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Investigating the Economic Impact of Emerging Vascular Streak Dieback Threat to Redbuds in the US Nursery Industry

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Abstract. **The nursery industry is a major economic driver in the United States, with an estimated worth of $4.5 billion. However, nursery production is often threatened by novel or existing pest and disease issues, and the economic impact of these threats can be devastating. The redbud production industry in the United States is currently facing production challenge due to vascular streak dieback (VSD), a novel threat that was recently reported in several states where nursery production is a major component of the state economy. Although the exact cause of VSD remains unknown, it results in considerable losses to nursery growers by reducing plant quality and marketability and increasing labor costs for necessary management practices. A multistate survey was conducted in 2023 to gather data from stakeholders within the redbud industry to assess the economic impact of VSD on redbud production and management practices. Forty-eight responses were collected from seven states: Kentucky, North Carolina, Ohio, Oklahoma, Oregon, Tennessee, and Virginia. Most growers were involved in container production, followed by ball and burlapped, bareroot, and liner production. Over the past 5 years, 77% of surveyed growers reported VSD symptoms in redbud plants, with 2022 having the highest incidence at 30%. Symptoms were most frequently observed in summer (37%), followed by spring, fall, and winter. VSD was identified as the primary cause of redbud losses, affecting about 70% of production, surpassing winter damage, root rot, and other factors. On average, growers reported around $375,000 worth VSD losses of ~25% in container plants. Key factors influencing future redbud production trends include growers having over 30 years of nursery experience, nursery size, the presence of VSD symptoms in landscape plants, the extent of container production, and the economic impact of VSD.**

The horticulture industry is rapidly growing within the US agricultural sector, making a significant contribution to its overall value, with a total revenue of $13.8 billion based on 2019 census data (US Department of Agriculture, National Agriculture Statistics Service 2020). Compared with other horticultural segments, nursery stock including woody ornamental production dominated the horticulture market in 2019, accounting for a substantial 33% of total sales and generating over $4.5 billion in revenue (US Department of Agriculture, National Agriculture Statistics Service 2020). According to the 2022 Census of Agriculture data, nursery crop sales reported around $8.1 billion representing 19,120 farms estimated nursery production area over 401,000 acres (US Department of Agriculture, National Agriculture Statistics Service 2022). Woody ornamental production covers a large and significant portion of horticultural sales, and California, Florida, Michigan, Oregon, and Texas were leading states in sales. Also, the majority of horticultural products, including woody ornamentals, were distributed through wholesale channels, representing 86% of the total horticultural market value (US Department of Agriculture, National Agriculture Statistics Service 2020).

Redbuds belong to the genus *Cercis* L. (Fabaceae) that includes a diverse range of species and subspecies according to their morphology and biogeography, numbering between seven and thirteen, which are found across North America, Europe, and Asia (Chen et al. 2010; Davis et al. 2002; Fritsch et al. 2009; Kidwell-Slak and Pooler 2018; US Department of Agriculture, National Agricultural Statistics Service 2017). According to the most recent US Department of Agriculture 2019 Census of Horticultural Specialties, redbuds are the fifth most valuable deciduous flowering tree crop in the United States, with a sales value of $28.4 million sold around 1000 wholesale or retail nurseries in 41 states (US Department of Agriculture, National Agriculture Statistics Service 2020). Redbud sales in 2019 have increased by 6.4% since 2014 and are valued at $26.7 million. Tennessee ranked number one in redbud production, with more than 23% of US total production, valued at $4.9 million and accounted for 17% of the nation's sales in 2019 followed by North Carolina (11.5%), Oregon (11.4%), California (10.9%), and Ohio (5.9%) as the top five states of redbud sales (US Department of Agriculture, National Agriculture Statistics Service 2020).

Eastern redbuds (*Cercis canadensis* L.) are known for their vibrant rose-purple flowers that bloom in early spring, glossy heart-shaped foliage, and adaptability to diverse environmental conditions (Kidwell-Slak and Pooler 2018). The eastern redbuds are widely found across the eastern United States and the Southern Great Plains (Brakie 2010). Its range extends from New Jersey and Pennsylvania to Michigan, Nebraska, Texas, and Florida, with isolated populations in South Texas and Mexico and expanding into US Department of Agriculture zones 4 to 9 (Dickson 1990; Raulston 1990; Robertson 1976).

In 2019, the Tennessee Department of Agriculture received the first redbud sample showing symptoms of vascular streaks, wilting, and dieback. Subsequently, laboratories across the country have been inundated with samples of plants exhibiting similar symptoms. These symptoms are currently collectively known as vascular streak dieback (VSD). VSD has been noted in redbud plants within nurseries located in Alabama, Kentucky, Maryland, Missouri, North Carolina, Oregon, Pennsylvania, South Carolina, Tennessee, and Virginia (Liyanapathiranage et al. 2025). Additionally, isolated incidents have been documented in nurseries in Indiana, Florida, and Oklahoma. VSD affects various stages of redbud, including seedlings, grafted plants, and older nursery stock, in both field and container systems. Furthermore, VSD has also been detected in newly planted landscape plants, within a botanical garden, and in various natural landscapes, highlighting its widespread impact (Liyanapathiranage et al. 2025).

Since the first report in redbud, VSD has been identified in more than 25 genera of ornamental and woody plants, with eastern redbud experiencing the greatest impact, followed by maple (*Acer* spp.) and dogwood (*Cornus* spp.) (Baysal-Gurel and Liyanapathiranage 2023; Lauderdale 2023). By 2022, nursery producers reported about a 64% loss in eastern redbud container production due to VSD (Liyanage et al. 2024). In 2023 alone, VSD caused reported losses exceeding $1.5 million for US growers, with its potential economic impact on redbud, maple, and dogwood estimated to exceed $134 million (Liyanage et al. 2024; US Department of Agriculture, National Agriculture Statistics Service 2020). Despite the unidentified causal agent, VSD significantly affects growers by reducing plant quality and marketability and increasing labor costs for management practices like scouting, pruning, and disposing of infected plants. Understanding the economic impact of VSD from the growers' perspective is crucial for addressing the challenges it poses to the US nursery industry. A multistate survey provides the most effective method to capture this information, offering a comprehensive view of both the financial effects and the management practices commonly used by growers. Additionally, analyzing these practices may reveal important correlations that can inform not only the conclusions of this study but also the development of future research and management strategies. Building on this foundation, this study aimed to assess the economic impact of emerging VSD and to identify redbud management practices that could potentially affect its spread within the US nursery industry, ultimately addressing the industry's needs more effectively.

Materials and Methods

Nursery producers involved in redbud production, whether as propagators, growers, or nursery owners across multiple states, were selected as our sample. Qualtrics XM survey software (Qualtrics, Provo, UT, USA) was used to develop the survey questionnaire. It was customized to use the skip and display logic features to allow each respondent to complete the survey within 10 to 12 min. The survey was structured into seven sections to capture the nursery and grower characteristics, covering redbud production, plant health, other crops, business information, management practices, sanitation, and demographic details. Altogether, this survey had 56 questions consisting of multiple-choice, single-choice, open-ended, and close-ended questions including a consent agreement. The survey questionnaire was approved by the Institutional Review Board at Tennessee State University (under approval no. HS-2022-4874).

A link to the survey was sent to the growers via electronic mail with an invitation to participate in the survey. Also, the survey was included in a QR code and promoted through *Tennessee Greentimes* magazine, *Nursery Management* magazine, the Oregon Association of Nurseries website, and the Baysal-Gurel Laboratory website. The survey was first sent via e-mail in Mar 2023, and data were collected until Dec 2023. The participation of these growers was voluntary, and no incentives were provided when they completed the survey. Survey responses were recorded anonymously in Qualtrics, and the data were coded, tabulated, and analyzed using Excel spreadsheet software (Microsoft, Redmond, WA, USA) and SAS statistical software (SAS Inc., Cary, NC, USA). The results are expressed as graphical summaries, percentages, descriptive statistics, and mean frequency distributions.

According to the growers' responses regarding how they see the redbud production change in their nursery operations in the next year, an ordinal logistic regression model was used to estimate the likelihood of growers changing their redbud production. The logit model was used to analyze the impacts of predictor variables, including demographics (age, education, experience), production (redbud production number and value for each stage), and business information (gross annual income and redbud income), on redbud production behavior. The decision to change redbud production in nurseries for the following year categorized as "increase in production," "the same or no change," and "decrease in production" was selected as the outcome/dependent variable.

The logistic model employed as follows:

$$ln\left[\frac{P_i}{1-P_i}\right] = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i + \varepsilon_i \quad [1]$$

where ln is the odds ratio; P_i is the probability of growers considering to increase redbud production; $1 - P_i$ is the probability of not considering to increase redbud production; β_0 is the intercept; $\beta_1X_1 \ldots \beta_iX_i$ are regression coefficients of predictor variables; and ε_i is the random residual error.

The responses were used to summarize descriptive statistics and perform statistical analysis to answer specific research questions to address our objectives. A total of 63 respondents have clicked the consent link to access the survey, with 15 incomplete responses. The remaining 48 completed surveys were used for the analysis. Respondents were from Kentucky, North Carolina, Ohio, Oklahoma, Oregon, Tennessee, and Virginia. Table 1 provides the summary statistics of the outcome variable and predictor variables used in the ordered logit model.

Results and Discussion

Redbud production. The average total size of the nurseries was around 212 acres. As far as the types of redbud business operations, 65% of the growers were involved in container production, 44% were involved in ball and burlapped production, 29% were involved in bareroot production, and 9% were involved in liner production. Around 18% of respondents were involved other types of redbud production such as landscape companies/contractors, local government, horticulturists, etc. According to the growers' responses of their production numbers the previous year, they produced 19,740 ball and burlapped plants worth $1,855,400, 14,390 container plants worth $1,068,000, 16,650 bareroot plants worth $59,000, 5,800 seedling liners (bareroot) worth $376,200, and 700 seedling liners (container) worth $10,000. Redbud producers respondent to the survey represented 12.6% of the total redbud production value in the United States. Additionally, the growers were asked to provide more information about the cultivars and species of redbud that they produce in their nurseries (Fig. 1). Eastern redbud was one of the most commonly produced redbuds, followed by some cultivars of redbud including Forest Pansy, Ruby Falls, Flame Thrower, Rising Sun, Appalachian, and Merlot. Cultivars that produced less than 5% include Black Pearl, Carolina Sweetheart, Royal White, Sparkling Wine, Burgundy Hearts, Rise and Shine, Heart of Gold, Little Woody, Oklahoma, and Bubble Gum. There are some other cultivars that growers like to produce such as Tennessee Pink, Golden Falls, Northern Herald, Pink Pom Poms, Garden Gems Amethyst, Alley Cat, Ace of Hearts, Traveller, Hearts A'fire, Kay's Early Hope, Whitewater, Lavender Twist, Don Egolf, and Shirobana (Alba). Over the past decade, the popularity of redbud plants has shown significant growth, with increasing demand driven by their aesthetic appeal and versatility in landscaping. As a result, the market now offers a diverse range of more than 60 distinct cultivars, each with unique characteristics that cater to various preferences and environmental conditions. In this survey, respondents identified more than 30 cultivars that they produced in their nurseries, further highlighting the growing popularity of redbud cultivars within the nursery industry. Considering the fact that many nurseries producing redbuds are also cultivating a wide variety of other plants, their current involvement in producing multiple cultivars of redbud indicates the popularity it holds in the customer market.

Plant health. Over the past few growing seasons, 77% of growers in our sample have

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Table 1. Summary statistics of the nursery growers sample.

Variable	Variable Description	Percentage	Mean (*SD*)[i]
Outcome variable			
Y_prod	Redbud production change in the next year		
	Increase in production = 2	15.2	
	Remain same/not decided = 1	39.4	
	Decrease in production = 0	45.5	
Predictor variables			
Age	Nursery grower's age		
	18 to 24	0.0	
	25 to 34	10.0	
	35 to 44	3.3	
	45 to 54	16.7	
	55 to 65	40.0	
	65+	20.0	
	Prefer not to say	10.0	
Education	Education level of the grower		
	Some high school	3.3	
	High school diploma	20.0	
	College degree	63.3	
	Master's degree	10.0	
	Prefer not to say	3.3	
Experience	Grower's experience in nursery industry		
	Less than 5 years	6.7	
	5 to 10 years	6.7	
	11 to 20 years	6.7	
	21 to 30 years	20.0	
	30+ years	60.0	
Nursery_size	Size of the nursery in acres		211.82 (218.57)
Rb_Bare root	Redbud growing type bare roots	28.6	
Rb_Container	Redbud growing type containers	64.7	
Rb_Bud stock	Redbud growing type bud stock	0.0	
Rb_B_B	Redbud growing type ball and burlapped	44.1	
Rb_Liners	Redbud growing type liners	8.8	
Rb_Other	Redbud growing type other methods	17.6	
Rb_income	Gross annual redbud sales income in dollars ($)		149,405.91 (120,571.09)
Rb_prodtype	Redbud production type observed VSD		
	Field	38.7	
	Container	29.0	
	Pot-in-pot	9.7	
	Landscape	12.9	
	Other	9.7	
Loss_VSD	Redbud loss due to VSD		
	Yes = 1	69.7	
	No = 0	30.3	
Loss_value	Redbud loss value due to VSD in dollars ($)		84,146.25 (80,103.11)

[i] Standard deviation (*SD*) in parentheses.

VSD = vascular streak dieback.

noticed VSD-related symptoms with redbud plants, and 23% did not notice symptoms. Survey respondents have been experiencing VSD issues for last 5 years, with 2022 showing the highest incidence at around 30% of responses. This was followed by 2021 at 28%, 2020 at 16%, and 2019 at 15%, according to the survey data. Although VSD was first observed in 2019 and confirmed in 2020 in Tennessee, 9% of respondents to this survey reported that they had observed VSD symptoms as early as 2018. This aligns with the existing literature, which documents the presence of VSD symptoms in North Carolina maple trees in 2018 (McClellan 2023). It is suggested that the VSD issue may have been present for several years, as identified by the survey respondents, even though it was not officially recorded until later.

According to the responses, VSD-related symptoms are most commonly observed in the summer (37%), followed by spring (32%), fall (20%), and winter (11%). This distribution of symptoms could be attributed to several factors, one of which may be related to the cultivars, as differences in symptom appearance have been previously reported to be associated with different cultivars (Liyanapathiranage et al. 2025). It was also found in the survey that respondents indicated leaves (25%) as the most affected plant part due to VSD, followed by stems (24%) and branches/twigs (25%). Respondents identified the most common VSD symptoms they have observed over the years, with wilting (16%), dieback on plant tip (14%), vascular streaking (12%), plant death (12%), yellowing (11%), and defoliation (10%) being the most frequently reported symptoms. VSD-related symptoms have been thoroughly described in a few recent publications, and the symptoms identified as major ones by the respondents have also been documented in these publications (Beckerman 2022; Bily et al. 2023; Liyanapathiranage et al. 2025; McClellan 2023). This suggests that the survey participants have substantial understanding of how to identify VSD symptomatic plants in their nurseries.

To understand the distribution of VSD symptoms in nurseries, the survey asked respondents to select the areas where they most observed VSD symptoms and whether the distribution was limited to general areas, scattered, or restricted to certain cultivars. According to the survey results, 32% of respondents observed a general distribution of symptoms, 27% reported a scattered distribution, and 16% believed the symptoms were linked to specific cultivars. Redbud plants in the life stages of ball and burlapped (29%), container (24%), bare root (17%), and budded liners (14%) were most commonly identified as exhibiting VSD symptoms. Respondents also identified the redbud production stages in which they observed the most VSD symptoms. According to the results, field (43%), container (28%), landscape (18%), and pot-in-pot (11%) were identified as the stages during which VSD symptoms were most observed. Many diagnostic laboratories across the country have confirmed VSD in redbud plants at different production stages as well as in natural settings, further supporting the observations indicated by the respondents (Beckerman 2022; Bily et al. 2023).

The survey questions were designed to assess respondents' awareness of redbud cultivars' susceptibility to VSD. Initially,

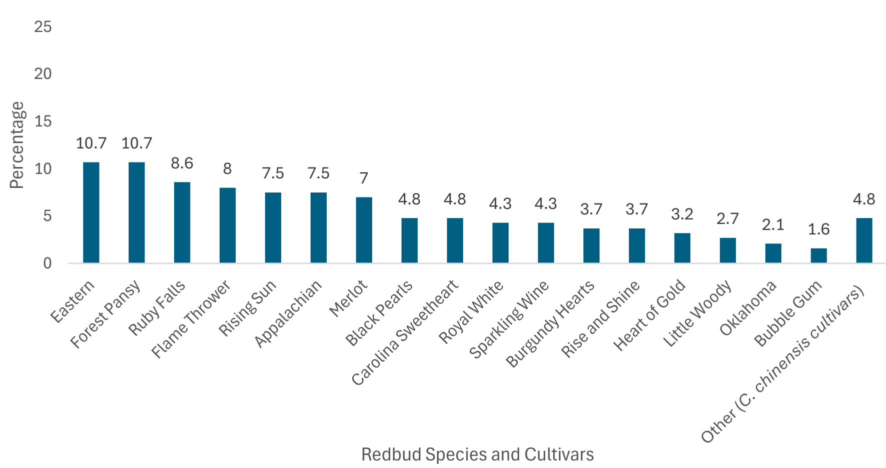

Fig. 1. Percentage of redbud species and cultivars of overall redbud production of the nurseries.

participants were asked whether the VSD symptoms they observed were specific to certain redbud cultivars, and 75% did not believe the symptoms were cultivar specific. Among the respondents who mentioned that VSD symptoms are cultivar specific, they specified that Forest Pansy, Appalachian, and Burgundy Hearts cultivars and *C. chinensis* cultivars are least affected by VSD symptoms, while bareroot *C. canadensis* and the cultivars Rising Sun, Black Pearl, and Ace of Hearts are most affected by VSD. Recent research findings in Tennessee indicate that redbud cultivars with yellow-colored foliage and papery leaf texture are more susceptible to VSD than those with dark green or purple foliage and thick, leathery leaves (Baysal-Gurel and Liyanapathiranage 2023). The fact that some of the least susceptible cultivars identified by respondents also possess these resilient traits supports the accuracy of their observations (Kidwell-Slak and Pooler 2018). Furthermore, the susceptibility of cultivars can vary depending on the region of redbud production, as some cultivars that have shown moderate tolerance to VSD in Tennessee were found to be susceptible in North Carolina (Chen H, personal communication). Different environmental factors and nursery management practices may contribute to the susceptibility of certain cultivars to VSD in different regions.

Other crops. Fifty-six percent of respondents have observed the symptoms of VSD on ornamental plants other than redbud. The survey results show that VSD symptoms were observed in dogwood by 46% of respondents, in maple by 33%, in black gum by 9%, and in magnolia, flowering cherry, and tulip poplar by 4% each. Respondents observed VSD symptoms on other crops with a frequency of 6% in both 2017 and 2018, 16% in 2019, increasing to 27% in 2020, then decreasing to 17% in 2021, and rising again to 28% in 2022. Thirty-three percent of respondents mentioned dying from the top, and plant death is the unique symptom observed in these other crops compared with 22.3% of respondents who observed wilting, scorching, or yellowing. According to current observations, ornamental plants belonging to more than 25 genera are included in the host list for VSD (Liyanapathiranage et al. 2025). However, recent findings suggest that the updated host list could be vastly extended beyond what we currently know (Bily D, personal communication). It was interesting to uncover that the respondents had knowledge regarding the expansion of the VSD host range through their years of experience, even though most scientific research on the topic is still in progress.

Business information. The majority of respondents (90%) purchased redbuds for their production. Among them, 50% of respondents made purchases in-state and 79% of respondents purchased redbuds from out of state. According to the responses, redbuds were mostly sourced from Tennessee (35%), followed by Oregon (21%), North Carolina (12%), and Virginia (9%), which are leading producers of redbuds in the United States. The remaining redbuds (23%) were sourced from other states.

Over three-quarters of respondents purchased liners, followed by one-third who bought 2-year-old plants, and 4% each, who bought bare root plants, 2-inch calipers, and seeds. Seventy-two percent of growers sold or shipped their redbuds out of state, while 28% of growers sold redbuds in state. According to the responses, growers sold 15,895 ball and burlapped plants with a value of $1,748,400, 9075 container plants with a value of $793,500, and 8500 bareroot plants with a value of $85,000. The total value of all plants sold in 2022 was $2,626,900. The average annual gross income of a nursery grower was around $2,583,853 from woody ornamental production, and redbud sales income was around 7.8% on average.

Demographic information. According to the respondent's ages, the majority were in the age group of 55 to 65 years (40%), followed by those older than 65 years (20%), 45 to 54 years (16.7%), and 35 to 44 years (3.3%); 10% preferred not to disclose their age. In the survey, respondents were asked to indicate their level of education. Most of the respondents (63.3%) had a college degree, followed by 20% with a high school degree and 10% with a master's degree. The rest had some high school education (3.3%) or preferred not to say. According to the results, majority of respondents (60%) have more than 30 years of experience in nursery industry. Additionally, 20% of growers have 21 to 30 years of experience, 6.7% have 11 to 20 years, 6.7% have 5 to 10 years, and the remaining 6.7% have less than 5 years of experience.

Management practices. The majority of the survey respondents (92.3%) were not involved in budding their redbuds. The smaller group of respondents who were practicing budding (7.7%) in their production setting could be producing their own cultivars. Because budding the plants requires wounding the stem tissue of a 1- to 2-year-old eastern redbud rootstock, this could be a potential stage during which VSD could be introduced into a healthy plant via the fresh wound. Additionally, if the bud sticks are taken from an already-infected mother plant, VSD could potentially be introduced to a healthy rootstock. This emphasizes the importance for redbud producers to accurately identify VSD symptoms to ensure VSD is not introduced into their production setting at this stage.

To understand growers' pruning practices in redbud production nurseries, survey questions were crafted meticulously. The data reveal that 92.6% of participants engage in pruning their redbuds. Pruning predominantly occurs in May, June, and July, with notable activity also recorded in all other months except September and October. It is important to note that all surveyed growers use manual pruning methods. Pruning activities are aimed at maintaining the plants' desired shape and size, which facilitates effective management practices. Nonetheless, it appears that some growers may not adhere strictly to the recommended pruning guidelines. Generally, pruning schedules are aligned with the flowering period of the plants; for instance, dogwood and redbud species are typically pruned postbloom in spring (Wade and Westerfield 2022). However, the survey indicates variability in the growers' adherence to these timings. Considering the limited understanding of VSD biology, the impact of pruning on VSD progression remains unclear. Additionally, the influence of aftercare practices, such as wound dressing and the disposal of plant debris, on the spread of VSD within nurseries is not well understood. This underscores the need for further research to develop evidence-based guidelines that mitigate the risk of VSD transmission during pruning.

Respondents were asked whether they held redbud containers or bare root plants inside shade houses during production. Twenty-eight percent of respondents stated they used shade houses, while 72% did not. Among those using shade houses, ∼57% held their plants for 2 to 3 months, and 43% held their plants for a week or a few weeks. Although redbuds are generally shade tolerant, they become less tolerant to shade and competition as they mature, conditions that can be present in a greenhouse (Dickson 1990). Conversely, severe sunburn during summer months can damage leaves of some redbud cultivars, reducing plant vigor and increasing susceptibility to pests and diseases. These survey results indicate a need for further research to better understand optimal growing conditions for redbuds and to prevent issues such as VSD.

Nursery growers were surveyed about the irrigation methods used in redbud production. The majority of growers reported using drip irrigation (42.9%), followed by sprinkler irrigation (37.1%), hand watering (11.4%), and other methods (8.4%) such as overhead irrigation or irrigation using tractor. Regarding irrigation frequency, 35.3% indicated they irrigate as needed, 32.4% irrigate daily, 17.6% irrigate twice a week, 11.8% use other frequencies, and 2.9% irrigate every other week. Water requirements differ significantly between field conditions and container stages and are also influenced by the season and geographical location. In field conditions, plants often receive natural rainfall, which must be supplemented strategically to avoid overwatering or underwatering. Conversely, container-grown plants rely more heavily on scheduled irrigation, with early morning watering recommended to reduce evaporative losses (Nambuthiri et al. 2014). Seasonal variations, such as increased evaporation during hot summer months or reduced water needs during cooler periods, can affect irrigation practices. Geographical differences, including variations in climate, soil type, and water availability, also play a crucial role in determining the appropriate irrigation strategy for redbud production. Prolonged wet conditions on leaves can create a conducive environment for disease development. These survey results highlight the variability in irrigation practices among redbud growers, emphasizing the need for tailored irrigation recommendations to optimize plant health and prevent disease.

Sanitation. Respondents were asked to indicate their choices regarding sanitation practices in redbud production (Fig. 2). According to the responses, more than 80% were not producing seedlings from seed, and 20% who did either clean or did not clean their seeds, with ∼9% in each group. Furthermore, follow-up questions were asked to identify whether the respondents are sanitizing their liners before planting and whether they are sanitizing the liners before storage. For both questions, only a few respondents, 13% and 4%, respectively indicated "yes." As previously indicated, pruning is a management technique employed by most of the respondents. However, when asked whether they sanitize their pruning equipment, ∼30% of the respondents indicated that they do not. Root pruning is another management technique employed by some nursery producers to improve plant growth (Bartlett Tree Experts 2024). However, freshly pruned roots can serve as an entry point for soilborne pathogens (Łakomy et al. 2019). Therefore, when respondents were asked whether they sanitize or treat the roots after pruning, only 9% reported practicing this. Furthermore, 65% of the respondents were not sanitizing or cleaning their tools after budding, which indicates another management practice that may have been overlooked.

Due to the difficulties with inoculation of the VSD causal agent(s), research is still underway to identify effective chemical treatments under natural infestation conditions (Baysal-Gurel et al. 2025). However, some growers are currently relying on their years of experience to select fungicides they have on hand to treat plants exhibiting VSD-related symptoms. This is evident from the 35% response rate to the survey question that inquired whether they apply any treatments to redbud plants showing VSD symptoms. Some of the most commonly mentioned fungicides were Subdue MAXX [mefenoxam (FRAC group 4)] and propiconozole 14.3 [propiconazole (FRAC group 3)] in a drench, Empress Intrinsic [pyraclostrobin (FRAC group 11)], Protect[DF] [mancozeb (FRAC group M3)], Orkestra Intrinsic [fluxapyroxad (FRAC group 7) + pyraclostrobin (FRAC group 11)], Pageant Intrinsic [boscalid (FRAC group 7) + pyraclostrobin (FRAC group 11)], and Avelyo [mefentrifluconazole (FRAC group 3)]. Currently, the only available information on the most effective treatments to suppress VSD-related leaf scorching in seedlings, 3-year-old plants, and 2-year-old grafted cultivars are preventative foliar application of Postiva [pydiflumetofen (FRAC group 7) + difenoconazole (FRAC group 3)] at 20 fl oz/100 gal and Mural [azoxystrobin (FRAC group 11) + benzovindiflupyr (FRAC group 7)] at 7 oz/100 gal in 14-d application intervals (Liyanapathiranage and Baysal-Gurel 2023; Liyanapathiranage et al. 2023a, 2025).

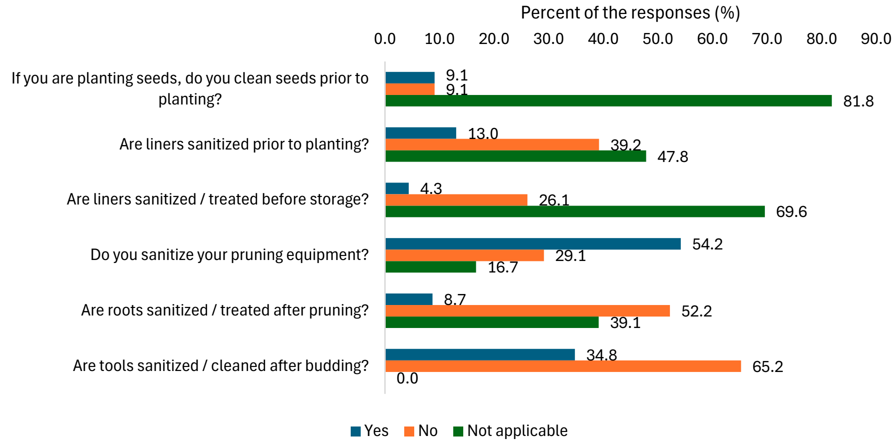

Fig. 2. Nursery growers' choices regarding sanitation practices followed in the redbud production of the nurseries.

To understand whether the respondents are currently dealing with other disease issues and whether they are using any chemical treatments to manage them, related questions were included in the survey. According to the responses, only 22% of them were applying treatments to redbuds to manage diseases such as Cercospora leaf spot and Phytophthora root rot diseases. In addition to well-established issues typically associated with redbuds, such as canker problems, recent research has identified novel pathogens affecting the redbud production in the United States, including root rot of redbud caused by *Phytopythium vexans* and crown and root rot on redbud caused by *Calonectria cylindrospora*, thereby enhancing our understanding of the challenges associated with redbud production (Liyanapathiranage et al. 2023b; Purdue University Extension n.d.; Subedi et al. 2025; Texas A&M AgriLife Extension Service n.d.).

Economic impact. Nursery growers were asked to mention whether they had lost their redbud production last year, reason or reasons affected for the loss of redbuds, and the percentages of the losses. Respondents have lost redbuds mainly due to VSD (69.7%), followed by winter damage (19.3%), root rot (2.5%), and other reasons (8.5%). Although accurately distinguishing VSD symptoms is challenging, considering that most respondents have over 30 years of experience in the nursery industry, it is reasonable to assume that they possess the ability to differentiate these new symptoms from other issues they have encountered in plants over the years.

Also, the survey asked respondents to report the average loss percentage of redbud production last year, based on each production category. They have lost 25.2% of container plants worth $375,037, 24.8% of bare root seedling liners worth around $369,084, 22.1% of ball and burlapped plants worth $328,901, 20.9% of container seedling liners worth around $311,042, and 7% of bare root plants worth around $104,176 in 2023 due to VSD. Ornamental nursey producers are often involved in growing a diverse range of plant species within their operations. However, when they face heavy losses in a particular plant species—especially those are at the final stage of production—it becomes particularly challenging. These plants have already required significant investments in time, labor, and financial resources. Consequently, such losses can have an impact on the producers, in terms of both financial strain and overall business sustainability. At the end of the survey, respondents were asked how they anticipated their redbud production operations would change in the coming year. The results showed a cautious outlook: 46% of respondents believed production would decrease due to the challenges they have faced, while 39% had not yet made a decision regarding their production plans or expected it to remain the same, reflecting uncertainty in the market. On the other hand, 15% were optimistic, anticipating an increase in redbud production despite the ongoing difficulties.

The ordinal logistic regression model was used to estimate the probability of survey participants altering their redbud production based on their responses throughout the questionnaire. As shown in Table 2, when the demographic data were tested, the results revealed that the coefficients for education level did not show significant correlations. The growers in 55- to 65-year age category showed a significant and negative correlation at 5% significance level. The 25- to 34-year age category is the reference category for age variable. Being age 55 to 65 years decreases by 0.158 times the odds of deciding to increase production compared with the reference category of being age between 25 to 34 years old. When the experience levels were tested, over 30 years of experience in nursery production showed a significant correlation at the 10% significance level, indicating its influence on the decision to alter redbud production in the coming year. Nursery growers with 30 years of experience are less likely to increase redbud production next year. According to the odds ratio, redbud production decreases by

Table 2. Estimated ordered logit model coefficients indicating the relative importance of nursery growers demographic and redbud production factors to change the redbud production next year based on survey data sample (n = 48).

Variable	Coefficient	*SE*	Wald χ^2	Odds ratio
Intercept 1	1.252**	4.628	4.907	3.497
Intercept 2	4.572***	5.411	7.251	96.737
Age				
25 to 34	Reference			
35 to 44	3.311	1.387	0.057	27.414
45 to 54	−2.773	6.231	0.198	0.067
55 to 65	−1.842**	1.046	0.312	0.158
65+	2.346	6.807	0.119	10.474
Prefer not to say	−2.533	5.179	0.002	0.078
Education				
Some high school	Reference			
High school diploma	2.285	5.274	0.188	9.828
College degree	−1.778	4.381	0.165	0.178
Master's degree	−1.251	5.742	0.047	0.286
Prefer not to say	−5.733	1.065	0.290	0.003
Experience				
Less than 5 years	Reference			
5 to 10 years	−8.611	2.956	0.085	0.001
11 to 20 years	3.542	1.128	0.241	34.576
21 to 30 years	−5.809	1.742	0.111	0.003
30+ years	−1.751*	1.448	0.365	0.173
Nursery size	0.007**	0.0033	4.706	1.007
Redbud production stage observed VSD				
Container	Reference			
Field	−0.027**	1.394	0.004	0.973
Pot-in-pot	−3.414*	1.827	3.493	0.034
Landscape	−4.134**	1.946	4.513	0.016
Other	4.367	2.212	3.897	80.988
Redbud production Type				
Bare root	1.247	0.763	2.673	3.475
Container	−0.303***	0.914	0.110	0.738
Ball and burlapped	4.789	1.839	6.776	120.181
Liner	0.398	1.176	0.115	2.221
Other	0.041	1.557	0.001	1.042
Redbud income	0.026	0.028	0.833	1.026
Redbud loss due to VSD				
Yes	−3.552**	1.460	5.914	0.028

Number of observations = 48, probability $> \chi^2$ = 0.008, Pseudo R^2 = 0.465. Statistical significance of ordered logit model estimates indicating how nursery growers' redbud production operation information and demographics affect their change in redbud production in future, where ***, **, and * indicate significance levels at 0.01, 0.05, and 0.10, respectively. *SE* = standard error; VSD = vascular streak dieback.

0.173 odds compared with growers having less than 5 years of experience. Nursery size has a positive and significant effect on redbud production behavior. The coefficient for nursery size was positive and significant at the 5% level. As nursery size increases, the odd ratio of increasing redbud production rise by 0.107 times, highlighting the influence on future production decisions. When the coefficients of redbud production stages in which VSD was observed by the respondents were tested, significant and negative correlations were found at 5% level for field production (−0.027) and landscape production (−3.414). Also, a significant and negative correlation at the 10% level was observed for pot-in-pot production (−4.134), compared with container production, which served as the reference group. If the field plants show VSD symptoms, increasing production shows 0.973 times lower odds compared with container plants. If pot-in-pot plants show VSD symptoms, growers show 0.034 times less odds to increase pot-in-pot production. Also, growers whose redbud landscape plants have VSD symptoms show 0.016 lower odds to increase redbud production in the future. When the coefficient of redbud container production category was tested, the results were negative and significant at the 1% level. This finding indicates that growers who produce container plants were 0.738 times less likely to increase redbud production in the future. Redbud production loss due to VSD compared with no loss was negative and statistically significant at the 5% level. Growers who had lost redbud plants due to VSD were 0.028 times less likely to increase redbud production next year. Findings from this analysis were useful in understanding the factors that most likely contributed to the decision-making of survey respondents regarding future redbud production. As described above, demographics, nursery production dimensions, and VSD acted as key factors influencing the decision to alter redbud production next year, particularly toward a decrease in production.

Conclusions

This study emphasizes the significant economic impact of VSD on redbud production. Seventy-seven percent of growers reported symptoms of VSD, which was responsible for nearly 70% of production losses. Nursery growers, in particular, faced substantial losses in 2022, with VSD accounting for 69.7% of these losses, which totaled around $1.5 million. The impact of VSD varied across different production stages, leading to notable losses in container plants, bare root seedlings, ball and burlapped plants, container seedling liners, and bare root plants.

VSD incidence was highest in 2022, peaking in the summer and affecting various plant parts. While most growers do not view VSD as cultivar specific, some observed variability in its impact on different cultivars. The majority of growers pruned redbuds between May and July using manual methods. Drip or sprinkler irrigation was the most often employed. Sanitation practices varied among growers; some applied fungicides to manage VSD, while others addressed additional diseases such as Cercospora leaf spot and Phytophthora root rot.

Critical management practices identified in this survey include budding, pruning, the use of shade houses, and irrigation methods. Furthermore, the survey revealed that sanitation practices, such as disinfecting tools after pruning and budding, using clean seeds and liners, and applying recommended fungicides, were less commonly observed among respondents. These findings underscore the need for heightened awareness and implementation of stringent management and sanitation protocols to mitigate the risk of VSD in redbud production.

The study also identified key factors influencing redbud production decisions, such as nursery size, grower experience, and VSD prevalence. Larger nurseries were more likely to expand production, while growers with over 30 years of experience were less inclined to increase output. VSD significantly influenced production decisions, especially in field, pot-in-pot, and landscape settings, discouraging growth in container production. This information is important for the development of strategies to mitigate the effects of VSD, thereby supporting the long-term sustainability and profitability of the nursery industry. By understanding and addressing these challenges, stakeholders can enhance the resilience and economic viability of redbud production.

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