

Harvest Maturity Affects Fruit Yield, Size, and Grade of Fresh-market Tomato Cultivars

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Abstract. Eight staked, determinate tomato (*Lycopersicon esculentum* Mill.) cultivars were harvested when green (before breaker stage) or when pink (breaker stage and riper) in two replicated field studies. In general, total yield and average fruit size were reduced when fruit were harvested at the green stage. Harvest maturity had only a small effect on occurrence of most fruit defects, except fruit cracking, which was more severe for pink than for green fruit in the early season experiment. Although total yields for pink harvested fruit were higher than for green harvested fruit in the early season study, the high incidence of fruit crack in pink fruit resulted in similar yields of U.S. combination grade (U.S. no. 1 and U.S. no. 2) fruit for both treatments. Because the largest fruit often bring a premium price, harvesting fruit when pink probably will result in a higher price per kilogram than harvesting fruit when green. Fruit harvested green, however, are generally firmer, more crack resistant, and require fewer harvests than fruit harvested pink.

Vine-ripened tomatoes generally are considered to be of higher quality and have better flavor than fruit harvested mature green (MC) and ripened (Kavanagh et al., 1986; Picha, 1986; Stevens, 1986). Throughout the eastern United States, many staked fresh-market tomatoes are harvested at breaker (first pink on blossom end) or riper stages of maturity. In Florida, however, most growers harvest tomatoes at the MG stage (Sherman, 1988) because fruit are firmer and ship with less bruising and crushing than fruit harvested at the breaker stage (Kavanagh et al., 1986). In addition, harvesting costs are reduced because MG fruit require an average of two to three harvests (Sherman, 1988) compared to six to eight harvests for fruit showing pink (Stevens, 1986). Because of the success of Florida's MG-harvest tomato industry and in the interest of reducing costs and increasing profit margins, fresh-market tomato growers in other regions where tomatoes were traditionally harvested at the breaker or later color stages are now harvesting MG fruit (M.E. Lancaster, North Carolina Dept. of Agriculture, personal communication).

Maturity of a green tomato is difficult to

determine without cutting the fruit and examining the interior (Kader et al., 1977; Sherman, 1988). In actual practice, most growers of so-called "mature-green" tomatoes wait until a small percentage of the fruit show pink, then all fruit on the first cluster, or all fruit meeting a minimum size requirement (usually 58 mm in diameter), or both are harvested (McLaurin et al., 1991; Sherman, 1988). As a result, a proportion of the harvested fruit are always immature (Kader et al., 1977; Kavanagh et al., 1986; Picha, 1986; Stevens, 1986), have an off-flavor, and are low quality when ripe (Kader et al., 1977; Kavanagh et al., 1986; Stevens, 1986). Because tomatoes continue to increase in size until color break, harvesting fruit when green results in smaller fruit than waiting until the breaker stage to harvest (Hayslip, 1979; Sayre et al., 1950).

In many fresh-market tomato production areas, determinate cultivars are transplanted to the field, pruned, staked, tied, trained to a string-weave system, and irrigated (Konsler and Gardner, 1990). In early studies on harvest maturity of tomatoes, indeterminate cultivars and other cultivars no longer produced commercially were used (Halsey and Jamison, 1950; Hayslip, 1979; Sayre et al., 1950). In addition, plants were direct-seeded (Taha et al., 1984) and grown without staking or pruning (Hayslip, 1979; Stoffella and Sherman, 1984). Sometimes the authors provided inadequate information for determining what cultural methods they used (Sayre et al., 1950). Our objective was to compare harvest at the so-called "mature-green" and the vine-ripe (breaker stage or riper) stages for eight determinate tomato cultivars currently grown in a staked production system.

'Flora-Dade', 'Sunny', 'Mountain Pride', 'Piedmont', 'Colonial', 'Summit', 'Mountain Delight', and the North Carolina breeding line NC 8267 (from here on referred to as a cultivar) were grown in two field experiments. All eight cultivars have a determinate growth habit and mature in mid- to late-season. These cultivars are used for production of tomatoes harvested at the vine-ripe and MG stages. Although the industry refers to fruit harvested when green as mature-green, we will refer to them as "green" because many of the fruit are not mature.

Two studies were conducted at the Mountain Horticultural Crops Research Station in Fletcher, N.C. For both tests a split-plot design was used with pink (breaker stage or riper) and green (before breaker stage) harvest stages as the main plots and cultivars as subplots. There were four replications. Subplots consisted of six plants spaced 0.6 m apart in the row with 1.5 m between rows. Plants were grown on bare ground, staked, and trained to the string-weave system (Konsler and Gardner, 1990). Axillary shoots were removed from the base of the plant up to, but not including, the one immediately below the first inflorescence. Soil was limed and fertilized according to soil test recommendations. Preplant N was applied at 73 kg·ha⁻¹. Plots were sidedressed with NH₄NO₃ at 56 kg N/ha one month after planting. Pest control practices, which included fungicide applications on a 5-day schedule, were applied according to recommendations for staked-tomato production in North Carolina (Konsler and Gardner, 1990). Overhead-sprinkler irrigation provided ≈40 mm water/week.

Plants were grown for 5 weeks in a soilless peat-vermiculite medium in a greenhouse in plastic flats with 5 × 5 × 6-cm cells. Plants were transplanted to the field on 3 and 23 June for the early and late-season studies, respectively. For the early season experiment, pink fruit were harvested weekly for 6 weeks beginning 6 Aug. All fruit exhibiting any pink on the blossom end or more advanced signs of ripening were removed. For the late-season study, pink fruit were harvested weekly for 7 weeks beginning 29 Aug. Green harvests were closely patterned after what commercial growers of MC fruit use; therefore, the first green harvest occurred when ≈10% of the fruit on the first inflorescence of 'Flora-Dade' and 'Sunny' were at the breaker stage. Green fruit were harvested on 2, 11, and 21 Aug. for the early season study and on 28 Aug. and 12 Sept. for the late-season study. For the first green harvest, all fruit were removed from the first two inflorescences. In both studies, fruit >63 mm in diameter were removed during the second green harvest. All fruit >50 mm in diameter were removed for the third green harvest in the early season study. In the late-season study, insufficient fruit were left after the second green harvest to justify a third harvest.

Fruit were graded into U.S. combination (U.S. no. 1 and U.S. no. 2), U.S. no. 3, and culls. Fruit in U.S. combination grade were

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sized according to diameter (North Carolina Dept. of Agriculture, 1986) into medium (58–63 mm), large (64–72 mm), and extra large (≥73 mm). Fruit in the U.S. no. 3 and cull grades were sorted according to defects and weighed.

Results and Discussion

In the early season study, there was a cultivar × harvest maturity interaction for total yields (Table 1). In general, ‘Colonial’, NC 8267, and ‘Summit’ produced higher total yields than the other cultivars. The interaction occurred because ‘Flora-Dade’ produced similar green and pink yields. Relative to the other cultivars, however, ‘Flora-Dade’ produced a high total yield of green fruit but the lowest total yield of pink fruit.

Harvesting fruit pink increased total yields 16% and 19% over green-harvested fruit in the early and late-season studies, respectively (Table 1), primarily a result of pink fruit being heavier than green fruit (Table 1). In earlier studies with indeterminate tomato cultivars, harvesting green fruit caused more fruit set late in the season, and the resulting total yields were higher than when fruit were harvested at the vine-ripe stage (Halsey and Jamison, 1950; Sayre et al., 1950). When determinate tomatoes are harvested green, however, the harvest period generally is restricted to three harvests and completed in 34 weeks (Konsler and Gardner, 1990; McLaurin et al., 1991; Sherman, 1988). As a result, all fruit that will reach sufficient size and maturity for harvest within the 3-4 week period are set by the time the first green fruit are harvested. Hayslip (1979) reported increased fruit size with increasing fruit maturity with five tomato selections (three related to the determinate ‘Walter’) grown without staking or pruning. Although Sayre et al. (1950) reported higher yields from indeterminate cultivars harvested green instead of pink, they too found fruit weight increased with harvest maturity. Cultivar affected fruit weight in both of these studies. Average fruit weight was highest with ‘Mountain Delight’ and ‘Summit’ in the early season study and with ‘Mountain Delight’, ‘Summit’, and ‘Piedmont’ in the late-season study (Table 1).

Harvest maturity × cultivar interactions for percent extra large and large fruit occurred because ‘Flora-Dade’ had similar percentages of both size fruit regardless of harvest maturity (Table 2). This result contrasts with that for other cultivars that had higher percentages of extra-large fruit and lower percentages of large fruit when the tomatoes were harvested pink instead of green. ‘Flora-Dade’ was the earliest maturing (data not shown) and smallest-fruited cultivar in these studies. Therefore, because all cultivars were harvested on the same dates, green ‘Flora-Dade’ fruit were more mature and closer to their maximum size than green fruit from later-maturing cultivars. These results suggest that, to more accurately estimate MG fruit yields and fruit size in cultivars with a range of maturities, it may be necessary to harvest each cultivar at its time of optimum

maturity to give the later-maturing cultivars time to reach maximum size before harvest.

Primary defects causing fruit to be graded U.S. no. 3 or cull for both harvest maturities were rough blossom scar, off-shape, and cracking (Table 3). In the late-season study, there was no difference in the incidence of rough blossom scar as a result of harvest maturity, probably because this defect is present at time of early fruit development. There was, however, a harvest maturity × cultivar interaction for incidence of rough blossom scar in the early season study. ‘Flora-Dade’ had 12% rough blossom scar when harvested pink and 21% when harvested green. In contrast, ‘Colo-

nial’ had 21% and 13% rough blossom scar when harvested pink and green, respectively. In the early season study, there also was a slightly higher percentage of off-shape fruit in fruit harvested pink than in fruit harvested green. As reported previously (Halsey and Jamison, 1950), in the early season study, fruit cracking was more severe in fruit harvested pink than green (Table 3). In our study, although total yields were higher for fruit harvested pink than for fruit harvested green (Table 1), the high percentage of cracking in the pink fruit resulted in similar yields of U.S. combination grade for both treatments (71.2 t·ha⁻¹). In the late-season study, there was no

Table 1. Fruit yields and fruit weights of eight determinate tomato cultivars harvested at pink (breaker stage or riper) and green stage of maturity.

Main effect	Total yield (t·ha ⁻¹)		Avg fruit wt (g)	
	Season of study			
	Early	Late	Early	Late
Harvest maturity				
Pink	104	74	268	263
Green	88	61	227	236
	Harvest maturity			
	Pink	Green		
Cultivar				
Colonial	109	93	71	245
Flora-Dade	89	92	69	200
Mountain Delight	104	82	67	281
Mountain Pride	96	85	65	259
NC 8267	121	91	65	222
Piedmont	98	81	68	259
Summit	115	93	68	272
Sunny	104	89	68	245
LSD _{0.05}	12 ^z		18 ^z	18 ^z
	14 ^y			
Significance				
Harvest maturity	**	**	**	**
Cultivar	**	NS	**	**
Interaction	*	NS	NS	NS

^zValue for comparing cultivars within a harvest maturity.

^yValue for comparing cultivars between harvest maturities.

NS, *, ** Nonsignificant or significant at P ≤ 0.05 or 0.01, respectively.

Table 2. Percentage of U.S. combination grade [extra large (EL; ≥73 mm) and large (L; 64–72 mm)] fruit of eight determinate tomato cultivars harvested at pink (breaker stage or riper) or green stages of maturity.

Main effect	Combination grade (%)							
	Early season				Late season			
	Pink		Green		Pink		Green	
Colonial	88	11	69	30	76	24	66	34
Flora-Dade	48	49	43	50	60	40	44	53
Mountain Delight	94	6	85	14	88	12	88	12
Mountain Pride	92	8	80	18	84	16	72	26
NC 8267	83	17	52	45	93	7	64	34
Piedmont	90	10	78	21	90	10	86	12
Summit	92	8	76	23	90	9	78	22
Sunny	85	14	74	24	85	15	72	27
LSD _{0.05} ^z	9	9	9	9	9	9	9	9
LSD _{0.05} ^y	12	11	12	11	10	9	10	9
Significance								
Harvest maturity	*		*		**		**	**
Cultivar	**		**		**		**	**
Interaction	**		**		**		**	**

^zValue for comparing cultivars within a harvest maturity.

^yValue for comparing cultivars between harvest maturities.

NS, *, ** Significant at P ≤ 0.05 or 0.01, respectively.

Table 3. Fruit defects of eight determinate tomato cultivars harvested at pink (breaker stage or riper) and green stages of maturity.

Main effect	Defects in total yield (%)					
	Rough blossom		Off-shape		Cracking	
	Season of study					
	Early	Late	Early	Late	Early	Late
Harvest maturity						
Pink	18	25	32	42	31	20
Green	19	22	27	40	3	10
Cultivar						
Colonial	17	22	31	41	21	22
Flora-Dade	17	24	36	42	26	22
Mountain Delight	18	20	21	36	10	9
Mountain Pride	16	16	25	38	12	6
NC 8267	9	16	27	43	13	13
Piedmont	22	26	26	41	10	3
Summit	28	32	40	46	21	19
Sunny	22	29	30	40	26	30
LSD _{0.05}	5	5	6	---	7	8
Significance						
Harvest maturity	NS	NS	*	NS	**	NS
Cultivar	**	**	**	NS	**	**
Interaction	*	NS	NS	NS	**	NS

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

difference in the percentage of cracking between the pink- and green-harvested fruit; consequently, yields of U.S. combination grade fruit were higher for fruit harvested pink instead of green—53 and 41 t·ha⁻¹, respectively.

Differences in resistance to fruit cracking were evident among cultivars in both studies (Table 3). When harvested pink, 'Flora-Dade' and 'Sunny' had 46% and 41% cracked fruit, respectively. In contrast, 'Mountain Pride', 'Mountain Delight', and 'Piedmont' had the lowest percentages of cracked fruit regardless of harvest maturity (data not shown). The interaction between harvest maturity and cultivar in the early season study was due primarily to 'Summit', which had one of the highest percentages of cracking when harvested pink (41%), but one of the lowest when harvested green (1%). This result indicates the importance of using crack-resistant cultivars for harvesting pink fruit.

In contrast to indeterminate tomato cultivars (Halsey and Jamison, 1950; Sayre et al., 1950), total yields of the eight determinate cultivars tested were generally higher when fruit were harvested at the breaker or riper

maturity stages compared to the green stage. Similar to other studies (Hayslip, 1979; Sayre et al., 1950), fruit were also larger when harvested pink instead of green. Often, a higher price is paid for extra-large than for large fruit (Davis, 1993), providing a possible economic advantage to allowing fruit to reach maximum size before harvesting. Because fruit size can increase appreciably just before color break (Hayslip, 1979), harvesting fruit at the breaker stage or later probably will result in a higher price per kilogram than for fruit harvested when green. Fruit harvested at the breaker stage may also have better quality in terms of color, flavor, sweetness, texture, and general acceptability compared to fruit harvested green (Kader et al., 1977; Kavanagh et al., 1986). Fruit harvested green, however, crack less, require fewer harvests, are generally firmer (Kavanagh et al., 1986), and are less susceptible to bruising (Sargent et al., 1992) than fruit harvested at the breaker stage. Because of the short season over which determinate tomatoes are harvested, increased late fruit set by removal of green fruit is not a factor in increasing yields.

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