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Sweet corn (*Zea mays* L.) growth and yield are influenced by establishment methods

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ABSTRACT

Six experiments were performed in the term of three years in order to explore and compare the effects of transplanting and direct sowing (DS) on sweet corn (*Zea mays* L.) growth, earliness and yield. Different genotypes, tray cell sizes (volume) and seedling ages were assayed. In all experiments, direct sowing was performed with a final separation of 0.25 m between plants in each row. Growth parameters (height, leaf area and ear size) were reduced with the increase of age and/or decrease of the tray cell size, mainly in cultivars with early flowering i.e., low cumulative corn heat unit (CHU) requirements. Earlier harvests were obtained in transplanting compared to direct sowing, although with lower yields. When the thermal time accumulated by plants in the trays was higher than 100 CHU, the yield decreased by 3.91% (R^2 = 0.79) for each unit of CHU. The results indicate that the transplanted sweet corn yield was generally lower than of direct seeded plants, and differences grew bigger as the tray cell volume was smaller and the seedlings age increased.

Keywords: tray cell volume; seedling transplant; transplant age; yield; direct sowing.

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INTRODUCTION

The yield potential of a crop depends on its capacity to obtain resources from the environment and use them to fix carbon dioxide (CO_2) into biomass (Grzebisz *et al*., 2013). For grain crops, it also depends on the proportion of its biomass that is partitioned to grains (Binkley *et al*., 2004; Long *et al*., 2006). Sweet corn (*Zea mays* L. var. saccharata Bailey), especially super sweet (sh2) and sugar-enhanced (se) sweet corn, is a preferred and widely grown variety (Zhao *et al.*, 2007). It is a warm-season crop adapted to temperate climates though usually affected by weak seed vigor and common poor emergence rates (Zhao *et al*., 2007).

In Argentina, sweet corn production has been steadily growing in recent years, and is currently a horticultural crop of great importance for both fresh consumption and the food industry (Bertolaccini *et al.*, 2010). Sweet corn transplanting has been undertaken in an attempt to increase this plant population and improve earliness. Early spring sweet corn is usually grown in cold soils at sub-optimal temperatures for seed germination (Hassell et a*l*., 2003). Soil and air low temperatures hamper sweet corn seed germination and early growth, especially in the shrunken-2 (*sh-2*) hybrid. Transplanting could improve field crop establishment (Aguyoh *et al*., 1999), but several factors influence transplant production and performance, such as tray cell size (volume) and age at the time of transplanting (NeSmith and Duval, 1998). Aguyoh *et al.* (1999) also mention a big shoot-to-root ratio, a lower rate of root regeneration after transplanting, and a lower older roots intake of nutrients as constraints for transplanting in this species. The scarce information about overcoming low seed vigor and disadvantageous environmental conditions during early spring for this cultivar, points out the importance in obtaining data for the management of this crop.

The aim of this work was to evaluate the effects of tray cell sizes (volume) and seedling ages of transplanting on growth parameters, earliness and fruit yield of sweet corn compared to direct sowing.

MATERIALS AND METHODS

Six experiments were conducted during three years to compare direct sowing to sweet corn transplants from different combinations of tray cell sizes, plant ages and genotypes. The seedlings were grown in plug trays filled with a dry commercial peat moss and vermiculite medium (Grow Mix S1, Terrafertil®) with pH 5.3-5.8 and EC 0.3-0.4 dS m^{-1}. Sweet corn seeds were sown with a compressed-air operated vacuum seeder (Sathya®); adjustments on the seeder were used to achieve high percentages of cells with a single seed per cell. After sowing, the trays were subirrigated to saturation, misted, and then transferred to a germination chamber. At the end of the germination period, half-strength Hoagland solution (Hoagland and Arnon, 1950) was added to the water reservoir and trays were placed in a heated nursery. The cumulative corn heat unit (CHU, base temperature = 10ºC) was calculated according to Jame *et al*. (1999). Temperatures in nursery and field were measured with an automatic weather station (Davis WeatherLink®). Plant leaf area was measured non-destructively with a Licor field meter (LI-3000®).

In the first year, three experiments were carried out: 1) transplants of 20- and 33-day-old seedlings and 20, 40, and 120 cm^3 tray cells with a normal sugary (*su*) cultivar of 760 CHU; 2) transplants of 19- and 27-day-old seedlings in the same cell type, but of the sugary enhanced (*se*) genotype variety (905 CHU); 3) transplants of 27-, 32-, and 39-day-old seedlings with 30 cm^3 cell type alone and shrunken-2 (*sh-2*) hybrid (955 CHU). In the second year: 4) transplants from 20- and 35- day-old plants using the same cell type and genotype as experiment 1; 5) transplants of 20- and 35- day-old plants and same cell type as the experiment 2 but using *sh-2* hybrid (870 CHU); 6) transplants of17-, 25-, and 33-day-old plants using the same cell types and genotype as the experiment 3. Measurements were made both in the nursery and field. The substrate for transplanting was a silt loam Molisoll (Aquic Argiudoll).

At transplanting, plant leaf area (LA), shoot dry weight (S), root dry weight (R) were measured in replicated seedlings; root/shot ratio (R/S) and specific leaf area (SLA) were subsequently calculated. Total yield and cob weight were determined when cobs maturity were considered suited to fresh market consumption. This phenological phase coincided with husk leaves remaining tight and green. In all experiments, direct sowing was performed with a final separation of 0.25 m between plants in the row. Seedlings were transplanted in a randomized, complete block design with four replications for each treatment. The statistical analysis was performed through ANOVA; the means between treatments were compared by Duncan's test, with a significance level of 5% and 1% in certain cases. The Statgraphics Plus 5.0® computer statistical program was used to perform the statistical analyses and graphs. ANOVA assumptions were met in all analyses.

RESULTS AND DISCUSSION

The general appearance of sweet corn seedlings allowed recognizing differences arising from the tray cell size used. At 20 days, seedlings grown in the 120 cm^3 cells were taller than those of 20 and 40 cm^3 cells (Fig. 1 a, c). Furthermore, in 35 days-old plants, a slight etiolation (Fig. 1 b, d) became noticeable. For experiment 6, a few days before the harvest onset, the plant roots differed in size depending on the age of transplant, with plant roots from direct sowing being the largest and most vigorous (Fig.2). The roots of the plants that remained in the trays the longest (33 days) were of the lowest development. This was also observed by Leskovar & Cantliffe (1993) in a similar work on pepper. Other research demonstrate the importance of transplanting in comparison with direct sowing, where the first reduce the occurrence of fungi attack in the nursery stage (Oswald *et al.*, 2001)

Nursery stage

Tray cell size affected LA, S and R significantly increasing their values in proportion to cell size (Tables 1 to 4, figure 1). The SLA also was proportionally increased to cell volume in experiments 1, 2 and 5 (Tables 1, 2 and 4, respectively), except for experiment 4 (Table 3). When R/S was analyzed, a smaller variation between treatments was observed, detecting a significant effect (P < 0.01) in experiment 1 only (Table 1). As expected, LA and S values raised significantly (P< 0.01) as the age of the seedlings increased (Tables 1 to 4). There was no interaction between volume and transplant age on seedlings LA.

Table 1. Effect of tray cell size and transplant age on leaf area (LA), shoot dry weight (S), root dry weight (R), root to shoot ratio (R/S) and specific leaf area (SLA) of sweet corn cv. ´Sundance´ (Experiment 1).

Volume (cm^3)	LA (cm^2)	(S) (g)	(R) (g)	R/S	SLA (cm^2 g^{-1})
20	50	0.23	0.16	0.82	227.3
40	60	0.18	0.18	1.11	323.8
120	110	0.33	0.54	1.45	323.2
F test	**	**	**	**	**
Age (days)					
20	49	0.17	0.17	1.08	283.9
33	97.6	0.32	0.41	1.17	298.9
Significance	**	**	**	n.s.	n.s.
Volume x Age	n.s.	n.s	*	*	*

n.s.: not significant; *. P < 0.05; **. P < 0.01.

Table 2. Effect of tray cell size and transplant age on leaf area (LA), shoot dry weight (S), root dry weight (R), root to shoot ratio (R/S) and specific leaf area (SLA) of sweet corn cv. ´Sundial (Experiment 2). Results from every cell volume are means of 19 and 27 days after transplant. Values for age are averages of all cell volume treatments.

Volume (cm^3)	LA (cm^2)	(S) (g)	(R) (g)	R/S	SLA (cm^2 g^{-1})
20	34.8	0.16	0.16	1.15	229.3
40	50	0.21	0.22	1.15	248.1
120	59.2	0.23	0.25	1.2	267.2
F test	**	*	*	n.s.	**
Age (days)					
19	36.1	0.13	0.19	1.45	275
27	60	0.27	0.23	0.88	221.4
Significance	**	**	*	*	**
Volume x Age	n.s.	n.s.	n.s.	n.s.	n.s.

n.s.: not significant; *. P < 0.05; **. P < 0.01.

Table 3. Effect of tray cell size (volume) and transplant age on leaf area (LA), shoot dry weight (S), root dry weight (R), root to shoot ratio (R/S) and specific leaf area (SLA) of sweet corn cv. ´Sundance´ (Experiment 4).

Volume (cm^3)	LA (cm^2)	(S) (g)	(R) (g)	R/S	SLA (cm^2 g^{-1})
20	83.8	0.22	0.14	1.1	365.3
40	97.7	0.27	0.25	1.11	347.5
120	115.3	0.31	0.27	0.93	387.2
F test	**	**	**	n.s.	n.s.
Age (days)					
20	34.3	0.10	0.12	1.37	351.8
35	163.6	0.43	0.32	0.73	381.6
Significance	**	**	**	**	n.s.
Volume x Age	n.s.	n.s.	*	*	n.s.

n.s.: not significant; *. P < 0.05; **. P < 0.01.

Table 4. Effect of tray cell size (Volume) and transplant age on leaf area (LA) shoot dry weight (S), root dry weight (R), root to shoot ratio (R/S) and specific leaf area (SLA) of sweet corn cv. ´Cacique´ (Experiment 5).

Volume (cm^3)	LA (cm^2)	S (g)	R (g)	R/S	SLA ($cm^2\ g^{-1}$)
20	67.4	0.21	0.15	0.92	304.2
40	91	0.29	0.21	0.88	286.1
120	125	0.37	0.25	0.88	317.3
F test	**	**	**	n.s.	n.s.
Age (days)					
20	38.7	0.15	0.19	1.26	253.2
35	150.3	0.43	0.22	0.52	351.9
Significance	**	**	n.s.	**	**
Volume x Age	n.s.	*	n.s.	n.s.	n.s.

n.s.: not significant; *. P < 0.05; **. P < 0.01.

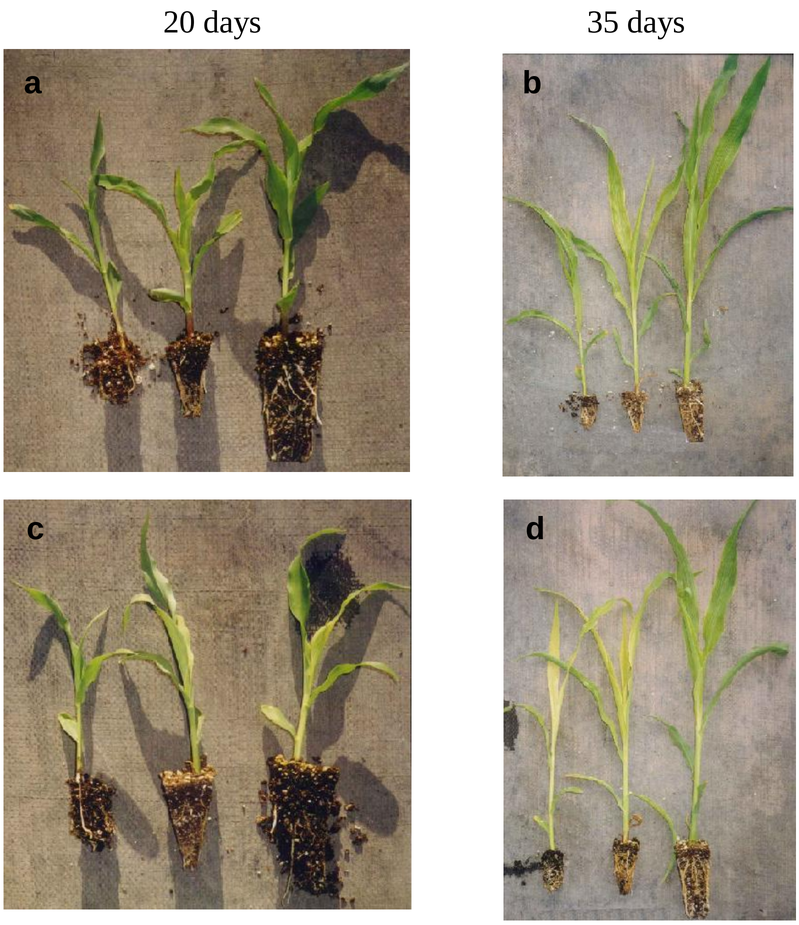

Fig. 1: General appearance of sweet corn seedlings at two transplant ages grown in (left to right at each panel) 20, 40 and 120 cm^3 tray cell sizes. (a) and (b): Experiment 4; (c) and (d): Experiment 5.

Field stage

When combinations of tray cell size and time at transplanting were compared, it was observed that the largest volume tray cells (120 cm^3) and shortest nursery staying (20 days) had the greatest yields, similar to those recorded in direct sowing (Table 5).

Although in experiments 3 and 6, only 40 cm^3 tray cells were used, the yields of 27 and 17 old-days transplants, were greater than of direct seeded plants ($P < 0.05$). This was not observed in the other experiments (Table 4). This could be attributed to the fact that a higher thermal time sweet corn genotype was used in the former experiments. Likewise, it may have influenced the seedling recovery from root confinement stress at the field stage. A strong decrease in yield was seen in all experiments when plants had exceeded 30 days in the trays ($P < 0.05$); the biggest yield loss observed at the smallest cell size (Table 5 and 6). These same trends were observed when cob sizes were analyzed (Table 7 and 8).

Table 5. Effect of direct sowing (DS) and tray cell volume (120, 40 or 20 cm^3)-transplant age (20 or 33 days) combinations on final yield ($t\ ha^{-1}$) in experiments 1, 2, 4 and 5.

Treatment (Exp. 1)	Yield ($t\ ha^{-1}$)	Treatment (Exp. 2)	Yield ($t\ ha^{-1}$)	Treatment (Exp. 4)	Yield ($t\ ha^{-1}$)	Treatment (Exp. 5)	Yield ($t\ ha^{-1}$)
DS	9.02[a] [1]	DS	13.09[a]	DS	10.45[a]	DS	12.70[a]
120-20	8.39[a]	120-19	13.03[a]	120-20	10.03[ab]	120-20	13.55[a]
40-20	6.78[b]	40-19	13.35[a]	40-20	9.15[b]	40-20	11.68[ab]
20-20	6.54[b]	20-19	12.82[a]	20-20	7.28[c]	20-20	9.71[b]
120-33	4.27[c]	120-27	7.68[b]	120-35	4.38[d]	120-35	6.22[c]
40-33	2.73[d]	40-27	6.95[b]	40-35	3.26[de]	40-35	5.35[cd]
20-33	2.19[d]	20-27	4.86[c]	20-35	2.62[e]	20-35	4.17[d]

[1] Mean separation within columns by Tukey's test at $p = 0.05$.

Table 6. Effect of direct sowing (DS) and 40 cm^3 tray cell volume - transplant age combination on final yield ($t\ ha^{-1}$) in experiments 3 and 6 at 955 CHU after sowing.

Treatment (Exp. 3)	Yield ($t\ ha^{-1}$)	Treatment (Exp. 6)	Yield ($t\ ha^{-1}$)
DS	13.68[a]	DS	12.86[b]
40-27	14.20[a]	40-17	15.17[a]
40-32	11.31[b]	40-25	11.91[b]
40-39	9.67[c]	40-33	6.94[c]

[1] Mean separation within columns by Tukey's test at $p = 0.05$.

Other yield components as cob number per plant and cob size (length and diameter), were reduced as the container volume decreased and transplant age increased (data not shown). When the thermal time accumulated by plants in the trays was higher than 100 CHU, the yield decreased by 3.91 % (R^2 = 0.79). However, this decrease was greater in the 20 cm^3 treatment and smaller in the 120 cm^3 treatment (Fig. 3). This indicates that the older transplant (higher thermal accumulation in nursery) had the lower final yield, although this yield loss is greater when a small cell volume is used. This was evidenced in the 20 cm^3 cell size treatment; the yield decreased almost 5% for each increase of CHU, whereas in the 120 cm^3 one, it was only of 3.19% (Fig. 3). Previous works have reported a slower growth rate and a lower yield of sweet corn transplants that were more than 3 weeks old at the time of transplanting (Waters *et al.*, 1990). These effects were attributed to more severe root damage on the older seedlings with a subsequent increase in plant stress (Waters *et al.*, 1990). Using cell trays of 30 cm^3, Aguyoh *et al.* (1999) determined that transplants must not exceed 2 weeks of age if the aim is to obtain a marketable yield similar to direct sowing.

Table 7. Effect of direct sowing (DS) and tray cell volume-transplant age combinations, on mean weight cob in experiments 1, 2, 4 and 5.

Treatment (Exp. 1)	Weight (g)	Treatment (Exp. 2)	Weight (g)	Treatment (Exp.4)	Weight (g)	Treatment (Exp. 5)	Weight (g)
DS	153.3[a] [1]	DS	245.0[b]	DS	183.3[a]	DS	190.6[bc]
120-20	126.7[ab]	120-19	280.0[ab]	120-20	175.7[ab]	120-20	222.0[a]
40-20	107.9[b]	40-19	290.4[a]	40-20	160.2[b]	40-20	203.8[ab]
20-20	104.2[b]	20-19	261.6[ab]	20-20	127.3[c]	20-20	170.0[c]
120-33	68.0[c]	120-27	131.4[c]	120-35	76.0[d]	120-35	124.9[d]
40-33	43.5[cd]	40-27	135.3[c]	40-35	52.0[e]	40-35	107.4[de]
20-33	34.8[d]	20-27	85.2[d]	20-35	61.6[de]	20-35	91.2[e]

[1] Mean separation within columns by Tukey's test at p = 0.05.

Table 8. Effect direct sowing (DS) and 40 cm^3 tray cell volume - transplant age combinations on weight cob (g) in experiments 3 and 6.

Treatment (Exp. 3)	Weight (g)	Treatment (Exp. 6)	Weight (g)
DS	209.5[b1]	DS	250.7[a]
40-27	217.3[ab]	40-17	234.3[b]
40-32	220.0[a]	40-25	184.5[c]
40-39	188.4[c]	40-33	135.0[d]

[1] Mean separation within columns by Tukey's test at p = 0.05.

As our data suggest, genotype ontogeny could be related to this yield decrease. In long cycles conditions (Table 6), the effect of radical restriction caused by cell size- plant age combination on final yield was smaller than in the other experiments (Table 5) (Welbaum *et al.*, 2001). However, is worth noticing that under stressful field conditions the sh-2 hybrid requires higher seeding rates to ensure stand establishment. The cultivars containing the sh-2 gene have a superior kernel quality but often germinate poorly and display low seedling vigor (Hartz and Caprile, 1995). The transplanting of sh-2 sweet corn with specific conditions could be a method to improve stand establishment. In this work, 20 days-old transplants grown in 120cm3 cells (Exp. 5, Table 7), allowed obtaining larger cobs while 27 days old transplant grown in 40 cm3 cells (Exp. 6, Table 6) produced a higher final yield compared with direct seeded plants.

These results lead to a general recommendation for growers considering switching to smaller cell sizes or older seedlings: they should do so with caution. Compared to direct sowing, sweet corn transplants grown in a smaller container or aged seedlings may produce lower and later yields.

Fig. 2. General appearance of the root systems in sweet corn plants in experiment 6, cv. 'Butter Sweet' at harvest time for direct sowing and of 17, 25 and 33 days-old transplants (from left to right, respectively).

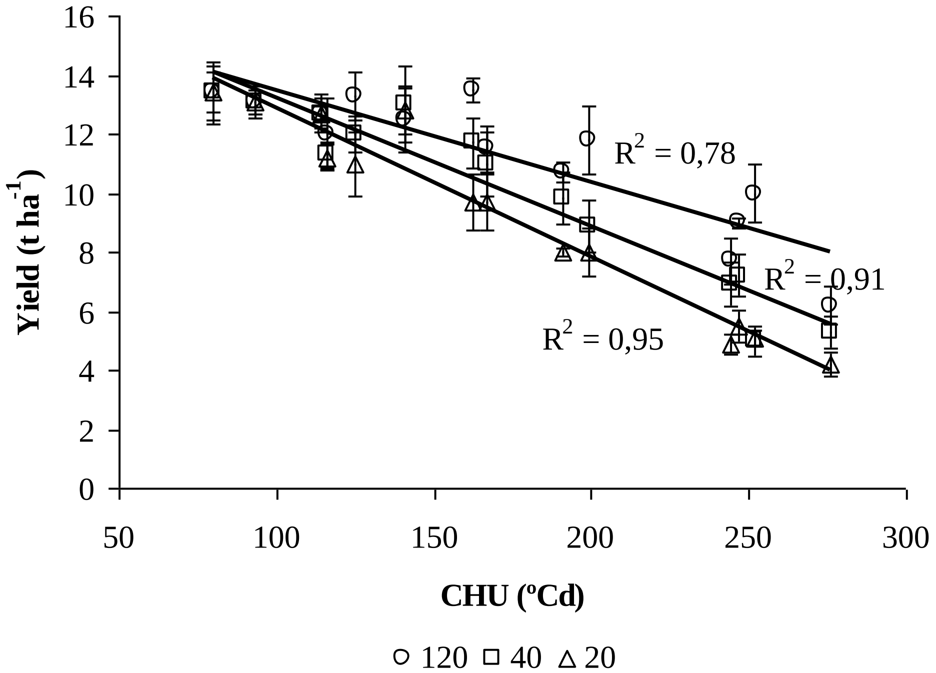

Figure 3. Relationship between thermal time (CHU. ºCd) accumulated during the nursery phase and final yield (Y) for all experiments considering cell size of 20 cm3 (Y = -0.0504 CHU + 17.905); 40 cm3 (Y = -0.0439 CHU + 17.634) and 120 cm3 (Y = -0.0319 CHU + 16.611).

CONCLUSIONS

This research has confirmed that the use of different tray cell volumes and transplant age influence dry-matter partitioning throughout growth and development of sweet corn seedlings. The increase in radical restriction (small tray cell) caused a sharp decrease in seedling LA and S, being the most affected variables by the treatments. When the thermal time accumulated by plants in the trays was higher than100 CHU, the yield decreased by 3.91% ($R^2 = 0.79$) for each unit of CHU. Greatest yields were obtained with greatest volume cell size and shortest transplant age (table 6, experiment 3 and table 8, experiment 3).

Transplanting technology is suitable if proper cell size (greater than 40 cm_3) and a suitable transplant age (less than 27 days) are chosen. This technology lead to avoid the difficulties of germination that hybrids of sweet corn presents in medium latitudes where soils have suboptimal soil germination temperatures.

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