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Original Research Article

How does transplant increase sweet maize (*Zea mays* L. *saccharata*) yield?

ABSTRACT

Aims: Little is known about the response of sweet maize to particular short- and long-term stresses such as the root restriction imposed by small plug cell trays when a transplant routine is used. The aim of this work was to describe the effect of a transplant routine on the physiological components of yield in two sweet maize mutants by means of experiments conducted in a marginal maize production area.
Study design: Two maize mutant hybrids: 'Canner' (*su1*) and 'Butter Sweet' (*sh2*) were sown in plastic plug trays (128 cells tray^{-1}) and transplanted 15 days after emergence or direct seed.
Place and Duration of Study: Experiment was conducted at the INTA Balcarce Experimental Station, Argentina (37° 45′ S, 58° 18′ W) during the 2009-2010 and repeated twice during 2010-2011 and 2011-2012 growing seasons.
Methodology: Plants from direct-seeded or transplant were grown under a field environment. A randomized complete factorial design with three blocks was used.
Results: Results showed that transplanted plants showed increased light interception, harvest index, and yield per unit area than direct-seeded ones. These responses were related to a change in leaf area development, crop architecture and anatomical traits such as the phloem/xylem ratio and vascular bundle/mesophyll ratio.
Conclusion: A change in leaf area development and crop architecture when using transplanted plants allow increasing sweet maize yield on an area basis. To understand the mechanisms associated to the morphological changes related to transplant and their importance on population architecture would be a key matter for a future breeding program.

Keywords: Biomass accumulation, crop architecture, radiation use efficiency, harvest index.

1. INTRODUCTION

~~Although~~ Sweet corn has been experimentally transplanted in an attempt to improve stands [1, 2, 3], this implantation routine remains a questionable practice because it increases production costs and often stunts plant development [4, 5]. However, in previous works we have found that transplanted and direct-seeded plants show similar plant yields [6]. We have also suggested the use of transplant as a tool to improve sweet maize productivity [7], in agreement with El-Hamed *et al*. [8] who have suggested that the feasibility of enhanced sweet corn seed propagation through transplanting and seed priming can improve emergence and field stand. In North Vietnam and

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northern India, Sharma *et al*. [9] and Khehra *et al*. [10] also reported yield benefits from transplanting tropical maize.

Wellbaum *et al*. [5] have indicated that corn does not transplant well because pruned roots do not branch, and that root replacement is generally poor compared with other vegetable crops. The root system of a corn seedling has seminal roots and a variable number of lateral roots that arise adventitiously at the base of the first internode of the stem, just above the scutellar node. In the study of Wellbaum *et al*. [5], seminal roots which were present in the embryo were broken during transplanting. Although the inability of corn roots to regenerate after transplanting resulted in stunted plants, the use of plastic plug trays instead of polystyrene plug tray gave the same height growth pattern [6].

A limited plug cell volume from sowing to transplant gives a vertical root restriction which it has been previously documented in different crops [11] including sweet corn [12]. Although the physiological mechanisms of the transplant response are unclear, both synthesis and translocation of hormones such as cytokinins from root apices would be associated with a change in root verticality and a root growth restriction from the plug cell base [13] which decreases total leaf area expansion [14, 15].

Grain formation in maize is the result of the photosynthetic ability of source leaves and the integrated process of allocation, accumulation and utilization of assimilated carbon at the whole plant level [16]. During development, the architecture of the stand depends on the growth pattern of individual plants which leads to differences in the distribution of radiation within the stand. In turn, it may be responsible for differences in productivity indices per unit area, especially when a transplant routine significantly changes maize plant morphology [7] and ensures population stand.

The aim of this work was to describe the effect of a transplant routine on the physiological components of yield in two sweet maize mutants by means of experiments conducted in a marginal maize production area.

2. MATERIALS AND METHODS

2.1. Plant Material, Treatments and Experiments

The experiment was conducted at the INTA Balcarce Experimental Station, Argentina (37°45'S, 58°18'W) from 27th November 2009 to 28th February 2010 on a Typic Argiudoll soil with an organic matter of 5.6% in the first 25 cm depth. The experiment was repeated twice from 16th November 2010 to 19th February 2011 and from 21st November 2011 to 25th February 2012. Water and nutrients were at non-limiting levels using an irrigation system which kept soil water above 50% of maximum soil available water in the first meter of depth. The experimental field was fertilized with 150 kg N ha^{-1} (18-46-0) at the beginning of experiments. Weeds and insec were adequately controlled.

The maize mutant hybrids 'Canner' (*su1*) and 'Butter Sweet' (*sh2*) provided by Semillería Basso (Argentina) were sown in plastic plug trays (128 cells $tray^{-1}$) using a commercial growing media or direct-seeded. Transplanted plants were grown under greenhouse facilities from sowing to transplant. Final population densities were 80,000 plants ha^{-1}.

2.2. Field environment

Weather records (daily maximum-minimum air temperature and global solar radiation) were recorded from a meteorological station 500 meters from the experimental site.

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2.3. Growth Evaluations

At each harvest, plant height, individual leaf area [using a leaf area meter LI-COR FL16 (LI-COR Inc., Lincoln, NE, USA)], expanded leaves and dead leaves were recorded. Dry matter accumulation was determined by taking plant samples at E-T (emergence-transplant) and V_4, V_7, V_9, V_T and R stages. The sample size was ten plants per block. Plants were cut at ground level, separated in stems, leaves and ears and oven dried at 80°C for ten days and weighed.

Photosynthetic active radiation (PAR) interception percentage was calculated as [1- (I_t/I_o)] x 100, where I_t is incident PAR just above the lowest layer of photosynthetically active leaves, and I_o is incident PAR at the top of the canopy. The values for I_t and I_o were obtained with a LI-COR 188 B radiometer (LI-COR Inc, Lincoln, NE, USA) connected to a line quantum sensor LI-COR 191 SB. The measurements were confined to midday (1130-1300 h) and taken on sunny days only. We carried out five measurements per block.

Daily total incident PAR was multiplied by the corresponding daily fraction of PAR interception and accumulated to obtain the PAR intercepted by the crop from sowing to harvest. Radiation use efficiency (RUE) was calculated as dry matter accumulated divided by the intercepted PAR accumulated both from E/T to V_T and from V_T to R_3.

The relative growth rate (RGR) was calculated as the slope of the regression of the natural logarithm (ln) of the whole plant on a dry weight basis *vs.* time (in days), while the rate of leaf area expansion (RLAE) was calculated as the slope of the regression of the ln of total leaf area *vs.* time (in days). Mean net assimilation rate (NAR) and leaf area ratio (LAR) were calculated as follows:

$$\mathbf{NAR = (k_w\, W_0\, e^{k_w\, t}) \,/\, (A_0\, e^{k_a\, t})}$$

$$\mathbf{LAR = k_a/[(A_0\, e^{k_a\, t})/(k_w\, W_0\, e^{k_w\, t})]}$$

Where W_0: extrapolated value of total dry weight (g) at time zero; k_w: relative growth rate (day^{-1}); A_0: extrapolated value of leaf area (cm^2) at time zero; k_a: relative leaf area expansion rate (day^{-1}); t: time (days) at the midpoint of the experimental period and e: base of natural logarithm.

Tissue from the middle region of the lamina was fixed in formalin-acetic-alcohol. Leaf thickness was determined from leaf lamina tissues embedded in paraffin, sectioned at 20 µm on a rotary microtome. Leaf samples were stained with safranin-crystal violet-fast green. Data are the mean of three leaves per treatment per block from ten leaf cross-sections per leaf. An image analysis system (Image Pro Express v 6.0, Media Cybernetics, USA) facilitated quantitative anatomical measurements (stomata density, phloem/xylem ratio and vascular bundle/mesophyll ratio).

2.4. Statistical Analysis

~~We used~~ a randomized complete factorial design with three blocks of four rows of 10 m (0.70 m apart) for each treatment. Data were subjected to one way ANOVA and means were separated by Tukey's test (*P* = 0.05). Regression slopes were tested for parallelism (test for equal slope) [17].

3.1. RESULTS

3.1. Climate

The air temperatures ranged between 10.34-14.85°C (minimum) and 26.33-30.38°C (maximum) during the 2009-2010 experiment, between 9.71-15.77°C (minimum) and 22.75-28.73°C

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(maximum) during the 2010-2011 experiment and between 10.42-15.45°C (minimum) and 23.83-30.35°C (maximum) during the 2011-2012 experiment. Solar radiation ranged between 18.49 and 24.61 MJ m^{-2} day^{-1} during the 2009-2010 experiment, between 20.36 and 25.00 MJ m^{-2} day^{-1} during the 2010-2011 experiment and between 19.45 and 22.18 MJ m^{-2} day^{-1} during the 2011-2012 experiment (Table 1).

Table 1: Daily solar radiation and maximum and minimum temperatures during the experiments. Monthly means for 2009-2010, 2010-2011 and 2011-2012 experiments are plotted.

	TEMPERATURE (°C)		SOLAR RADIATION (MJ m^{-2} day^{-1})
	Maximum	Minimun	
2009-2010			
November	27.92	10.34	23.22
December	30.38	14.54	24.61
January	29.59	14.85	20.45
February	26.33	14.67	18.49
2010-2011			
November	22.75	9.71	20.93
December	28.64	13.13	25.00
January	28.73	15.77	22.76
February	25.98	14.20	20.36
2011-2012			
November	23.83	10.42	20.47
December	25.70	12.56	21.79
January	30.35	15.45	22.18
February	25.99	14.67	19.45

3.2. Plant architecture

Total leaf area in direct-seeded plants increased between E-T and V_T and decreased between V_T and R_3, whereas those in transplanted plants increased between E-T and V_T but remained without changes between V_T and R_3 (Fig. 1). There were highly significant differences ($P < .001$) for the single Sowing routine effect but no significant differences for the others single, double or triple effects related to the genotype ('Canner' or 'Butter Sweet' maize hybrids) or year.

Individual leaf size in direct-seeded plants increased between the first and the twelfth leaf and then decreased, whereas that in transplanted plants showed a similar pattern, but the absolute values were significantly lower, especially for 'Canner' (Fig. 2). There were highly significant differences ($P < .001$) for the single Sowing routine effect but no significant differences for the others single, double or triple effects related to the genotype ('Canner' or 'Butter Sweet' maize hybrids) or year.

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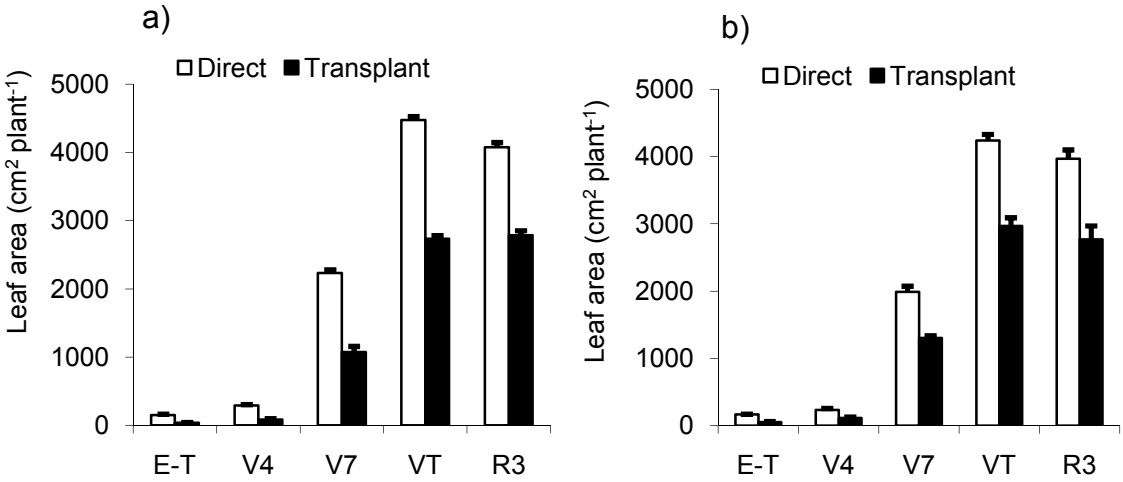
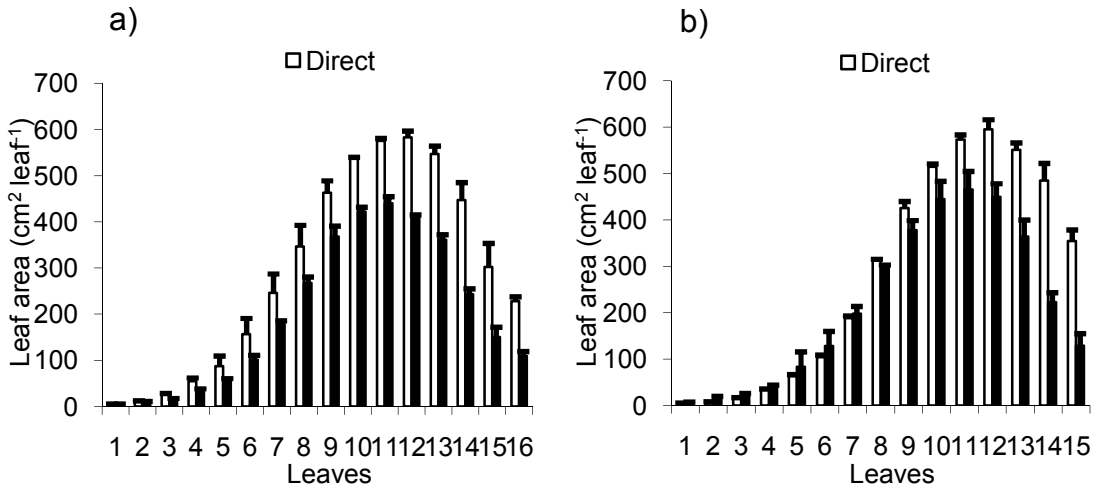


~~Significantly~~	~~ANOVA~~
Sowing routine	***
Hybrids	ns
Year	ns
Sowing routine x hybrids	ns
Sowing routine x years	ns
Year x hybrids	ns
Sowing routine x hybrids x years	ns

*Significance *** 0.001 ~~** 0.01~~ ~~* 0.05~~ 'ns' No significant*

Fig.1. Changes in total leaf area between emergence-transplant and R_3 stages for 'Canner' (A) and 'Butter Sweet' (B) sweet maize mutants either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010 and 2010-2011) (n = 9, *P*). The standard errors over each bar are indicated.



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	~~ANOVA~~
~~Significantly~~	
Sowing routine	***
Hybrids	ns
Year	ns
Sowing routine x hybrids	ns
Sowing routine x years	ns
Year x hybrids	ns
Sowing routine x hybrids x years	ns

*Significance *** 0.001 ~~** 0.01 * 0.05~~ 'ns' No significant*

Fig.2. Individual leaf area of all leaves expanded during the experiments for 'Canner' (A) and 'Butter Sweet' (B) sweet maize mutants initiated either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010 and 2010-2011) (n = 9, *P* = .001). The standard errors over each bar are indicated.

Plant height increased between E-T and R_3 in both sweet maize hybrids but was higher in direct-seeded plants than in transplanted ones. At R_3, direct-seeded plants showed a significantly higher number of expanded leaves but higher number of dead leaves than transplanted plants as well (Table 2). We found highly significant differences (*P* < .001) for the single Sowing routine effect but no significant differences for the others single, double or triple effects related to the genotype or year.

Table 2: Changes in plant height between the emergence-transplant and R_3 stages and number of expanded and dead leaves at the R_3 stage for two sweet maize mutants either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010, 2010-2011 and 2011-2012) (n = 9). Standard errors are indicated. Lowe-case letters indicate statistically significant differences (*P* = .05) between direct-seeded and transplanted plants for each sweet maize hybrid and each growth stage tested.

	Plant height (cm plant^{-1})					Leaves expanded (leaves plant^{-1})	Leaves dead (leaves plant^{-1})
	E-T	V_4	V_7	V_T	R_3	R_3	
'Canner'							
Direct	35.28^a	43.04^a	105.17^a	178.17^a	179.57^a	15.93^a	7.20^a
Transplant	21.02^b	26.26^b	70.04^b	157.87^b	157.54^b	14.27^b	6.26^b
'Butter Sweet'							
Direct	34.70^a	39.65^a	98.50^a	172.58^a	177,02^a	15.97^a	7.53^a
Transplant	24.00^b	27.55^b	84.02^b	155.45^b	157.50^b	14.67^b	6.27^b

ANOVA			
	Plant height	**Leaves expanded**	**Leaves dead**
Significantly			
Sowing routine	***	***	***
Hybrids	ns	ns	ns
Year	ns	ns	ns
Sowing routine x hybrids	ns	ns	ns
Sowing routine x years	ns	ns	ns
Year x hybrids	ns	ns	ns
Sowing routine x hybrids x years	ns	ns	ns

*Significance *** 0.001 ~~** 0.01 * 0.05~~ 'ns' No significant*

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3.3. Light interception and radiation use efficiency

The leaf area index (LAI) and radiation use efficiency (RUE) were higher in direct-seeded plants at V_T in both sweet maize hybrids tested. However, differences in light interception and RUE at R_3 were higher for transplanted ones (Table 3). We found highly significant differences ($P < .001$) for the single Sowing routine effect but no significant differences for the others single, double or triple effects related to the genotype or year.

Table 3: Leaf area index, light interception and radiation use efficiency for two sweet maize mutants either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010, 2010-2011 and 2011-2012) (n = 9). Standard errors are indicated. Lower-case letters indicate statistically significant differences (*P* = .05) between direct-seeded and transplanted plants for each sweet maize hybrid and each growth stage tested.

	LAI (cm^2 m^{-2})	Light interception (%)	RUE (g m^{-2} $day^{-1}MJ^{-1}$)	
	V_T	R_3	E/T-V_T	R_3
'Canner'				
Direct	3.58^a	66.97^b	0.027^a	0.056^a
Transplant	2.19^b	70.15^a	0.010^b	0.055^a
'Butter Sweet'				
Direct	3.39^a	64.66^b	0.027^a	0.052^a
Transplant	2.37^b	72.65^a	0.015^b	0.050^a

ANOVA				
	LAI	Light interception	RUE	
			E/T-V_T	R_3
Significantly				
Sowing routine	***	***	***	ns
Hybrids	ns	ns	ns	ns
Year	ns	ns	ns	ns
Sowing routine x hybrids	ns	ns	ns	ns
Sowing routine x years	ns	ns	ns	ns
Year x hybrids	ns	ns	ns	ns
Sowing routine x hybrids x years	ns	ns	ns	ns

*Significance *** 0.001 ~~** 0.01 * 0.05~~ 'ns' No significant*

3.4. Dry weight accumulation

At V_T dry weight accumulations were higher in stems than in leaves and higher in direct-seeded plants than in transplanted ones. At R_3, we observed the same pattern, but no significant differences in ear dry weight (Table 4). There were highly significant differences ($P < .001$) for the single Sowing routine effect but no significant differences for the others single, double or triple effects related to the genotype or year.

Table 4: Distribution of dry weight at the V_T and R_3 stages for 'Canner' and 'Butter Sweet' sweet maize mutants either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010, 2010-2011 and 2011-2012) (n = 9). Standard errors are indicated. Lower-case letters indicate statistically significant differences (*P* = .05) between direct-seeded and transplanted plants for each sweet maize hybrid and each growth stage tested.

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	Dry weight (g plant^{-1})				
	V_T		R_3		
	Stem	Leaves	Stem	Leaves	Ear
'Canner'					
Direct	42.06^a	21.18^a	63.23^a	28.03^a	65.53^a
Transplant	29.38^b	11.92^b	33.80^b	17.17^b	70.59^a
'Butter Sweet'					
Direct	40.59^a	22.21^a	58.27^a	26.50^a	63.73^a
Transplant	37.08^b	15.87^b	38.33^b	19.30^b	68.47^a

	ANOVA				
	V_T		R_3		
	Stem	Leaves	Stem	Leaves	Ear
Significantly					
Sowing routine	***	***	***	***	ns
Hybrids	ns	ns	ns	ns	ns
Year	ns	ns	ns	ns	ns
Sowing routine x hybrids	ns	ns	ns	ns	ns
Sowing routine x years	ns	ns	ns	ns	ns
Year x hybrids	ns	ns	ns	ns	ns
Sowing routine x hybrids x years	ns	ns	ns	ns	ns

*Significance *** 0.001 ~~** 0.01 * 0.05~~ 'ns' No significant*

Relative leaf area expansion rate (RLAE) and relative growth rate (RGR) were significant higher in direct-seeded plants than in transplanted ones. The last, was the result of significant higher net assimilation rate (NAR) from transplanted plants and lesser significant values for leaf area ratio (LAR) (Table 5). There were highly significant differences (P < .001) for the single Sowing routine effect but no significant differences for the others single, double or triple effects related to the genotype ('Canner' or 'Butter Sweet' maize hybrids) or year.

Table 5: Relative leaf area expansion rate (RLAE), relative growth rate (RGR), net assimilation rate (NAR) and leaf are ratio (LAR) for 'Canner' and 'Butter Sweet' sweet maize mutants either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010, 2010-2011 and 2011-2012) (n = 9). Standard errors are indicated. Lower-case letters indicate statistically significant differences (*P* = .05) between direct-seeded and transplanted plants for each sweet maize hybrid and each growth stage tested. The probability of the slope being zero was *P* = .001 for all growth parameters.

	RLAE (cm^2 cm^{-2} day^{-1})		RGR (g g^{-1} day^{-1})		NAR (g cm^{-2} day^{-1})		LAR (cm^2 g^{-1})	
	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'
Direct	0.0510^a	0.0517^a	0.0779^a	0.0795^a	0.0010^a	0.0010^a	78.93^b	78.79^b
Transplant	0.0462^b	0.0473^b	0.0624^b	0.0644^b	0.0008^b	0.0008^b	81.99^a	80.55^a

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ANOVA				
	RLAE	RGR	NAR	LAR
Significantly				
Sowing routine	***	***	***	***
Hybrids	ns	ns	ns	ns
Year	ns	ns	ns	ns
Sowing routine x hybrids	ns	ns	ns	ns
Sowing routine x years	ns	ns	ns	ns
Year x hybrids	ns	ns	ns	ns
Sowing routine x hybrids x years	ns	ns	ns	ns

*Significance *** 0.001 ~~** 0.01~~ ~~* 0.05~~ 'ns' No significant*

3.5. Yield

The number of kernels per ear and ear yield expressed on a fresh weight basis per plant showed no significant differences between direct-seeded and transplanted plants. On the other hand, harvest index (HI) and ear yield expressed on a cultivated area basis were significantly higher in transplanted plants than in direct-seeded ones (Table 6). We found highly significant differences (*P* < .001) for the single Sowing routine effect in the ANOVA HI and Yield (on a surface area) but no significant differences for the others single, double or triple effects related to sowing routine (Kernels per ear and Yield per plant) the genotype or year.

Table 6: Changes in Harvest Index from V_T to R_3 stages, number of kernels per ear and yield for 'Canner' and 'Butter Sweet' sweet maize mutants under either a direct seeding or transplant routine (data are the mean of three years: 2009-2010, 2010-2011 and 2011-2012) (n = 9). Standard errors are indicated. Lower-case letters indicate statistically significant differences (*P* = .05) between direct-seeded and transplanted plants for each sweet maize hybrid and each growth stage tested. Yield (ton fresh weight ha^{-1}) was calculated as the product of ear fresh dry weight by ear number on an area basis (ha^{-1}). Ear number in direct-seeded plants was decreased by germination-emergence losses (mean 14% for both maize mutant hybrids). Mean pos-transplant losses were 1% and 2% for 'Canner' and 'Butter Sweet' respectively.

	HI	Kernels per ear	Yield (g fresh weight $plant^{-1}$)	Yield (ton fresh weight ha^{-1})
'Canner'				
Direct	0.273^b	434.96^a	254.09^a	17.48^b
Transplant	0.367^a	459.70^a	262.53^a	20.79^a
'Butter Sweet'				
Direct	0.309^b	436.10^a	255.43^a	17.57^b
Transplant	0.365^a	434.87^a	265.17^a	20.78^a

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ANOVA				
	HI	**Kernels per ear**	**Yield (plant^{-1})**	**Yield (ha^{-1})**
Significantly				
Sowing routine	***	ns	ns	***
Hybrids	ns	ns	ns	ns
Year	ns	ns	ns	ns
Sowing routine x hybrids	ns			
Sowing routine x years	ns			
Year x hybrids	ns	ns	ns	ns
Sowing routine x hybrids x years	ns			

*Significance *** 0.001 ~~** 0.01 * 0.05~~ 'ns' No significant*

3.6. Anatomical measurements

Leaf thickness and stomata density were not significant different between direct-seeded plants than transplanted ones. However, transplanted plants showed higher vascular bundles and phloem/xylem ratio than direct-seeded ones (Table 7). We found highly significant differences (P < .001) for the single Sowing routine effect in the ANOVA Leaf thickness, Phloem/Xylem ratio and Vascular bundle/mesophyll ratio but no significant differences for the others single, double or triple effects related to sowing routine (Stomata density), the genotype or year.

Table 7: Changes in leaf traits such as leaf thickness, stomata density, phloem/xylem ratio and vascular bundle/mesophyll ratio for 'Canner' and 'Butter Sweet' sweet maize mutants either under a direct seeding or transplant routine (data are the mean of three years: 2009-2010, 2010-2011 and 2011-2012) (n = 9). Standard errors are indicated. Lower-case letters indicate statistically significant differences (P = .05) between direct-seeded and transplanted plants for each sweet maize hybrid and each growth stage tested.

	Leaf thickness (µm leaf^{-1})	**Stomata density (stomata mm^{-2})**	**Phloem/Xylem ratio (%)**	**Vascular bundle/mesophyll ratio (%)**
'Canner'				
Direct	186.25^{a}	103.50^{a}	337.50^{b}	23.65^{b}
Transplant	188.75^{a}	99.52^{a}	393.33^{a}	28.96^{a}
'Butter Sweet'				
Direct	191.43^{a}	127.39^{a}	320.93^{b}	31.21^{b}
Transplant	188.67^{a}	133.31^{a}	584.00^{a}	43.53^{a}

ANOVA				
	Leaf thickness	**Stomata density**	**Phloem/Xylem ratio**	**Vascular bundle/mesophyll ratio**
Significantly				
Sowing routine	***	ns	***	***
Hybrids	ns	ns	ns	ns
Year	ns	ns	ns	ns
Year x hybrids	ns	ns	ns	ns

*Significance *** 0.001 ~~** 0.01 * 0.05~~ 'ns' No significant*

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4. DISCUSSION

Under non-stressed environmental conditions, such as ample available water, fertile soil and absence of disease, radiation is the key driving force of the ideal growth environment. To analyze this, three important indices should be considered: (i) the fraction of intercepted radiation, (ii) RUE and (iii) HI**.** Of the two components of dry-matter production (intercepted radiation and RUE), light interception has received more attention. Accumulation of maize dry matter is more closely related to the amount of radiation absorbed by the crop than to RUE [18]. In the present study, we found no significant differences in light interception between transplanted and direct-seeded plants at the R_3 stage but higher LAI for direct-seeded plants until the V_T stage (Table 3). In maize, LAI and grain yield are strongly correlated [19]. Radiation interception varies from seedling emergence to crop harvest and depends largely on the canopy leaf area and plant height. Critical LAI, defined as the plant biomass which allows intercepting 99% of radiant photosynthetic light, was never achieved by either of the two sweet maize hybrid mutants tested (Table 3). The leaf area development phase occurs between seedling emergence and anthesis and depends on number of leaves, the rate at which leaves are initiated and subsequently appear in the whorl, and both the rate and duration of leaf expansion [20]. Our results showed that the higher leaf area (Fig. 1) and relative rate of leaf expansion (RLAE) (Table 5) achieved by direct-seeded plants was a result of the higher leaf number (Table 2) and leaf size (Fig. 2) as compared to those of transplanted ones. However, transplanted plants showed lower number of dead leaves and plant height (Table 2) and early senescent leaves (data not shown) at the R_3 stage which would decrease leaf shading and improve light interception.

In recent years, optimum populations for field corn in temperate climates have ranged from 79,000 to 84,000 plants ha^{-1} [21, 22]). Such densities exceed the populations densities appropriate for sweet corn. Williams [23] has indicated that populations for maximum sweet corn yield vary greatly depending of the hybrid, ranging from 48,100 to 70,200 plants ha^{-1}. However, we have previously shown that a transplant routine gives smaller plants but allows population densities of near 120,000 plants ha^{-1} [7].

Greater light penetration to the ear level of the canopy may confer a significant yield advantage. The importance of leaves in the vicinity of the ear to plant photosynthesis has been demonstrated. These leaves have the highest photosynthetic rates in the canopy and they senesce more slowly than all other leaves [24], maintaining a high photosynthetic rate during the grain filling period. The kernel set in maize [25] has been associated with intercepted radiation around anthesis. The use of a transplant routine maintains RUE (Table 3) at R_3 through a larger number of functional leaves and a lower number of senescent leaves (Table 2).

When dry accumulation changes over time were separated in shoots, leaves and ears, we found a clear greater accumulation in shoots and leaves in direct-seeded plants but no significant differences in ear dry weight in transplanted ones (Table 4). Shoot dry weight of crops is strongly correlated to the amount of radiation intercepted by the canopy. The slope of this relationship, called RUE, is often assumed to be very constant within each cultivated species. Many authors have suggested that RUE is relatively stable over a range of environmental and management variables [26]. Our experiments showed that RUE there were no significant differences between transplanted plants and direct-seeded ones at the R_3 stage when 'Canner' (a *su* hybrid) and 'Butter Sweet' (a *shu2* hybrid) were tested (Table 3).

Although it has been indicated that transplant decreases sweet maize yield [5, 27], we have previously found that yield (g fresh weight $plant^{-1}$) was not significantly different between direct-seeded and transplanted plants grown at low or high populations [6, 7]. The results of the present study (Table 6) are in agreement with this recent information.

Spacing uniformity, timing and rate of emergence, and plant population in a maize stand are the most common characteristics used by growers to evaluate yield performance. Plant spacing and emergence variability may ultimately affect plant growth and maize grain yield [28]. Uniform plant

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height, which is an indication of uniform emergence, is associated with higher yields [29]. In addition to spacing variability, a maize stand may also emerge non-uniformly. Late-emerging plants within a row must compete for incident solar radiation, moisture, and nutrients with earlier-emerging neighboring plants which are often taller and have a more developed root system. If competition is severe, late-emerging plants may not produce grain and may actually function as weeds in the canopy [20]. Missing plants in the field are inevitable [30]. In our experiments, 14% of direct-sown seeds failed to produce plants (Table 6). Given that missing plants in the field is a common problem, and that neighbouring plants fail to fully compensate for yield of missing plants, the final grain yield per unit area decreases. Our results showed that both effects, i.e. missing plants and lower plant growth rate (Table 5), are possible when using a direct-seeded routine. This allows explaining the beneficial effects of the transplant on the emergence rate and crop yield (ton fresh weight ha^{-1}) in the two maize mutant hybrids tested (Table 6).

Grain formation in maize is the result of the photosynthetic ability of source leaves and the integrated process of allocation, accumulation and utilization of assimilated carbon at the whole plant level [16]. Biomass accumulation can be described through RGR. Table 5 shows that RLAER and RGR (including only shoot dry weights) in direct-seeded plants were higher as a result of higher values in the RGR-physiological component (NAR) and lower values in the RGR-morphological component (LAR) from those in transplanted ones. We found no significant differences in anatomical traits such as leaf thickness (usually related to the light-saturated rate of photosynthesis per unit leaf area) [31] or stomata density (associated with CO_2 diffusion through the cytosol to the chloroplast surface area) [32] (Table 7).

Although in the last years HI has largely remained constant between 0.49 and 0.51 [33], we found a higher HI In transplanted plants which allow explaining the yield per plant (Table 6). Table 7 shows that the phloem/xylem ratio and vascular bundle/mesophyll ratio were significantly higher in transplanted plants than in direct-seeded ones, which would ensure photo-assimilate translocation from roots. Plug cell trays may cause root restriction effects, i.e. a physical stress imposed on a root system which leads to a significant decrease in post-transplant growth [13, 11, 34]. A single exogenous application of cytokinin 6-benzylaminopurine (BAP) to plants grown in small pots at the pre-transplant stage may override the shoot growth limitation due to root restriction [11, 14,15, 34; 35]. Correct vascular development includes hormone interactions between auxins and cytokinins [36, 37] but, the precise hormonal mechanisms associated with container root restriction involved in maize plants require further research but would be a key matter for a future breeding program [38].

5. CONCLUSION

Our results showed that the transplant sowing routine increase light interception at the stage of kernel filling and RUE. The higher dry weight accumulation in ears determines an increase in HI. A change in leaf area development and crop architecture when using transplanted plants allow increasing sweet maize yield on an area basis. To understand the mechanisms associated to the morphological changes related to transplant and their importance on population architecture would be a key matter for a future breeding program.

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