

## Letter to the Editor

### Vessels do end!

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Some years ago we presented evidence for the trapping of spores and spore-sized colored particles on perforation plates and end-walls of mature, functional (i.e., water-transporting) vessels in banana roots (1). A reviewer of a submitted paper asked, "Do vessels end?". Last year we presented evidence that *Verticillium* spores and colored vinyl particles also are trapped on end-walls that occur periodically in vessels of cotton (3). A reviewer of this article stated categorically, "Vessels do not end".

It seems from these two responses, from reading papers on vascular structure and function elsewhere, and from our own experience in plant anatomy and physiology, that we often develop a misconception. The misconception is that because water moves continuously by mass flow from rootlet to leaf lamina, vessels must be completely open tubes for that distance. Continuous mass flow within the vessel is a fact, but the conclusion concerning vessel structure is not valid.

We wish to make two points in this letter: first, that vessels have, by definition and in fact, a finite length; second, that this finite vessel length is of utmost importance to the survival of plants. With respect to point 1 we first quote Esau (4, p. 229): "Each vessel (that is, a series of vessel members joined end to end) is limited in length, and the vessels in a series are connected to each other by imperforate walls in the same manner as tracheids. Water and aqueous solutions pass through these imperforate walls, but such substances as mercury and gases fail to do so." Fahn (5, p. 120) states that "Vessels are limited in length and those vessel members which terminate a vessel are perforated at one end only, i.e., the terminating end is not perforated".

We are convinced that much of the confusion arises from the use of the term "imperforate walls" with respect to vessel endings. Vessel endings are "imperforate" in the sense that the pit membranes between secondary thickenings do not erode completely to provide large openings, as do perforation plates. Although some substances apparently disappear from these membranes, the remainder persists (7). These membranes, however, are porous (8, 9, 10), because, although they retain gas embolisms, spores, and particles 1  $\mu$ m in size, they permit the mass flow of water, solutes and very fine colloidal particles (10).

Unfortunately, such vessel endings are difficult to detect in normal microscopic preparations (6). We have developed a method that permits the relatively easy determination of vessel length in fresh plant material (1, 2). Using this method, we have found that particles (1 nm in size or above) in aqueous suspension, including brightly-colored, red vinyl particles and fungal spores, are

readily transported in the transpiration stream but fail to pass through imperforate walls of vessel endings in all of 13 species tested. These species are:

- Citrus aurantium*, L. (sour orange)
- Cucurbita sepo*, L. (squash)
- Dianthus caryophyllus*, L. (carnation)
- Geranium* sp., L. (geranium)
- Gossypium hirsutum* L. (cotton)
- Helianthus annuus*, L. (sunflower)
- Ipomoea batatis*, Lam. (sweet potato)
- Lycopersicon esculentum*, Mill. (tomato)
- Musa nana*, Laur. (banana)
- Phaseolus vulgaris*, L. (bean)
- Pisum sativum*, L. (pea)
- Ricinus communis*, L. (castor bean)
- Solanum melongena*, L. (eggplant)

Vessel endings for banana, carnation, citrus, cotton, geranium, and tomato are shown in Fig. 1-(A to H).

Now we will deal with point 2; i.e., that vessel endings are essential to the normal functioning of plants. Thus far, the primary function of vessel endings (that has been generally agreed upon) is that they prevent the passage and extension of gas embolisms in the vascular system (10). We too have concluded that vascular plants could not survive without the presence of imperforate vessel endings, but for a second reason. Breaks in the vascular system from wind, chewing rodents, or whatever cause, are an everyday occurrence in plants. Free soil water and the microbes it contains are sucked into these broken vessels. It is essential that these wounds, including the open, infected vessels, be sealed off by a wound-healing process. But the numerous steps of the sealing-off process require several days for completion.

Herein, we believe, lies another vital function of vessel endings. They screen out microbial spores from the transpiration stream, thus preventing immediate, systemic infection. Generally 2-3 days are required for these spores to germinate, to penetrate the vessel endings and then to produce secondary spores in the next vessel above. This delay in distribution of parasite propagules provides time for the host plant to begin the sealing-off process (1). Thus, vessel endings serve as the first vital part in a check-valve system that automatically seals off ruptured parts of the water conducting system.

#### LITERATURE CITED

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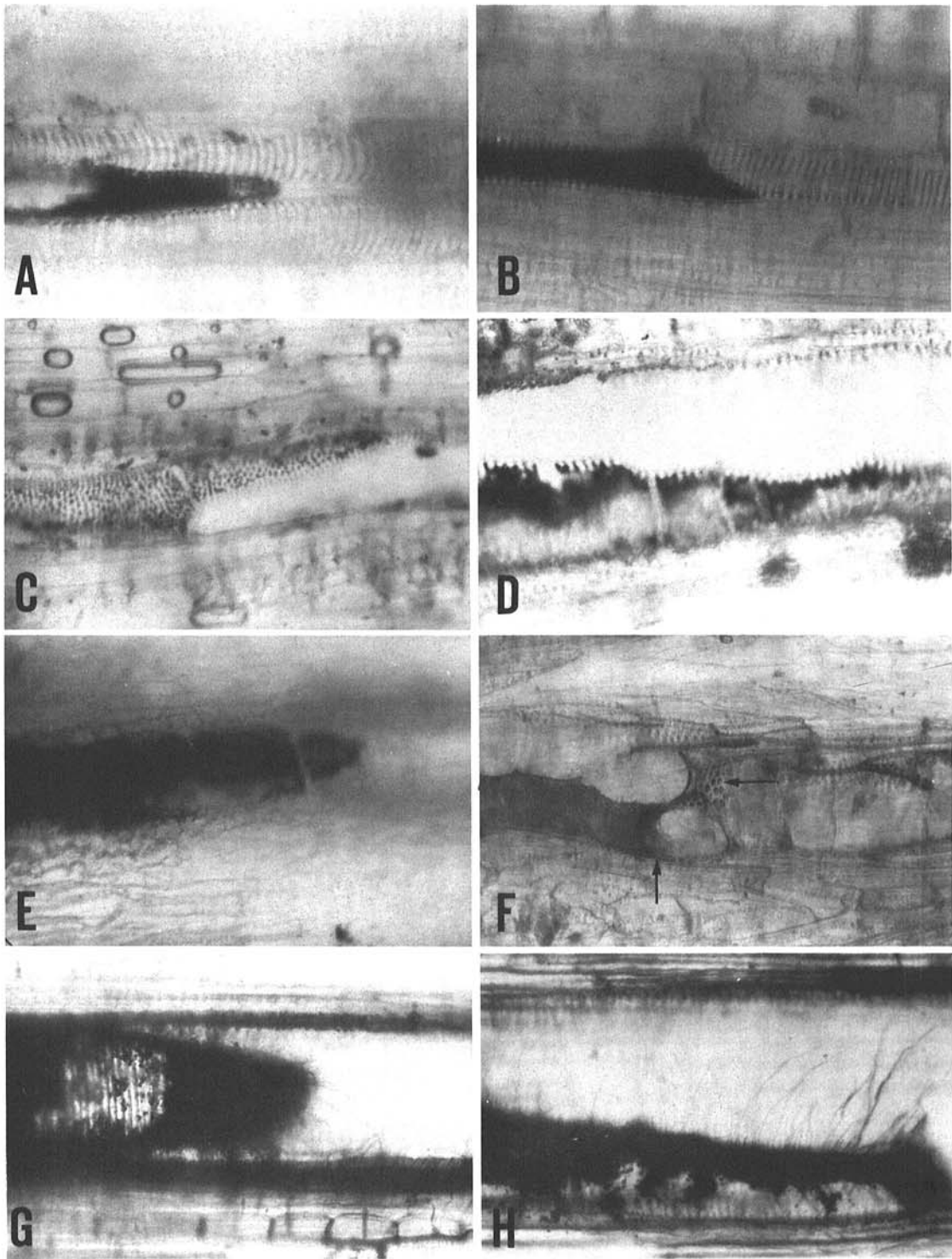


Fig. 1-(A to H). Trapping of red vinyl particles at vessel endings showing: A) a top view and B) a side view of vessel endings in geranium; vessel endings in C) cotton, D) sweet potato, and E) squash. F) Reticulate vessel ending (horizontal arrow) and localization of a root floral infection at vessel ending (vertical arrow) in tomato. G) Top view and H) side view of scalariform vessel endings that separate overlapping vessels in banana roots, showing trapped particles and hyphae extending from spores trapped on the lower surface of the common wall.

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