Grafting Eggplant and Tomato for Verticillium Wilt Resistance

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Abstract
Verticillium dahliae affects many crops in Washington State, and in 2011 was present at 3-4 cfu.g⁻¹ soil in two sampled eggplant (Solanum melongena) and tomato (Solanum lycopersicum) fields in the Columbia Basin of eastern Washington, and at 18 cfu.g⁻¹ soil in one northwestern Washington vegetable field. Field studies showed that ‘Epic’ eggplant was susceptible to Verticillium wilt at both locations, but ‘Cherokee Purple’ heirloom tomato was not. Grafting ‘Epic’ eggplant onto ‘Beaufort’ rootstock decreased eggplant wilt severity by 25% (P≤0.05), even though microsclerotia of the pathogen were recovered from all stems, indicating this rootstock is tolerant but not resistant to the pathogen. Grafting eggplant onto Solanum aethiopicum rootstock did not decrease disease severity as compared to the susceptible non-grafted control. In a replicated study in 2013 at the 18 cfu.g⁻¹ soil field, ‘Millionaire’ eggplant grafted onto ‘Java’, ‘Red Scorpion’, and ‘Meet’ rootstocks all had comparable Verticillium wilt incidence (98-100%; P=0.52) and severity (34-40%; P=0.83) relative to non-grafted ‘Millionaire’ (the susceptible control) at the end of the growing season. Area under disease progress curve (AUDPC) values based on seven weekly disease ratings ranged from 1480 to 1777, and did not differ significantly among treatments (P=0.84). For tomato at the same field site, ‘Stupice’ grafted onto ‘Beaufort’, ‘Maxifort’, ‘Colossus’, ‘Supernatural’, ‘Dro138TX’, and ‘Estamino’ rootstocks showed 5% disease severity on average throughout the growing season, and did not differ significantly from non-grafted ‘Stupice’ (the susceptible control) (P=0.60). AUDPC values ranged from 123 to 295, and again did not differ significantly among treatments (P=0.37). However, foliar symptoms on tomato in these studies were not typical of Verticillium wilt. In 2014, additional rootstocks will be evaluated to identify resistance/tolerance to Verticillium wilt for eggplant, and heirloom tomato cultivars will be further observed for Verticillium wilt symptom expression.

INTRODUCTION
Verticillium wilt, caused by Verticillium dahliae, can cause significant losses to many crops worldwide, especially eggplant (Solanum melongena) which is highly susceptible. Commercial eggplant cultivars offer only limited resistance to this disease (Bletsos, 1997; Lockwood et al., 1970; Nicklow, 1983; O’Brien, 1983; Pegg and Brady, 2002). In contrast, many commercial tomato (Solanum lycopersicum) cultivars have resistance to V. dahliae race 1 (Bryan, 1925; Pegg and Brady, 2002). However, heirloom tomato cultivars may be susceptible (Rivard and Louws, 2008). Recently in Washington State, ‘Epic’ eggplant, both non-grafted and grafted with ‘Beaufort’ (S. lycopersicum × S. habrochaites) and Solanum aethiopicum rootstocks, was found to be susceptible to Verticillium wilt at three field sites in the Columbia Basin where V. dahliae was present at 3-4 colony forming units (cfu)g⁻¹ soil as well as at one field site in northwestern Washington where V. dahliae was present at 18 cfu.g⁻¹ soil. However, ‘Cherokee Purple’ heirloom tomato both non-grafted and grafted with ‘Beaufort’ and ‘Maxifort’ (S. habrochaites).
lycopersicum × S. habrochaites) was not susceptible at either site (Buller et al., 2013; Johnson et al., 2013).

Grafting may be an effective method for managing Verticillium wilt in eggplant, but resistant rootstocks are needed. A better understanding of the susceptibility and symptomology of heirloom tomato is needed to determine if grafting is a worthwhile strategy in areas where this disease is problematic.

**MATERIALS AND METHODS**

In 2013, two field studies, one with eggplant and one with tomato, were planted in adjacent plots at the Washington State University (WSU) Northwestern Washington Research and Extension Center (NWREC) at Mount Vernon, WA, US. The field site had a history of *V. dahliae*, with 18 cfu·g⁻¹ soil measured in 2011. To re-confirm, soil was sampled in 2013 on 27 June, placed in a greenhouse to dry, processed on 17 July using the salt shaker method (modified from Butterfield and DeVay, 1977), and examined on 13 Aug. For both studies, the experimental design was a randomized complete block. Raised beds were covered with black plastic mulch and plant spacing was 0.9 m in-row and 3 m between-row. Each eggplant plot contained 10 plants, and was 9 m long with 4 replicates. Each tomato plot contained 5 plants and was 4.5 m long with 2 replicates. Preplant fertilizer (Wil-Gro 8-2-4 Organic; Wilbur Ellis, Mount Vernon, WA, US) was applied at a rate of 56 kg·ha⁻¹ N, 6 kg·ha⁻¹ P, and 23 kg·ha⁻¹ K, and plots were fertigated (Converted Organics 5-2-1 liquid fertilizer; Gonzales, CA, US) with 3.88 kg·ha⁻¹ N, 0.68 kg·ha⁻¹ P, and 0.64 kg·ha⁻¹ K, each week from 1 July through 22 Aug. (total of six applications). Plots were drip-irrigated at a rate of 25 mm·wk⁻¹ until 27 Aug., then irrigation ceased to promote onset of Verticillium wilt.

Eggplant ‘Millionaire’ was grafted on 31 May onto ‘Java’, ‘Red Scorpion’, and ‘Meet’ rootstocks (all hybrids of *S. melongena*); heirloom tomato ‘Stupice’ was grafted on 31 May onto ‘Beaufort’, ‘Maxifort’, ‘Colossus’, ‘Supernatural’, ‘Dro138TX’, and ‘Estamino’ rootstocks (all *S. lycopersicum*). Plants were placed in the field on 17 June, observed twice per week for onset of Verticillium wilt symptoms (chlorosis, necrosis in the form of V-shaped lesions, and wilting), and Verticillium wilt severity (percent of the entire plot canopy displaying symptoms) was recorded once per week beginning at first disease detection until the end of the growing season when cold temperature affected eggplant overall plant health and late blight (caused by *Phytophthora infestans*) affected tomato. Disease progress curves were generated from the severity measurements over time and an area under the disease progress curve (AUDPC) value was calculated for each entry.

**RESULTS AND DISCUSSION**

*V. dahliae* was found to be present at 17 cfu·g⁻¹ soil at the field site. There was virtually no change in the soil population compared to 2011 after the field had been planted to watermelon and winter squash in the intervening year. Symptoms of Verticillium wilt were first observed on 9 Aug. in both eggplant and tomato. The last disease rating for eggplant was 19 Sept. after which cold temperature caused plant decline, while the last rating for tomato was 3 Sept. when late blight severely impacted crop health and plants were removed from the field.

‘Millionaire’ eggplant either non-grafted (the susceptible control) or grafted onto ‘Java’, ‘Red Scorpion’, and ‘Meet’ rootstocks showed statistically equivalent Verticillium wilt incidence throughout the growing season (*P*=0.52; Table 1) that reached 98-100% by 24 Aug., and remained at this level until the end of the growing season (data not shown). Verticillium wilt severity also did not differ significantly due to grafting treatment (*P*=0.83), peaked at 50-60% by the end of Aug., and declined to 34-40% by the end of the growing season (Fig. 1). AUDPC values ranged from 1480 to 1777, and did not differ significantly among treatments (*P*=0.84). The climate at the field site was relatively cool throughout the growing season, and Aug. through Sept. mean temperature ranged from 15-20°C with an overall average of 17°C. Verticillium wilt was not favored by these cool
conditions, and new eggplant stems and leaves that emerged from the base of the plant were healthy, thus as older tissue died off, overall plant health appeared to improve.

‘Stupice’ heirloom tomato non-grafted (the susceptible control) and grafted onto ‘Beaufort’, ‘Maxifort’, ‘Colossus’, ‘Supernatural’, ‘Dro138TX’, and ‘Estamino’ rootstocks all showed statistically equivalent Verticillium wilt incidence throughout the growing season ($P=0.24$; Table 1), that reached 100% by 12 Aug., and ranged from 60-100% until the end of the growing season (data not shown). Verticillium wilt severity also did not differ statistically due to grafting treatment ($P=0.60$), was 3-10% in early Aug. and peaked at 8-15% at the end of the season (Fig. 2). Overall average Verticillium wilt severity was 5% for the growing season. AUDPC values ranged from 123 to 295, and did not differ statistically among treatments ($P=0.37$). In this study, foliar symptoms were not typical of Verticillium wilt, and included very mild leaf chlorosis, small necrotic leaf spotting, and no wilting.

**CONCLUSIONS**

Rootstocks used for eggplant in this 2013 study (‘Java’, ‘Red Scorpion’, and ‘Meet’) were all eggplant hybrids, and appeared to be equally susceptible to Verticillium wilt, similar to the non-grafted eggplant control cultivar ‘Millionaire’. In contrast, in a recent 2-year study at the same site, when eggplant ‘Epic’ was grafted onto ‘Beaufort’, an interspecific tomato hybrid ($S. lycopersicum \times S. habrochaites$), Verticillium wilt severity was reduced significantly compared to the non-grafted control (Johnson et al., 2013). In areas of Washington where Verticillium wilt can cause economic crop loss, hybrid tomato rootstocks rather than hybrid eggplant rootstocks may be suitable for use with eggplant. However, further studies are needed to determine the impact of hybrid tomato rootstocks on eggplant fruit yield and quality.

Like heirloom tomato ‘Cherokee Purple’ in a recent 2-year study at the same site (Buller et al., 2013), heirloom tomato ‘Stupice’ did not appear susceptible to Verticillium wilt. Observations of other heirloom tomato cultivars (‘Black Krim’, ‘Brandy Wine’, ‘Green Zebra’, ‘Matt’s Wild Cherry’, ‘Mortgage Lifter’, ‘Roma’, and ‘San Marzano’) at the same site in recent years also indicate that none have been noticeably affected by Verticillium wilt. These results suggest that the soil population of the pathogen was not sufficiently high, that the relatively cool growing conditions of northwestern Washington were not favorable for the disease, and/or that these heirloom tomato cultivars may have unknown levels of resistance to the race(s) present at this site. Since Verticillium wilt on tomato does not appear to be a serious problem in northwestern Washington, grafting may not provide a production advantage in this region. However, further studies on how tomato roots may harbor soil populations of this pathogen, and possibly lead to atypical foliar symptoms may be warranted to gain a better understanding of Verticillium wilt in a cool, maritime climate.

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**Literature Cited**


**Tables**


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<sup>z</sup> Data were rank transformed to meet the assumptions of normality for analysis of variance (Statistical Analysis System Version 9.2 for Windows™; SAS Institute, Cary, NC).

<sup>y</sup> Days after transplanting (DAT).
Figures

Fig. 1. Disease progress curves for non-grafted and grafted ‘Millionaire’ eggplant in a field study at WSU Mount Vernon NWREC, WA, US in 2013. Verticillium wilt severity was recorded as the percent of the entire plot canopy displaying characteristic symptoms of chlorosis, necrosis (in the form of V-shaped lesions), and wilting. Rootstocks for grafting were ‘Java’, ‘Red Scorpion’, and ‘Meet’. Error bars represent standard error of the mean (least square means, $P \leq 0.05$).

Fig. 2. Disease progress curves for non-grafted and grafted ‘Stupice’ heirloom tomato in a field study at WSU NWREC, WA, US in 2013. Verticillium wilt severity was recorded as the percent of the entire plot canopy displaying characteristic symptoms of chlorosis, necrosis (in the form of V-shaped lesions), and wilting. Rootstocks for grafting were ‘Beaufort’, ‘Maxifort’, ‘Colossus’, ‘Supernatural’, ‘Dro138TX’, and ‘Estamino’. Error bars represent standard error of the mean (least square means, $P \leq 0.05$).