Soil Moisture and Cultivar Influence Cracking, Blossom-end Rot, Zippers, and Yield of Staked Fresh-market Tomatoes

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Summary. Two crack-resistant and two crack-susceptible fresh-market tomato (*Lycopersicon esculentum* Mill.) cultivars were evaluated at varied soil moisture levels for physiological fruit defects and yield. Cultural practices recommended for staked-tomato production in North Carolina with raised beds, black polyethylene mulch, and drip irrigation were used. Soil moisture levels of less than -15.0, -30 to -40, and greater than -70 kPa were maintained and monitored using daily tensiometer readings. Soil moisture level had no effect on fruit cracking, blossom-end rot, zippers, or yield. However, there were large differences among cultivars for fruit defects and total and marketable yields.

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Fruit cracking in tomato defaces the fruit and facilitates disease infection and insect feeding, reducing marketable yield and income. Milad and Shackel (1992) defined fruit cracking as a failure of the fruit skin resulting from stresses on the skin causing small cracks that later develop into larger cracks. Considine and Brown (1981) explained that, in an intact fruit, internal forces caused by growth or hydration of the fruit flesh result in proportional stresses acting on the skin which facilitates cracking. Internal stress has been attributed to high cell turgor potential (Milad and Shackel, 1992). In prunes (*Prunus domestica* L.), cracking has been correlated with high solute accumulation and high water potential (Uriu et al., 1962). Milad and Shackel (1992) theorized that, after relief from water stress, fruit cells near the stem are likely to experience solute accumulation and excessive water potential, which can lead to end cracks. The phenomena of solute movement within fruit, however, have not been elucidated (Milad and Shackel, 1992). Changing mechanical properties of fruit skin may also play a role in cracking (Kamimura et al., 1972). Lawlor and Leach (1985) explained how skin stiffening due to an altered geometry of the dermal cell walls occurs during water stress. This agrees with Kamimura et al. (1972), whose studies revealed stronger skin tensile strength of fruit from plants grown in soil with low than high moisture. They also demonstrated that fruit skin strength declined when water-stressed plants received irrigation. Milad and Shackel (1992) suggested that a stronger skin could result in a higher amount of pressure and stress in the whole fruit.

Peet (1992) studied the effects of irrigation on cracking in greenhouse tomatoes and found that less cracking occurred in tomatoes receiving the least amount of water. Brown and Price (1934) also showed that reduced irrigation reduced cracking. Abbot et al. (1986) clearly demonstrated a genetic influence on tomato cracking. Traits such as plant architecture and plant vigor have also been implicated as influencing susceptibility to cracking (Peet, 1992).

Generally two types of cracks are prevalent in tomato: concentric cracks, which develop as curved fractures on the shoulders of fruit, and radial or end

cracks, which are longitudinal splits, usually on the shoulders of the fruit (Mrozek and Burkhardt, 1973; Peet, 1992). According to Uriu et al. (1962) concentric cracks are more prevalent when an extended water stress is followed by irrigation. Some cultivars, however, are simply more resistant to radial cracks and susceptible to concentric cracks and *vice versa* (R.G. Gardner, personal communication).

Another fruit disorder attributed to soil moisture stress is blossom-end rot. Blossom-end rot is the result of Ca deficiency at the blossom end of fruit (Stevens and Rick, 1986). Susceptibility to blossom-end rot varies tremendously among tomato cultivars and is usually associated with changes in soil moisture content (Stevens and Rick, 1986). Shaykewich et al. (1971) reported that blossom-end rot increased in plants grown in soils with low moisture. In other research where a cultivar known to be less susceptible to blossom-end rot was grown at low soil moisture, Ca levels in leaves were reduced but fruit Ca levels remained normal (Adams, 1986). Anther scarring or zipper defects are characterized by thin, brown, necrotic scars that start at the stem scar and extend part or all of the way to the blossom end of the fruit (Jones et al., 1991). Zipper defects occur as the result of fusion of anthers to the ovary during floral formation and are attributed to cold temperature stress (R.G. Gardner, personal communication). The cause of zippers has also been attributed to blossoms remaining attached to newly forming fruit in cooler temperature conditions (Jones et al., 1991). No literature was found associating zipper defects to soil moisture levels.

Many methods and devices can be used to measure soil moisture. These include the "feel" method, tensiometers, gravitational method, electrical resistance blocks, neutron probe, and time domain reflectometer. Most of these methods and devices do not measure soil moisture directly; they measure a property of the soil that can be related to soil water status and are thus called indirect methods. Currently, the instrument most commonly used by growers and researchers is the tensiometer. A tensiometer measures negative water pressure in the soil, which is expressed as tension. This tension is equivalent to the force or energy plants must use to take up

water from the soil. Tensiometers are best suited for use in soils that release most of their soil water between zero and -80 kPa (Evans et al., 1991). Soils of this type are sand, loamy sand, sandy loam, coarse-textured loams, and sandy clay loams (Evans et al., 1991). Tensiometers are recommended for tomatoes and other vegetable crops when irrigation is scheduled before 50% of the plant-available water is depleted from the soil (Evans et al., 1991).

Most research on relationships between water and tomato cracking has been conducted in greenhouses or laboratories. Field research dealing specifically with soil moisture and its relationship to tomato fruit quality problems is very limited. We investigated the effect of soil moisture on cracking, blossom-end rot, zippers, and yield of field grown, staked, fresh-market tomatoes.

Materials and methods

Tomatoes were seeded on 28 Apr. 1992 and grown to transplant size in a greenhouse. Plants were moved to a plastic-covered cold frame on 27 May 1992 and field set on 9 June at the Mountain Horticultural Crops Research Station in Fletcher, N.C. Soil was a Bradson gravelly loam (clayey, oxidic, mesic, Typic Hapludult) at an elevation of 631 m. Limestone, P, K, and 70 kg N/ha, based on soil test results (North Carolina Dept. of Agriculture, 1987), were broadcast-applied and incorporated. Beds were formed and fumigated with a mixture of 67% methylbromide and 33% chloropicrin (CCl_3NO_2) at $224 \text{ kg} \cdot \text{ha}^{-1}$ 3 weeks before planting. At the same time, black polyethylene mulch (1.5 m wide $\times$ 0.04 mm thick) and drip-irrigation tape (46-cm emitter spacing) (Typhoon; Netafim, Valley Stream, N.Y.) were applied. The drip-tape was placed 4 cm deep and 10 cm from the center of the bed. Plots consisted of three 6.1 m-long rows spaced 1.5 m apart with a 46-cm in-row plant spacing. Recommended weed (metribuzin), disease (chlorothalonil, anilazine, mancozeb, basic copper sulfate, metalaxyl-chlorothalonil), and insect (esfenvalerate, endosulfan) controls were used (North Carolina State Univ., 1992). Data were collected on eight plants from the center row; the outer rows served as guard rows. Plants were staked and trained to the string-weave system (Konsler and Gardner, 1990).

Lateral shoots, 5 to 10 cm long, were removed from the base of the plant up to, but not including, the shoot immediately below the first flower cluster.

Four cultivars—Mountain Pride, Mountain Spring, Rutgers, and Celebrity—were selected for use in this study based on previous knowledge of their susceptibility or resistance to fruit cracking. 'Mountain Pride' and 'Mountain Spring' are crack resistant, whereas 'Rutgers' and 'Celebrity' tend to be crack susceptible (R.G. Gardner, personal communication). Three soil water potential levels were maintained at less than -15.0 , -30.0 to -40.0 , and greater than -70.0 kPa. Experimental design was a split plot with the three irrigation levels as main plot treatments and the four cultivars as subplot treatments with five replications.

Soil moisture levels in plots were monitored using tensiometers placed in the middle of the plots, 20 cm deep and 10 cm off the center of the bed opposite the drip tape. Readings were taken in morning and afternoon, and adjustments in irrigation were made as needed. Supplemental fertilization was applied through the drip tape beginning 5 weeks (14 July) after transplanting. Nitrogen and K were applied weekly as 45.4 kg KNO_3 and $22.7 \text{ kg Ca}(\text{NO}_3)_2/\text{ha}$. Irrigation treatments were initiated when the first blossoms opened on 6 July. Harvest began on 14 Aug. and continued weekly through

18 Sept. for a total of six harvests. Fruit exhibiting any pink or more advanced color were harvested. Yields reported are weight of marketable yield (U.S. combination and U.S. no. 3 grades) (North Carolina Dept. of Agriculture, 1986), total yield (marketable plus culled fruit), and yield of fruit having concentric or radial cracks, blossom end rot, or zipper defects. Data for cultivars were combined over moisture levels before analysis. Data were analyzed by ANOVA and Duncan's multiple range test (SAS Institute, Cary, N.C.).

Results and discussion

The cause of fruit cracking has yet to be conclusively determined. Kamimura et al. (1972) hypothesized that high soil moisture decreased tomato skin strength, leading to more cracking. In contrast, Peet (1992) hypothesized that, in areas where summer rains are frequent, maintaining high soil moisture levels reduces cracking. We found no differences, however, in incidence of cracking of fruit from plants grown at low, optimum, or high soil moisture levels (data not shown). Frazier (1934) and Peet

Fig. 1. Weekly tensiometer readings from field plots in three soil moisture treatments with staked fresh-market tomato. Treatments were started on 6 July. Vertical bar represents $LS D_{0.05}$.

Table 1. Fruit defects and yield of four fresh-market tomatoes.

Cultivar	Concentric cracks	Radial cracks	Blossom end rots	Zippers	Yield (Mg·ha ⁻¹)	
	(%)				Total	Marketable
Celebrity	64.6 a ^z	44.8 a	5.90 a	4.78 b	75.9 a	16.5 d
Rutgers	31.2 b	36.1 b	0.75 b	7.47 b	53.9 c	26.0 c
Mountain Pride	23.6 b	21.3 c	0.84 b	10.8 a	71.8 ab	42.1 a
Mountain Spring	25.2 b	21.7 c	0.83 b	13.5 a	65.0 b	33.8 b

^zMean separation by Duncan's multiple range test ($P \leq 0.05$)

(1992) stated that the most frequent cause of fruit cracking in the field is a period with high soil moisture tensions (i.e., dry conditions) followed by heavy rain or irrigation. This was not observed in our study, even though short-duration afternoon rain storms occurred throughout the growing season. The raised-bed, black polyethylene mulch system prevented changes in soil moisture due to rain, and desired soil moisture levels were maintained (Fig. 1). Still, the fruit and foliage were exposed to rain and, according to Kamimura et al. (1972) and Frazier (1934), absorption of external moisture by minute cracks, corky spots, or the corky layer around the stem of the fruit is one of the main factors associated with cracking. Perhaps, a sudden change in soil moisture is required for cracking (Frazier, 1934), which was prevented here by the plastic mulch. No literature was found comparing bare ground and plastic mulch effects on tomato cracking. Another explanation is that cracking is genetically controlled (Abbott et al., 1986). 'Celebrity' and 'Rutgers', crack-susceptible cultivars, had a higher percentage of radial cracks than the two crack-resistant cultivars (Table 1). 'Rutgers', however, had fewer concentric cracks than 'Celebrity', demonstrating, as mentioned earlier, that some cultivars are less prone to specific types of cracks. There were no differences in blossom-end rot or zippers among the soil moisture treatments (data not shown); however, there were differences among cultivars (Table 1). 'Celebrity' had more blossom-end rot than the other cultivars, whereas 'Mountain Pride' and 'Mountain Spring' had the most zippers.

There were no differences in average total (29.8 t·ha⁻¹) or marketable yields (13.3 t·ha⁻¹) among the soil moisture treatments. This agrees with results from a study by Lin et al. (1983), in which tomatoes grown in Taiwan

with drip irrigation at 80%, 65%, 50%, or 25% soil water availability exhibited no differences in yield. In a 3-year study in Alabama, Doss et al. (1980) showed that tomato yields were not different among plots which were furrow-, sprinkler-, or microirrigated when microirrigated plots received less than half the moisture of that applied with the other methods. In contrast, Rendon-Poblete (1980) and Rudich et al. (1977) found that soil moisture had major effects on tomato yields in California and Israel, respectively. In contrast to the other studies, in California and Israel, tomatoes are grown either in a dry season or where long rainless periods during the growing season might limit normal fruit development.

There were major yield differences among cultivars (Table 1). 'Celebrity' and 'Mountain Pride' had the highest total yields (Table 1). 'Mountain Pride' also had the highest marketable yields, but 'Celebrity' had the lowest (Table 1). This was a result of the large number of fruit with cracks and blossom-end rot (Table 1) for 'Celebrity'.

Soil moisture level had no effect on incidence of fruit cracking, blossom-end rot, or zippers in field-grown, staked, fresh-market tomatoes when the three soil moisture treatment levels were maintained fairly constant. There were, however, major differences among cultivars for all defects and yields. The true cause of fruit cracking is still unclear; however, our results support the theory that cracking is mostly genetically controlled. Comparisons between field-grown tomatoes grown with plastic mulch or on bare ground are needed beyond our one season–location study to elucidate their effects on cracking. In this study, plastic mulch appeared to negate drastic changes in soil moisture tension by rain, which is a common explanation for cracking in field-grown tomatoes.

Literature Cited

- Abbot, J.D., M.M. Peet, D.H. Willits, D.C. Sanders, and R.E. Gough. 1986. Effects of irrigation frequency and scheduling on fruit production and radial fruit cracking in greenhouse tomatoes in soil beds and in a soil-less medium in bags. *Scientia Hort.* 28:209-219.
- Adams, P. 1986. Mineral nutrition, p. 281-334. In: J. G. Atherton and J. Rudich (eds.). *The tomato crop*. Chapman and Hall, Univ. Press, Cambridge, Great Britain.
- Brown, H.D. and C.V. Price. 1934. Effect of irrigation, degree of maturity, and shading upon the yield and degree of cracking of tomatoes. *Proc. Amer. Soc. Hort. Sci.* 32:524-528.
- Considine, J. and K. Brown. 1981. Physical aspects of fruit growth. Theoretical analysis of distribution of surface growth forces in fruit in relation to cracking and splitting. *Plant Physiol.* 68:371-376.
- Doss, B.D., J.L. Turner, and C.E. Evans. 1980. Irrigation methods and in-row chiseling for tomato production. *J. Amer. Soc. Hort. Sci.* 105:611-614.
- Evans, R.O., D.K. Cassel, and R.E. Sneed. 1991. Measuring soil water for irrigation scheduling: monitoring methods and devices. North Carolina Coop. Ext. Serv., North Carolina State Univ. AG-452-2.
- Frazier, W.A. 1934. A final study of some factors associated with the occurrence of cracks in the tomato fruit. *Proc. Amer. Soc. Hort. Sci.* 32:519-523.
- Jones, J.P., R.E. Stall, and T.A. Zitter. 1991. *Compendium of tomato diseases*. APS Press. St. Paul, Minn.
- Kamimura, S., H. Yoshikawa, and K. Ito. 1972. Studies on fruit cracking in tomatoes. *Bul. Hort. Res. Sta. Ministry Agr. For. Ser. C. No. 7*. Morioka, Japan.
- Konsler, T.K. and R.G. Gardner. 1990. Commercial production of staked tomatoes in North Carolina. *Agr. Ext. Serv., North Carolina State Univ. Publ.* AG-405.
- Lawlor, D.W. and J.E. Leach. 1985. Leaf growth and water deficits: biochemistry in relation to biophysics, p. 267-294. In: N.R. Baker, W.J. Davies, and C.K. Ong (eds.). *Control of leaf growth*. Soc. Expt. Biol. Seminar Ser. 27, Cambridge, Cambridge Univ. Press.
- Lin, S.M., J.N. Hubbell, S.C.S. Tsou, and W.E. Splittstoesser. 1983. Drip irrigation and tomato yield under tropical conditions. *HortScience* 18:460-461.
- Milad, R.E. and K.A. Shackel. 1992. Water relations of fruit end cracking in French prune (*Prunus domestica* L. cv. French). *J. Amer. Soc. Hort. Sci.* 117:824-828.

Mrozek, R.F. and T.H. Burkhardt. 1973. Factors causing prune side cracking. Trans. Amer. Soc. Agr. Eng. 16:686-692,695.

North Carolina Department of Agriculture. 1986. Tomato grade booklet. North Carolina Dept. Agr., Raleigh.

North Carolina Department of Agriculture. 1987. Crop fertilization based on N.C. soil tests. North Carolina Dept. of Agr., Raleigh. Circ. no. 1.

North Carolina State University. 1992. Agricultural chemicals manual. North Carolina State Univ., Raleigh.

Peet, M.M. 1992. Fruit cracking in tomato. HortTechnology. 2:216-223.

Rendon-Poblete, E. 1980. Effect of soil water status on yield, quality, and root development of several tomato genotypes. PhD diss. Univ. of California, Davis.

Rudich, J., D. Kalmer, C. Geiaenberg, and S. Harel. 1977. Low water tension in defined growth stages of processing tomato plants and their effects on yield and quality. J. Hort. Sci. 52:391-400.

Shaykewich, C.F., M. Yamaguchi, and J.D. Campbell. 1971. Nutrition and blossom end rot of tomatoes as influenced by soil water regime. Can. J. Plant Sci. 51:505-511.

Stevens, M.A., and C.M. Rick. 1986. Genetics and breeding, p. 96. In: J.G. Atherton and J. Rudich (eds.). The tomato crop. Chapman and Hall, Univ. Press, Cambridge, Great Britain.

Uriu, K., C.J. Hansen, and J.J. Smith. 1962. The cracking of prunes in relation to irrigation. Proc. Amer. Soc. Hort. Sci. 80:211-219.