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Research Article

Meeting the Challenge of Viral Disease Management in the US Wine Grape Industries of California and Washington: Demystifying Decision Making, Fostering Agricultural Networks, and Optimizing Educational Resources

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Leafroll and red blotch are two of the most consequential viral diseases threatening the sustainability of the wine grape industry. To promote uptake of management practices, there is a critical need to understand the motivating factors for decision makers and optimize the dissemination and acquisition of knowledge. From 2019 to 2020, we conducted semi-structured interviews with 42 wine grape industry professionals ("decision makers") in the Western United States, from California ($n = 32$) and Washington ($n = 10$). The interview questions explored the perceptions and experiences of these decision makers as they learned about disease ecology, interacted with their immediate and extended community, and adopted management practices. Utilizing qualitative thematic analysis, we identified nine economic, knowledge, and social-behavioural factors along with 24 sub-factors. These factors illustrated the interplay between knowledge, communication, economics, labour, government subsidies, regulatory practices, and collaborative efforts that influence adoption. The quality of knowledge dissemination emerged as a critical aspect. Using the interview data along with a quantitative survey ($n = 145$), we also explored how growers use 14 educational resources to learn about grapevine viruses. Using these findings, extension educators can optimize their activities to disseminate knowledge on grapevine viral disease management. In total, this study provides context for the agricultural industry, research scientists, extension educators, and other supporting partners of the financial, interpersonal, and technical issues that must be overcome to successfully manage grapevine viral diseases.

1. Introduction

Grapevines are host to 86 identified species of virus, of which Grapevine leafroll-associated virus 3 (GLRaV-3) and Grapevine red blotch virus (GRBV) are two of the most significant [1]. GLRaV-3 is the predominant virus causing grapevine leafroll disease ("leafroll"), and GRBV is the causal agent of grapevine red blotch disease ("red blotch") [2–4]. Both diseases threaten the economic sustainability of the wine grape industry as they reduce vine growth, fruit quality, and yield [5–12]. Leafroll is a disease of worldwide economic significance, colonising grapevines in virtually all commercial growing regions. Occurrence of the etiological agents and studies of disease management have been reported from the Nearctic, Palearctic, and Australian regions [2, 3, 5, 10, 13–18]. Conversely, GRBV is a more recently

recognized threat, occurring extensively in certain regions of North America, with reports of detections extending into Europe, Asia, and Australia [7, 12, 19–24].

Evidence-based management practices for leafroll and red blotch focus on prevention and suppression [13] (Supplemental Data File: Table 1). Planting ("clean") virus-screened plant material reduces the risk of introduction via infected planting stock [25]. Removal (roguing) of individual diseased vines or entire blocks and vector control are strategies to suppress the spread of leafroll [2, 14–17, 26, 27]. Practices related to these core activities include scouting, trapping, mapping, diagnostic assays, application of selective insecticides, mating disruption, and biological control. Agronomic practices such as residual root removal may be implemented during the roguing and/or replant process [28]. Although the ecology of red blotch is not fully understood, suppression focuses primarily on detecting and removing infected vines [8, 19, 29] and may include management of vegetation harbouring insect vectors [30, 31].

Global adoption of management practices for grapevine viral diseases has been characterized as suboptimal, and there is a paucity of explanatory studies [1]. When managing an emerging pest or disease, growers must overcome uncertainty and risk to increase their capability by adopting new practices; otherwise, they tend to fall back on standard practice [32, 33]. Factors affecting adoption are broadly characterized as economic, knowledge, and social-behavioural [32, 34, 35]. Economic considerations include the cost-benefit outcomes of practices in relation to profit, yields, and product quality. They also include the ability to sell products ("saleability") and site-specific aspects such as existing financial resources, cost and availability of labour, and tools to implement practices [32, 34, 36]. Acquisition of key knowledge reduces uncertainty and perceived risk, increasing the likelihood of adoption [37–39]. Thus, important knowledge factors facilitating adoption relate to the state of scientific knowledge and technology, the development of appropriate, user-friendly technology, local informational resources, and economic models [35, 40]. Additionally, growers should have the opportunity to access and absorb technical knowledge, typically through applied research and educational programs [35].

Agricultural knowledge is created and disseminated collaboratively through formal and informal social networks of actors including extension educators, research scientists, industry organizations, and growers [41, 42]. Social-behavioural factors surrounding these actors as individuals, in collaboration and in relation to public policy instruments, have emerged as important considerations for the adoption of practices [36]. Individual growers differ in their willingness to try new practices and in the level of support within their organizations for knowledge acquisition and implementation [32, 39]. Cooperative action within the larger community affects knowledge dissemination and influences the success of coordinated programs [32, 43]. The strength of social networks in terms of the quality of interactions, communication, and connections determines the speed and level of adoption [44]. For practices to "take off," key social processes within these networks must be engaged and play a larger role than simply broadcasting information to growers [33, 45]. Effective outreach programs reduce the uncertainty surrounding disease management by effectively communicating current knowledge and encouraging the formation of favourable attitudes, beliefs, and perceived ability to implement practices [32, 37–39, 46–48]. Finally, adoption is impacted by public policies such as funding for extension activities, economic incentives, and certification programs [35].

Previously, we applied this framework to leafroll and red blotch, using a survey tool to characterize the economic and knowledge factors influencing adoption of management practices among grape growers in California (CA) and Washington (WA), USA [35]. We documented a neat convergence of disease prevalence and practice adoption among this population, suggesting that important lessons about adoption can be learned from their experiences. However, that survey constrained the extent of our understanding as a priori assumptions determined question selection, social-behavioural factors were not considered, and the explanatory power of how and why factors influenced adoption was limited.

As a follow-up, we conducted this study, which included interviews and a survey to broaden our understanding of the motivating factors affecting adoption of grapevine viral disease management and evaluate how decision makers use educational resources to learn about grapevine viruses. By understanding motivating factors and the influence of educational tools, there is an expectation that we can improve the adoption of best management practices and mitigate the damage caused by grapevine viral diseases.

2. Materials and Methods

2.1. Part 1: Decision Making and Viral Disease Management

2.1.1. Interview Method. In-depth semi-structured interviews were conducted employing the qualitative methodology of thematic analysis [49, 50] that has been used to understand adoption of other farming practices [51, 52]. Thematic analysis is a method for systematically identifying patterns of meaning (themes) across a dataset [49]. The method allows researchers to minimally organize an interview transcript and describe the data in rich detail by collating chunks of the text under labelled codes representing salient responses. The codes are used to develop descriptive themes capturing patterned responses or meaning within the dataset [49]. This allowed us to highlight factors affecting adoption within the sample population but does not seek to test hypotheses. Although the interview data are not generalizable beyond the sample population, the data may be used subsequently to direct empirical investigations.

2.1.2. Sample. Interviews were conducted in CA and WA. Theoretical sampling, a nonprobability technique [53], was used to intentionally capture participants with certain characteristics. In this case, the sample included the full range of job roles involved in the decision-making process of viral disease management ("decision makers") and covered

multiple geographical areas of grape production. Forty-two wine grape industry professionals (13 females) were interviewed between December 2019 and June 2020 from the CA North Coast region ($n = 24$), CA Lodi ($n = 3$), CA Central Coast ($n = 5$), and WA ($n = 10$). Job titles included viticulturist ($n = 19$), vineyard manager ($n = 4$), vineyard director ($n = 7$), owner ($n = 4$), consultant ($n = 6$), winemaker ($n = 1$), and nursery owner ($n = 1$). Interviewees worked in vineyard management companies (41%), combined vineyards and wineries (45%), consulting companies (12%), and a nursery (2%). Interviewees were recruited through informal networks. Sample size was determined by the concept of saturation, defined as when no new information could be learned in this region because the data had become repetitive [54].

2.1.3. Interview Protocol. Interviews of 40 to 80 minutes were conducted in-person or with video conference software (Zoom Video Communications, San Jose, California), audio recorded, and transcribed for analysis. Twelve core, open-ended questions were asked in each interview (Supplemental Data File: Table 2) to prompt interviewees to talk about their experiences of leafroll and red blotch disease management and to keep the conversation on topic. Interviewers asked follow-up questions as necessary to clarify responses and explore them in more detail.

2.1.4. Thematic Analysis. Data analysis was conducted by two authors who developed the themes through a series of blind analyses followed by joint review. Initial codes were generated using the R program RQDA [55]. Together, the two authors reviewed the codes and blindly sorted them under top-level "economic," "knowledge," and "social-behavioural" categories. Code assignments were then compared, and discrepancies were discussed and resolved. Another round of blind sorting, comparison, and discussion followed to develop sub-themes. The approach to the data was partly deductive [50] in that a loose framework based on prior literature, not necessarily linked to the semantic content of the interviews, was imposed by assigning codes to the top-level categories. However, the approach was primarily inductive in that initial coding and the development of sub-themes were driven by the semantic data without clear reference to the overarching theoretical framework.

2.2. Part 2: Optimizing Informational Resources and Extension Programming

2.2.1. Survey Method. Responses were collected from 145 decision makers (49 females) from CA ($n = 126$) and WA ($n = 18$). Job roles included viticulturist ($n = 41$), vineyard manager ($n = 27$), vineyard director ($n = 14$), owner ($n = 9$), consultant ($n = 22$), winemaker ($n = 9$), and field scout ($n = 6$). Sample sizes do not total 145 because some participants did not provide responses to demographic questions. Participants reported which of 14 educational resources (Figure 1) they had accessed to learn about grapevine viruses and rated their usefulness on a 6-point Likert scale (0 = not at all useful; 5 = extremely useful). Data were collected using polling software (Turning Technologies, LLC, Youngstown, OH, US) at regional meetings and using online software (Qualtrics, LLC, Provo, UT, US). Comparisons were made between the percentage of decision makers that had used each resource and rated them as highly useful ("very" or "extremely useful").

2.2.2. Interview Method. Participants were the same 42 decision makers interviewed in part one about their experiences with leafroll and red blotch. Short answer, open-ended questions comprised a distinct section in the same interview session. Interviewees were asked to (1) describe their personal process when learning about grapevine viruses and (2) explain their views of the importance of the 14 educational resources (Figure 1) (a) to their own learning process and (b) to teach or disseminate knowledge to co-workers or other decision makers. The data were analyzed using content analysis, a method related to thematic analysis, suited to short answer questions [56]. Transcripts were coded to characterize how and why decision makers used each resource. Two researchers blindly generated codes for each resource and conducted a joint review to decide on final categories. Responses were blindly sorted into each category. Content analysis allowed us to determine the level of agreement between the researchers using Cohen's K calculation for inter-rater reliability [57]. When values were under 0.80, disagreements were discussed, and the sorting was repeated until sufficient agreement was reached to achieve a value of 0.80 or greater. The primary aim was to characterize decision-maker views of resources. The percentage of decision makers that mentioned each code was calculated to provide insight into the level of consensus within the sample. The prevalence of views cannot be generalized beyond this sample population, and some percentages are low because individual interviewees had not used a resource or did not articulate a clear opinion.

3. Results

3.1. Part 1: Decision Making and Factors Affecting Viral Disease Management. Nine economic, knowledge, and social-behavioural factors (themes) were identified, along with 24 sub-factors. Typically, themes' analysis results are presented as detailed descriptions with accompanying interview quotes from participants that act as illustrations of the data [50]. For brevity, we summarize each of the factors and provide example quotes in the Supplemental Data File (Supplemental Tables 3 to 11). These summaries reflect the views of the participants and not the authors. Instances where author comments were necessary to clarify or provide relevant background information were noted.

3.1.1. Economic Factors. As identified previously [34], the cost of implementing management practices and product (fruit or wine) saleability were key economic themes,

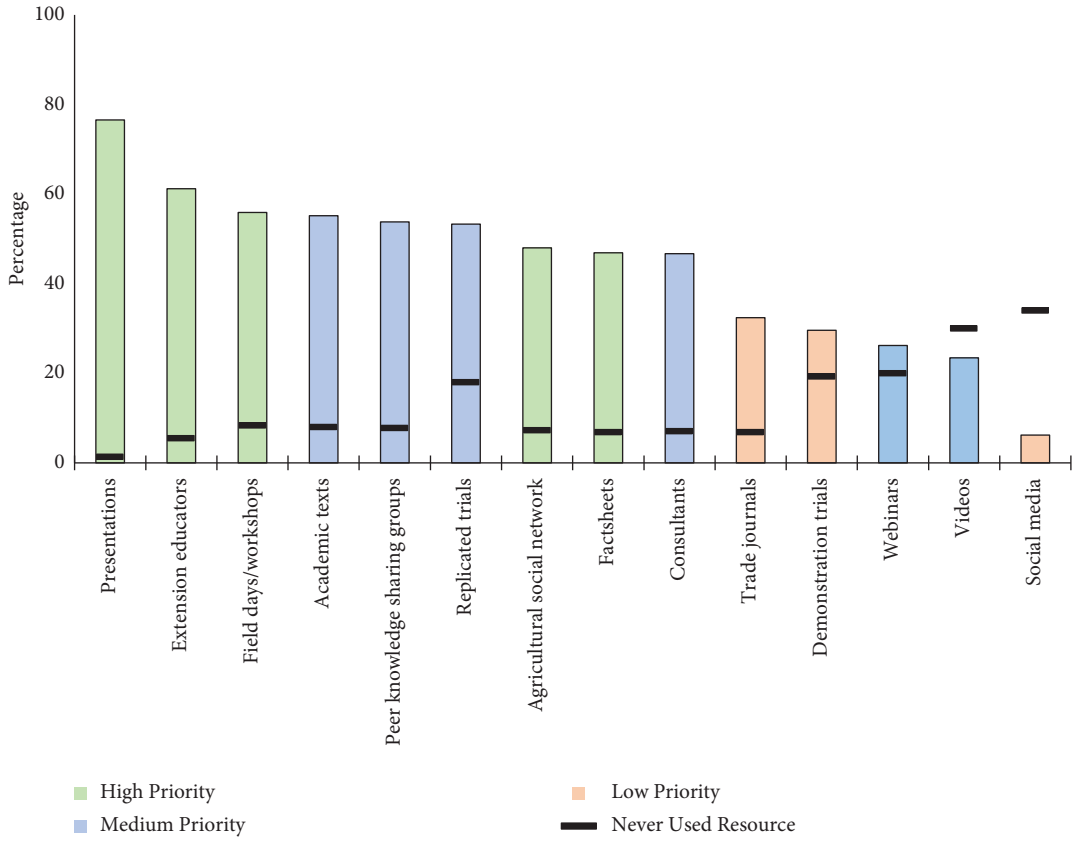

FIGURE 1: Percentage of respondents ($n = 145$) who accessed resources and rated highly useful for grapevine viruses. Resources were defined as (1) formal presentations; (2) direct contact with extension educators; (3) field days and interactive workshops; (4) academic texts; (5) informal grower meetings and discussions; (6) replicated research trials; (7) informal social network; (8) factsheets, newsletters, booklets, and pamphlets; (9) paid consultants; (10) trade journals; (11) in-house demonstration trials; (12) webinars; (13) educational videos; and (14) social media. The ratings and content analysis were used to categorize resources as high, medium, and low priority, which was judged by evaluating their reach, persuasiveness, and impact.

whereas vineyard production demand was newly identified as a contributing factor (Table 1).

(1) Theme 1: Costs of Practices. The capital expense of redeveloping a vineyard was a universal economic barrier, and the cost-effectiveness of other management practices was measured in relation to their ability to delay or avoid large-scale replanting. Mitigation strategies such as selective harvesting of fruit from healthy versus diseased vines and blending leafroll-diseased fruit in the winery were used to lengthen the time an infected vineyard could stay in production. Managing leafroll and red blotch were often viewed as the necessary "costs of doing business," even if they carried a significant financial burden. Reducing the base costs of management would encourage adoption, but site-specific characteristics of vineyards are also important. For example, decision makers tended to adopt evidence-based guidance on roguing [18, 27] in blocks with low infection rates and in younger plantings where it was considered cost-effective. However, roguing was frequently abandoned in mature blocks due to higher costs, including those associated with farming mixed-age vineyards. In blocks with higher incidence, as one interviewee noted, they would "keep farming. . .until it gets to a threshold level where we can't make decent wine from it." Pertinent labour constraints included a lack of trained staff to scout, rogue, replant, and tend to young vines. Staff also needed to balance disease management with other pressing tasks.

(2) Theme 2: Production Demand. Decision makers experiencing reduced yields from leafroll and red blotch disease frequently adopted practices to maintain production at an economically viable level and prolong vineyard longevity. However, adoption may lag when production remains economically viable without managing diseased vines. The capacity of production demand to affect adoption was influenced by the price of grapes, industry wide demand, and risk of disease spread. When grape prices are low, decision makers are less inclined to rogue because of a lack of financial resources. Conversely, when grape prices are high, or the wine can be sold at a premium, resources could be dedicated to disease management. High demand for fruit made it easier to sell and lessened the incentive to adopt management practices. High demand also incentivized some decision makers to plant noncertified vines as a shortcut to get vineyards into production, despite this being contrary to recommended practice. Risk assessments are also an important component. For example, decision makers from the

Table 1: Economic themes and sub-themes contributing to the uptake and implementation of grapevine viral disease management programs.

Theme	Sub-theme	Detail
Costs of practices	Economy of practice versus large-scale replanting	The cost of large-scale replanting is a universal barrier to removal of diseased vines. The cost-effectiveness of other practices is measured against their ability to avoid or delay large-scale replants.
	Vineyard site-specific aspects	Examples include (i) Available financial resources (ii) Organic or conventional farming practices (iii) Rapid rates of disease spread or elevated disease pressure (iv) Cost and logistics of farming mixed-age vineyards (v) Compatibility with mechanization (vi) A reluctance to remove heritage vines
	Labour costs and availability	Labour shortages, high labour costs to adopt practices, and time commitment for implementation
Production demand	Reduced yields	Reduced yields and oversupply are primary drivers of adoption, except when prices are low
	Grape prices	Low grape or wine prices limit the resources available to implement practices, whereas high prices drive adoption
	Industry-wide demand	During periods of high demand, decision makers may take shortcuts to boost production
	Risk assessments	Risk to fruit yield (and quality, see below) and rate of spread determine the level of response
Product saleability	Fruit and wine quality	Low fruit quality and oversupply generally drive adoption of disease management practices. Risk assessments for yield and quality are interlinked, particularly in certain regions.
	Market demand	High demand or alternate markets (bulk wine) may make it easier and cost-effective to sell fruit from diseased vines
	Cultivar-specific traits	Cultivar-specific traits may make it easier to sell white wine grapes or more difficult to achieve quality standards for red wine grapes

Table 2: Knowledge themes and sub-themes contributing to the uptake and implementation of grapevine viral disease management programs.

Theme	Sub-theme	Detail
Decision-maker knowledge and experience	Disease ecology	Knowledge acquisition drives initial adoption of practices. Inadequate knowledge hinders adoption and implementation.
	Ability to quantify disease and vector incidence	Identifying visual symptoms and quantifying incidence of vectors and disease are critical facets: (i) Diagnostic assays used to overcome the challenge of visual symptom identification (ii) Roguing hindered by inability to visually assess or assay every vine (iii) Vector management hampered by challenge of detecting sessile mealybugs by visual scouting; pheromone-baited traps can overcome this obstacle.
	Experience using practices	Positive prior experience and successful outcomes with virus management promoted adoption and continued use. Varied success with red blotch management limited adoption with strong regional differences.
Current scientific understanding	Disease ecology	Scientific studies that develop practical tools and understanding of disease ecology and transmission biology support adoption; contrast between leafroll and red blotch
	Perceived knowledge gaps	Poor understanding of red blotch vector(s) and transmission biology reduces adoption. Other gaps included (i) "Digestible" economic models and digital calculators (ii) Mitigation of insecticide resistance for mealybug (iii) New tools for detecting viruses (iv) Availability of mealybug-resistant rootstocks (v) Additional control options for organic growers (vi) Region-specific studies of disease management (vii) Evidence of effectiveness of new strategies
Extension and outreach	Extension educators	Extension educators generate and disseminate critical, regional information to promote adoption. In CA, there was concern over diminishing number of extension educators.
	Quality of dissemination	Suboptimal knowledge dissemination specific to certain topics hinders adoption. User-friendly resources for decision makers are needed.

CA Central Coast viewed red blotch as high risk due to declines in fruit yield. Conversely, the absence of a vector and overall lower incidence of red blotch in WA led decision makers to focus on sourcing virus-screened plant material as their principal mitigation strategy.

(3) Theme 3: Product Saleability. Fruit quality and wine quality were important motivating factors for decision makers and were often linked to risk assessments of yield and rate of disease spread. They were more inclined to remove vines when fruit and wine quality was poor and reluctant to do so when fruit met quality standards. White wine grapes were easier to sell, regardless of infection status, whereas it was harder to achieve and maintain quality standards for red wine grapes. Production demand factored into these decisions: during periods of oversupply, buyers may demand higher quality fruit, leading to increased adoption. Ultimately, decisions regarding quality were heavily influenced by the perceptions of the winemakers using the fruit, even if other decision makers had concerns about disease incidence and spread.

3.1.2. Knowledge Factors. As identified previously [34], decision-maker knowledge of the disease system was an important theme. Additional themes included current scientific understanding, extension, and outreach (Table 2).

(1) Theme 4: Decision-Maker Knowledge and Experience. The acquisition of knowledge of disease ecology is critical for adoption. Inability to detect mealybug vectors, confusion surrounding certified plant material, inappropriate use of crop protection products, or inefficient roguing could lead to improper implementation and a loss of confidence in agreed management responses, thereby resulting in reduced adoption. A critical facet was the ability to distinguish whether visual symptoms were consistent with leafroll, red blotch, or another vine health issue, such as a mineral deficiency. Training and retaining experienced staff increased decision makers' confidence in visual assessments. Even those confident in their identification skills agreed that asymptomatic vines, latent symptom expression, and cultivar-specific differences were challenges that could be partially overcome by diagnostic assays. The impossibility of testing all vines inhibited effective roguing programs. Strategies such as composite sampling—testing multiple vines with a single assay—were used to overcome these hurdles.

Virus management decisions typically required the consensus of a group of decision makers who varied in their understanding of disease ecology and connection to farming operations. Greater knowledge within the group made it easier to advocate for adoption, whereas limited knowledge and erroneous preconceptions can derail the process. Positive experiences and prior successful outcomes influenced continued implementation. Evidence-based guidelines for leafroll disease management were generally viewed as favourable. Previous experience managing leafroll was considered beneficial to the red blotch response. In WA, where the risk of secondary spread of red blotch is low, sourcing virus-screened vines was viewed as an effective preventative tool. In contrast, the experience with red blotch in CA varied widely, with some decision makers reporting positive experiences, while others struggle despite intensive management efforts.

(2) Theme 5: Current Scientific Understanding. Scientific studies that develop an understanding of disease ecology, and the creation of practical tools for disease management, were viewed as key drivers of adoption. Understanding vector and transmission biology was of critical importance, and contrasts between leafroll and red blotch were emphasized. The uncertainty expressed by CA decision makers created pessimism surrounding red blotch. Subsequent evidence for threecornered alfalfa hopper (TCAH) as a vector [20] has improved the situation. However, with respect to red blotch, the remaining uncertainties of transmission efficiency, vector management, and the potential for other vectors present an ongoing challenge. In contrast, incontrovertible evidence that mealybugs transmit GLRaV-3 drove the adoption of vector management, expanded the number of available management options, and increased confidence that spread of leafroll can be minimized.

(3) Theme 6: Extension and Outreach. Extension educators are an important and influential source of disease management information. Agricultural knowledge-sharing networks that include extension educators, local industry groups, crop consultants, and growers can be particularly effective. Extension educators were praised for disseminating technical knowledge of leafroll and alerting growers about the emerging threat of red blotch. There is continued demand for user-friendly, practical resources to distil the volume of information into more accessible formats. Extension educators could improve their messaging on certain issues, such as economic models for leafroll, the impact of red blotch on wine quality, and vectors of red blotch. There were concerns that the number of extension educators (UC Advisors) in CA is insufficient, leaving them overstretched or unavailable in some regions. The authors note that recent increases to state funding for UC Agriculture and Natural Resources has improved that situation.

3.1.3. Social-Behavioural Factors. Social-behavioural factors included organizational variables within vineyard companies, regional cooperation, and public policy instruments (Table 3).

(1) Theme 7: Organizational Factors. Organizational variables such as interpersonal working relationships, effective communication, and trust between individuals within management teams influenced knowledge acquisition. Strong decision making and team processes resulted in effective implementation of virus management, whereas dysfunctional processes hindered implementation or led to the adoption of inappropriate practices. Viticulturists and consultants viewed themselves as educators and advocates, responsible for raising awareness of viral disease issues and management solutions. Once the decision is made to adopt certain tactics, the responsibility shifts to the farming team to implement those practices. High value was placed on the

Table 3: Social-behavioural themes and sub-themes contributing to the uptake and implementation of grapevine viral disease management programs.

Theme	Sub-theme	Detail
Organizational	Decision-making processes	Viticulturists and consultants are strong advocates for adoption of evidence-based practices. Effective team processes within management teams drives adoption of practices.
	Teamwork and training in the vineyard	Implementation of practices by the farming team requires effective team processes. High value placed on training of field scouts and vineyard workers.
Regional cooperation	Neighbouring vineyards	Communication and cooperation between neighbours promote effective practice implementation. Barriers to cooperation included logistical challenges; sensitive conversations; and multiple neighbours with different farming philosophies.
	Peer knowledge-sharing groups	Forum for open conversations about virus management. Potential to drive adoption and coordinate cooperation if challenges of group organization are overcome.
Public policy instruments	Nursery standards and regulation	Perceptions of nursery standards, including the rigor of certification programs and the strength of regulatory enforcement. Suggestions for cooperative solutions: (i) More mandated screening of certified vines in the nursery (ii) Subsidies for virus screening (iii) Greater funding for public inspectors (iv) Tax incentives to lessen the cost of certified plants (v) Public production blocks in isolated regions
	Pesticide regulation	More stringent pesticide regulations in the USA and export markets are a barrier to managing mealybug vectors of leafroll
	Government assistance programs	Federal subsidies defray costs of replanting infected vines. Funds may be difficult to access. Local programs leverage grower assessments to monitor pests and diseases.

provision of training for scouts and field crews. Specifically, trained workers who pay careful attention to detail are needed to scout for and identify vectors and visual disease symptoms.

(2) Theme 8: Regional Cooperation. Local spread of leafroll and red blotch was a major concern. Cooperation among neighbours involved sharing information about disease and vector incidence, coordinating practices (pesticide applications, mating disruption, and replanting), and sharing costs. Coordinating the logistics to align management practices is challenging. For example, replanting includes internal scheduling and external coordination with nurseries, further complicating the additional step of neighbour coordination. Peer knowledge-sharing groups foster local communication and cooperation [27], even though voluntary participation can be challenging to initiate and sustain. Participants agreed that these groups facilitated conversation, even though it is a sensitive topic and "a hard thing to go over to your neighbour and tell them to pull their vineyard up, or that I think that you should manage your vineyard this way." Compounding this is a reluctance to publicly admit virus problems and a disinclination to share "proprietary information." Such conversations were reported as easier when there were fewer neighbours, they used similar control strategies, and as community knowledge of disease ecology increased.

(3) Theme 9: Public Policy Instruments. Discussion of public policy centred around nursery standards and regulation, pesticide restrictions, and government assistance programs.

(4) Nursery Standards and Regulations. Decision makers were sympathetic to the challenges of maintaining and delivering clean plant material. Many found regulatory standards adequate given these challenges. However, they also blamed poor regulatory standards for viral disease issues and voiced high expectations of certification programs. Failure to meet expectations produced feelings of anger and powerlessness. Frustrated decision makers wanted tougher consequences for nurseries that supply "dirty" material, either through stricter regulation or legal options in the form of "penalties, fines, and license revocations." Others emphasized a more collaborative approach, building on the transparency and trust that are essential between nurseries and their customers. The nursery owner agreed that a common-sense approach is needed "that caters towards their pressures" and appropriately allocates resources based on risk. This includes continued federal funding for clean plant material through the Farm Bill and directing much of that to ensuring that foundation blocks at University of California Davis are regularly screened for pathogens. One decision maker had abandoned certified plant material and returned to propagating their own vines, although the authors note this strategy is inherently risky as it may increase the chance of planting infected vines. Controlled studies demonstrating the value of planting certified grapevines [25] reinforce the importance of this practice. Also, structured, transparent regulatory programs that enforce nursery standards can improve the confidence in certified material.

(5) Pesticide Restrictions. Pesticide regulations, particularly recent trends restricting the use of certain pesticides, were challenging with the industry slow "to get new chemistries on the market to supplement the ones that they are taking out." As one interviewee mentioned, limiting the timing of the application or total applied amount means that decision makers must choose between using them for mealybug or other insects [58]. At times, these regulations extend beyond the US borders as decision makers must comply with regulations in countries targeted for export.

(6) Government Assistance Programs. Assistance or incentives from the federal government could support greater adoption of practices, particularly the costs of vine removal and replanting. Federal programs such as the United States Department of Agriculture Tree and Vine Assistance Program (TAP) were praised, although others considered TAP a worthy idea but inaccessible for larger farms and logistically challenging as it "is very difficult to negotiate." Local monitoring and management programs were highly valued. For example, programs in Napa County (CA) are coordinated by the Agricultural Commissioner and funded by landowner assessments collected through the Winegrape Pest and Disease Control District (https://www.countyofnapa.org/1562). Although perceived government interference or overreach concerned some decision makers, others suggested local government should mandate or coordinate the use of certain technologies, such as mating disruption, and use subsidies or incentives to broaden adoption.

3.2. Part 2: Optimizing Informational Resources and Extension Programming. A very high proportion of survey respondents (>80%) had accessed each of the educational resources for learning about grapevine viruses, except for videos (70%) and social media (66%) (Figure 1). In-person presentations were considered the most useful resource, with 77% rating these as "highly useful." Social media ranked the least useful with only 6% rating it as "highly useful." The other resources were rated between these extremes (23–61%). For the purposes of discussion, we used the survey ratings in combination with the interview content analysis to categorize the resources into high, medium, and low priority (Table 4) for promoting adoption of virus management practices. We based these judgments on resources' actual or potential audience reach, persuasiveness such as perceived reliability or trustworthiness, and impact in terms of their effectiveness in disseminating information further.

3.2.1. High-Priority Resources. Extension educators and outreach events (presentations and field days) were judged high-priority resources because they reach a large audience, are applicable across grape growing regions, are viewed as persuasive, and are effective at disseminating information due to their links with other resources. Factsheets and social

Table 4: Results of the content analysis characterising decision-maker views of educational resources

Resource and codes	Frequency mentioned (%)	Cohen's K
High-priority resources		
Extension educators		
Highly regarded for knowledge generation and dissemination	74	1.0
Provide support for disease management in multiple ways	67	1.0
Generate valued and trusted educational resources	40	1.0
Well connected to researchers and local industry	26	1.0
Consultants more appropriate for specific situations	2	1.0
Agricultural social network		
Shared experiences of disease management	38	0.89
Trusted and experienced peers	33	0.80
Information can be unreliable	21	0.81
Vit Women (CA) network praised for sharing information	12	1.0
Formal presentations		
Source of latest, high-quality information	70	1.0
Useful for teaching viticultural technicians, scouts, interns, and managers	50	1.0
Repetitive or do not like those about unfinished research	31	0.95
Promote informal social networking	19	1.0
Best combined with field days	10	1.0
Some researchers could be better presenters	5	1.0
Too busy to attend	2	1.0
Field days and interactive workshops		
Useful for learning to identify virus symptoms and vectors	36	0.80
Scheduling could be improved	24	0.88
Lack of these events for viruses	17	1.0
Friendly format that promotes informal social network	12	0.88
Not preferred learning style	10	0.88
Factsheets, newsletters, booklets, and pamphlets		
Used to train supervised employees and disseminated to other decision makers	50	1.0
Valued when from a reputable source	36	0.90
Valued when well presented	29	0.94
Highly convenient source of information	21	1.0
Information lacking in detail, misleading or quickly outdated	10	0.88
Medium-priority resources		
Academic texts		
Journal pay walls make access difficult	36	1.0
Need to invest time to read and digest content	33	1.0
Source of latest high quality, relevant information	26	1.0
Identify key findings and justify decisions to others	24	1.0
Webinars and educational videos		
Convenient and efficient format	48	0.86
Source and quality of production important	35	0.87
Not preferred learning style	26	0.82
Lack of awareness (related to virus)	19	0.82
Used for training	17	1.0
Replicated research trials		
Reliable information with opportunity to access recent data and researchers	21	1.0
Provides information specific to own vineyard or region	21	1.0
Hard to get information on own vineyard from researchers	10	1.0
No interest: disruptive of operations or reluctant to share data	5	1.0
Paid consultants		
Good knowledge source	38	0.81
Variable in reliability	19	1.0
Good for teaching other staff about viruses	12	1.0
No point in having consultant	14	1.0
Can have conflicts of interest	14	1.0
Peer knowledge-sharing groups		
Valued for communications about virus management	31	1.0
Uncertain about effectiveness for disseminating knowledge	14	1.0
Promotes informal social network	10	1.0
Limited suitability in areas with polyculture or few neighbours	10	1.0

Table 4: Continued.

Resource and codes	Frequency mentioned (%)	Cohen's K
Could be more welcoming to organic growers	7	1.0
Low-priority resources		
Social media		
Unsuitable for viruses	69	0.82
Accessibility potentially useful	26	0.88
Information unreliable	19	0.86
Used social media for virus information	7	1.0
Trade journals		
Information overly simplified or outdated	31	0.94
Provide overview of virus problems	31	1.0
Reliability questionable and opinion-based articles	12	0.87
In-house demonstration trials		
Vineyards lack expertise and resources for replicated trials	24	0.93
Useful for demonstration and exploration	17	1.0
Not essential or cannot see how applies to viruses	14	1.0

The ratings and content analysis were used to categorize resources by priority, which was judged by evaluating their reach, persuasiveness, and impact. In the content analysis, the level of agreement between the researchers was determined using Cohen's K calculation for inter-rater reliability, with sufficient agreement represented when a value of 0.80 or more was reached [57].

networks were judged as high-priority resources for the same reasons, although their persuasiveness was judged to be dependent on the source and construction of the fact-sheet, or the particular individual in the social network.

(1) Extension Educators. The central role of extension educators in agricultural knowledge networks was confirmed, with 95% of survey respondents having direct contact with them, either through Washington State University, University of California, or an industry group such as the Lodi Winegrape Commission. Extension educators helped 67% of interviewees by responding to questions, sharing resources, connecting them with experts, and providing in situ support for disease management. Extension educators are highly regarded by 74% of interviewees for their reliable, relevant, and current knowledge, and 61% reported direct contact with extension advisors as highly useful. They were also valued for generating educational resources (40%) and for their connections to agricultural knowledge networks (26%). Reasons for lower ratings include confused messaging of certain information and insufficient coverage in CA, due to budget constraints. One interviewee (2%) did not seek contact with extension educators because they felt their needs were better served by paid consultants.

(2) Agricultural Social Network. Peer communication with respected and more experienced colleagues was valued by survey respondents. Most (93%) interacted with their peers to learn about viruses, but only 48% reported them as highly useful. Social networks were used extensively by 38% of respondents to share experiences of virus management and tap into the "big reservoir" of peer knowledge. They understood that peer information can be unreliable (21%) but put high confidence in information from more experienced and respected peers (33%), who were also valued as being readily accessible. These interpersonal, peer-to-peer methods of communication and social learning are essential for widespread adoption to occur [39, 59, 60]. Effective communication and persuasion are more likely to occur among similar and respected peers, and before risking adoption, most decision makers will require assurance from trusted peers that a practice can be successfully implemented and provides benefits [39, 61]. Social learning also reduces the costs of information gathering to individuals and increases the speed of adoption through conformity and imitation of prestigious or more productive members of a social network [60]. Extension educators can influence conversations within social networks by interacting with respected and well-connected decision makers for knowledge dissemination, creating situations that promote the development of social networks, and integrating themselves into their local community so that they are themselves viewed as trusted peers. Peer-networking can also be promoted in novel ways among sub-groups. For example, the Vit Women group (CA) supports female decision makers and was highly valued as an informal knowledge network (12%).

(3) Formal Presentations, Field Days, and Workshops. These structured learning opportunities are core methods for the transfer of the essential knowledge of disease ecology to decision makers. Nearly all survey respondents (91–99%) had participated in these events to learn about viruses. They were typically organized by extension educators or industry groups. There was consensus that formal presentations were highly useful (77%) as a source of the latest, high-quality information (70%) and for teaching about viruses across all job roles (50%). Field days and workshops were useful to learn how to identify virus symptoms and vectors (36%). Four interviewees (10%) thought formal presentations were best combined with field days and workshops. For some (31%), formal presentations were often repetitive, but this might be necessary to "get the message across." Some of these same interviewees did not like presentations on "in-process" research because they attended primarily to learn current guidelines and recommendations and considered presentations that did not articulate firm conclusions as

a poor use of their time. In some cases (12%), field days and workshops provided a friendlier format, highlighting the wider role of these learning environments as social networking opportunities (19%). Suggestions for improvement included offering more events dedicated to viruses, and in multiple languages, including Spanish. Scheduling that made attendance difficult could be improved through alternative timings and repeated sessions (24%).

(4) Factsheets. These were widely used (93%) by survey respondents but only rated as highly useful by 47%. The ambivalent view was attributed to variable quality. Some (10%) expressed frustration that factsheets quickly become outdated and do not contain sufficient information and complained that recent examples contained misleading information. However, they were valued when well-constructed (29%) and originating from reputable sources (36%). Attributes of persuasive factsheets include limited text with relevant images, concise (1-2 pages), accessible language, topic specific, key points in clearly labelled sections, easily interpretable data, actionable practical information, and references to other resources. An important characteristic of factsheets is that they can reach a broad audience and are often used by decision makers to diffuse information through their networks. Interviewees (50%) used factsheets as teaching aids with scouts, interns, viticultural technicians, and vineyard labourers, for whom native language versions were valued. In the Western United States, Spanish is the most common native language among vineyard fieldworkers. In addition, factsheets and newsletters were used to justify recommendations to other decision makers such as owners, winemakers, and clients.

3.2.2. Medium-Priority Resources. Medium-priority resources can be persuasive and effective for disseminating knowledge but are limited in that they only appeal to select audiences or regions.

(1) Academic Texts. Most survey respondents (92%) had used academic texts to learn about viruses but were divided on their perception of them as highly useful (55%), an ambiguity primarily relating to peer-reviewed journal articles which were almost exclusively discussed in the interviews. Some (26%) saw journal articles as high-quality sources of the latest information, but others (33%) found it difficult to understand the content or did not have time to read them. Interviewees (24%), typically viticulturists and consultants, disseminated journal articles to other decision makers, often summarizing the material into a more user-friendly format to justify their recommendations or actions. A frequently cited frustration (36%) was limited access due to pay walls. Drawing on diffusion theory [33], journal articles are likely to be read by a small number of early adopters, especially those with relevant educational backgrounds. Later ("majority") adopters may not read the articles but want to know there is scientific backing for a practice, confirmed by trusted sources. Extension educators can make effective use of journal articles by publishing in open-access journals, distributing them through their networks of early adopters, and helping with access when requested and where copyright is not infringed.

(2) Online Videos and Webinars. Interviewees did not distinguish between online videos and webinars, which were combined for the content analysis. In the survey, both had lower usage than most other resources (70–80%) and were only rated as highly useful by 34–38%, with 26% of interviewees saying they were not their preferred learning style. Poor survey feedback obscured the nuance behind what can be an effective outreach tool when implemented properly. The source and quality of videos and webinars was important (35%). Those originating from trusted organizations were viewed favourably and when "not too amateurish." Good videos were considered a convenient and efficient learning format by 48% of interviewees, and webinars made presentations accessible to a wider audience. Data collection overlapped with the COVID-19 pandemic, and several interviewees hoped webinars would continue post-pandemic as they are often logistically easier to attend. Online videos were valued by some (17%) as tools for improving virus symptom and vector identification, with alternate (Spanish) language versions appreciated for training purposes. There was an overall lack of awareness of virus-related videos (17%), and greater promotion will likely increase their use.

(3) Consultants. In the survey, 93% of respondents had used a paid consultant and 47% reported them as highly useful for viruses. Consultants included pest control advisers, chemical company representatives, and (in CA) viticulture consultants. Consultants were considered useful among interviewees (38%) due to their high level of education, experience across many vineyards, and connections to other experts within agricultural networks (59). They can teach staff about viruses (12%), including technical aspects such as visual symptom identification or act as third-party support to persuade other decision makers. The reliability of consultants' information on viruses was viewed as variable (19%), depending on their diligence in keeping updated and their level of scientific knowledge. Some also believed information could be compromised by commercial conflicts of interest (14%). Another view (14%) was that there was no point in having a consultant because the information is readily available elsewhere.

(4) Replicated Research Trials. Replicated research trials conducted by public sector scientists were regarded as highly useful (85%) by survey respondents, and 82% reported collaborating on such projects. Fewer interviewees had participated in research trials, and many did not comment on this resource. Among those that had, great value was placed on participation because they received the latest scientific data and communicated directly with researchers (21%) on aspects of relevance to their own vineyard (21%). Early adopters are the most likely to seek out participation in research trials because they seek to get ahead of an issue and gain access to privileged knowledge that they will

disseminate through their networks. Suggestions for improvement (10%) included increased communication and access to site-specific data. Two interviewees (5%) had no interest participating because they viewed them as disruptive of operations and were reluctant to share data.

(5) Peer Knowledge-Sharing Groups. A broad definition of regional grower meetings was used in the survey, of which 92% had attended, and 78% rated as highly useful. Discussion during the interviews focused solely on growers from Lodi and Napa who had participated in these groups. Congruent with their purpose of fostering cooperation, the groups helped members network with other decision makers (10%), communicate knowledge of virus management (31%), share experiences, and develop innovative strategies. Examples of coordinated efforts include replanting, sharing regional vector trapping data, and timing insecticide applications. These groups are valuable forums for peer-to-peer communication, and extension educators can positively influence the content of their activities by connecting with these groups where they exist. Care should be taken to ensure that the knowledge and information shared is accurate and reliable. Three decision makers (7%) felt that their local groups could make organic growers feel unwelcome, were overly focused on conventional farming methods, and wanted more discussion of, or groups dedicated to, organic practices. Four decision makers (10%) in WA and the CA Central Coast thought that peer knowledge-sharing groups were only suitable in regions like Napa, where there is a monoculture of small vineyards with multiple vineyard neighbours.

3.2.3. Low-Priority Resources. Low-priority resources, including social media, trade journals, and in-house research trials, are those that decision makers viewed as unreliable or unsuitable for learning about grapevine viruses.

(1) Social Media. Social media has been suggested as a useful tool for dissemination of knowledge by extension educators [62, 63], but in this context, it was viewed as ineffective. It was utilized by the least growers (66%) and only 6% rated the resource as highly useful. Three interviewees used social media for viruses, two for tracking educational resources and one to discuss virus problems with others. Although the accessibility of social media platforms is potentially useful, most do not use it for work (69%), felt the information lacks detail, and were concerned it would publicize their virus problems, negatively impact fruit sales, and damage reputations. They also voiced concerns about the reliability of information on social media (19%).

(2) Trade Journals and In-House Research Trials. Trade journals had high utilization (93%) but low ratings of usefulness because the articles were not aimed at participants' professional demographic, and information on viruses was too simplified, outdated (31%), or opinion-based (12%). Trade journals were considered useful as an introductory overview of viral diseases (31%). In-house research trials had low ratings of usefulness and relatively low utilization (81%), compared to the other resources. These trials may be useful to explore new ideas and demonstrate practices to other decision makers, even though they are not scientifically rigorous (17%). Other limitations are that most vineyards lack the training and resources to conduct replicated trials (24%), past trials have not yielded essential information, or that the decision maker could not see how they would apply their own hypotheses to trials on viral diseases (14%).

4. Discussion

The motivating factors for viral disease decision making are broadly categorized into economic, knowledge, and social-behavioural. However, these factors are complex and interrelated, encompassing the vineyard production system, disease ecology, the costs and considerations of management, and the community of people involved in knowledge dissemination, decision making, and implementation.

The principal economic consideration is removal and replanting of entire blocks. Other interventions are adopted to delay this inevitability and are evaluated against the cost of establishing a new vineyard block, which can range from 15,000 to 50,000 USD per acre (37,050 to 123,500 USD per hectare) in our study area [64, 65]. Adoption lags when decision makers cannot justify the expense of implementing practices, particularly removing vines that are sufficiently productive or in blocks that require recuperation of initial investment, despite this being contrary to recommended practice and in conflict with the best interests of the wider industry. Site-specific considerations weigh heavily in the decision-making process and are principally related to the product marketplace. Long-term contracts, fruit and wine quality, price, and demand factor into these decisions. Suggested interventions for viral diseases should account for these factors and consider how the specific financial situation of each vineyard and winery will impact adoption. While broad economic trends in viral disease management can inform the process [5, 11, 66], each decision is unique to the farm and situation in which it is made. Sustained funding support through subsidies, certification programs, or local districts can aggregate community resources to defray private sector costs. Ongoing, dedicated funding for research and education is also needed to generate and diffuse evidence-based information through the agricultural community.

Generation and diffusion of knowledge reduce perceived risk by providing trusted, accessible resources in a positive learning environment, leading to favourable attitudes, beliefs, and perceptions of disease management [32, 37, 39]. Individual decision makers are unique in their training, experience, approach, and situational factors. Thus, preference, perceived usefulness, and access to educational resources by decision makers can differ across agricultural sectors, regions, and demographic variables [59, 67, 68]. The effectiveness of different educational resources varies between early and late adopters of innovations [39, 69]. Seminars, workshops, field days, and factsheets are popular,

traditional resources for virus education. Fundamentally, the resources must be well-constructed, accessible, appropriate for the audience, and promoted extensively to increase uptake. Leafroll disease has been intensively studied, and guidelines have been widely disseminated through multiple pathways [1, 2, 15, 27, 70]. In contrast, the existing knowledge gaps for red blotch, particularly related to transmission ecology, have fostered doubts about the viability of management practices. For an emerging pest or disease, such as red blotch, investing in knowledge generation and dissemination is paramount to reduce the perceived risk, promote adoption, and mitigate negative consequences.

Social processes figure prominently in knowledge dissemination, acquisition, and decision making. In general, media (e.g., articles and presentations) are effective at spreading awareness but widespread adoption requires peer-to-peer communication through agricultural social networks [39, 59, 60]. Early adopters need little persuasion to adopt a practice and will be self-motivated to seek information, either in print or in person. They are often well-connected opinion leaders who spread knowledge through their own networks [39, 59, 60]. Extension educators who meaningfully engage early adopters can harness these attributes to expand their reach and build confidence within the community. Specifically, networks can be essential to persuading later adopters who require clear, accessible scientific evidence communicated by trusted sources, principally their respected peers. Fostering peer interactions is therefore critical to outreach and can be accomplished in varying ways. For example, in addition to structured learning, formal outreach events are opportunities for peers to develop their social network, discuss timely issues, and share experiences. Leveraging these human tendencies and fostering peer interactions in traditional and unique ways can spread knowledge quickly through a region and promote widespread adoption.

High-level vineyard farming decisions in CA and WA are not typically made by individuals in isolation but by management teams with members who vary in their job roles, knowledge, experience, and level of risk aversion. Decisions are enacted by operational vineyard teams who feed key information back to the management teams. Working relationships and team dynamics are therefore integral to decision making. Extension efforts can overcome knowledge gaps between management team members by targeting outreach efforts at underserved decision makers (e.g., winemakers; financial officers; and vineyard owners) or by helping viticulturists build their capacity to advocate for adoption more effectively within their teams and wider community. In addition to skilled workers with sufficient resources to complete tasks, interpersonal working relationships, effective communication, capacity-building, and trust within management and operational teams are necessary to implement management programs. Healthy external relationships must also be fostered, including with those who maintain, distribute, and regulate certified plant material.

Decision makers within these trusted communities can advocate strongly for evidence-based practices and viral disease management. As community knowledge increases, conversations around disease management become more palatable for all actors in the agricultural network, leading to widespread adoption of practices. Our results are therefore relevant across the agricultural industry, to decision makers, research scientists, extension educators, and policy makers, who can use them to address the critical issues of viral disease management in perennial crops. The successes reported herein should provide confidence to the agricultural community that given the right tools and resources delivered in a supportive and collaborative environment, viral diseases can be effectively managed, and their economic consequences can be mitigated.

Data Availability

The raw data consist primarily of interview transcripts from which it is possible to identify individuals and companies which need to be kept anonymous to abide by University of California ethical guidelines. For this reason, the raw data are not available.

Ethical Approval

The study protocol was approved by the University of California Davis Ethics Committee (IRB ID 1516920-1; exempt).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The supplementary file contains a summary of management practices for grapevine leafroll and red blotch diseases, a list of the core open-ended questions from part one of the interviews, and a selection of sample quotes from the part one interview transcripts that illustrate each of the reported themes. (*Supplementary Materials*)

References

[1] M. Fuchs, "Grapevine viruses: a multitude of diverse species with simple but overall poorly adopted management solutions in the vineyard," *Journal of Plant Pathology*, vol. 102, no. 3, pp. 643–653, 2020.

[2] R. P. P. Almeida, K. M. Daane, V. A. Bell et al., "Ecology and management of grapevine leafroll disease," *Frontiers in Microbiology*, vol. 4, pp. 94–13, 2013.

[3] H. J. Maree, R. P. P. Almeida, R. Bester et al., "Grapevine leafroll-associated virus 3," *Frontiers in Microbiology*, vol. 4, pp. 82–21, 2013.

[4] L. M. Yepes, E. Cieniewicz, B. Krenz et al., "Causative role of grapevine red blotch virus in red blotch disease," *Phytopathology*, vol. 108, no. 7, pp. 902–909, 2018.

[5] S. Atallah, M. Gomez, M. Fuchs, and T. Martinson, "Economic impact of grapevine leafroll disease on *Vitis vinifera* cv. Cabernet franc in Finger Lakes vineyards of New York," *American Journal of Enology and Viticulture*, vol. 63, no. 1, pp. 73–79, 2012.

[6] B. Blanco-Ulate, H. Hopfer, R. Figueroa-Balderas et al., "Red blotch disease alters grape berry development and metabolism by interfering with the transcriptional and hormonal regulation of ripening," *Journal of Experimental Botany*, vol. 68, no. 5, pp. 1225–1238, 2017.

[7] P. Bowen, C. Bogdanoff, S. Poojari, K. Usher, T. Lowery, and J. R. Urbez-Torres, "Effects of grapevine red blotch disease on Cabernet franc vine physiology, bud hardiness, and fruit and wine quality," *American Journal of Enology and Viticulture*, vol. 71, no. 4, pp. 308–318, 2020.

[8] E. Cieniewicz, S. J. Pethybridge, G. Loeb, K. Perry, and M. Fuchs, "Insights into the ecology of grapevine red blotch virus in a diseased vineyard," *Phytopathology*, vol. 108, no. 1, pp. 94–102, 2018.

[9] J. Martínez-Lüscher, C. M. Plank, L. Brillante et al., "Grapevine red blotch virus may reduce carbon translocation leading to impaired grape berry ripening," *Journal of Agricultural and Food Chemistry*, vol. 67, no. 9, pp. 2437–2448, 2019.

[10] R. Naidu, A. Rowhani, M. Fuchs, D. Golino, and G. P. Martelli, "Grapevine leafroll: a complex viral disease affecting a high value fruit crop," *Plant Disease*, vol. 98, no. 9, pp. 1172–1185, 2014.

[11] K. D. Ricketts, M. I. Gomez, S. S. Atallah et al., "Reducing the economic impact of grapevine leafroll disease in California: identifying optimal disease management strategies," *American Journal of Enology and Viticulture*, vol. 66, no. 2, pp. 138–147, 2015.

[12] M. R. Sudarshana, K. L. Perry, and M. F. Fuchs, "Grapevine red blotch-associated virus, an emerging threat to the grapevine Industry," *Phytopathology*, vol. 105, no. 7, pp. 1026–1032, 2015.

[13] V. Maliogka, G. P. Martelli, M. Fuchs, and N. Katis, "Control of viruses infecting grapevine," in *Control of Plant Viruses, Advances in Virus Research*, G. Loebenstein and N. Katis, Eds., pp. 175–227, Elsevier, Amsterdam, Netherlands, 2015.

[14] V. A. Bell, D. I. Hedderley, G. Pietersen, and P. J. Lester, "Vineyard-wide control of grapevine leafroll-associated virus 3 requires an integrated response," *Journal of Plant Pathology*, vol. 100, pp. 399–408, 2018.

[15] G. Pietersen, N. Spreeth, T. Oosthuizen et al., "Control of grapevine leafroll disease spread at a commercial wine estate in South Africa: a case study," *American Journal of Enology and Viticulture*, vol. 64, no. 2, pp. 296–305, 2013.

[16] S. Poojari, J. Boule, N. DeLury et al., "Epidemiology and genetic diversity of grapevine leafroll-associated viruses in British Columbia," *Plant Disease*, vol. 101, no. 12, pp. 2088–2097, 2017.

[17] T. Sokolsky, Y. Cohen, T. Zahavi, G. Sapir, and R. Sharon, "Potential efficiency of grapevine leafroll disease management strategies using simulation and real spatio-temporal disease infection data," *Australian Journal of Grape and Wine Research*, vol. 19, no. 3, pp. 431–438, 2013.

[18] V. A. Bell, P. J. Lester, G. Pietersen, and A. J. Hall, "The management and financial implications of variable responses to grapevine leafroll disease," *Journal of Plant Pathology*, vol. 103, no. 1, pp. 5–15, 2021.

[19] A. N. Kc, J. B. DeShields, A. D. Levin, R. Hilton, and J. Rijal, "Epidemiology of grapevine red blotch disease progression in southern Oregon vineyards," *American Journal of Enology and Viticulture*, vol. 73, no. 2, pp. 116–124, 2022.

[20] M. Flasco, V. Hoyle, E. J. Cieniewicz et al., "Grapevine red blotch virus is transmitted by the threecornered alfalfa hopper in a circulative, nonpropagative mode with unique attributes," *Phytopathology*, pp. 1851–1861, 2021.

[21] S. Lim, D. Igori, F. Zhao, J. S. Moon, I.-S. Cho, and G.-S. Choi, "First report of grapevine red blotch-associated virus on grapevine in korea," *Plant Disease*, vol. 100, no. 9, p. 1957, 2016.

[22] N. Bertazzon, D. Migliaro, A. Rossa et al., "Grapevine red blotch virus is sporadically present in a germplasm collection in northern Italy," *Journal of Plant Diseases and Protection*, vol. 128, no. 4, pp. 1115–1119, 2021.

[23] A. Marwal, R. Kumar, S. M. Paul Khurana, and R. K. Gaur, "Complete nucleotide sequence of a new geminivirus isolated from *vitis vinifera* in India: a symptomless host of grapevine red blotch virus," *Virusdisease*, vol. 30, no. 1, pp. 106–111, 2019.

[24] J.-S. Reynard, J. Brodard, N. Dubuis et al., "Screening of grapevine red blotch virus in two European ampelographic collections," *Journal of Plant Pathology*, vol. 104, no. 1, pp. 9–15, 2022.

[25] K. L. Arnold, N. McRoberts, M. L. Cooper, R. Smith, and D. A. Golino, "Virus surveys of commercial vineyards show value of planting certified vines," *California Agriculture*, vol. 73, no. 2, pp. 90–95, 2019.

[26] J. G. Charles, K. J. Froud, R. Van den Brink, and D. J. Allan, "Mealybugs and the spread of Grapevine leafroll-associated virus 3 (GLRaV-3) in a New Zealand vineyard," *Australasian Plant Pathology*, vol. 38, no. 6, pp. 576–583, 2009.

[27] S. L. MacDonald, T. E. Schartel, and M. L. Cooper, "Exploring grower-sourced data to understand spatiotemporal trends in the occurrence of a vector, *Pseudococcus maritimus* (Hemiptera: pseudococcidae) and improve grapevine leafroll disease management," *Journal of Economic Entomology*, vol. 114, no. 4, pp. 1452–1461, 2021.

[28] V. A. Bell, R. G. E. Bonfiglioli, J. T. S. Walker, P. L. Lo, J. F. Mackay, and S. E. McGregor, "Grapevine leafroll-associated virus 3 persistence in *Vitis Vinifera* remnant roots," *Journal of Plant Pathology*, vol. 91, pp. 527–533, 2009.

[29] E. Cieniewicz, S. J. Pethybridge, A. Gorny et al., "Spatio-temporal spread of Grapevine red blotch-associated virus in a California vineyard," *Virus Research*, vol. 241, pp. 156–162, 2017.

[30] E. N. Bick, C. R. Kron, and F. G. Zalom, "Timing the implementation of cultural practices for Spissistilus festinus (Hemiptera: membracidae) in California vineyards using a stage-structured degree-day model," *Journal of Economic Entomology*, vol. 113, no. 5, pp. 2558–2562, 2020.

[31] A. C., K. Billings, K. Flores, K. A. McCalla, K. M. Daane, and H. Wilson, "Use of ground covers to control Three-Cornered Alfalfa Hopper, *Spissistilus festinus* (Hemiptera: membracidae), and other suspected vectors of grapevine red blotch virus," *Journal of Economic Entomology*, vol. 114, no. 4, pp. 1462–1469, 2021.

[32] M. Lefebvre, S. R. H. Langrell, and S. Gomez-y-Paloma, "Incentives and policies for integrated pest management in

Europe: a review," *Agronomy for Sustainable Development*, vol. 35, no. 1, pp. 27–45, 2015.

[33] M. Marra, D. J. Pannell, and A. Abadi Ghadim, "The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve?" *Agricultural Systems*, vol. 75, no. 2–3, pp. 215–234, 2003.

[34] M. Hobbs, S. Vengco, S. Bolton, L. Bettiga, M. Moyer, and M. Cooper, "Adoption of best management practices for grapevine leafroll and red blotch diseases: a survey of west Coast growers," *PhytoFrontiers*, vol. 2, no. 3, pp. 181–191, 2022.

[35] R. Peshin, R. S. Bandral, W. Zhang, L. Wilson, and A. K. Dhawan, "Integrated pest management: a global overview of history, programs and adoption," in *Integrated Pest Management: Innovation-Development Process*, R. Peshin and A. H. Dhawan, Eds., pp. 1–81, Springer, Berlin, Germany, 2009.

[36] J. S. Buurma and N. J. A. van der Velden, "New approach to integrated pest management research with and for horticulture: a vision from and beyond economics," *Crop Protection*, vol. 97, pp. 94–100, 2017.

[37] I. Ajzen, "The theory of planned behavior," *Organizational Behavior and Human Decision Processes*, vol. 50, no. 2, pp. 179–211, 1991.

[38] I. Ajzen, "The theory of planned behaviour: reactions and reflections," *Psychology and Health*, vol. 26, no. 9, pp. 1113–1127, 2011.

[39] E. Rogers, *Diffusion of Innovations*, Free Press, London, UK, 5th edition, 2003.

[40] A. L. Sterio, V. Kvakkestad, T. A. Breland, and A. Vatn, "Integrated pest management adoption by grain farmers in Norway: a novel index method," *Journal of Crop Protection*, vol. 135, pp. 105–201, 2020.

[41] M. Lubell, M. Niles, and M. Hoffman, "Extension 3.0: managing agricultural knowledge systems in the network age," *Society and Natural Resources*, vol. 27, no. 10, pp. 1089–1103, 2014.

[42] C. Phelps, R. Heidl, and A. Wadhwa, "Knowledge, networks, and knowledge networks: a review and research agenda," *Journal of Management*, vol. 38, no. 4, pp. 1115–1166, 2012.

[43] G. McKee, "Coordinated pest management decisions in the presence of management externalities: the case of greenhouse whitefly in California-grown strawberries," *Agricultural Systems*, vol. 104, no. 1, pp. 94–103, 2011.

[44] R. Peres, "The impact of network characteristics on the diffusion of innovations," *Physica A: Statistical Mechanics and Its Applications*, vol. 402, pp. 330–343, 2014.

[45] E. Michel-Guillou and G. Moser, "Commitment of farmers to environmental protection: from social pressure to environmental conscience," *Journal of Environmental Psychology*, vol. 26, no. 3, pp. 227–235, 2006.

[46] C. M. Coughenour, "Innovating conservation agriculture: the case of no-till cropping," *Rural Sociology*, vol. 68, no. 2, pp. 278–304, 2009.

[47] T. Greenhalgh, G. Robert, F. Macfarlane, P. Bate, and O. Kyriakidou, "Diffusion of innovations in service organizations: systematic review and recommendations," *The Milbank Quarterly*, vol. 82, no. 4, pp. 581–629, 2004.

[48] H. Zhang and Y. Vorobeychik, "Empirically grounded agent-based models of innovation diffusion: a critical review," *Artificial Intelligence Review*, vol. 52, no. 1, pp. 707–741, 2019.

[49] V. Braun and V. Clarke, "Using thematic analysis in Psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006.

[50] V. Braun and V. Clarke, "Thematic analysis," in *APA Handbook of Research Methods in Psychology*, H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, and K. J. Sher, Eds., vol. 2, pp. 57–71, American Psychological Association, Washington, DC, USA, 2012.

[51] A. Pascaris, C. Schelly, and J. Pearce, "A first investigation of agriculture sector perspectives on the opportunities and barriers for agrivoltaics," *Agronomy*, vol. 10, no. 12, p. 1885, 2020.

[52] M. Senyolo, T. Long, V. Blok, and O. Omta, "How the characteristics of innovations impact their adoption: an exploration of climate-smart agricultural innovations in South Africa," *Journal of Cleaner Production*, vol. 172, pp. 3825–3840, 2018.

[53] J. Corbin and A. Strauss, *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, Sage Publishing, Thousand Oaks, CA, USA, 2012.

[54] B. Saunders, J. Sim, T. Kingstone et al., "Saturation in qualitative research: exploring its conceptualization and operationalization," *Quality and Quantity*, vol. 52, no. 4, pp. 1893–1907, 2018.

[55] R. Huang, "Rqda: r-based qualitative data analysis, r package version 1.2.5033," 2019, http://rqda.r-forge.r-project.org/.

[56] C. Erlingsson and P. Brysiewicz, "A hands-on guide to doing content analysis," *African Journal of Emergency Medicine*, vol. 7, no. 3, pp. 93–99, 2017.

[57] B.-S. Leclerc and C. Dassa, "Interrater reliability in content analysis of healthcare service quality using Montreal's conceptual framework," *Canadian Journal of Program Evaluation*, vol. 24, no. 2, pp. 81–102, 2009.

[58] D. R. Haviland, B. Stone-Smith, and M. Gonzalez, "Control of Pierce's disease through areawide management of glassy-winged sharpshooter (Hemiptera: cicadellidae) and roguing of infected grapevines," *Journal of Integrated Pest Management*, vol. 12, pp. 1–10, 2021.

[59] M. Hoffman, M. Lubell, and V. Hillis, "Network-smart extension could catalyze social learning," *California Agriculture*, vol. 69, no. 2, pp. 113–122, 2015.

[60] L. Shaw, M. Lubell, and C. Ohmart, "The evolution of local partnerships for sustainable agriculture," *Society and Natural Resources*, vol. 24, no. 10, pp. 1078–1095, 2011.

[61] E. J. Lee, J. Lee, and D. W. Schumann, "The influence of communication source and mode on consumer adoption of technological innovations," *Journal of Consumer Affairs*, vol. 36, pp. 1–27, 2002.

[62] P. Brinkman, J. Kinsey, and A. Henneman, "Increasing the capacity of social media to extend your outreach," *Journal Of Extension*, vol. 55, 2017.

[63] Christiansen, "The social media marketing map (Part 1): a tool to empower the digital leaders of extension," *Journal of Extension*, vol. 53, 2015.

[64] S. K. Kurtural, D. Stewart, and D. A. Sumner, *Sample Costs to Establish a Vineyard and Produce Wine Grapes-Napa County (Crush District 4)*, University of California, Division of Agriculture and Natural Resources with UC Davis, Department of Agricultural and Resource Economics, Davis, CA, USA, 2020.

[65] P. V. Verdegaal, D. A. Sumner, and J. Murdock, *Sample Costs to Establish a Vineyard and Produce Wine Grapes-San Joaquin Valley (Crush District 11)*, University of California, Division of Agriculture and Natural Resources with UC Davis,

Department of Agricultural and Resource Economics, Davis, CA, USA, 2016.

[66] K. D. Ricketts, M. I. Gomez, M. F. Fuchs et al., "Mitigating the economic impact of grapevine red blotch: optimizing disease management strategies in US vineyards," *American Journal of Enology and Viticulture*, vol. 68, no. 1, pp. 127–135, 2017.

[67] R. A. Corner-Thomas, P. R. Kenyon, S. T. Morris et al., "Farmer perceptions of the relative usefulness of information providers and technology transfer methods," *New Zealand Journal of Agricultural Research*, vol. 60, no. 3, pp. 245–262, 2017.

[68] E. A. Szymanski, "Extension resource use among Washington state wine makers and wine grape growers: a case for focusing on relevance," *Journal of Extension*, vol. 54, pp. v54-1a2, 2016.

[69] O. Dedehayir, R. Ortt, C. Riverola, and F. Miralles, "Innovators and early adopters in the diffusion of innovations: a literature review," *International Journal of Innovation Management*, vol. 21, no. 08, pp. 1740010–1740027, 2017.

[70] K. Arnold, D. A. Golino, and N. McRoberts, "A synoptic analysis of the temporal and spatial aspects of grapevine leafroll disease in a historic Napa vineyard and experimental vine blocks," *Phytopathology*, vol. 107, no. 4, pp. 418–426, 2017.