# Flowering, Fecundity, Seed Germination, and Seed Viability of *Viburnum opulus* L. Cultivars[1]

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## Abstract

Mature specimens of *Viburnum opulus* and cultivars 'Leonard's Dwarf' and 'Roseum' were assessed over 2 years for flower and seed production, seed germination, and seed viability as determined by a tetrazolium test to understand their invasive potential. 'Aureum', 'Compactum', 'Losely's Compact', 'Nanum', and 'Xanthocarpum' were also tested for germination and viability of seeds. Cultivars differed in flower and seed production, seed germination, and seed viability. 'Roseum' prolifically produced highly viable seed that germinated at moderate rates under greenhouse conditions (8,354, 100%, and 73%, respectively). *Viburnum opulus* and 'Leonard's Dwarf' produced fewer viable seed which showed moderate to low germination rates (609, 100%, and 53%; 712, 100%, and 5%, respectively). 'Aureum' and 'Xanthocarpum' seeds germinated at moderate rates (55 and 25%, respectively) and were highly viable (100%). 'Compactum', 'Losely's Compact', and 'Nanum' germinated at low rates or failed to germinate (0, 0, and 5%, respectively), yet seeds were moderately viable (37, 65, and 55%, respectively). Seeds of all cultivars germinated at low rates or failed to germinate at both outdoor sites (0 to 5%) which suggests these plants may be weakly invasive. Short-term studies on biological traits such as these provide only limited information to assess the invasive potential of cultivars.

**Index words:** European cranberrybush viburnum, invasive, greenhouse, landscape, forest, ornamentals.

**Species used in this study:** European cranberrybush viburnum (*Viburnum opulus* L.) and cultivars 'Aureum', 'Compactum', 'Leonard's Dwarf', 'Losely's Compact', 'Nanum', 'Roseum', and 'Xanthocarpum'.

**Chemicals used in this study:** Roundup (glyphosate), N-(phosphonomethyl)glycine; Basamid (dazomet), Tetrahydro-3, 5-dimethyl-2H-1, 3, 5-thiadiazine-2-thione; Tetrazolium Red (TTZ), 2, 3, 5-Triphenyltetrazolium chloride.

### Significance to the Nursery Industry

Invasive species threaten biodiversity and annually cost the United States $138 billion (20). The ecological community and public at large are looking to the green industry to help solve the dilemma of invasive plant management. Many approaches are being taken to prevent new invasive introductions and to reduce the potential impact of presently used landscape plants on the environment. For plants such as *Viburnum opulus* and its cultivars that are heavily used in the trade the question becomes, what is the invasive potential? At this time, little is known about the biological traits of *V. opulus* cultivars or their invasive potential; although, the species is listed as potentially invasive based on observations outside of the managed landscape (21).

For this reason, flower and seed production, seed germination, and seed viability were collected for *V. opulus,* 'Leonard's Dwarf', and 'Roseum'. Additionally, seed germination and seed viability were assessed for 'Aureum', 'Compactum', 'Losely's Compact', 'Nanum', and 'Xanthocarpum'. 'Roseum' plants were observed to produce prolific seeds, while *V. opulus* and 'Leonard's Dwarf' yielded fewer seeds. Greenhouse seed germination for 'Roseum', *V. opulus,* 'Aureum', and 'Xanthocarpum' was moderate, whereas, 'Leonard's Dwarf' was low. These five cultivars were highly viable. 'Compactum', 'Losely's Compact', and 'Nanum' seeds germinated at low rates or failed to germinate and were moderately viable. In the open landscape and forest, cultivars germinated at low rates or failed to germinate, which suggest that the cultivars may be weakly invasive. Further long-term research would be suitable to fully determine the cultivars invasive potential.

### Introduction

Invasive species are recognized as the second greatest threat to biodiversity after habitat destruction in the United States. The predicted annual economic loss due to invasive species in the United States is more than $138 billion (20). One way that invasive plants affect biodiversity outside the landscape is by displacing native plants and harming natural ecosystems through prolific seed production (15). Seeds from such highly productive plants located next to a meadow or field may escape cultivation and germinate or remain viable in the seed bank for several years (11, 18). Once dormancy is broken and the proper environmental conditions experienced, the subsequent seedlings can become competitive interlopers into more fragile native plant populations thus creating shifts in the natural landscape over time (11, 25). European cranberrybush viburnum *(Viburnum opulus)* has been reported to escape cultivation and is listed as potentially invasive throughout Pennsylvania with a perceived potential threat to native plant communities (21) even though it possesses short-lived seeds (13).

Less invasive or noninvasive cultivars of invasive species may presumably exist but have yet to be biologically characterized. Few studies have addressed flower and seed yields, seed germination, and seed viability along with other biological traits in determining the invasive potential of cultivars of known invasive species. Of the studies reported, all have focused on shrub (2, 12, 15, 17, 28, 29) perennial grass (18), or herbaceous species (27). In defining biological character-

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istics of cultivars, this information may assist organizations and legislative bodies who have been placed in a position to ban landscape plants solely based on information about the species (e.g., New Hampshire, 19).

The purpose of this study was to characterize flower and seed production, seed germination under a wide range of conditions, and seed viability of *V. opulus* cultivars. This report is the first in which *V. opulus* cultivars have been evaluated to aid in defining their invasive potential. This study is preliminary and meant to research the *potential* variation in the biologic traits of *V. opulus* cultivars. Subsequent studies would appropriate to further assess each cultivar's invasiveness.

## Materials and Methods

*Plant material and site selection. Viburnum opulus* along with cultivars 'Leonard's Dwarf' and 'Roseum' were assessed for 2 years (2004 to 2005) to document flower and seed production, seed germination, seed viability, and plant size (Table 1). Additionally, seeds were collected from 'Aureum', 'Compactum', 'Losely's Compact', 'Nanum', and 'Xanthocarpum' both years of the study for seed germination and seed viability testing only, because replicate plants were unavailable for collecting flower and seed yield or plant size. Evaluation plots of replicate cultivars that were 5 to 7 years old and of a visually similar plant size, were located at Longwood Gardens (Kennett Square, PA; latitude 40°N, longitude 76°W; USDA Hardiness Zone 6) and the Pennsylvania State University (University Park, PA; latitude 40°N, longitude 77°W; USDA Hardiness Zone 6).

*Estimation of flower and seed production.* Flowers and seeds were collected based on average bloom or seed dispersal dates and visual observation of full bloom or seed maturity. Drupes were considered mature when fruit changed from a green to red color in late summer.

To assure consistency in flower and seed collection, two different collection methods were employed based on cultivar size. For all cultivars (three to four plants per cultivar), four entire lateral branches per plant were randomly selected from each cardinal direction and marked to estimate flower and seed production throughout the shrub. In late spring to early summer (May 20 to 21 and June 4, 2004; May 23 to 24 and 28, 2005), total flower clusters and the average flowers per cluster from ten randomly selected clusters were recorded on each marked branch. Annual flower production estimates were calculated (total flower clusters × average flowers per cluster). Branch length and diameter were also recorded to calculate the surface area of each branch [$SA=2 \times \pi \times r \times l$, where SA = surface area, $\pi = 3.14$, r = branch radius (branch diameter ÷ 2), and l = branch length]. This formula was chosen because it represents the branch shape of *V. opulus* cultivars. Flower densities were then calculated (annual flower production estimates ÷ branch surface area) to standardize estimates per unit area. Height and canopy dimensions were also collected to monitor plant size for the cultivars over the study. In late summer to early fall (August 26 to 27 and September 5, 2004; August 22 to 24, 2005), cultivars' seed densities were determined on previously marked branches by using the same methods. Additionally, seed set was calculated (average seeds per cluster ÷ average flowers per cluster).

In 2004, an alternative collection method was used on small stature cultivars ('Leonard's Dwarf'). Cultivars that were ≤ 1.8 m (5.9 ft) tall and possessed canopy dimensions of ≤ 2.0 × 1.8 m (6.6 × 5.9 ft) had annual flower and seed estimates determined for the entire plant rather than from a representative sample. Canopy dimensions and height were recorded to calculate the surface area of each plant {$SA = \pi \times (h^2 + r^2)$, where SA = surface area, $\pi = 3.14$, h = height, r = radius [(canopy length + canopy width) ÷ 2]} (16). Flower and seed densities were then calculated (annual flower or seed production estimates ÷ canopy surface area) to standardize estimates per unit area.

*Seed harvesting and processing.* Approximately 500 drupes from each cultivar (one to four plants per cultivar) were harvested and bulked in bags to provide a uniform seed lot for germination and viability experiments. Seed lots were collected annually and evaluated for 1 year each over the study (2004 to 2005). Drupes were macerated with a commercial blender and rinsed with water by using a screen to remove inhibitors. Seed was cleaned immediately following harvest before the pulp began to ferment.

*Greenhouse germination*. Five replications of eight seeds per replication of each cultivar were randomly chosen and soaked in water overnight at room temperature to assure imbibition. Seeds were then warm stratified at 20 to 21C (68 to 70F) for 60 days followed by cold stratification at 5C (41F) for 42 days to break dormancy (6). After this period, seeds were sown by hand (January 27 and December 5, 2005) in community flats [51 × 36 × 10 cm (20 × 14 × 4 in)] using a completely randomized design. Seeds were uniformly sown at a depth of 1 cm (0.5 in) in a soilless medium (Sunshine Mix #4; Sun Gro Horticulture, Bellevue, WA) and placed in a greenhouse with root zone heat at 21C (70F) (30) and misted every 20 minutes for 7 seconds. After 84 days, germination rates were recorded (May 13, 2005; February 27, 2006). 'Germination' was defined as the emergence of a radicle or plumule.

**Table 1. Plant size measurements of *V. opulus* cultivars and species from Longwood Gardens and the Pennsylvania State University averaged over a period of 2 years. Values are means ± standard errors.**

| Plant source | Sample (no.) | Site location | Planting date (yr) | Height (m) | Canopy dimensions (m) | Light exposure | Branch diameter (cm) | Branch length (m) |
|---|---|---|---|---|---|---|---|---|
| 'Leonard's Dwarf' | 3 | Longwood | 1998 | 1.9 ± 0.1 | 2.0 ± 0.2 × 1.8 ± 0.1 | Part shade | 1.6 ± 0.1 | 1.5 ± 0.1 |
| 'Roseum' | 3 | Longwood | 1997 | 2.7 ± 0.2 | 3.4 ± 0.4 × 3.3 ± 0.5 | Full sun | 3.0 ± 0.1 | 2.1 ± 0.1 |
| *V. opulus* | 4 | Longwood and PSU[z] | 1997 | 2.8 ± 0.2 | 2.7 ± 0.3 × 2.3 ± 0.2 | Part shade | 2.0 ± 0.1 | 2.4 ± 0.1 |

[z]PSU = Pennsylvania State University.

*Open landscape germination.* To define germination under ambient environmental conditions, germination trials were conducted at the Landscape Management Research Center Pot-in-Pot Nursery (University Park, PA). Soil at this site was classified as a Hagerstown silt loam (4), a Typic Hapludalf (3) prior to amending with 8 cm (3 in) of Sunshine Mix #4 to produce a uniform seed bed for germination trials. Five replications of eight seeds per replication of each cultivar were sown in the fall (November 8, 2004) within the beds at a depth of 1 cm (0.5 in) in a completely randomized design.

During the first season, each replication was confined in a plastic mesh bag [10 × 10 cm (4 × 4 in), mesh size 2 × 3 mm (0.1 × 0.1 in)]. Mesh bags were enclosed in two hardware cloth strips [120 × 15 cm (47 × 6 in), mesh size 1 × 1 cm (0.5 × 0.5 in)] and planted in the bed to protect seed from animal predation. The seed bed perimeter was enclosed with hardware cloth to further prevent seed bed disruption. Overwintered seeds were assessed the following year in the early summer for germination (June 1, 2005). Seeds from the 2004 seed lot were overwintered for an additional year to assess germination over an extended time period. Beds were weeded by hand (June 1 and July 5, 2005; May 16, 2006), and Roundup (glyphosate) was applied as a directed spray (July 7 and August 19, 2005) to control unwanted weeds in the seed bed.

The experimental set up for the second season (2005) changed slightly to reduce the potential for disease organisms and weed seed germination. Germination beds were sterilized with Basamid (dazomet) and tested for Basamid dissolution before sowing seeds. Seeds were loosely planted within wooden frames in rows without confinement in plastic mesh bags and hardware cloth units. A completely randomized design was again used to plant five replications of eight seeds per replicate of each cultivar in the fall (October 31, 2005) to a depth of 1 cm (0.5 in). A poison bait trap was placed within the center of each frame to prevent rodent predation on the seeds. Bamboo stakes were arched and plastic deer netting [mesh size 3 × 3 cm (1 × 1 in)] was stapled over the frame to exclude animal activity in the bed. Seeds were then overwintered and germination assessed in the early summer the following year (June 1, 2006).

*Forest germination.* Germination experiments were conducted under a forest canopy at the Russel E. Larson Agricultural Research Center (Rock Springs, PA). Preparation and the experimental design were similar that of the open landscape site except that the germination beds were in non-amended soil and were not sterilized. Leaf litter was initially removed with rakes, competing canopy tree roots were severed with pruners, and the soil was loosened with shovels, mattocks, hoes, and trowels to create a uniform seed bed. The beds remained free of leaf litter over the study. Cultivation and herbicide use were unnecessary due to the lack of weeds. Trials were duplicated each fall (November 8, 2004; November 1, 2005). Seeds were then overwintered and germination assessed in the early summer the following year (June 1, 2005; June 1, 2006).

*Seed viability.* Two replications of 40 seeds per cultivar were randomly selected for viability testing each year (11) due to the limited seed availability for some cultivars. Undeveloped seeds were excluded from tetrazolium tests. 'Aureum' was only tested in 2005 and 'Compactum', 'Losely's Compact', and 'Nanum' were only tested in 2004.

Seeds were soaked overnight at room temperature followed by hand removal of seed coats to aid metabolic activation and absorption of the Tetrazolium Red (TTZ) solution. The solution was prepared by dissolving Tetrazolium Red powder in tap water to produce a 2% solution at a pH between 6 and 8 for adequate staining. Seeds were soaked in the 2% Tetrazolium Red solution at room temperature for 22 hours. Seeds were observed at several points during the tetrazolium test to prevent over exposure to the stain which would allow any present fungi or bacteria to stain dead tissues red. Seeds were removed from solution and visually assessed for viability (October 20, 2004; August 26, 2005). 'Nonviable seeds' were those that remained unstained and 'viable seeds' were those that stained red in color.

*Statistical analysis.* Annual flower and seed densities, for each of the 2 years, were subjected to one-way analysis of variance (ANOVA) using SAS's MIXED procedure to define if cultivars influenced these variables. The shrub and branches nested in the shrub were considered to be random effects, whereas the cultivar or species were fixed effects. Fisher's least significant difference was then used to make pair-wise comparisons of the least squares means (lsmeans) if cultivar effects were significant ($P < 0.05$). Annual seed set and germination (e.g., greenhouse, open landscape, or forest) for each study year were subjected to one-way ANOVA using SAS's GLM procedure to determine if cultivars influenced these variables. Duncan's multiple range test was then used to make pair-wise comparisons of the means if cultivar effects were significant ($P < 0.05$). Statistics were completed with SAS (version 9.1; SAS Institute Inc., Cary, NC) and graphs generated with SigmaPlot (version 9.0; Systat Software, Inc., San Jose, CA).

## Results and Discussion

Preliminary research presented in this study is useful to define the *potential* variation in flower and seed production, seed germination, and seed viability of *V. opulus* cultivars. Subsequent studies would be an appropriate next step to assess the biologic traits of each cultivar.

*Flower and seed production.* An obvious constraint in evaluating landscape shrubs and related cultivars of a species for flower and seed production is the availability of replicated accessions. As this represents the first attempt to address the invasiveness of *V. opulus* cultivars, the cultivars and number chosen were the most practicable to begin the investigation of flower and seed production. These cultivars do not represent the full compliment of available cultivars in the market place.

We were able to find replicates of cultivars that were 5 to 7 years old at both sites. All cultivars and the species were physiologically mature because *V. opulus* flowers when plants are 3 to 5 years old (13). Cultivar plots were located in rows which caused some shading to occur as the light moved over the field. Among the test shrubs, marked branches on 'Roseum' plants grew in what appeared to be a sunny location with limited light interference. Two to three marked branches of 'Leonard's Dwarf' and *V. opulus* were observed to grow in partial shade as the sun traversed the sky because of competing nearby shrubs in rows that may have

Table 2. **Flower and seed densities standardized per unit area and seed set on marked branches of *V. opulus* cultivars or species at Longwood Gardens and the Pennsylvania State University over a 2-year period.**

| Plant source | Flowers/m² | | Seeds/m² | | Seed set (%) | |
|---|---|---|---|---|---|---|
| | 2004 | 2005 | 2004 | 2005 | 2004 | 2005 |
| 'Leonard's Dwarf'[z] | 63 | 8,503b | 5 | 712b | 18 | 8b |
| 'Roseum' | 24,531a | 63,611a | 3,240a | 8,354a | 12a | 15a |
| *V. opulus* | 7,699b | 39,685a | 609b | 102b | 15a | 5b |

[z]'Leonard's Dwarf' was not compared with 'Roseum' or *V. opulus* in 2004 since data were collected from the entire plant.

[y]Mean separation within columns followed by different letters are significantly different according to Fisher's LSD test for flower and seed densities and Duncan's multiple range test for seed set, α = 0.05, n = 3 to 4.

decreased flower and seed production. To be certain that the partial shading was not a contributing factor would require a second series of replicate shrubs among the evaluation plots; however, such a replicate set without shading was not available for this study.

Among the cultivars researched, flower and seed densities on marked branches significantly differed each year, whereas, seed set differed in only 2005. 'Roseum' produced prolific flowers and seeds that more than doubled from year to year. *Viburnum opulus* and 'Leonard's Dwarf' produced fewer flowers and seeds over the study. Seed set was low among the cultivars during the study (Table 2). Similar variation in flower and seed productivity among cultivars has been reported on barberry (*Berberis*), butterfly bush (*Buddleja*), and heavenly bamboo (*Nandina*) (12, 17, 28).

Variation in flower and seed production was obvious for most cultivars from year to year, whereas, seed set was similar for the cultivars during the study. 'Roseum' plants produced the highest increase in flowers (39,080) and seeds (5,114). *Viburnum opulus* plants had a similar increase in flower production (31,986) and decreased seed productivity to 507 (Table 2). Such observations on cultivar differences from one year to the next agree with similar studies on *Nandina* (12). Year to year variations may produce high flower and seed yields due to the environment, endogenous cycles (26), or nutrient availability (22).

When deciding between landscape plants of similar quality, those with low seed production should be chosen, since few seeds exist on these plants which may escape cultivation and germinate in natural areas (2, 17, 18). Because 'Roseum' produced prolific flowers and seeds, it may be an invasive threat in landscapes that adjoin natural areas. Although *V. opulus* and 'Leonard's Dwarf' yielded fewer flowers and seeds, these plants need to be further assessed before determining their invasive potential.

*Greenhouse germination.* When assessing the invasive potential of any plant species, germination is one important factor that must be considered (27, 29). Previous research on cultivars of landscape species labeled as potentially invasive

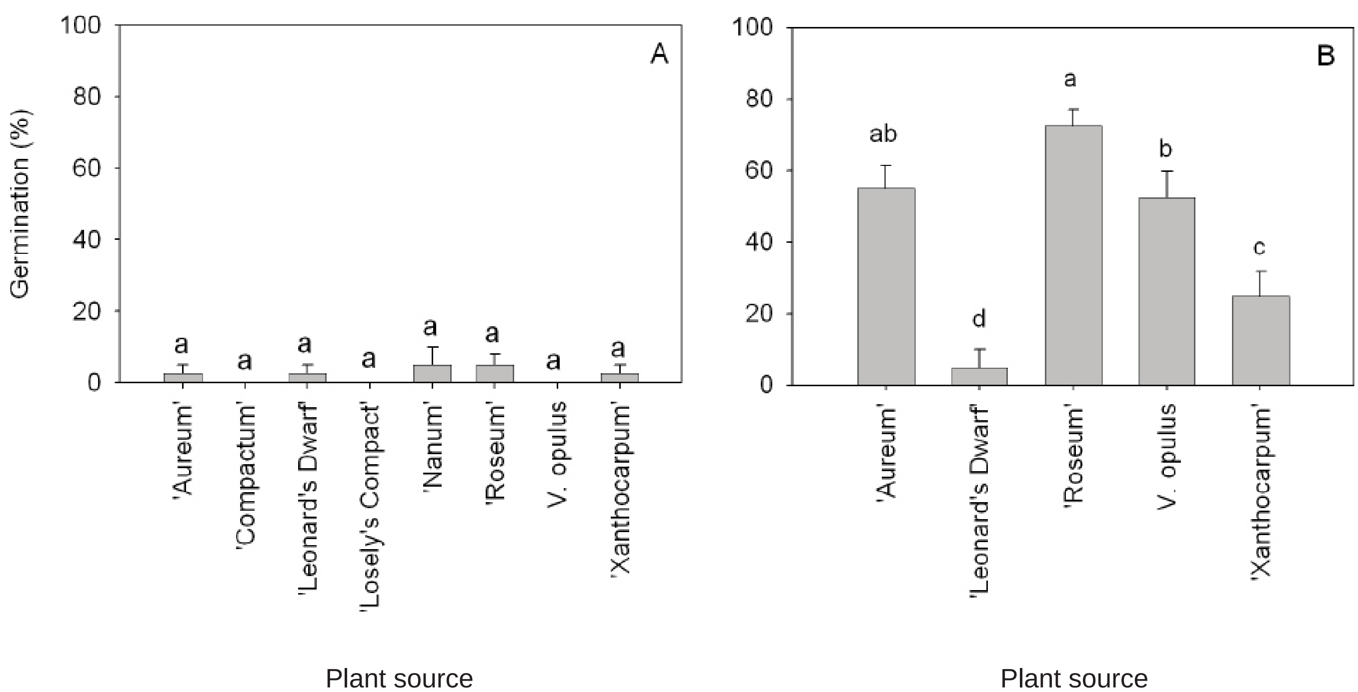


Fig. 1. **Greenhouse germination for *V. opulus* cultivars and the species with the 2004(A) and 2005(B) seed lots. All values are means ± standard errors. Different letters indicate a significant difference according to Duncan's multiple range test, α = 0.05.**

have classified high germination rates from 70 to 100% and low germination from 0 to < 30% (2, 17, 18, 29). In keeping with these defined germination rates, high rates in this study were from 75 to 100%, moderate rates from 25 to 74%, and low rates from 0 to 24%.

Greenhouse germination rates of *V. opulus* cultivars were similar in 2004; however, rates differed in 2005 (Fig. 1A and B). 'Aureum', 'Leonard's Dwarf', 'Nanum', 'Roseum', and 'Xanthocarpum' germinated in 2004 at low rates from 3 to 5%. *Viburnum opulus,* 'Compactum', and 'Losely's Compact' failed to germinate during this period (Fig. 1A). In 2005, 'Compactum', 'Losely's Compact', and 'Nanum' were not available for testing due to seed shortages. 'Aureum', 'Leonard's Dwarf', 'Roseum', *V. opulus,* and 'Xanthocarpum' germinated at low to moderate rates from 5 to 73% (Fig. 1B). Similar variation in germination among cultivars has been reported for *Buddleja* and *Miscanthus* (2, 18).

In the greenhouse, seed germination of cultivars was much higher in 2005 (5 to 73%) than in 2004 (0 to 5%). Lower rates may have been observed with the 2004 seed lot because seeds were misted more often (every 10 minutes for 10 seconds) than the 2005 seed lot which caused fungus growth. Germination flats from the 2004 seed lot were sprayed with ZeroTol (hydrogen dioxide; March 25, April 4, and April 26, 2005) to control fungal attack.

'Roseum' (68%), *V. opulus* (53%), 'Aureum' (52%), and 'Xanthocarpum' (22%) demonstrated the highest variation over the 2-year study. 'Leonard's Dwarf' (2%) displayed few changes (Fig. 1A and B). Such observations on plant differences from one year to the next are similar to studies on *Miscanthus* (18). Changes in germination rates from year to year demonstrate the need to research rates for more than one season to reveal each cultivar's long-term germination accurately and the need to conduct preliminary studies to define optimal germination conditions (e.g., mist frequencies).

*Open landscape and forest germination.* Seeds enclosed in plastic mesh bags failed to germinate in 2004. For this reason, a follow-up experiment was conducted on the most productive and highest germinating 2004 seed, 'Roseum'. This experiment was performed as described under greenhouse germination with or without plastic mesh bags to determine if bags inhibited germination (five replications of eight seeds per replication with bags, five replications of eight seeds per replication without bags). Few differences were found between the germination rates with (15%) or without (13%) bags. From this, we concluded that bags failed to influence germination. Drewitz and DiTomaso (7) conducted similar field germination studies on jubatagrass (*Cortaderia jubata*) in nylon organza bags and found that seeds germinated. Mesh bags protected seeds from predation and allowed for proper water, air, and microorganism movement (24).

Results from the Plant Disease Clinic (University Park, PA) identified two fungal pathogens, *Alternaria* and *Mucor*, and possible insect damage among the seeds recovered from the field experiments in 2004. *Alternaria* or *Mucor* may have infected and killed seeds before or after germination (1, 5). Because the open landscape site was not sterilized before to the germination trial, seeds may have been attacked by soil-borne pathogens.

Overall, seeds from all cultivars or the species failed to germinate at the open site. Only 'Leonard's Dwarf' germinated at a low rate of 5% under the forest canopy in 2005. When compared to the two outdoor sites, much higher germination was noted in the greenhouse (0 to 73%) among the cultivars. Differences in germination under varying conditions demonstrated that cultivars needed to be tested under a wide range of conditions to define each cultivar's full germination potential.

Variation in germination at these locations for the cultivars might be due to species-specific responses to environmental conditions (14). Unpredictable outdoor conditions often lead to decreased germination, whereas laboratory conditions produce the highest germination rates (26). Cultivars germinated at low rates or failed to germinate at both outdoor sites which suggest that the plants may be only weakly invasive. Without further extensive germination trials over time, the invasive potential of these cultivars remains a question.

*Seed viability.* For individual seed crop years (2004 to 2005), the tetrazolium test revealed that seeds from all cultivars were viable. Viability rates in 2004 varied from 13 to 75%, whereas 2005 rates for seeds from all tested cultivars were 100%. 'Xanthocarpum' seeds were the least viable (13%) in 2004. 'Losely's Compact' (65%), 'Leonard's Dwarf' (63%), 'Nanum' (55%), and 'Compactum' (37%) seeds were moderately viable. Seeds of 'Roseum' (75%) and *V. opulus* (75%) were highly viable. Over the 2-year study, viability of 'Roseum' and *V. opulus* seeds was the most consistent (75 to 100%). Seeds of 'Xanthocarpum' (13 to 100%) and 'Leonard's Dwarf' (63 to 100%) had the most inconsistency in viability.

Large variation in viability from year to year is common, and similar results have been found for the sycamore maple (*Acer pseudoplatanus*) (8). Reasons for large differences in viability might be due to mechanical damage, microorganisms, nonuniform seed lots (9), or environmental conditions (11). No sign of microbial attack was observed among the seeds, and environmental conditions were the same for all cultivars. Since the seeds were bulked among the replicates for each cultivar, nonuniform seed lots may have been created or seeds damaged despite the care taken to prevent this damage.

Viability tests should be conducted in conjunction with germination experiments to define the potential to germinate over time. Previous research indicates that the results from both these tests should be similar to one another, within 3 to 12% (7, 29). Differences higher than this do not automatically mean that the tetrazolium test was conducted in error and may occur because of nonuniform seed lots, low quality seeds, or dormant seeds (9). In keeping with these defined differences in seed germination and viability rates for the purposes of this study, differences in rates from both experiments ≤ 10% were considered to be similar, while those ≥ 15% were considered to be different.

For most *V. opulus* cultivars, the highest seed germination observed under all test conditions for individual seed crop years (Fig. 1B) and seed viability differed by ≥ 15%. 'Xanthocarpum' was the only cultivar whose seeds showed similar rates for 1 year. Similar variation between seed viability and seed germination tests has been found for drummond's milk vetch (*Astragalus drummondii*), wild licorice (*Glycyrrhiza lepidota*), smooth blue beard-tongue (*Penstemon nitidus*), and slender blue beard-tongue (*Penstemon procerus*) (23).

An explanation for the variation between viability and germination among the *V. opulus* cultivars may be seed dormancy and maturity. Seeds at various maturity levels or of the same species harvested from varying positions on the mother plant may show differences in dormancy (26). Seed dormancy is not always relieved by following procedures to break dormancy (10). Although cultivars were stratified for the desired period, seeds may have experienced different dormancy levels and some may have remained dormant to result in large differences between germination and viability rates.

From this research, 'Roseum' was found to produce prolific seeds that germinated at moderate rates only in the greenhouse and were highly viable according to a tetrazolium test. *Viburnum opulus* and 'Leonard's Dwarf' produced fewer seeds that were highly viable. *Viburnum opulus* germinated at moderate rates, while 'Leonard's Dwarf' germinated at low rates. 'Aureum' and 'Xanthocarpum' seeds germinated at moderate rates and were highly viable. Seeds of 'Compactum', 'Losely's Compact', and 'Nanum' failed to germinate or did so at low rates and were moderately viable. At the open landscape and forest sites all cultivars germinated at low rates or failed to germinate. Findings from outdoor germination trials suggest that the cultivars researched may be only weakly invasive. Without further long-term studies (5 to 10 years), there remains a question as to the invasive potential of each cultivar.

Many other areas exist where future work might be conducted. To further understand 'Leonard's Dwarf' potentially weedy nature in the landscape, more replicates of seed production trials may be appropriate for comparison with seed germination and seed viability findings. With only seed germination and seed viability performed for 'Aureum', 'Compactum', 'Losely's Compact', 'Nanum', and 'Xanthocarpum', these cultivars need to be further researched to define their seed production before determining their invasive potential. Additionally, the relationship between flower and seed yields for each cultivar could be determined which would require the use of uniform, complete stands of shrubs. More representative *V. opulus* cultivars could be researched to determine their invasiveness by defining flower and seed yields, germination (e.g., greenhouse, open landscape, and forest), and seed viability. Cultivars' competitive abilities, pollen viability, level of seed predation, and distance of seed dispersal could also be studied to aid in determining *V. opulus* cultivars invasive potential.

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