**Puccinia sambuci Infection of American Elderberry Plants**

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Additional index words. Carex frankii, Sambucus nigra subsp. canadensis, fungal pathogen, sedge, fruit quality, vegetative growth

**Abstract.** Elderberry rust (*Puccinia sambuci* Schwein.) Arthur (= *P. bolleyana*) (Arthur, 1921) disease is frequently found in commercial American elderberry (*Sambucus nigra* L. subsp. *canadensis* L.) plantings when an alternate host, *Carex* sp., is present. To evaluate potential infection periods of *P. sambuci* on elderberry plants, micrometeorological conditions were monitored. Rust symptoms were observed on elderberry on 5 Apr. 2016, and conditions favorable for possible infection were 9 to 18 °C, 23 hours of continuous leaf wetness, and ≥85% relative humidity. Studies were also conducted to ascertain whether *P. sambuci* with varying pustule numbers affects fruiting, berry puree quality, or vegetative growth. Fruit yield was reduced by 31% when potted ‘Bob Gordon’ elderberry averaged six rust pustules per plant compared with noninfected plants. In another experiment, field-grown ‘Wyldewood’ plants averaging 137 rust pustules/cane at harvest had 47% less fruit weight on canes than uninfected canes. Titratable acidity of fruit puree from plants was lower when plants had either 690 rust pustules/plant or 137/ pustules/cane, but soluble solids and pH of puree were unaffected by *P. sambuci* infection. The effect of rust infection on vegetative growth of elderberry plants also varied with pustule numbers. With a low infection level (six pustules per plant), *P. sambuci* did not induce premature leaf loss on ‘Bob Gordon’ plants or adversely affect shoot dry weight at the end of the growing season. When *P. sambuci* infection on ‘Wyldewood’ plants was more severe (137 pustules/cane), greater leaf loss occurred on infected canes than on uninfected canes. At very high infection levels (690 pustules/plant), ‘Bob Gordon’ plant dry weight was reduced. Because of the potential for fruit yield loss on elderberry plants, control of *P. sambuci* at relatively low infection levels on this plant may be warranted. Strategies that eliminate or suppress the alternate host would likely reduce the *P. sambuci* inoculum and limit the potential for elderberry plant infection.

Elderberry [ *Sambucus nigra* L. ssp. *canadensis* (L.) Boil] is a high-value crop that is grown and processed into products for niche markets (Charlebois et al., 2010; Mohebalian et al., 2012). Elderberry plants are fruit-bearing, multi-stemmed shrubs with compound leaves native to eastern and central North America. Inflorescences are indeterminate compound umbels, where the outer fruit is the first to mature (Zomlefer, 1994). With the increasing production of elderberry, wild germplasm with vigorous vegetative growth and a high number of umbels with large fruit size has been selected to enhance yields. ‘Wyldewood’, a cultivar that matures during the late season and has high-quality fruit, was selected near Brash Hill, OK, in 1998 (Byers et al., 2010). ‘Bob Gordon’, a productive midseason-ripening cultivar with pendulous umbels, was selected in Osceola, MO, in 1999 (Byers and Thomas, 2011).

Because of continuous elderberry production in a monoculture system, pests have become prevalent. Elderberry rust (*Puccinia sambuci* Schwein.) Arthur (*P. bolleyana*) is a common disease found on American elderberry that causes foliar and shoot distortion (Arthur, 1962; Kellerman, 1904; Warmund, 2017). *Puccinia sambuci* is a heteroecious fungus that requires two hosts, sedge (*Carex* spp.) and American elderberry, to complete its lifecycle (Mims, 1981; Saccardo, 1891). Of the five spore stages of *P. sambuci*, pycniospores and aeciospores develop on elderberry, whereas urediniospores, teliospores, and basidiospores develop on *Carex* spp. (Mims, 1981). At least 13 species of sedge have been reported as an alternate host for *P. sambuci* (Afshan and Khalid, 2009; Arthur, 1962).

Pycnia are the first signs observed on elderberry leaflets and petioles during early spring and appear as small yellow pustules on adaxial and abaxial surfaces of leaflets and stems. Pycnia are flask-shaped and contain receptive hyphae and pycniospores (Littlefield and Heath, 1979; Petersen, 1974). When pycniospores contact and adhere to receptive hyphae of a compatible mating type, they undergo plasmogamy, resulting in the formation of dikaryotic mycelium (Mims, 1981). After dikaryotization, mycelia grow intercellularly on the abaxial leaf surface of elderberry plant tissue while producing intracellular haustoria to gain nutrients and develop aecia containing aeciospores (Petersen, 1974). *Puccinia sambuci* aecia are often observed on elderberry in May, with large yellow-orange pustules that cause deformed leaves, stems, and petioles. Aecia produce chains of aeciospores that are wind-blown to the alternate host, a *Carex* species (Mims, 1981). After germination and subsequent infection of sedge leaf tissue in the summer, uredinia form on the adaxial surface of leaflets and produce urediniospores that can re-infect sedge plants (Bolley, 1889). During the late summer, uredinia develop into telia that produce two-cell, thick-wall teliospores that can withstand low winter temperatures (Arthur, 1962). During favorable environmental conditions in March or April, each cell of the teliospore germinates and produces a basidium, the site of meiosis, resulting in four haploid basidiospores that are wind-blown to elderberry plants (Petersen, 1974). Basidiospore germination occurs on elderberry tissue and a germ tube is produced, which penetrates the host directly through the cuticle and epidermis, with subsequent development of monokaryon hyphae that form pycnia (Agrios, 2005).

Although the disease cycle of *P. sambuci* has been described, the epidemiology of elderberry rust and the consequences of infection on host productivity have not been investigated. Therefore, studies were conducted to: 1) determine the effect of *P. sambuci* infection on fruiting and vegetative growth of elderberry plants; 2) compare soluble solids, pH, and titratable acidity of berry puree from infected and uninfected plants; and 3) characterize environmental conditions associated with potential rust infection of elderberry.

**Materials and Methods**

**Inoculation of elderberry plants in 2014.** Twenty-five sedge (*Carex frankii* Kunth) plants producing *P. sambuci* teliospores were obtained from a commercial elderberry planting near Hartsburg, MO, on 15 Sept. 2013. Plants were placed in 8.5-L polyethylene containers (A.M. Leonard, Piqua, OH) with native soil (Hammond silt loam) and transported to the University of Missouri Horticulture and Agroforestry Research Center (HARC) near New Franklin, MO. On 26 Nov. 2013, potted plants were maintained in an isolated nursery area until they were covered with a polyethylene foam blanket (Hummer International, St. Louis, MO) and plastic sheeting for winter protection. On 20 Apr. 2014, sedge plants were uncovered.

One-year-old ‘Bob Gordon’ plants were obtained from a commercial nursery (Botany Shop, Joplin, MO) on 10 Mar. 2014 and were transplanted to 8.5-L polyethylene containers using Pro-Mix BX (Premier Tech Horticulture, Quakertown, PA). Plants were pruned to a height of 30 cm above the medium surface, leaving three canes per plant. Dormant oil (Damor oil; Drexel Chemical Company, Memphis, TN) was applied to elderberry plants at 7.5 mL·L⁻¹ to control overwintered eriophyid mites (*Phyllloptectes wisconsinensis* Kiefer). On 14 Mar. 2014, 50 g 15N–9P–12K controlled-release fertilizer (Osmocote; Scotts...
calculated. Acidity, expressed as citric acid, was then diluted with 48 mL of degassed deionized water. To measure titratable acidity, another 10-mL aliquot was used to determine soluble solids concentration of elderberry leaf and leaflet numbers were recorded in a completely randomized design in the nursery area at HARC. Plants were irrigated with an overhead sprinkler system as needed to prevent moisture stress. The number of rust pustules on each leaflet was recorded on 17 June 2014. At peak ripeness (all berries were dark purple) in August, umbels were removed and the harvest dates were recorded. Berry number and fresh weights of destemmed berries were recorded before fruit was sealed in polyethylene bags and stored at 22 °C. On 1 Oct. 2014, leaves and petioles were harvested and oven-dried for 24 h at 65 °C for dry weight measurements. On 13 Nov. 2014, canes were pruned to 30 cm above the medium surface for dry weight measurements and covered on 28 Nov. 2014 for winter protection (as previously described).

After 60 d in cold storage, fruit was thawed for compositional analyses. Berries from each elderberry plant were pooled and randomly sampled for analyses. To prepare each berry puree sample, 50 g of fruit was placed in a blender cup (Waring, Stamford, CT) with 50 mL of double-distilled water and processed for 30 s. A 0.3-mL aliquot of puree was used to determine soluble solids concentrations with a digital refractometer (Atago USA, Bellevue, WA), and a 10-mL aliquot was used to measure pH (HI222; Hanna Instruments, Woonsocket, RI). To measure titratable acidity, another 10-mL aliquot was diluted with 48 mL of deashed deionized water and titrated (G20 Compact Titror; Mettler-Toledo, Columbus, OH) to 8.2 pH with 0.1 N of sodium hydroxide. Titratable acidity, expressed as citric acid, was then calculated.

On 1 Apr. 2015, elderberry plants were uncovered, fertilized as described, and maintained in the nursery without further P. sambuci inoculation. Fruit yield was recorded during Aug. 2015 (the second season after infection). To determine plant dry weight, roots were washed so they were free of soil and oven-dried (as previously described) on 15 Nov. 2015.

Data for fruit yield, mean berry weight, puree characteristics, and vegetative dry weight were analyzed using the T TEST procedure of SAS software (SAS 9.4; SAS Institute Inc., Cary, NC). To test mean differences, a pooled test was used when variances were equal; the Satterthwaite test was used when variances were unequal (P ≤ 0.05).

Rust infection of potted ‘Bob Gordon’ plants in 2016. ‘Bob Gordon’ and ‘Wyldewood’ elderberry plants were obtained from a commercial source (Botany Shop, Joplin, MO) and transplanted to 8.5-L polyethylene containers at HARC on 14 Nov. 2015 (as described for the previous experiment). Plants were then covered for winter protection 12 d later. Sedge plants originally obtained in 2013 were also covered and overwintered in an isolated nursery area at HARC. On 11 Mar. 2016, elderberry plants were uncovered, pruned to five nodes, treated with dormant oil, and fertilized as described. For P. sambuci infection, elderberry plants were arranged in six experimental blocks with four symptomatic sedge plants centrally located within each block. In each cardinal direction (i.e., each north, south, east, and west) of the block, three ‘Bob Gordon’ elderberry plants were positioned at 23, 59, and 95 cm from sedge plants (Fig. 1). One block similarly arranged but without any sedge plants was used as an uninoculated control treatment. For pollination, one ‘Wyldewood’ elderberry plant was placed in the northwest, southwest, and southeast quadrants of each block. A clear polyethylene curtain (2.5-m-tall) was placed between blocks with and without sedge plants to prevent P. sambuci infection of control plants. Plants were sub-irrigated by filling 4-L saucers (Hummert International, St. Louis, MO) underneath pots as needed. Elderberry leaf and leaflet numbers were recorded on 12 Mar., 29 Apr., 19 May, and 19 Aug. 2016. Rust pustules were mechanically transferred to tomato plants used as the inoculum source (Carex frankii) and introduced to ‘Bob Gordon’ elderberry plants; the three light gray circles represent ‘Wyldewood’ elderberry plants used for pollination. Spacing between each potted ‘Bob Gordon’ pot was 10 cm.

To evaluate rust pustule development in relation to the cardinal direction and distance of elderberry plants (1 = closest to sedge plants; 3 = furthest from sedge plants) from the inoculum source, data for pustule number and the number of infected leaves and leaflets per plant were analyzed as a 4 x 3 factorial experiment using the PROC GLIMMIX procedure of SAS (SAS Institute Inc.). Means were separated by Fisher’s protected least significant difference test (P ≤ 0.05). Because of deer herbivory during the growing season, 30 ‘Bob Gordon’ elderberry plants were excluded from the study. Therefore, the T TEST procedure of SAS (SAS Institute Inc.) was used to analyze the effect of P. sambuci on plant growth and fruiting. To test mean differences, a pooled test was used when variances were equal; the Satterthwaite test was used when variances were unequal (P ≤ 0.05).

Natural rust infection of ‘Wyldewood’ elderberry canes of a commercial elderberry planting in 2016. Three-year-old ‘Wyldewood’ elderberry plants growing in Weller silt loam soil of a commercial planting near New Bloomfield, MO, were used for this study in 2016. Eleven elderberry canes at each of three P. sambuci rust infection levels (low = 10 to 99 pustules/cane; medium = 100 to 199 pustules/cane; high = 200 to 299 pustules/cane) were visually assessed, selected, and flagged on individual plants on 18 May. Eleven individual canes without visual symptoms of rust were also flagged in a completely randomized design. Total leaf number, number of P. sambuci-infected leaves, and number

Fig. 1. One of six experimental blocks used to infect potted ‘Bob Gordon’ elderberry plants in 2016. Central black circles represent sedge (Carex frankii) plants used as the inoculum source; open circles represent ‘Bob Gordon’ elderberry plants, and the three light gray circles represent ‘Wyldewood’ elderberry plants used for pollination. Spacing between each potted ‘Bob Gordon’ pot was 10 cm.
of pustules per leaf on each elderberry cane were recorded on 31 May. Fruit harvest, berry number, and berry weight were recorded from 20 July to 23 Aug. 2016. Leaves on each cane were counted on 26 Aug., and the number of those lost since 18 May was calculated. Canes were pruned to 10 cm on 13 Oct., and the dry weight of canes with their foliage was determined. Fruit compositional analyses from berry puree were performed as described. When the harvested fruit was fewer than 50 g per cane, the 1:1 berry weight/double-distilled water volume was used to prepare the puree. A t test using pooled data from rust-infected canes and uninfected canes was performed for statistical analyses of fruit yield per cane, mean berry weight, puree characteristics, leaf loss, and cane weight data.

Results

Elderberry plants inoculated in 2014. ‘Bob Gordon’ elderberry inoculated with *P. sambuci* averaged 690 pustules/plant on 17 June 2014, whereas no rust symptoms were observed on noninoculated plants. Infected plants had lower fruit yield, lower mean berry weight, and lower shoot dry weight than that of noninoculated controls (Table 1). Soluble solids of fruit puree were unaffected by *P. sambuci* infection. Additionally, the pH levels of puree from inoculated (4.7 pH) and noninoculated (4.8 pH) plants were similar (*P* = 0.21). However, fruit puree processed from *P. sambuci*-inoculated plants had lower titratable acidity than that from noninoculated plants. During the following growing season, plants that had been inoculated with *P. sambuci* in 2014 still had reduced yield and plant dry weight compared with those of noninoculated plants, even though rust pustules were not observed in 2015.

Potential infection periods of *P. sambuci* in 2016. Between 11 Mar., when ‘Bob Gordon’ elderberry plants were uncovered, and 17 May 2016, there were 30 potential infection periods, as defined by Beraha et al. and 17 May 2016, there were 30 potential infection periods; five of these infection periods, as defined by Beraha et al.

Table 1. Fruit characteristics, berry puree composition, and vegetative dry weights of ‘Bob Gordon’ elderberry plants inoculated with *Puccinia sambuci* or noninoculated plants in 2014.3

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fruit yield/plant (g)</td>
<td>Mean berry wt (mg)</td>
</tr>
<tr>
<td>Inoculated</td>
<td>138 b</td>
<td>113 b</td>
</tr>
<tr>
<td>Noninoculated</td>
<td>180 a</td>
<td>146 a</td>
</tr>
</tbody>
</table>

3In 2014, inoculated plants averaged 690 rust pustules/plant. In 2015, none of the elderberry plants were re-infected with *P. sambuci*. Values represent the means of eight replications of each treatment. Means followed by different letters in columns are significantly different (*P* = 0.05). Means were separated by a Satterthwaite test when variances were unequal or by a pooled test when variances were equal.

Discussion

Foliar symptoms of *S. sambuci* rust (i.e., pustules) were first observed on ‘Bob Gordon’ elderberry plants as early as 5 Apr. Many rust pustules were observed later (29 May) on foliage and stems of ‘Wyldewood’ elderberry of the commercial planting, with the initial infection occurring earlier. In some cases, stem distortion occurred when numerous rust pustules were present. The numbers of pustules on leaflets and stems for each cane or plant were recorded during these studies, but the severity of stem distortion was not evaluated. Although rust pustules were also observed on a few closed flowers and pedicels before bloom through harvest on ‘Wyldewood’ elderberry of the field planting, canes with infected floral tissue were not included in this study. Rust infection on floral tissue, which has not been previously reported, contributed to mortality and fruit loss.

*P. sambuci* infection occurs when germinated basidiospores from sedge plants penetrate susceptible elderberry tissue under favorable environmental conditions, including high humidity or adequate moisture on the plant tissue, for a long enough time over a suitable range of temperatures. During the initial rust infection observed on 5 Apr. 2016, there were five potential infection periods before the first observation of disease symptoms and signs (Table 2). Temperatures during these periods ranged from 10.9 to 13.2 °C, and leaf wetness durations ranged from 3 to 18 h. Of these potential infection periods, conditions occurring from 12 to 13 Mar. may have resulted in pustule development because 5.6 mm of precipitation occurred with 18 h of leaf wetness and the mean hourly temperature was 13.2 °C. The number of plants infected and the number of observed pustules (both pycnia and aecia) increased throughout April and May 2016. From 6 to 27 Apr., there were 14 potential infection periods; five of these occurred during precipitation events. Conditions from 18 to 19 Apr. may have resulted in significant infection since 58.7 mm of precipitation occurred with 16 h of leaf wetness and the mean hourly temperature was 16.2 °C. From 29 Apr. to 19 May, 50 more
Table 2. Continuous elderberry leaf wetness periods with corresponding mean maximum hourly temperatures and precipitation recorded at the Horticulture and Agroforestry Research Center near New Franklin, MO, during Spring 2016.

<table>
<thead>
<tr>
<th>Date</th>
<th>Continuous leaf wetness (no. hours)</th>
<th>Mean hourly temp during wetness period (°C)</th>
<th>Precipitation during leaf wetness period (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Mar.</td>
<td>3</td>
<td>12.5</td>
<td>3.1</td>
</tr>
<tr>
<td>12–13 Mar.</td>
<td>18</td>
<td>13.2</td>
<td>5.6</td>
</tr>
<tr>
<td>13–14 Mar.</td>
<td>13</td>
<td>10.9</td>
<td>0.0</td>
</tr>
<tr>
<td>14–15 Mar.</td>
<td>13</td>
<td>11.4</td>
<td>0.0</td>
</tr>
<tr>
<td>31 Mar.</td>
<td>7.5</td>
<td>13.1</td>
<td>5.1</td>
</tr>
<tr>
<td>6 Apr.</td>
<td>3</td>
<td>13.3</td>
<td>0.5</td>
</tr>
<tr>
<td>10–11 Apr.</td>
<td>13</td>
<td>11.9</td>
<td>17.5</td>
</tr>
<tr>
<td>16 Apr.</td>
<td>5</td>
<td>10.8</td>
<td>0.0</td>
</tr>
<tr>
<td>16 Apr.</td>
<td>10</td>
<td>10.8</td>
<td>0.0</td>
</tr>
<tr>
<td>17 Apr.</td>
<td>11</td>
<td>12.3</td>
<td>0.0</td>
</tr>
<tr>
<td>18–19 Apr.</td>
<td>16</td>
<td>16.2</td>
<td>58.7</td>
</tr>
<tr>
<td>19–20 Apr.</td>
<td>11</td>
<td>15.0</td>
<td>35.1</td>
</tr>
<tr>
<td>20–21 Apr.</td>
<td>13</td>
<td>9.7</td>
<td>0.0</td>
</tr>
<tr>
<td>22 Apr.</td>
<td>9</td>
<td>8.9</td>
<td>0.0</td>
</tr>
<tr>
<td>23 Apr.</td>
<td>7</td>
<td>11.4</td>
<td>0.0</td>
</tr>
<tr>
<td>25–26 Apr.</td>
<td>10</td>
<td>16.2</td>
<td>0.0</td>
</tr>
<tr>
<td>26 Apr.</td>
<td>3</td>
<td>15.4</td>
<td>0.0</td>
</tr>
<tr>
<td>27 Apr.</td>
<td>3</td>
<td>15.8</td>
<td>1.9</td>
</tr>
<tr>
<td>27 Apr.</td>
<td>4</td>
<td>12.4</td>
<td>0.0</td>
</tr>
<tr>
<td>29–30 Apr.</td>
<td>15</td>
<td>14.2</td>
<td>34.5</td>
</tr>
<tr>
<td>1 May</td>
<td>8.5</td>
<td>12.0</td>
<td>0.0</td>
</tr>
<tr>
<td>6–7 May</td>
<td>9.5</td>
<td>12.2</td>
<td>0.0</td>
</tr>
<tr>
<td>7 May</td>
<td>3</td>
<td>17.8</td>
<td>0.0</td>
</tr>
<tr>
<td>8 May</td>
<td>7</td>
<td>14.3</td>
<td>0.0</td>
</tr>
<tr>
<td>8–9 May</td>
<td>16</td>
<td>17.1</td>
<td>0.0</td>
</tr>
<tr>
<td>9–10 May</td>
<td>11</td>
<td>16.0</td>
<td>6.9</td>
</tr>
<tr>
<td>10–11 May</td>
<td>14</td>
<td>16.1</td>
<td>1.0</td>
</tr>
<tr>
<td>12 May</td>
<td>5</td>
<td>14.4</td>
<td>0.0</td>
</tr>
<tr>
<td>15–16 May</td>
<td>10</td>
<td>11.2</td>
<td>17.3</td>
</tr>
<tr>
<td>16–17 May</td>
<td>22</td>
<td>10.4</td>
<td>81.8</td>
</tr>
</tbody>
</table>

*On 5 Apr., five pustules were first observed on elderberry plants. By 29 Apr., a total of 304 pustules were observed on 59 plants, and 350 total pustules on 63 plants were observed on 19 May.

Table 3. Mean number of *Puccinia sambuci*-infected leaves, leaflets, and rust pustules on ‘Bob Gordon’ elderberry plants at three distances from *Carex frankii* plants on 29 Apr. 2016.

<table>
<thead>
<tr>
<th>Distance from sedge (cm)</th>
<th>No. of pustules/plant</th>
<th>No. of infected leaves/plant</th>
<th>No. of infected leaflets/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>7.6 a</td>
<td>3.3 a</td>
<td>5.8 a</td>
</tr>
<tr>
<td>59</td>
<td>1.7 b</td>
<td>1.7 b</td>
<td>2.5 b</td>
</tr>
<tr>
<td>95</td>
<td>2.8 ab</td>
<td>2.8 ab</td>
<td>3.4 ab</td>
</tr>
</tbody>
</table>

*Values represent 24 replications of each spacing from sedge. Means followed by different letters in columns are significantly different according to Fisher’s protected least significant difference test (*P* ≤ 0.05).

Table 4. Fruit characteristics, berry puree composition, and shoot dry weight of ‘Bob Gordon’ elderberry plants with or without *Puccinia sambuci* rust infection in 2016.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fruit yield/plant (g)</th>
<th>Berry wt (mg)</th>
<th>Total soluble solids (°Brix)</th>
<th>Titratable acidity (g/100 mL)</th>
<th>Shoot dry wt (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rust-infected</td>
<td>84 b</td>
<td>116 b</td>
<td>10.6 a</td>
<td>0.68 a</td>
<td>49 a</td>
</tr>
<tr>
<td>Uninfected</td>
<td>121 a</td>
<td>127 a</td>
<td>11.2 a</td>
<td>0.48 a</td>
<td>31 b</td>
</tr>
</tbody>
</table>

*Pooled data from rust-infected elderberry plants (n = 42) and noninfected plants (n = 12) were subjected to a t test. Means followed by different letters in columns are significantly different (*P* ≤ 0.05). Means were separated by a Satterthwaite test when variances were unequal or by a pooled test when variances were equal. Rust-infected plants averaged six pustules per plant on 19 May 2016. Shoots harvested 10 cm above the medium surface on 10 Oct. 2016.

Table 5. Fruit characteristics, berry puree composition, leaf loss, and cane dry weight of ‘Wyldewood’ elderberry canes with or without *Puccinia sambuci* rust infection in 2016.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fruit yield/cane (g)</th>
<th>Berry wt (mg)</th>
<th>Total soluble solids (°Brix)</th>
<th>Titratable acidity (g/100 mL)</th>
<th>Leaf loss (no.)</th>
<th>Cane dry wt (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rust-infected</td>
<td>47 b</td>
<td>43 a</td>
<td>10.9 a</td>
<td>0.68 b</td>
<td>19 a</td>
<td>58 a</td>
</tr>
<tr>
<td>Uninfected</td>
<td>88 a</td>
<td>41 a</td>
<td>11.7 a</td>
<td>0.78 b</td>
<td>10 b</td>
<td>86 a</td>
</tr>
</tbody>
</table>

*Pooled data from rust-infected elderberry plants (n = 33) and noninfected plants (n = 11) were subjected to a t test. Means followed by different letters in columns are significantly different (*P* ≤ 0.05). Means were separated by a Satterthwaite test when variances were unequal or by a pooled test when variances were equal. Rust-infected plants averaged 137 pustules/cane. Shoot dry weight was 28 g less than that of controls on 13 Oct. (Table 5). Because shoot dry weights were limited to tissue removal at 10 cm above the potting medium surface, and plants varied in the number of stems, the smaller size of elderberry plants used in the inoculation study, or perhaps a lower level of inoculum (i.e., teliospores) on alternate sedge hosts.

On other plants, such as asparagus, pyenia and aecia of *Puccinia asparagi* can develop on stems with at least 3 h of continuous wetting with temperatures ranging from 10 to 30 °C (Beraha et al., 1960). Maximum infection intensity of *P. asparagi* aecia occurred when mean temperatures remained between 19 and 22 °C for several days (Beraha et al., 1960). Both *P. sambuci* and *P. asparagi* occur during early spring; however, similarities in fungal spore germination and the subsequent infection of hosts by these two pathogens under identical environmental conditions are unknown and have not been investigated.

Elderberry plant proximity to the alternate host plants also influenced the incidence of rust infection, with those located closest to the sedge developing more pustules. These results suggest that rust infection can be reduced by elimination of the alternate host within or near elderberry plants. However, because many *Carex* species are perennial plants that spread by rhizomes (Mohlenbrock, 1999), eradication by mechanical means can be difficult.

Results from these studies indicate that the effect of *P. sambuci* on vegetative growth of elderberry plants varies with infection intensity, as measured by the pustule number. At low levels of infection (six pustules per plant), the number of leaves on ‘Bob Gordon’ near the end of the growing season was unaffected by *P. sambuci*. However, ‘Bob Gordon’ elderberry plants had more leaves early in the growing season and may have been more vigorous plants than the controls at the time of infection, resulting in infected plants with higher shoot weight on 10 Oct. (Table 3). Alternatively, a mean infection of six pustules per plant may not have been great enough to reduce shoot dry weight.

In experiments in which *P. sambuci* infection was more severe, premature leaf loss occurred (Table 5). In the 2016 experiment, by 26 Aug., ‘Wyldewood’ canes averaging 137 pustules/cane lost nearly twice as many leaves compared with control canes. Rust-infected ‘Wyldewood’ canes also had shoot dry weight that was 28 g less than that of controls on 13 Oct. (Table 5). Because shoot dry weights were limited to tissue removal at 10 cm above the potting medium surface, and plants varied in the number of stems,
statistical differences among rust-infected and control canes may not have been detected during this experiment. However, vegetative growth (evaluated by dry weight) was reduced when ‘Bob Gordon’ elderberry plants averaged 690 pustules/plant or 137 pustules/cane. The lower titratable acidity of puree resulting from *P. sambuci* infection would alter the sugar–acid balance and may adversely affect the flavor of processed elderberry juice or wine products compared with juice products from uninfected fruit.

In conclusion, *P. sambuci* infection of elderberry plants occurred during early spring when sedge plants were in close proximity. Conditions favorable for possible infection were 9 to 18 °C, ≥3 h continuous leaf wetness, and ≥85% relative humidity. Low infection rates of *P. sambuci* did not adversely affect vegetative growth, even on young elderberry plants, whereas higher infection levels (137/pustules/cane) resulted in premature leaf loss. In contrast, low infection levels of rust resulted in fruit yield loss. Because of the potential for fruit yield loss on elderberry plants at relatively low infection levels, control of *P. sambuci* with fungicides may be warranted. Additionally, strategies that eliminate the alternate host or suppress its spread by underground rhizomes may be useful for reducing the leaf area on which rust inoculum resides, thereby limiting the potential for elderberry plant infection.

**Literature Cited**


