lower or higher moisture contents (Table 1). In the SGCT, FLASS seed harvested at 0.23 to 0.57 g H₂O/g fresh weight had the highest percent germination in the SGCT (Table 1). The reduced germination of seed harvested at 0.52 g H₂O/g fresh weight may be due to overdrying of that seed lot to 0.06 g H₂O/g fresh weight. The data from this harvest were included to demonstrate how overdrying can adversely affect the terminability and normal growth of seedlings and increase the time to germination (Heydecker, 1972). Moisture contents <0.06 g H₂O/g fresh weight have been observed in some commercial seed lots and may account for some of the lower germination percentages observed in commercial seed (data not shown). Seedling dry weight in the SGCT was not adversely affected by overdrying. The greatest seedling dry weights were produced from seed harvested at 0.23 to 0.52 g H₂O/g fresh weight and this test is recommended for evaluating SGCT results since it has been correlated with field emergence (Waters and Blanchette, 1983).

There were no significant differences in standard germination test results for either hybrid at the four maturity levels in 1988 (data not shown). Percent germination for both hybrids ranged from 97% to 100%. In 1989, percent germination for both hybrids in the standard test was $\geq 99.5\%$ at maturity levels 1, 2, and 3. The highest percent germination in the SGCT was obtained by seed of both hybrids harvested at maturity levels 2, 3, and 4 in 1988 and maturity levels 2 and 3 in 1989 (Table 2). Seedling dry weight generally increased for seed collected subsequent to maturity level 1 for both hybrids in both years.

Seed weight. Weight of 100 seeds of FLASS in 1987 indi-

Table 1. Standard laboratory germination test results and criteria of vigor based on SGCT for FLASS seed harvested at eight moisture contents in 1987.

Seed moisture (g H ₂ O/gfw)	DAP ^z	Standard germination ^y (%)	SGCT ^y		
			Germination ^x (%)	Abnormal seedlings (%)	Seedling dry wt (mg)
0.76	25	84 $\pm$ 3	36 $\pm$ 9	28 $\pm$ 8	8 $\pm$ 2
0.72	37	97 $\pm$ 2	65 $\pm$ 13	51 $\pm$ 13	12 $\pm$ 2
0.63	43	99 $\pm$ 2	65 $\pm$ 17	43 $\pm$ 20	13 $\pm$ 3
0.57	51	100 $\pm$ 1	96 $\pm$ 2	41 $\pm$ 9	16 $\pm$ 3
0.52	58	100 $\pm$ 1	73 $\pm$ 11	44 $\pm$ 11	18 $\pm$ 2
0.44	66	100 $\pm$ 1	98 $\pm$ 2	55 $\pm$ 13	19 $\pm$ 3
0.31	69	99 $\pm$ 1	89 $\pm$ 8	43 $\pm$ 20	20 $\pm$ 3
0.23	73	96 $\pm$ 2	98 $\pm$ 3	59 $\pm$ 20	22 $\pm$ 3
LSD (0.05)		3	14	23	4

^zDays after pollination.

^yMean $\pm$ SD.

^xNormal + abnormal seedlings.

Table 2. Criteria of vigor based on SGCT for FLASS and CNS harvested at four and three maturity levels in 1988 and 1989, respectively

Cultivar	Maturity level	Seed moisture (g H ₂ O/gfw)		DAP ^a		SGCT					
		1988	1989	1988	1989	Germination ^y (%)		Abnormal seedlings (%)		Seedling dry wt (mg)	
						1988	1989	1988	1989	1988	1989
FLASS	1	70	72	34	42	95	96	32	22	17	18
	2	59	58	43	51	98	99	28	16	20	20
	3	50	51	52	59	96	99	19	24	22	21
	4	41	47	65	66	100	---	21	---	23	---
Significance						*	NS	*	NS	*	*
Linear						NS	NS	NS	NS	NS	NS
Quadratic											
CNS 710	1	71	71	40	43	69	89	46	37	11	24
	2	58	65	53	52	89	96	42	34	20	24
	3	53	54	58	62	90	96	38	33	24	27
	4	46	44	70	69	89	---	36	---	23	---
Significance						*	*	NS	NS	*	*
Linear						*	NS	NS	NS	*	NS
Quadratic											

^aDays after pollination.

^yNormal + abnormal seedlings.

NS, * Nonsignificant or significant at $P \leq 0.05$.

Table 3. Seed weight and leachate conductivity for FLASS seed harvested at eight moisture contents in 1987.

Seed moisture (g H ₂ O/gfw)	Seed wt ^a (g/100 seed)	Conductivity ^a (μamps)
0.76	8 ± 0.3	81 ± 16
0.72	11 ± 0.2	92 ± 27
0.63	12 ± 0.1	95 ± 25
0.57	11 ± 0.3	84 ± 24
0.52	12 ± 0.4	59 ± 19
0.44	12 ± 0.3	47 ± 15
0.31	12 ± 0.3	44 ± 14
0.23	11 ± 0.2	43 ± 18
LSD (0.05)	0.4	3

^aMean ± SD.

cated that seed harvested from 0.23 to 0.72 g H₂O/g fresh weight would be more vigorous than that at 0.76 g H₂O/g fresh weight (Table 3). Seed dry weight is considered an accurate predictor of seedling vigor because it estimates the amount of stored reserves in the seed (Knittle and Burris, 1976). However, seed weight was not a reliable indicator of seed vigor in 1988 and 1989. There was no significant difference in seed weight of either FLASS or CNS at any maturity level in 1988 (Table 4). Seed produced in 1989 was slightly heavier than 1988 seed and results were not consistent between the two hybrids (Table 4). Seeds of FLASS harvested at maturity level 3 and CNS seeds harvested at maturity level 1 were the heaviest. The lighter weight seed in 1988 may have resulted from the extreme high temperatures during seed development. Plots were irrigated to ensure 2.5 cm of water each week, but photosynthesis was probably hindered and respiration increased by the high temperatures, although data were not collected. The reduced seed weight in 1988 did not seem to influence the vigor of FLASS. Germinability and seedling dry weight in the SGCT were reduced in CNS in 1988; but they are not correlated to reduced seed weight ($r^2 = 0.10$ for percent germination, and $r^2 = 0.05$ for seedling dry weight).

Table 4. Seed weight and leachate conductivity for FLASS and CNS harvested at four and three maturity levels in 1988 and 1989, respectively.

Cultivar	Maturity level	Seed wt (g/100 seed)		Conductivity (μamps)	
		1988	1989	1988	1989
FLASS	1	10.7	11.8	53.9	64.8
	2	10.9	12.1	52.6	52.2
	3	10.7	12.9	41.5	43.9
	4	10.8	---	34.4	---
Significance					
Linear		NS	*	*	*
Quadratic		NS	NS	*	NS
CNS 710	1	11.8	13.4	65.4	71.3
	2	11.9	12.7	40.2	43.6
	3	11.5	11.5	33.5	30.4
	4	11.6	---	34.5	---
Significance					
Linear		NS	*	*	*
Quadratic		NS	NS	*	*

NS, * Nonsignificant or significant at $P \leq 0.05$.

Seed leachate conductivity. Conductivity of seed leachates from FLASS seed in 1987 generally decreased with decreasing seed moisture (increasing seed maturity) (Table 3). The lowest conductivity readings were measured on seeds harvested from 0.23 to 0.52 g H₂O/g fresh weight. For both hybrids in 1988, seed leachate conductivity was lowest in seed harvested at maturity levels 3 and 4 and in 1989 at maturity level 3 (Table 4). Styer and Cantliffe (1983b) also found that seed leachate conductivity generally decreased with increasing seed maturity (from 18 and 46 days after pollination). Leachate conductivity has been found to be highly correlated with field emergence (Tracy and Juvik, 1988; Waters and Blanchette, 1983). Even though terminability may be normal, Warm (1986) suggested metabolite leakage may also be indicative of relative seed vigor, and

high membrane permeability and/or broken pericarps maybe responsible for the greater leakage of metabolizes during imbibition of *sh₂* seed.

Endosperm : embryo ratios. Endosperm and embryo weights at each harvest were regressed against seedling dry weight in the SGCT to elucidate the relationship of endosperm and embryo weight to seedling vigor. In the case of **FLASS**, both endosperm and embryo dry weight increases did not correlate with seedling vigor in all 3 years (endosperm : $r^2 = 0.41, 0.00, 0.01$ and embryo: $r^2 = 0.52, 0.00, 0.08$). The relationships were also similar for CNS in 1988 and 1989 (endosperm: $r^2 = 0.01, 0.03$; and embryo: $r^2 = 0.01, 0.02$). Our results agree with Bennett et al. (1988) who observed a large decrease in the endosperm : embryo ratio as seed of a *su* inbred matured but concluded that endosperm weight may not be related to sweet corn seedling vigor. Warm (1980) had suggested that endosperm : embryo weight ratios reflect the relative amount of nutrient reserves available to the embryo during germination and that selection to increase the ratio maybe a means to improve seedling vigor. This endosperm : embryo relationship may have some credence when comparing seeds with similar maturities but is not a reliable indicator of seedling vigor in a seed maturity study.

The seed industry typically harvests seed at maturity level 4 (0.40 to 0.48 g H₂O/g fresh weight) or lower, yet seed vigor of *sh₂* genotypes continues to be poor. Our results indicate that seed maturity influences germination and vigor of *sh₂* seed and that seed can be harvested at higher moisture levels than is currently practiced. Earlier harvests could help to reduce the pathogen load to which *sh₂* genotypes are subjected during seed development and maturation (Styer and Cantliffe, 1984b). High moisture seed may be more easily damaged during production and handling and it may be necessary to modify current mechanical operations.

Literature Cited

- Amaral, A. 1981. Several aspects of seed vigor. *Lavoura Arrozeira* 34:58-63.
- Andrew, R.H. 1981. Factors influencing early seedling vigor of shrunken-2 maize. *Crop Sci.* 22:263-266.
- Bennett, M. A., L. Waters, Jr., J.H. Curme. 1988. Kernel maturity, seed size, and seed hydration effects on the seed quality of a sweet corn inbred. *J. Amer. Soc. Hort. Sci.* 113:348-353.
- Borowski, A.M. and V.A. Fritz. 1990. Comparison of moisture determination techniques over a range of sweet corn seed maturities. *HortScience* 25(3):361.
- Boyer, C.D. and J.C. Shannon. 1983. The use of endosperm genes for sweet corn improvement. *Plant Breeding Rev.* 1:139-161.
- Churchill, G.A. and R.H. Andrew. 1984. Effects of two maize endosperm mutants on kernel maturity, carbohydrates, and germination. *Crop Sci.* 24:76-81.
- Daynard, T.B. and W.G. Duncan. 1969. The black layer and grain maturity in corn. *Crop Sci.* 9:473-476.
- Fritz, V. A., H. Cloud, R. Deef, and A. Borowski. 1990. A versatile heat pump seed dryer. *HortScience* 25:977-978.
- Barrington, J. 1972. Seed storage and longevity, p. 145-245. In T.T. Kozlowski (ed.). *Seed biology*. vol. III, Academic, New York.
- Heydecker, W. 1972. Vigour, p. 209-252. In: E.H. Roberts (ed.). *Viability of seeds*. Syracuse Univ. Press, Syracuse, N.Y.
- International Seed Testing Assn. 1976. The germination test. *Seed Sci. & Tech.* 4:23-28.
- Knittle, K.H. and J.S. Burris. 1976. Effect of kernel maturation on subsequent seedling vigor. *Crop Sci.* 16:851-855.
- Styer, R.C. and D.J. Cantliffe. 1983a. Relationship between environment during seed development and seed vigor of two endosperm mutants of corn. *J. Amer. Soc. Hort. Sci.* 108:717-720.
- Styer, R.C. and D.J. Cantliffe. 1983b. Changes in seed structure and composition during development and their effects on leakage in two endosperm mutants of sweet corn. *J. Amer. Soc. Hort. Sci.* 108:721-728.
- Styer, R.C. and D.J. Cantliffe. 1984a. Dependence of seed vigor during germination on carbohydrate source in endosperm mutants of maize. *Plant Physiol.* 76:196-200.
- Styer, R.C. and D.J. Cantliffe. 1984b. Infection of two endosperm mutants of sweet corn by *Fusarium moniliforme* and its effect on seedling vigor. *Phytopathology* 74: 189-194.
- Tracy, W. and J. Juvik. 1989. Pericarp thickness of a shrunken-2 population of maize selected for improved field emergence. *Crop Sci.* 29:72-74.
- Warm, E.V. 1980. Seed vigor and respiration of maize kernels with different endosperm genotypes. *J. Amer. Soc. Hort. Sci.* 105:31-34.
- Warm, E.V. 1986. Leaching of metabolizes during imbibition of sweet corn seed of different endosperm genotypes. *Crop Sci.* 26:731-733.
- Waters, L., Jr., and B.L. Blanchette. 1983. Prediction of sweet corn field emergence by conductivity and cold tests. *J. Amer. Soc. Hort. Sci.* 108:778-781.