Effects of determinate growth and obscure veins on water use efficiency in California processing tomatoes

Felipe H. Barrios-Masias[1], Roger T. Chetelat[2] and Louise E. Jackson[1]

(1) Dept. of Land, Air and Water Resources, and (2) Dept. of Plant Sciences; University of California-Davis, Davis, CA

Introduction

- Determinate growth habit is a trait bred into California processing tomato cultivars that allows synchronous fruit production for mechanized harvest.
- An obscure vein trait increases chloroplast density near leaf veins, and it is present in a majority of California processing tomato cultivars (Fig. 1 a-c).
- These two traits are located near each other on chromosome 5, i.e.,
  - The gene conferring obscure veins, *obscuravenosa* (*obv*), is near the *SP5G* gene, a paralog of the *self-pruning gene that* controls the switch between determinate and indeterminate growth, located on chromosome 5 at or near a QTL for plant height and flowering time (Jones et al., 2007. Am J Bot 94, 935-947) (Figure 1a).
- Along with these traits, agronomic water use efficiency (yield/applied water) in California processing tomatoes has increased by keeping evapotranspiration rates constant even as productivity has increased >50% since the 1970's (Hanson and May, 2006. Irrig Sci 24, 211-221).

Objectives

1. Determine the effect of obscure veins on leaf gas exchange and how it affects physiological WUE (CO_2 assimilation/H_2O transpired, i.e., A/E).
2. Measure how determinate growth alters resource allocation to leaves, stems and fruits, and how it relates to increased agronomic WUE in modern California processing tomatoes.

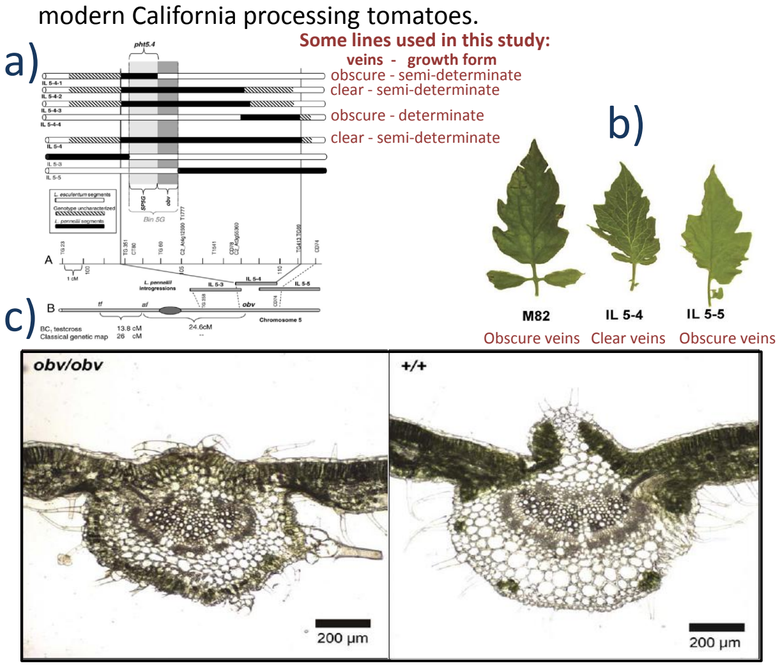
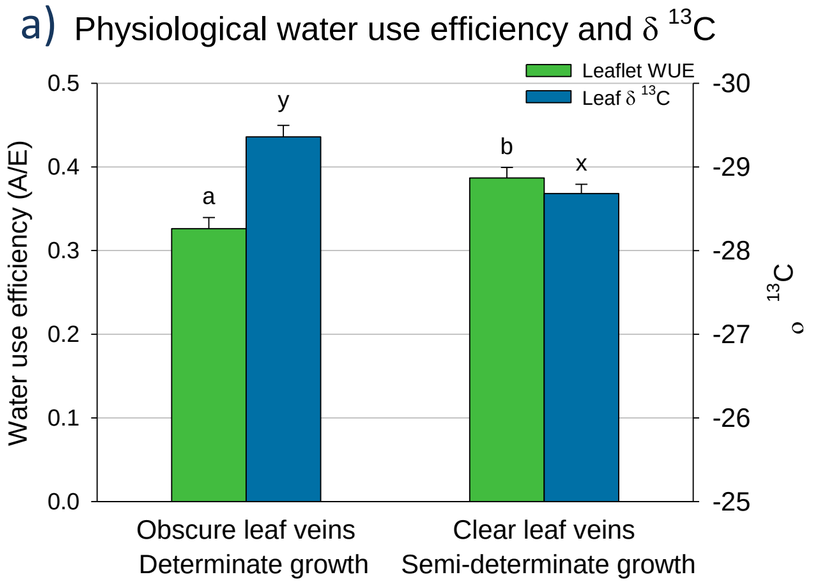


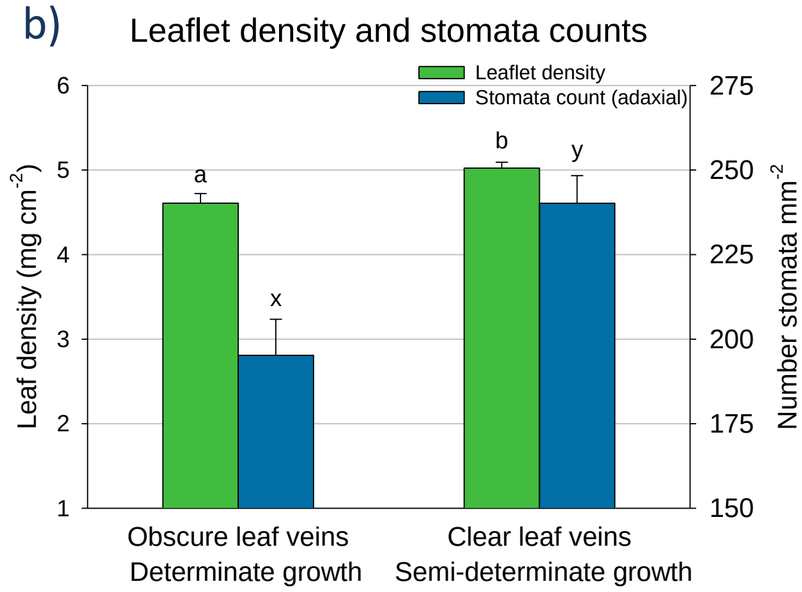
Figure 1. a) Integrated genetic map showing the position of *obv* and *SP5G* in chromosome 5. ILs used in the present study are labeled on the right; cultivar M82 and IL 5-4-5-44 (not shown) were also used. **b)** Tomato leaflets showing the obscure and clear vein traits of cultivar M82 and introgression lines (IL). **c)** Transverse section of tomato leaflets with obscure veins, i.e., higher chloroplast density on the left, and clear veins on the right (Modified from Jones et al., 2007. Am J Bot 94, 935-947)

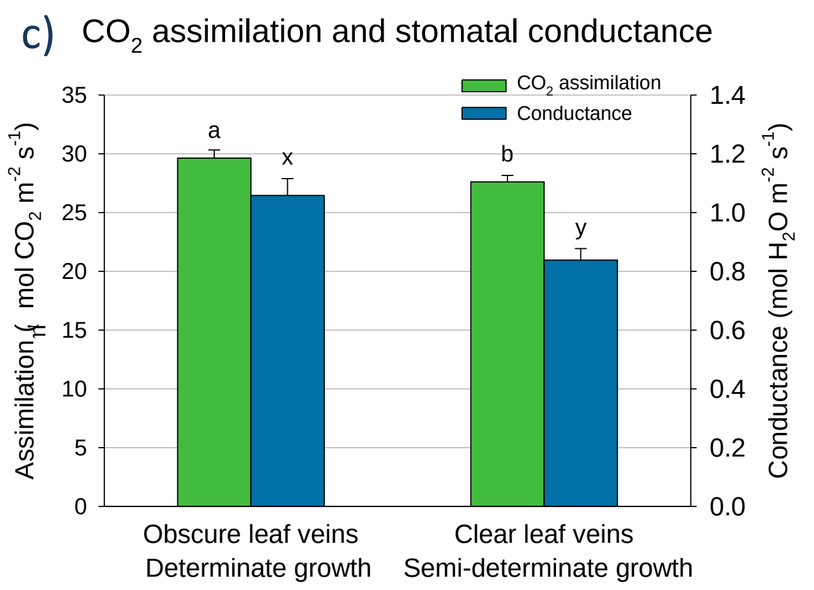
Methodology

- A field study was conducted at the UC Davis research facilities under best management practices of fertilization and irrigation.
- A group of introgression lines with defined segments of the *Solanum pennellii* genome in the genetic background of cultivated tomato, *S. lycopersicum* cv. M82, were compared (Fig. 1 a-c).
- Evaluations included:
  - Leaf gas exchange measurements during a 4 week period in three 3-day runs using the LI-6400 (LI-COR Inc., Lincoln, NE, USA).
  - Chlorophyll content determination from leaflet disks taken from fully mature and light-exposed leaves, frozen in liquid N_2 and extracted with 80% acetone (Lichtenthaler, 1987. Methods Enzymol, vol 148).
  - Leaf density calculated from total dry biomass per leaflet area. Sampling was done similarly as for chlorophyll determination.
  - Stomata counts from leaflet imprints on clear nail polish, transferred to clear tape, and pictured under a x400 magnification microscope (Gailing et al., 2008. Global Change Biol 14, 1934-1946).
  - Canopy growth monitoring using an infrared digital camera (Dycam, Woodland Hills, CA).
  - $\delta\ ^{13}C$ from leaves: dried, ground, and analyzed in the Stable Isotope Facility at UC Davis.
  - Aboveground biomass: stems, leaves and fruits, at 10 weeks after transplanting.

Field data obtained in a 4 week period of maximum plant growth







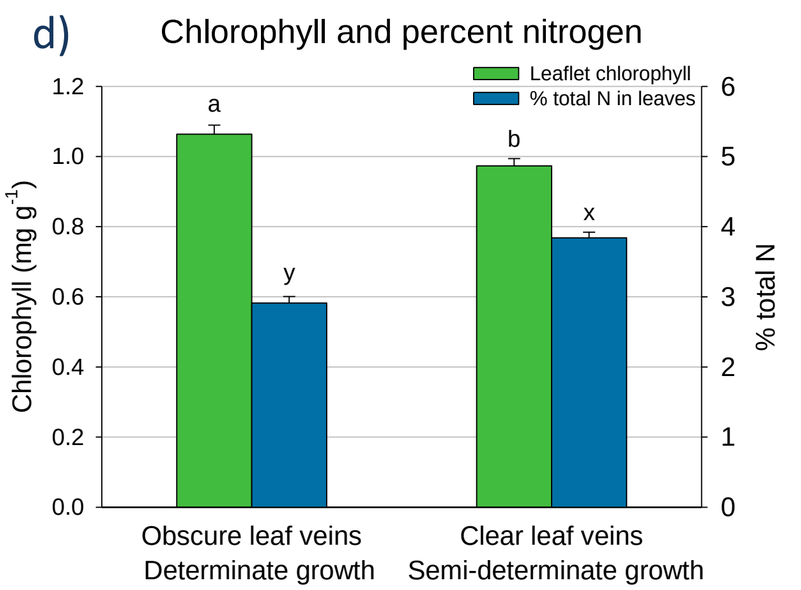


Figure 2. Comparison of two California processing tomato traits using introgession lines (ILs): obscure leaf veins + determinate growth vs. clear leaf veins + semi-determinate growth. Shown are leaf gas exchange and leaf characteristics that relate to gas exchange and physiological water use efficiency (WUE). ANOVA contrast analysis in a RCBD design. Includes cultivar M82 and IL 5-4-4 for obscure leaf veins and determinate growth, vs. IL 5-4 and IL 5-4-2 for clear leaf veins and semi-determinate growth **(4 lines total).**

Measurement	Number of dates	*n* on each date	Obscure vs clear leaf veins		Determinate vs semi-determinate growth	
			Trend	P value	Trend	P value
Conductance (mol H_2O m^{-2} s^{-1})	9	4	higher	0.0022	higher	0.0084
CO_2 assimilation (µmol CO_2 m^{-2} s^{-1})	9	4	higher	0.0130	=	0.1257
Physiological Water use efficiency	9	4	lower	0.0023	lower	0.0036
Leaf $\delta\ ^{13}C$	2	4	lower	0.0005	lower	0.0005
Leaflet chlorophyll (mg g^{-1} FW)	1	6	higher	0.0177	higher	0.0027
Leaflet chlorophyll (ug cm^{-2})	1	6	=	0.9005	=	0.5215
%N in leaves	1	4	lower	0.0002	lower	0.0002
Leaflet density (mg cm^{-2})	1	6	lower	0.0008	lower	0.0060
Stomata count mm^{-2} (adaxial)	1	6	lower	0.0022	lower	0.0307
Canopy % light intercepted m^{-2}	1	6	lower	<0.0001	lower	<0.0001
Total fruits (g)	1	6	higher	0.0173	higher	<0.0001
Total aboveground biomass (g)	1	6	lower	<0.0001	lower	0.0012

Table 1. Physiological and morphological parameters measured in a field study on **5 introgression lines + cultivar M82** with differing traits for chloroplast presence in vein leaves and growth habit (Figure 1). ANOVA contrast analysis in a RCBD design. Significance is preceded by 'higher', 'lower' or 'equal' in reference to the mean of obscure leaf vein or determinate growth in relation to its counterpart.

Results

- Obscure leaf veins increased leaf CO_2 assimilation and conductance, but lowered physiological WUE compared to clear leaf vein ILs (Fig. 2a, Table 1).
- ILs with determinate growth had higher leaf conductance and reduced physiological WUE (Table 1).
  - Decreased WUE is corroborated by results of leaf $\delta\ ^{13}C$ (Table 1), and by gas exchange measurements and total water applied under control conditions in a greenhouse study (data not shown).
- A reduction in leaflet density of ILs with determinate growth and obscure leaf veins may be compensated by increased chlorophyll content per g of leaf fresh weight (Fig. 2b, 2d, Table 1).
  - More chloroplasts per leaflet area may increase rates of photosynthesis. Chlorophyll content per unit area is similar among ILs.
- Percent total N in leaves is unexpectedly lower in ILs with determinate growth and obscure leaf veins despite higher CO_2 assimilation rate and increased chlorophyll content (Fig 2c, 2d). This still needs to be explained.
- Total aboveground biomass was lower in determinate growth and obscure leaf vein ILs, but allocation to fruits was higher. The reduction in stems and leaves decreased canopy size and light interception (Table 1).

Conclusions

- Purpose selection of determinate growth in California processing tomatoes resulted in the inadvertent selection of the obscure-leaf-vein trait which conferred higher CO_2 assimilation rates, but at the expense of decreasing physiological WUE.
- Morphological and phenological changes, e.g., reduced canopy size and higher allocation to fruits, may be the main drivers, at the ecophysiological level, for an increase in agronomic WUE (yield/water applied) observed in the last 40 years.

Acknowledgements

Funding for this project was provided by grants from USDA: USDA NIFA SCB09036, and the Western Sustainable Agriculture Research and Education (Western SARE) grant GW 10-010.