A Comparison of the Growth, Establishment, and Maturity of Direct-seeded and Transplanted *sh₂* Sweet Corn

Gregory E. Welbaum¹, Jonathan M. Frantz², Malkanthi K. Gunatilaka, and Zhengxing Shen

Department of Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0327

Additional index words. hydroponics, stand establishment, vegetable production, mineral nutrition, *Zea mays*

Abstract. Sweet corn (*Zea mays* L.) cultivars containing the shrunken-2 (*sh₂*) gene have superior kernel quality but often germinate poorly and display poor seedling vigor. The transplanting of *sh₂* sweet corn was investigated as a method to improve stand establishment and hasten maturity. Three-week-old plants (*sh₂* cv. Krispy King) were raised in 200-cell polystyrene trays in either plug-trays (PT), float beds (FB), or ebb-and-flood (EF) production systems and compared with direct-seeded (DS) controls for transplant quality, successful establishment, and early harvest. In 1994, when plants were established in early June, PT plants matured 1 week earlier than DS and FB plants, which had similar mean times to harvest. In 1995, when field planting occurred in July, all plants flowered prematurely when only 60 cm tall. In 1996, the experiment was begun in early May, and survival of all transplants was >85% vs. 54% for DS plants. In 1996, transplants matured 10 to 13 days earlier than DS plants, however, >90% of DS plants produced marketable ears vs. 63%, 49%, and 44% of EF, FB, and PT plants, respectively. The DS plants were also taller with better root development than transplants in all years. Transplants produced smaller, lower-quality ears than did DS plants, thus nullifying the benefits of greater plant populations and earlier maturity. The EF system produced high-quality seedlings because of the greater control of water availability during seedling development. In some areas, the increased value of early *sh₂* sweet corn may be worth the additional cost of transplanting and greater percentage of unmarketable ears.

Shrunken-2 (*sh₂*) sweet corn cultivars have greater sugar content, slower rates of sugar to starch conversion, and a more tender pericarp than do sugary (*su*) or sugary enhanced (*se*) cultivars. However, many *sh₂* cultivars germinate slowly and exhibit poor seedling vigor (Parera and Cantliffe, 1994). Poor germination is a particular problem with early spring plantings in cold soils. Seed priming, biopriming, prehydration, coating, and vari-

ous fungicides treatments may improve the stand establishment of *sh₂* sweet corn (Bennett et al., 1991; Parera and Cantliffe, 1994; Waters et al., 1990). Field corn and sweet corn have been transplanted experimentally in an attempt to improve stands and hasten maturity (Khehra et al., 1990; Miller, 1972; Waters et al., 1990; Wyatt and Mullins, 1989). However, transplanting sweet corn remains a questionable practice because it increases production costs and often stunts plant development.

Some growers in the mid-Atlantic region transplant *sh₂* sweet corn to improve establishment and hasten maturity. Transplanting corn is feasible because transplant technologies such as carousel-style planters and hydroponic transplant production in float beds enable large-scale transplant production with minimal labor (Frantz et al., 1998; Miglianti, 1987). However, little information is available on whether transplanting *sh₂* corn can increase stand establishment and hasten maturity compared with the standard practice of direct-seeding (DS). In this study, early seedling growth, seedling mineral content, stand counts, and early harvest dates were compared among direct-seeded (DS) plants and *sh₂* sweet corn transplants produced in overhead-watered plug-tray (PT), float-bed (FB), and ebb-and-flood (EF) systems in three separate years.

Sweet corn, *sh₂* cv. Krispy King (lot NW 3313, Rogers, Boise, Idaho), seed treated with thiram (tetramethylthiuram disulfide, Rhone-Poulenc Ag. Co., Research Triangle Park, N.C.), was seeded in 2-cm-deep, 200-cell (single-cell dimensions, 28 × 28 × 76 mm) polystyrene trays (Southern States Cooperative, Richmond, Va.) in June 1994, July 1995, and May 1996. Trays for FB and EF systems were loosely filled with soilless mix (Tobacco Mix; Carolina Soil Co., Kinston, N.C.). For the PT system, cells in the polystyrene trays were filled with Sunshine Mix I (Fisons, Vancouver, B.C.). Three trays of transplants were produced in PT, FB, and EF systems in a greenhouse with a pad-and-fan cooling system in Blacksburg, Va., with a maximum and minimum temperature of 30.5 and 19.6 °C, respectively. The transplant systems were arranged randomly in the center of the greenhouse. For both the FB and EF systems, a galvanized, metal trough (3.3 × 0.8 × 0.3 m), lined with a double layer of 0.075-mm-thick, black plastic film (Carlisle Plastics, Minneapolis) was filled 28 cm deep with tap water for a total volume of 570 L in each bed. Water-soluble fertilizer, 20N–2.2P–25K, with Mg, B, Cu, Fe, Mn, Mo, and Zn (Peters Professional; The Scotts Co., Marysville, Ohio), was added in 1994 to produce nutrient concentrations of 114N, 13P, 143 K, 0.29 Mg, and 0.29 Fe (mg·L⁻¹), and 39 B, 20 Cu, 142 Mn, 5.7 Mo, and 14.8 Zn (µg·L⁻¹). In 1995 and 1996, nutrient solution concentrations were 66 N, 7 P, 83 K, 0.17 Mg, and 0.17 Fe (mg·L⁻¹), and 22 B, 12 Cu, 83 Mn, 3.3 Mo, and 8.6 Zn (µg·L⁻¹). The sources of elemental N were 10% ammoniacal, 40% nitrate, and 50% urea. Actual concentrations of NO₃⁻, K⁺, and total dissolved salts were measured daily using hand-held meters (Spectrum Technologies, Plainfield, Ill.) (Hartz et al., 1994). The initial pH values ranged from 6.3 to 6.8. Tap water or fertilizer was added periodically to adjust nutrient concentrations to initial values.

Only three treatments, i.e., PT, FB, and DS, were evaluated in 1994. The EF bed was flooded with nutrient solution at a rate of 114 L/min from a holding tank for 6 h every 12 h or 1 h every 6 h in 1995 and 1996, respectively, using submersible pumps (Rule Industries, Gloucester, Mass.) activated by programmable, digital plug-timers (DT1; Intermatic, Spring Grove, Ill.). To facilitate drying between flood cycles, trays in the EF beds were supported on polyvinyl-chloride pipe placed 23 cm above the bottom of each bed. Open areas on FB and EF beds were covered with black plastic film or sheets of polystyrene to minimize algal growth. The FB and EF plants were acclimated for 3 d prior to transplanting by placing trays outdoors between 0800 and 1500 hr each day. Overhead watered PT were placed on benches with an open lattice metal frame top to air-prune roots. The PT system was hand-watered daily and fertilized weekly with the same nutrient solution used in the FB system.

Four rows of 25 3-week-old plants each

Received for publication 24 Apr. 2000. Accepted for publication 1 Sept. 2000. This work was funded in part by Southern States Cooperative, Richmond, Va. We thank Arthur Pfister for help with field plot preparation and transplanting. Mention of a trademark, proprietary product or vendor does not constitute a guarantee or warranty of the product by the Virginia Polytechnic Institute and State Univ. or the Virginia Cooperative Extension Service and does not imply its approval to the exclusion of other products or vendors that may also be suitable. 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.

¹To whom requests for reprints should be addressed. E-mail address: welbaum@vt.edu

²Current address: Dept. of Plant, Soils, and Biometeorology, Utah State Univ., Logan, UT 84322-4820. E-mail address: slvyt@cc.usu.edu

were hand planted for each treatment on 9 June 1994 in a field of Hayter loam (fine-loamy, mixed, mesic Ultic Hapludalf) near Blacksburg, Va. in a complete-block design with each row serving as a replication. Rows were spaced 45 cm apart with an in-row spacing of 10 cm between plants based on seed company recommendations.

In 1995 and 1996, 3-week-old seedlings were transplanted with a between-row spacing of 90 cm and an in-row spacing of 30 cm using a subsurface-tiller transplanter (B&B No-Till, Laurel Fork, Va.) (Morse et al., 1993). In 1995 and 1996, the field was arranged in a randomized complete-block design with three blocks, and each replication contained four rows with 25 plants in each row. On the day of transplanting in all three years, 25 seeds were hand-seeded 2.5 cm deep at the same spacing as the transplants. A liquid, starter-fertilizer solution (10N-4.3P-8.3K) was applied around the roots at a rate of $\approx 150 \text{ kg} \cdot \text{ha}^{-1}$. Granular fertilizer was surface-banded 8 cm from each row at 112N-98P-93K $\text{kg} \cdot \text{ha}^{-1}$ at planting in accordance with soil-test results. Herbicides Dual® [metolachlor; 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methyl-ethyl)acetamide] and atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] were applied at a rate of 2.2 and 1.6 $\text{kg} \cdot \text{ha}^{-1}$, respectively, and sprays of insecticides were applied as needed in accordance with published extension recommendations for sweet corn (Baldwin et al., 1994). In 1995, immature plants were harvested in the field or transplant trays in the greenhouse and transported to the laboratory in self-sealing bags for leaf-area measurement (model 3050A; LICOR, Lincoln, Nebr.). At transplanting in 1996, the mineral content of the above-ground portions of 3-week-old transplants or direct-seeded plants 3 weeks after emergence were analyzed using a wet-ash extraction procedure of 70% nitric : 60% perchloric acid (2:1). Tissue samples were filtered, diluted, and analyzed using an inductively coupled plasma spectrophotometer (Thermo Jarrel Ash Cooperative, Franklin, Mass.). Samples for nitrogen analysis were digested (Kjeltec System 20; Tecator, Herndon, Va.) in concentrated H_2SO_4 , distilled, and analyzed (Kjeltec Auto 1030 Analyzer) by the Protein Nutrition Laboratory at Virginia Polytechnic Institute and State Univ. (Virginia Tech.)

The harvest data were taken from the inner

two rows. Ears were harvested and transported immediately to the laboratory where data were recorded within 1 h of harvest. Since plot size and in-row spacing varied among years, yield data were normalized and expressed on a hectare basis even though plots were much less than one hectare in size. The mean time to harvest was determined graphically by plotting the cumulative number of ears harvested during the season on a probit scale against the time of each harvest in days. The probit scale transformed the normal distribution of ears harvested over time to a straight line so the mean time of harvest could be extrapolated. ANOVA and mean separation were performed using the computer program CoStat (CoHort Software, Minneapolis).

Results and Discussion

1994. Nearly all seeds planted in PT emerged in the greenhouse in 1994 (Table 1). Emergence in float beds was lower (90.5%) because the medium was too moist for optimum germination. In the field, 89% emergence was recorded in direct-seeded plots. Transplanted plants matured ≈ 1 week earlier than DS plants in 1994. More of the transplants produced ears than did DS plants, in part due to the variable emergence of DS corn. Earlier emerging plants crowded those that emerged later, inhibiting ear formation. As a result, $\approx 25\%$ of the DS plants were barren. By comparison, nearly all transplants produced ears that were uniform in size and maturity. At maturity, DS plants were the tallest.

Generally, DS corn had shorter but heavier ears than transplanted corn, primarily because of greater kernel development on DS ears (Table 1). The percentage of marketable ears was low for all treatments because the high plant densities inhibited ear development on some plants, but PT transplants produced the highest percentage of marketable ears. There was no difference in yield between DS and FB plants.

1995. In-row and between-row spacing was also increased in 1995 and 1996 to better monitor transplant performance independently of plant-to-plant competition. The switch to wider spacing, along with different planting dates, made simple data comparisons among years problematic. In 1995, transplants were hardened to reduce the shock exhibited by FB plants during the previous year. The FB and

EF transplants grew more rapidly than did PT or DS plants with FB plants producing the greatest leaf area 4 weeks after planting in 1995 (Fig. 1). The final plant stands in the field were 83%, 80%, 82%, and 83% for PT, FB, EF, and DS, respectively (data not shown). Since all plants flowered prematurely when only ≈ 60 -cm tall and none flowered prematurely in 1994 or 1996 using earlier planting dates, we conclude that 'Krispy King' is not suited for late planting in Virginia. Premature flowering caused most ears to be small and unmarketable, so no harvest data are presented for 1995.

1996. The FB seedlings had the greatest dry weight at transplanting in 1996 (Table 2). Survival percentages for all transplants were at least 30% greater than for DS plots, indicating that transplanting improved early season stand establishment. Transplants also matured at least 10.5 d earlier than did DS plants, with FB plants maturing earliest (Table 2). Direct-seeded plants yielded the greatest percentage of marketable ears, while FB and PT transplants yielded the lowest. Ears on DS plants were generally longer, heavier, and thicker than ears from transplants. Direct-seeded plants were also taller than transplants (Table 2), as in 1994 and in previous studies as well (Waters et al., 1990; Wyatt and Mullins, 1989). The EF plants produced the largest number of marketable ears because more plants survived relative to direct-seeded plots, which more than compensated for the lower percentage of marketable ears (Table 2). However, when yield was calculated on the basis of marketable ear fresh weight, DS and EF plants were more productive than plants grown in PT (Table 2).

Root development. Corn does not transplant well because pruned roots do not branch, and root replacement is generally poor compared with crops such as cabbage (*Brassica oleracea* L. Capitata Group) or tomato (*Lycopersicon esculentum* L.) (Loomis, 1925; Waters et al., 1990). At harvest, most mature plants in transplanted plots could be easily uprooted by hand while DS plants could not, indicating that transplanted corn had a less extensive root system. The inability of corn roots to regenerate after transplanting resulted in stunted plants that produced a greater percentage of cull ears (Table 2). The root system of a corn seedling has seminal roots that consist of the radicle or primary root and a variable

Table 1. Effects of planting method on emergence, time to harvest, yield, and plant and ear characteristics of 'Krispy King' sh_2 sweet corn in 1994.

Planting method	Emergence (%) ²	Mature plant ht. (cm)	Mean time to harvest (d)	Plants producing ears (%)	Marketable ears		Ear		
					Percent ³	Fresh wt (kg·ha ⁻¹) ⁴	No. (ears/ha) ⁵	Length (cm)	Wt (g)
Plug-tray	99.5 a ¹	186 $\pm$ 4 ^u	66.9 b	95 a	42.5 a	12,078 a	89,780 a	16.2 a	134.3 b
Float bed	90.5 b	179 $\pm$ 2	66.8 b	85 b	30.0 b	7,146 b	56,548 b	15.3 b	126.2 b
Direct seeded	89.0 b	202 $\pm$ 5	73.6 a	74 c	35.7 b	8,740 b	58,760 b	14.6 c	148.8 a

¹In greenhouse trays and in direct seeded field plots 3 weeks after seeding.

²U.S. No. 1 husked grade standards (U.S. Dept. of Agriculture, 1992).

³Marketable ears/ha times mean ear weight.

⁴Calculated by multiplying percentage of plants producing ears by the number of plants per hectare at a between-row spacing of 45 cm and an in-row spacing of 10 cm.

⁵Mean separation within columns by LSD at $P \leq 0.05$.

^uMean $\pm$ SE

number of lateral roots that arise adventitiously at the base of the first internode of the stem, just above the scutellar node. The seminal root initials are present in the embryo and are the most important for early growth and establishment (Kiesselbach, 1999). When seminal roots were severed at 3 weeks of age, the plants yielded 9% less grain (Kiesselbach, 1999). In this study, seminal roots were broken during transplanting as they were pulled from transplant trays or transplanted, because the polystyrene trays were not optimal for corn transplant production. Seminal roots were also air pruned in the PT system because the cell shape and size were not optimal for seminal root development. Some roots grew into the polystyrene and were broken when pulled from the trays. More research is needed to

identify a more suitable tray for corn transplant production.

There were distinct differences among transplant treatments. The constant moisture in FB favored the growth of root systems, causing greater seedling dry weight at transplanting in 1996 (Table 2). However, many of these roots were destroyed when FB plants were pulled from trays during transplanting. Plants from the PT system had smaller root balls than did FB plants because roots were air pruned before they could grow through the bottom of each cell. Ebb and flood plants had intermediate root development because dry cycles limited root growth outside the trays (data not shown). The greater field productivity of EF plants in 1996 than in 1994 may have been due to better root development and less

root loss during transplanting (Table 2). Hardening plants in 1995 and 1996 also helped reduce the visible symptoms of transplant shock observed in 1994.

Mineral nutrition. Variable transplant performance may have been due to differences in mineral nutrition among transplant production systems. The rapid succulent growth of FB seedlings in 1994 suggested that nutrient solution concentrations of 114N–13P–143K ($\text{mg}\cdot\text{L}^{-1}$) may have been excessive. In 1995 and 1996, concentrations were reduced to 66 N (with initial 40% NO_3^-), 7 P, and 88 K ($\text{mg}\cdot\text{L}^{-1}$), and plants grew rapidly without apparent deficiency symptoms. In 1996, differences were noted in transplant nutrition among treatments (Table 3). The DS plants had the most tissue N while PT transplants had the least, which was below the sufficient range and may have contributed to the poorer performance of PT plants (Table 3). The N level was intermediate for the hydroponic transplants. The FB and EF transplants had the highest K, while levels in plug and DS plants were lower but still in the sufficient range. The PT plants and FB transplants had the highest P; plants from EF and DS treatments contained less P but levels were still sufficient. Calcium was adequate in all treatments, and no significant differences in Ca were found among treatments (Table 3).

Conclusions

Of the transplant systems tested, EF offered the best control of water availability, which promoted uniform root and shoot growth and resulted in high-quality transplants. Whether transplanting *sh₂* sweet corn is worth the extra expense and effort is debatable. Previous studies have shown no clear advantage to growing sweet corn from transplants (Waters et al., 1990; Wyatt and Mullins, 1989). Our study showed fewer benefits when crops were established from transplants during June and July (Table 1). The primary objective for transplanting sweet corn is early maturity. The 1996 data illustrated that, under early season conditions typical for the mid-Atlantic region, significant increases in stand counts and earliness were achieved through transplanting as compared with DS (Table 2). However, transplants produced a greater percentage of culls and smaller, lower-quality ears than did DS, which may nullify the benefits of improved stands obtained through transplanting. Trays

Fig. 1. Changes in leaf area after field planting of 'Krispy King' *sh₂* sweet corn in 1995. The LSD value was determined from the pooled variance of all treatments.

Table 2. Effects of planting method on mean transplant and harvest data for 'Krispy King' *sh₂* sweet corn in 1996.

Planting method	Seedling dry wt (g)	Surviving plants ² (%)	Mature plant ht. (cm)	Mean time to harvest (d)	Marketable ears			Ear		
					Percent ^y	Fresh wt (kg·ha ⁻¹) ^x	No. (ears/ha) ^w	Length (cm)	Wt (g)	Diam. (cm)
Plug-tray	0.80 b ^v	88.3 b	99 c	72.0 b	43.8 c	1756 c	13,874 c	14.9 b	127 c	38.7 c
Float bed	1.10 a	97.5 a	135 b	68.8 c	48.7 c	2352 b	17,031 b	15.2 b	138 bc	40.0 b
Ebb and flood	0.86 b	85.4 b	138 b	71.2 b	63.0 b	2937 a	19,298 a	16.8 a	152 b	40.4 b
Direct seeded	---	54.2 c	181 a	82.5 a	90.5 a	3192 a	17,594 b	17.0 a	181 a	44.2 a

²Determined 4 weeks after transplanting and field seeding.

^vUS No. 1 husked grade standards (U.S. Dept. of Agriculture, 1992).

^xMarketable ears/ha × mean ear fresh wt.

^wCalculated by percentage of survival × number of plants/ha at a between-row spacing of 90 cm and an in-row spacing of 30 cm.

^yMeans followed by the same letter within columns are nonsignificant by LSD at $P \leq 0.05$.

Table 3. Effects of planting method on nutrient contents of the above-ground portions of 3-week-old transplants or seedlings of 'Krispy King' *sh₂* sweet corn in 1996.

Treatment	N	K	P	Ca	Mg	S	Na
	---	---	---	(%)	---	---	(mg·kg ⁻¹)
Plug-tray	2.59 c ^x	3.83 b	0.51 a	0.37 a	0.49 a	0.38 ab	233 a
Float bed	3.31 b	5.85 a	0.56 a	0.36 a	0.36 b	0.49 a	232 a
Ebb and flood	3.12 bc	5.65 a	0.40 b	0.30 a	0.32 b	0.43 a	170 b
Direct seeded	4.58 a	4.47 b	0.32 b	0.30 a	0.23 c	0.31 b	177 b
Sufficient ^y	3.50–5.00	2.50–4.00	0.03–0.50	0.30–0.70	0.15–0.45	0.15–0.50	---

^xMean separation within columns by LSD at *P* ≤ 0.05.

^ySufficiency range for the whole top of corn plants <30 cm high according to Jones et al. (1991).

that minimize trauma to sweet corn roots may improve transplant field performance. If growers can produce *sh₂* sweet corn before the competition in a particular market does, the extra crop value may justify the greater production costs of transplanting.

Literature Cited

- Bennett, M.A., N.M. Callan, and V.A. Fritz. 1991. Seed treatments for disease control. *HortTechnology* 1:84–87.
- Baldwin, R.E., H.E. Hohlt, C.R. O'Dell, J.S. Speese, S.B. Sterrett, and H.P. Wilson. 1994. Commercial vegetable production recommendations, Virginia. Publ. No. 456–420. Va. Coop. Ext. Serv., Blacksburg.
- Frantz, J.M., G.E. Welbaum, Z. Shen, and R.D. Morse. 1998. Comparison of cabbage seedling growth in four transplant production systems. *HortScience* 33:976–979.
- Hartz, T.K., R.F. Smith, K.F. Schulbach, and M. LeStrange. 1994. On-farm nitrogen tests improve fertilizer efficiency, protect groundwater. *Calif. Agr.* 48:29–32.
- Jones, J.B., B. Wolf, and H.A. Mills. 1991. Plant analysis handbook. Micro-Macro Publishing, Athens, Ga.
- Khehra, A.S., H.S. Brar, R.K. Sharma, B.S. Dhillon, and V.V. Malhotra. 1990. Transplanting of maize during the winter in India. *Agron. J.* 82:41–47.
- Kiesselbach, T.A. 1999. The structure and reproduction of corn, p. 18. In: 50th Anniversary Ed. Cold Spring Harbor Lab. Press, Cold Spring Harbor, N.Y.
- Loomis, W.E. 1925. Studies in the transplanting of vegetable plants. Cornell Memoir 87. (cited by Thompson and Kelly. 1957. p 101).
- Miglianti, C.G. 1987. Speedling float growing tobacco transplants on water. Amer. Soc. Agr. Eng. fiche no. 87–1573.
- Miller, R.A. 1972. Forcing sweet corn. *HortScience*. 7:424.
- Morse, R.D., D.H. Vaughn, and L.W. Belcher. 1993. Evolution of conservation tillage systems for transplanted crops; Potential role of the subsurface tiller transplanter (SST-T), p. 145–151. In: P.K. Billich (ed.). Proc. Southern Conserv. Till. Conf. Sustainable Agr., Monroe, La., 15–17 June 1993.
- Parera, C.A. and D.J. Cantliffe. 1994. Presowing seed treatments to enhance supersweet sweet corn seed and seedling quality. *HortScience* 29:277–278.
- Thompson, H.C.T. and W.C. Kelly. 1957. Vegetable Crops. 5th ed., McGraw-Hill, New York.
- U.S. Department of Agriculture. 1992. United States standards for grades of sweet corn. Agricultural Marketing Service. U.S. Govt. Printing Office, Washington, D.C.
- Waters, L.J., R.L. Burrows, M.A. Bennett, and J. Schoenecker. 1990. Seed moisture and transplant management techniques influence sweet corn stand establishment, growth, development and yield. *J. Amer. Soc. Hort. Sci.* 115:888–892.
- Wyatt, J.E. and J.A. Mullins. 1989. Production of sweet corn from transplants. *HortScience* 24:1039.