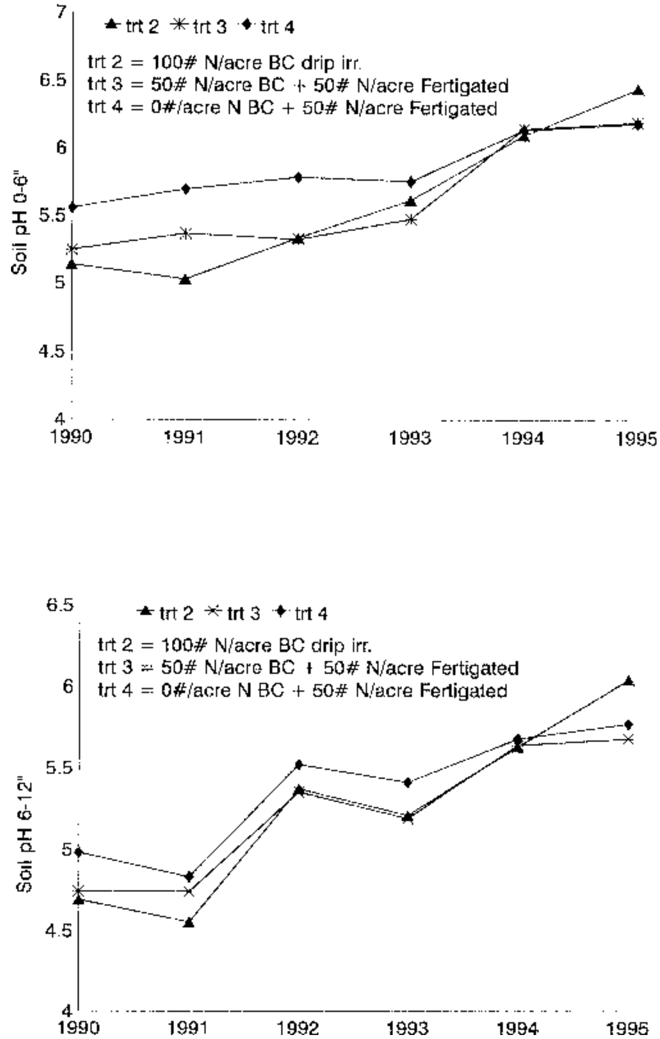


Fig. 4. Soil pH in the wetted zone of the emitters in the 0- to 6 and 6- to 12-inch layer over years and method and rate of N application. The year ¥ fertilization interaction was significant. BC = broadcast, Fert. = fertigated.

applied through a drip irrigation system. J. Amer. Soc. Hort. Sci. 107:1142–1148.

Gaines, T.P. and G.A. Mitchell. 1979. Chemical methods for soil and plant analysis. UGA CPES Agron. Hdbk. no. 1.

Helrich, K. (ed.). 1990. Official methods of analysis of the Association of Agricultural Chemists. 15th ed. vol. 1, p. 74, Section 984.13. Assn. of Official Agricultural Chemists, Washington, D.C.

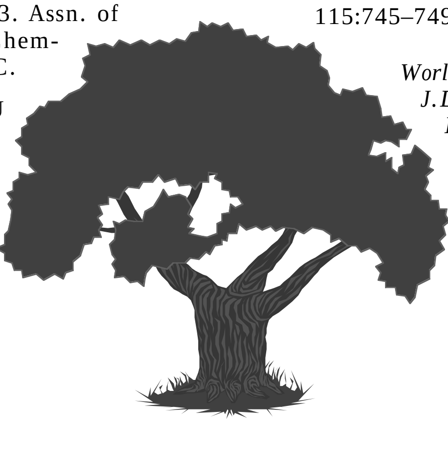
O'Barr, R.D. 1985. LSU pecan nutritional research. Proc. Southeastern Pecan Growers Assn. 78:93–100.

Plank, C.O. 1989. Plant analysis handbook for Georgia (unnumbered special publication).

Worley, R.E. 1985. Use of leaf analysis for basing N applications for Stuart pecans. Proc. Southeastern Pecan Growers Assn. 78:79–83.

Worley, R.E. 1990. Long-term performance of pecan trees when nitrogen application is based on prescribed threshold concentrations in leaf tissue. J. Amer. Soc. Hort. Sci. 115:745–749.

Worley, R.E., J.W. Daniel, J.D. Dutcher, K.A. Harrison, and B.G. Mullinix. 1995. A long-term comparison of broadcast application vs. drip fertigation of nitrogen for mature pecan trees. HortTechnology 5:43–47.



Assessing Vascularization Response of Three Tomato (*Lycopersicon esculentum* Mill.) Cultivars to Soil Type, Nutrient Stress, and Water Stress

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Summary. Amount of vascular development (veininess) is an important quality factor for processing whole-pack tomatoes. The influences of nutrient and soil moisture stress on the amount of vascular development in 'Chico III', 'Dorchester', and 'Roma' tomato fruit were studied. Fruit subjected to nutrient stress showed the highest amount of veininess. Fruit exposed to moisture stress after initial fruit set did not differ from controls in amount of veininess. Amount of vascularization did not differ among cultivars. A method for quantifying veininess was developed and compared with a traditional subjective rating scale. There was a high correlation ($r^2 = 0.77$) between the subjective rating and quantitative measurement of veininess.

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The important quality factors in processing tomatoes are color, flavor, wholeness, and absence of defects (Gould, 1975). Another character of interest, primarily to growers and processors in the eastern United States, is the veininess of the whole-pack tomatoes. The veins extend over the surface of peeled fruit in a network and may range from barely visible to so large that they nearly cover the entire fruit. Fruit veininess is not included as a USDA quality standard for processing tomatoes; however, it plays an indirect role in color. Excessive veininess can lessen the color intensity of the processed fruit and result in a lower grade.

Vascular bundles are embedded in the mesocarp and may be clearly visible in peeled fruit (Figs. 1–6). A large, prominent bundle is found in the center of each locule from which smaller secondary bundles branch. The veins radiate from the stem end of the fruit where few connecting bundles are present. Near the blossom end, the veins anastomose freely to form an intricate network (Bewley and White, 1926; Seaton and Gray, 1936). Several layers of large, thin-walled parenchyma cells surround the bundles.

Excessive vascularization should not be confused with blotchy ripening. Blotchy ripening occurs sporadically and appears as hard, discolored patches. Veininess is found more consistently from fruit to fruit within a lot and covers essentially all vascular tissue in a fruit.

Few reports on tomato quality have been concerned with the causes of excessive vascularization. In studies of pericarp anatomy, no differences were found in the vascular development among different positions on the cluster, locations of clusters on the same plant, or among plants of the same cultivar (Cotner et al., 1969). However, there do appear to be differences in degree of vascular development among cultivars of tomatoes. For example, crack-resistant fruit had more vascular bundles per locule than crack-susceptible fruit (Cotner et al., 1969).

In our study, we examined the effect of nutrient and water stress on the vascularization of three cultivars of processing tomatoes: 'Roma', 'Chico III', and 'Dorchester'. Field experiments indicated veininess is more pronounced when tomatoes are grown in sandy soils (Sanders, 1976). Our study included two soil types: a peat–sand–soil mix and a sandy loam. We also compared an objective method of evaluating veininess to the traditional subjective rating method.

Materials and methods

GREENHOUSE GROWTH CONDITIONS. 'Roma', 'Chico III' and 'Dorchester' seeds were sown in sand-filled flats on 5 Jan. 1977 in a greenhouse. After 3 weeks, the seedlings of each cultivar were transplanted into twelve 10-L pots containing a 1 peat : 1 sand : 1 soil mixture or 12 pots of a sandy loam soil. Two plants were grown in each of the pots. The plants were fertilized weekly for 3 weeks with a 0.05% water-soluble 20N–20P–20K nutrient solution. Plants were supported on strings and pruned to one stem. Flower clusters were vibrated mechanically every other day to ensure fruit set. When a sufficient fruit load had been established, the fertilizer was withheld. The soil in all pots was leached of soluble nutrients by flushing the pots with 50 mm of water every third day for 2 weeks. Fruit >1.3 cm in diameter were removed from all plants, ensuring that harvested fruit had developed and matured under the specific stress or control treatment.

Stress and control treatments were initiated on 2 Mar., 56 d after planting. Two stress treatments and a nonstress control treatment were imposed on four pots of each cultivar grown on each soil type: 1) a water stress and 2) a nutrient stress. Harvested fruit quality was compared to a nonstressed control. Soil moisture was measured with a tensiometer placed 180 mm deep. Nonwater-stressed plants were maintained at –0.01 and –0.02 MPa by watering daily with 15 mm of water. Water-stressed plants were maintained at about –0.07 MPa by watering with 15 mm of water every other day. Nonnutrient-stressed plants received N at 67 mg / pot and K at 67 mg / pot as a mixture of NH_4NO_3 and KNO_3 on 2, 10, and 18 Mar. This level of N and K was used because previous research showed that it resulted in the least degree of vascularization in field-grown fruit (Sanders, unpublished data). Nutrient-stressed plants received no fertilizer after leaching. Nitrogen deficiency symptoms were visible in nutrient-stressed plants by the second week after leaching. Fruit were harvested at the mature-red stage on 2, 10, and 15 May and were frozen immediately. Five fruit from each pot were rated subjectively and analyzed quantitatively for vascular content. A factorial analysis of variance was used to analyze data, with cultivar, soil type, stress (water, nutrient, or control), and their interactions as sources of variability and the residual error as the error term. The least significant difference (LSD) was calculated for significant main effects (Steele and Torrie, 1960).

FIELD STUDY. The field data included in Fig. 7 refer to clusters of fruit of these cultivars grown in a fertilizer experiment in a Wagram sandy loam in 1976. They are means of 36 samples per cultivar collected before leaching and establishing fertilizer treatments.

QUANTIFICATION OF TOMATO FRUIT VEININESS. A single experienced individual subjectively rated fruit for veininess by on a scale of 1 to 5, where 1 = excessive veining, 2 = pronounced veining, 3 = acceptable veining, 4 = slight veining, and 5 = vein-free (Fig. 3). The fruit then were frozen. Frozen fruit were thawed in warm water and then scalded in 95 °C water for 3 to 4 min. The epidermis and exocarp were discarded. The mesocarp layer containing the vascular tissue separated from the rest of the pericarp easily. Sections (6.66 cm^2) were taken from the middle of a locule around the central bundle of each of five fruit (33.3 cm^2) with a double-bladed knife (Fig. 4) and placed onto a 60-mesh screen. The tissue was rinsed (Fig. 5) with a forceful spray of water until only the vein material remained (Fig. 6). The vascular tissue was dried at 70 °C for 48 h and weighed. Veininess then was expressed as milligram dry weight per 33.3 cm^2 fruit surface.

Results

Nutrient stress significantly increased the amount of veininess in all cultivars and soil types. Neither cultivar nor water stress nor soil type significantly affected fruit veininess (Table 1).

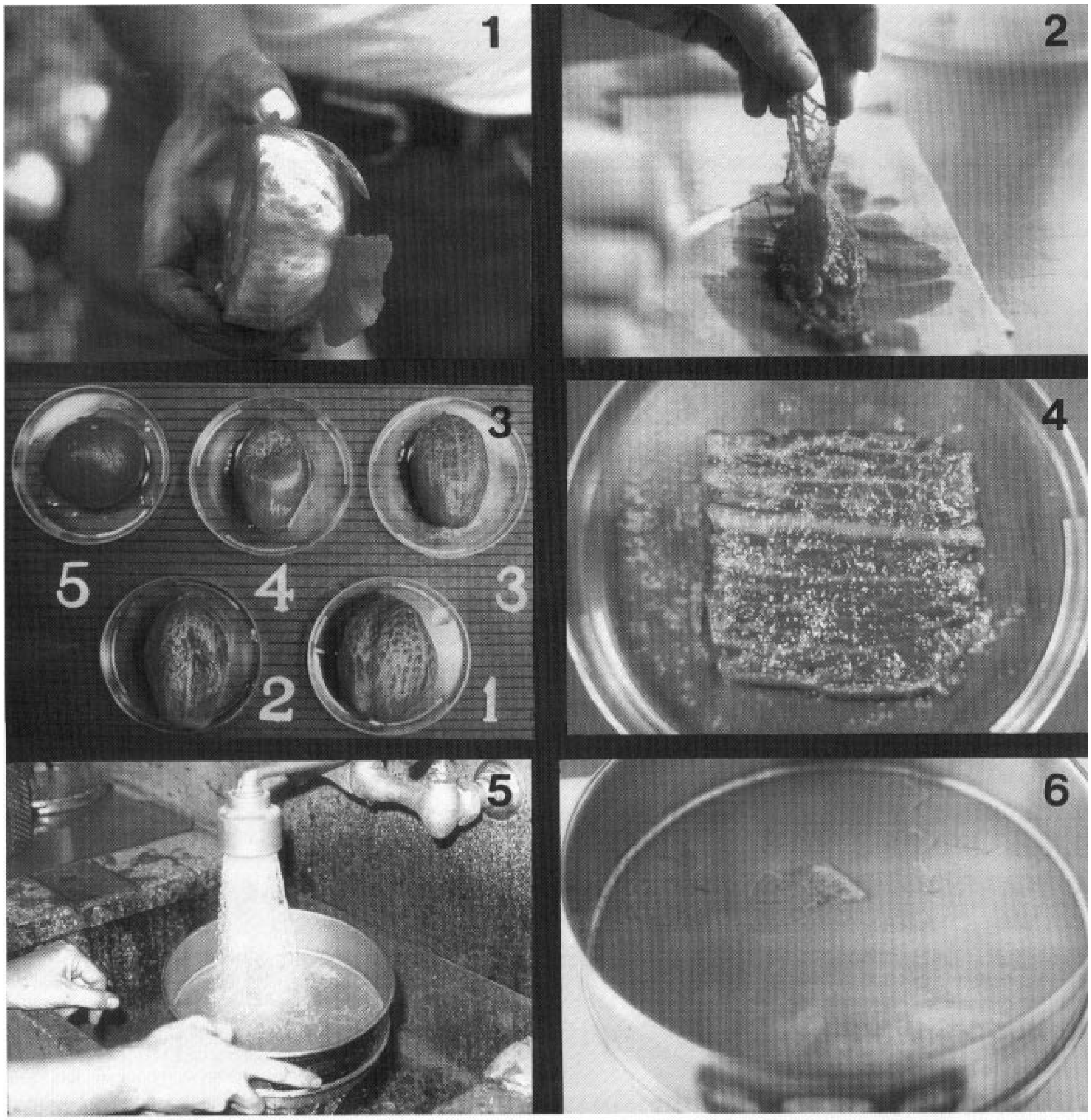
The relationship between subjective rating for veininess and the more quantitative method of extracting and drying the vascular tissue embedded in a uniform area of fruit tissue was evaluated by plotting the data graphically (Fig. 7). Data plotted in Fig. 7 are from field and greenhouse studies; however, there is no apparent break in the linearity of the relationship. Note the relatively high degree of veininess of samples grown on a Wagram sandy loam before leaching and imposition of any fertilizer treatment.

Discussion

To our knowledge, no one has previously addressed the causes of tomato fruit veininess. While chronic water stress had no effect on veininess, the increase in veininess due to nutrient stress was highly significant. The evidence in this study implicates stress from lack of N, K, or both in the occurrence of excessive vascularization. There were no apparent differences among cultivars in sensitivity to the nutrient deficiency (Table 1).

Incidence of tomato veininess is more pronounced in soils of high porosity (Sanders, 1976). This association may result from nutrient stresses that occur in porous soils. In this greenhouse study, fruit were not influenced by the soil type in which they were grown. This result may be explained by the fact that fertilization control in pots in the greenhouse was superior to the control that can be exerted on sandy soils under field conditions.

Although blotchy ripening and



Figs. 1–6. (1) The veins are easily observed in peeled fruit, lowering its quality for the consumer. (2) Extensive collenchyma tissue surrounding the vascular tissue renders it tough and stringy. (3) Subjective ratings of freedom from veining for tomato fruit: 1 = excessive veining, 2 = pronounced veining, 3 = acceptable veining, 4 = slight veining, 5 = vein free. (4) A piece of tissue of standard size. (5) Rinsing the collenchyma tissue. (6) Collenchyma tissue prepared for oven-drying and weighing.

excessive veininess occur independently in the field, in our greenhouse study, there was a high incidence of blotchy ripening in the fruit from nutrient-stressed plants. Others have reported a high incidence of blotchy ripening in fruit when N and K were withheld (Bewley and White, 1926; Collin and Cline, 1966; Ozburn et al., 1967). However, blotchy ripening also is associated with other environmental stresses. These include low light intensity and large diurnal temperature fluctuations (Woods, 1966), such as might occur in the greenhouse in early spring.

In our study, when the vascular strands were separated from the rest of the pericarp in blotchy-ripened fruit, the bundles appeared thicker than bundles in the pericarp of normal fruit. This may be due to the lignification of the thin-walled parenchyma cells of the vascular rays of blotchy-ripened fruit, as described by Sadik and Minges (1966). This harder tissue remained attached to the vascular strands throughout the extraction procedure. Thus, there may be a confounding effect on this evaluation procedure when blotchy ripening and excessive veininess occur together. Vein dry weight provides a means of quantifying the degree of veininess but should be used with caution if blotchy ripening is present.

Table 1. Effects of water stress and nutrient stress on veininess of greenhouse-grown 'Chico III', 'Roma', and 'Dorchester' tomatoes.

	Vein dry wt ($mg/33.3\ cm^2$)	
Control	Water stress	Nutrient stress
14[z]	11	23
$LSD_{0.05}$ = 8		

[z]*Data are means of 24 pots, five fruits per pot.*

When would vein dry weight be a more advantageous method than subjective ratings for evaluating veininess? Successful breeding programs are dependent on using subjective rating systems that allow for rapidly evaluating many fruit and plant characteristics on large numbers of plants in the field. Fruit from plants with the best combinations of desired characters then are harvested for seed. Collecting fruit and measuring the dry weight of vascular tissue requires more effort than subjective ratings. Also, seed would have to be collected from all of the plants from which samples were taken rather than from desirable phenotypes alone. Because the desirability of the processed product is determined subjectively by appearance of the fruit, a subjective approach is entirely appropriate for evaluating fruit in a breeding program. The more objective system would have application under controlled experimental conditions (e.g., in evaluating cultural factors affecting vascularization). It also could be useful when comparing a limited number of cultivars if objective measures, rather than subjective ratings, are required. The correlation between objective and subjective measures for veininess verifies the usefulness of the simple subjective rating scale for screening large numbers of lines in a breeding program.

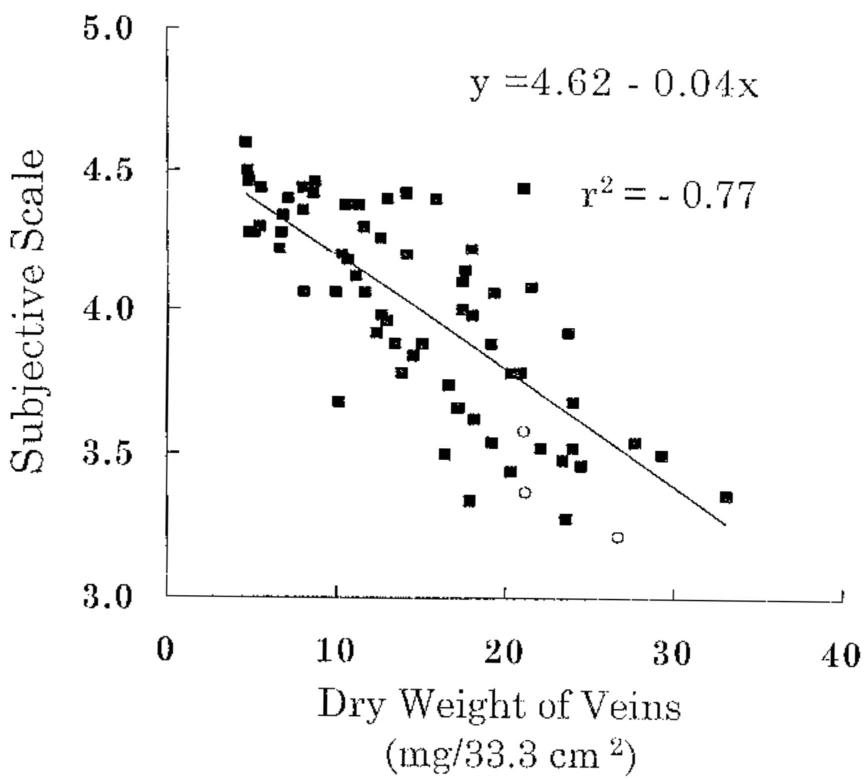


Fig. 2. Comparison of the subjective and objective rating methods for measuring tomato fruit veininess. Open circles represent data from the field study.

Literature Cited

Bewley, W.F. and H.L. White. 1926. Some nutritional disorders of the tomato. Ann. Biol. XIII:323–339.

Collin, G.H. and R.A. Cline. 1966. The interaction effect of potassium and environment on tomato ripening disorders. Can. J. Plant Sci. 46:369–387.

Cotner, S.D., E.E. Burns, and P.W. Leeper. 1969. Pericarp anatomy of crack-resistant and susceptible tomato fruits. J. Amer. Soc. Hort. Sci. 94:136–137.

Gould, W.A. 1975. Tomato production, processing and quality evaluation. AVI Publ., Westport, Conn.

Ozburn, J.L., C.E. Boutonnet, S. Sadik, and P.A. Minges. 1967. Tomato fruit ripening. I. Effect of potassium nutrition on occurrence of white tissue. J. Amer. Soc. Hort. Sci. 91:566–572.

Sadik, S. and P.A. Minges. 1966. Symptoms and histology of tomato fruits affected by blotchy ripening. J. Amer. Soc. Hort. Sci. 88:532–543.

Sanders. D.C. 1976. Report to the coastal plains regional commission: Tomatoes for processing. Hort. Res. Ser. 37.

Seaton, H.L. and G.F. Gray. 1936. Histological study of tissue from greenhouse tomatoes affected by blotchy ripening. J. Agr. Res. 52:217–224.

Steele, R.G.D. and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw Hill, New York.

Woods, M. 1966. The effect of some nutritional and environmental factors on fruit quality in tomatoes, p. 313–323. In: Potassium and the quality of agricultural products. The Potash Inst., Brussels, Belgium.