

Ohio 9241, Ohio 9242, and Ohio E3259: Tomato Breeding Lines for the Improvement of Color and Lycopene Content.

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Objective measurements of color, chromaticity values, can be used to estimate the concentration of lycopene the predominant red pigment in tomato (D'Souza et al, 1992). Selection for improved color should therefore improve lycopene content with a potential health benefit to consumers. Clinical nutrition studies show a correlation between increased consumption of red tomato products and a reduced risk of developing cancers. The antioxidant effects of lycopene suggest a possible mechanism of activity (Clinton, 1998; Nguyen and Schwartz, 1999). Chemical measurement of lycopene can be accomplished by spectrophotometric methods of extracts and by High Pressure Liquid Chromatography (HPLC) using a polymeric C₃₀ column (Emenhiser et al., 1995). The advantage of HPLC methodology is that individual pigments can be quantified and isomers can be separated. Thus the concentration of all-trans-lycopene, the most significant red pigmented isomer, can be accurately measured.

Improving the color and lycopene content of tomatoes can be accomplished using classically defined genes (Gross 1991), quantitative trait loci from wild species (Fulton et al., 1997), and quantitative trait loci from cultivated tomato. The genes dark green (*dg*), high pigment-1 (*hp-1*), high pigment-2 (*hp-2*), and old gold crimson (*og^c*) are examples of genes that have a positive effect on the concentration of lycopene. The genes *dg*, *hp-1*, and *hp-2* improve the red color of tomatoes by increasing the number of chloroplasts and, therefore, chromoplasts. This mechanism increases the concentration of all fruit carotenoids, but the use of these genes in breeding programs has been limited due to undesirable pleiotropic effects such as poor seed germination and brittle stem (Jarret et al. 1984). The old gold crimson (*og^c*) gene increases the level of lycopene through a biochemical mechanism at the expense of beta-carotene. *Og^c* has been widely used in breeding programs to improve red-fruited tomatoes. A recent study by Sacks and Francis (2001), indicates that *og^c* accounted for only 18-27% of the genotypic

variation for color when evaluated among red-fruited breeding lines, open-pollinated cultivars, and hybrids adapted to the Midwest and Mid-Atlantic states. These findings suggest that quantitative trait loci (QTL) affecting fruit color exist within cultivated tomato germplasm. Sampling strategies that use objective measurements and extended replication were designed in order to increase the precision of selection as an aide in identifying germplasm with improved red color.

The tomato breeding lines Ohio 9241, Ohio 9242, and Ohio E3259 were selected on the basis of objective color measurements using the sampling strategies developed by Sacks and Francis (2001). Subsequent chemical analysis indicated that these breeding lines have a higher lycopene content than industry standards. These breeding line releases should be useful as parents in developing hybrids with improved color and lycopene content. Furthermore they should be useful as sources of both the *og^c* allele and QTL for improved color and lycopene content.

Origin . Seed for Ohio 9241 and Ohio 9242 was increased at the F₈ generation. Both selections are derived by single seed descent from independent F₂ progeny resulting from a cross between O9149 (Montagno et al., 1989) and Ohio 8556 (Berry et. al. 1993). The line O9149 is a selection from a population of Ohio 832 (Berry and Gould, 1986) regenerated from cotyledon cultures. Ohio E3259 is a single F₈ selection from a cross between Ohio 8556 and Ohio 8245 (Berry et al., 1991). Both Ohio 832 and Ohio 8556 carry the *og^c* allele. Ohio 8556 and Ohio 8245 carry the *j²* allele for jointless pedicel.

Description. Selection for color was based on chromaticity values in the CIELAB color space (Commission Internationale de L'Eclairage, 1978) measured using a CR300 colorimeter (Minolta, Ramsey, N.J.). Measurements of fruit flesh were taken as described in Sacks and Francis (2001) with sampling expanded to include 24 fruit per plot, two plots per location, three locations per year, and three years of trials between 1997 and 1999. Trial locations were in Fremont, Wooster, and Wood County, Ohio. The lycopene content was confirmed in fruit from replicated trials at the Fremont location in two years (1997 and 1998) using both spectrophotometric methods and HPLC. High population transplant culture, machine harvest yield, and bulk handling under humid growing environments were evaluated in three years of replicated trials at the Fremont location.

Ohio 9241 vines are medium in size and determinate (sp). Foliage cover is excellent for ensuring good fruit quality and the vines cover the row area uniformly at maturity. The average maturity from transplant to harvest of Ohio 9241 is 98.2 days measured over three years of field testing, and is comparable to the major early to main-season variety TR12. The average machine harvest yield of Ohio 9241 was 58.0 T ha^{-1} over three years of testing, less than but not significantly different from commercial open pollinated varieties Ohio 7983 (Berry et al., 1992) and Ohio 8245. Yields of Ohio 9241 are less than commercial hybrids of comparable maturity (Table 1). Fruit of Ohio 9241 are ovate in shape and average 65 gm with two to three locules. Fruit have a small stem scar and core, are uniform ripening (u), are attached by a jointless pedicel (j^2), and are crimson (og^c). The color (Table 2) and lycopene content (Table 2) for fruit from Ohio 9241 is superior to commercial varieties in the same maturity class. Ohio 9241 has excellent color uniformity even under conditions favorable to YSD.

Ohio 9242 vines are medium in size and determinate (sp). Foliage cover is excellent for ensuring good fruit quality and at maturity the vines are somewhat upright. The average maturity from transplant to harvest of Ohio 9242 is 102.8 days measured over three years of testing in the field, and is comparable to the major main-season variety Peto 696. The average machine harvest yield of Ohio 9242 was 67.0 T ha⁻¹ over three years of testing, comparable to commercial open pollinated varieties Ohio 7983 (Berry et al., 1992) and Ohio 8245. Yields of Ohio 9242 tended to be less than commercial hybrids of comparable maturity (Table 1). Fruit of Ohio 9242 average 73 gm with two to three locules. The shape is ovate to round. Fruit have a small stem scar and core, are uniform ripening (u), are attached by a jointless pedicel (j²), and are crimson (og^c). The color (Table 1) and lycopene content (Table 2) for fruit from Ohio 9242 is superior to commercial varieties in the same maturity class. Ohio 9242 has excellent color uniformity even under conditions favorable to YSD. The soluble solids content for fruit from Ohio 9242 tends to exceed varieties developed in the Midwest, though these differences are not always significant (Table 1).

Ohio E3259 vines are small to medium in size and determinate (sp). Foliage color is comparable to Ohio 8245 and cover is excellent for ensuring good fruit quality. The vines cover the row area uniformly at maturity. The average maturity from transplant to harvest of Ohio E3259 is 103 days measured over three years of field testing, and is comparable to the late season standard, Ohio 8245. The average machine harvest yield of Ohio E3259 was 68.8 T ha⁻¹ over three years of testing, comparable to the commercial open pollinated varieties Ohio 7983 and Ohio 8245. Yields of Ohio E3259 are less than commercial hybrids of comparable maturity (Table 1). Fruit of Ohio E3259 are ovate in shape and average 65 gm with two to three locules. Fruit have a small stem scar and core, are uniform ripening (u), are attached by a jointless

pedicel (*j-2*), and are crimson (*og^c*). The absolute color (Table 1) and lycopene content (Table 2) for fruit from Ohio E3259 is superior to commercial varieties in the same maturity class.

Disease resistance. Ohio 9241, Ohio 9242, and Ohio E3259 are resistant to fusarium wilt caused by *Fusarium oxysporum* Schlecht f. sp. *Lycopersici* (Sacc.) S. & H. (*I-1*) and verticillium wilt caused by *Verticillium dahliae* Kleb (*ve-1*). They have field tolerance to early blight (*Alternaria solani* spp.) and to anthracnose fruit rot (*Colletotrichum* spp.). Ohio E3259 has field tolerance to bacterial spot (*Xanthamonas* spp.). We believe this tolerance traces back to C28 in the pedigree of both Ohio 8556 and Ohio 8245.

Availability. Ohio 9241, Ohio 9242, and Ohio E3259 are inbred tomato breeding lines.

Material transfer agreements are available from the Office for Technology Licensing, The Ohio State University, 1960 Kenny Road, Columbus, OH 43210-1063, (614)292-3911; FAX (614)292-8907. Small samples of seed are available from the corresponding author.

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Table 1. Yield, fruit color, firmness, and soluble solids content of selected tomato varieties.

Genotype	Type	Maturity	Yield ¹ T ha ⁻¹	L ²	Chroma ²	Hue ²	Force ³ (Kg)	Brix ⁴
Ohio 7983	OP	Early	69.3	41.6	35.9	44.0	5.5	4.7
Ohio OX 52	F ₁	Early	90.6	41.9	36.1	45.1	5.0	4.2
Ohio 9241	OP	Early-Mid	58.0	40.0	36.1	41.5	5.2	4.6
TR 12	F ₁	Early-Mid	83.1	40.1	36.2	42.6	5.6	4.1
Heinz 9423	F ₁	Mid	75.5	43.3	40.6	41.2	7.2	4.4
PS 696	F ₁	Mid	92.4	42.6	37.3	44.8	5.6	4.2
Ohio 9242	OP	Mid	67.0	38.8	35.4	38.8	4.9	4.8
Ohio E3259	OP	Late	68.8	38.4	32.7	44.1	5.7	4.5
Ohio 8245	OP	Late	74.5	42.8	37.3	44.6	5.8	4.3
		mean	75.5	41.0	36.4	43.0	5.6	4.4
		LSD (0.05)	21.1	2.7	1.8	ns	0.6	0.63
		LSD (0.30)	11.0	1.4	0.9	2.4	0.3	0.33

¹ Data for red-ripe fruit after once-over harvest using a Johnson mechanical harvester. Fruit were sorted by hand into ripe, green, and cull categories. The ripe fruit from 1997 graded at 98% to 100% usable by United States Department of Agriculture inspectors.

² L, Chroma, and Hue are in the CIELAB color space (Commission Internationale de L'Eclairage, 1978). Data were obtained using a CR300 colorimeter from three years, three locations per year, two plots per location, and 24 fruit per plot.

³ Firmness was measured as force to puncture (0-25 Kg) with an Accu Force Cadet digital force gauge (Ametek Co., Largo, FL) attached to a 1 cm diameter probe. The rate of descent was controlled by attaching the force gauge to a drill press.

⁴ Soluble solids were estimated in Brix using a Leica ABBE refractometer (Leica, inc., Buffalo, NY) and juice from a puree of ten fruit per plot.

Table 2. Lycopene content for selected tomato varieties grown in Fremont, Ohio during 1997 and 1998.

Genotype	Maturity	Lycopene ¹	
		uv/vis	HPLC
Ohio 7983	Early	11.6	10.4
Ohio OX 52	Early	11.4	8.2
Ohio 9241	Early-Mid	13.4	12.9
TR 12	Early-Mid	9.6	7.3
Heinz 9423	Mid	11.7	11.3
PS 696	Mid	9.9	8.4
Ohio 8556	Mid	10.6	9.6
Ohio 9242	Mid	13.0	12.4
Ohio E3259	Late	13.5	12.6
Ohio 8245	Late	9.4	7.9
	mean	11.5	10.2
	LSD (0.05)	2.8	2.7
	LSD (0.30)	1.4	1.3

¹ Lycopene concentration was estimated in mg/100 gm dry wt using spectrophotometric methods (uv/vis) or HPLC to estimate the concentration of all-trans isomer (Emenhiser et al., 1995). Data are from Fremont (1997 and 1998), two plots per year.