AJEV Papers in Press. Published online March 30, 2022.

AJEV PAPERS IN PRESS • AJEV PAPERS IN PRESS

American Journal of Enology and Viticulture (AJEV). doi: 10.5344/ajev.2022.21052
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Research Note

Cooperation and Compensation to Mitigate Fungicide Resistance

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Acknowledgments: This work was financially supported by the USDA-NIFA-SCRI program, under award number 2018-03375 titled "FRAME: Fungicide Resistance Assessment, Mitigation, and Extension Network for Wine, Table, and Raisin Grapes."

Manuscript submitted Nov 16, 2021, revised Jan 12, 2022, Feb 7, 2022, and Feb 9, 2022, accepted Feb 28, 2022

Abstract: We evaluated grape growers' awareness of fungicide resistance and willingness to adjust fungicide use practices to mitigate this problem in vineyards. We conducted a pilot study surveying a small group of United States grape growers to assess their knowledge about fungicide resistance and willingness to adjust fungicide use based in the impact that use had on their own farm, and their neighboring farms' profits. We found that though growers are generally willing to adjust their fungicide use practices if it assisted with the mitigation of resistance, they

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were less willingness to do so when that adjustment would negatively impact their profits. We also evaluated their willingness to adjust their fungicide use when lost profits were remediated with compensation. To understand the relationship between their willingness to change their practices with compensation and their baseline willingness to do so (without compensation), we conducted a logistic regression. Given the small sample inference, we used bootstrapped estimates and observed an increase on growers' willingness to adjust their fungicide use when compensation is available. Our analysis underscores the importance of monetary compensations as an incentive tool to fight against fungicide resistance.

Key words: cooperation. disease management, FRAC, grape powdery mildew, grower perceptions

Introduction

Management of the fungal disease grape powdery mildew (GPM; fungal species *Erysiphe necator*) is expensive for grape growers (Sambucci et al. 2019). GPM is also a primary cause for loss of grape quality and yield worldwide. Most of the management of this disease focuses on the use of fungicides (Fuller et al. 2014). Unfortunately, the rise of fungicide resistance in grape powdery mildew creates a challenge for maintaining disease control (examples: Gubler and Ypema, 1996, Ypema et al. 1997, Wong and Wilcox 2002, Miller and Gubler 2004, Miles et al. 2012, Ouimette 2012, ; Yamagata et al. 2016).

The risk of fungicide resistance increases when fungicides with the same mode of action are repeatedly applied (Brent and Hollomon 2007). This is exacerbated with the co-occurrence of other conditions that favor resistance selection, such as inappropriate applications (below labelled rates), incomplete spray coverage, and application of fungicides to already-infected plant tissue

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(Brent and Hollomon 2007). These occur as a part of on-farm choices and application approaches. Thus, to reduce the likelihood of fungicide resistance on a commercially-relevant scale, we must consider what drives these decisions.

A recent survey of the United States grape industry (252 members) showed that 55% of the respondents consider fungicide resistance to be a moderate to severe problem; the survey also showed that most possessed the knowledge of resistance management practices (Oliver et al. 2021). But knowledge of a practice does not always mean application of that practice. For instance, Lybbert et al. (2016) finds evidence that despite growers knowledge on GPM risk (through the use of formal risk indices) they kept their usual spray timing, without reducing the number of sprays. Ultimately Lybbert et al. (2016) found that growers engaged in complex, multidimensional responses to risk information, and specific to the study, those decisions resulted in a net negative environmental impact. Their findings point to a need for a comprehensive examination of grower behavior in response to information, as access to information does not necessary result in anticipated changes in action.

Disease management often focuses on on-farm choices, but some diseases impact broader areas within a region. This is especially important given the aerial dispersion of grapevine powdery mildew (Falacy 2007). Regional cooperation disseminating information about how to manage the invasive European grapevine moth in California proved valuable in creating a network of growers who then practiced those management approaches (Cooper et al. 2014). Could understanding the drive behind an individual's choice of fungicide use, particularly if they were presented with information on how their choices might impact their own farm, or their neighbor's farm, help us to better develop educational approaches and avoid wide-spread regional losses of disease control?

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Here, we present a study on grape growers' perceptions of fungicide resistance, and how that perception might change when considering how neighbor's choices can impact each other. The basic assumption in this study is that actions are primarily financially-driven; that the catalyst for an individual to change a current practice is associated with a financial incentive, or conversely, to avoid a cost. We assumed that in order for a management approach to expand to a regional activity, cooperation to mitigate fungicide resistance would come from two actions: (i) an individual's general interest in reducing at-risk fungicide use without compensation, and/or (ii) enticement of compensation to reduce the use of at-risk fungicides, if not for their own benefit, but for the benefit of their neighboring farms. This study aimed to identify grape grower's willingness-to-cooperate based on fungicide use decisions, and how that willingness was driven by compensation of profit loss.

Materials and Methods

We used a similar survey strategy to that of Llewellyn et al. (2002). They develop hypothetical scenarios in their surveys for participants to consider. Our survey included different scenarios relating to fungicide use choices, potentially corresponding compensation for the adoption of those choices, and how fungicide use might influence fungicide resistance on the participant's or their neighbor's farm.

The survey had 64 questions (see **Supplemental Information**) that were distributed among grape growers in the US between October and December 2019, using Qualtrics XM Online Survey Software (Qualtrics.com, LLC). The survey was distributed using viticulture University Extension networks across the US, using their regional Extension email listservs, publicizing the survey and providing QR code links during regional grape grower meetings, and individual direct

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emails from Extension specialists to regional grower groups and representative co-ops. It was also posted on the Fungicide Resistance Assessment, Mitigation, and Extension (FRAME) project website (framenetworks.wsu.edu), Twitter, and Facebook pages, where it was re-shared by Extension specialists to their networks of growers, crop consultants, and other industry members.

The survey was composed of three sections: (i) identification of fungicide-use practices, (ii) growers' willingness to cooperate and (iii) demographics. To identify practices in section (i) we asked questions to gauge growers' current fungicide use practices, such as overall understanding of fungicide resistance, and management philosophies. In this study, we defined fungicide use practices as those that influenced: (i) the timing of fungicide application, and (ii) the rotational choices between different fungicide classes (i.e., FRAC groups, www.frac.org). We also asked questions regarding their knowledge about neighbors use of fungicide. To identify cooperation in section (ii), we developed questions to directly assess growers' willingness-to-adjust fungicide practices to mitigate fungicide resistance. This was done through variations of a central question, which was about whether a grower would change their current practices to mitigate fungicide resistance. The varying scenarios allowed for growers to express whether they would be willing to make this adjustment (cooperate) with or without compensation. It also included information on the varying impacts that adjustment would have on their profits, or on the profits of their neighboring growers. Our demographic questions (iii) provided information about age, education, and farming location.

Statistical analyses. We conducted a logistic regression analysis to understand the relationship between a grower's choice to cooperate (adjust practices) with compensation and an index of their own baseline willingness-to-adjust to mitigate fungicide resistance development.

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We controlled for a grower's baseline willingness-to-adjust fungicide use practices in resistance mitigation efforts and whether they have a neighbor grower. The specific model we used was:

$$C_i = \beta_0 + \beta_1 X_i + \beta_2 N_i + e_i$$

where C_i is a binary variable indicating whether grower *i* is willing to adopt fungicide mitigation efforts if they are compensated (C_i=1 if grower *i* responded "Yes" and C_i=0 if grower *i* responded "No" or "Unsure" to survey question 37, **Supplemental Information**).

The variable X_i is an index indicating grower *i*'s baseline willingness-to-adjust fungicide use practices. We defined baseline as willingness-to-adjust without compensation. The index is composed of the survey questions 26-30 and 32-35 (**Supplemental Information)**. These questions were related to each grower's willingness-to-adjust some aspect (general practice, frequency, timing, or FRAC groups used) when presented with alternate scenarios (either related to consequences of their compliance or preexisting circumstances). Note, that the questions used in the index did not contain either implicit or explicit compensation (unlike question 37, **Supplemental Information**) for their fungicide-resistance-reducing cooperation. Therefore, a higher value for this index represents a general willingness to alter fungicide use practices, without monetary compensation, to mitigate fungicide resistance development.

The final variable, N_i specifies whether grower *i* indicated they have a neighboring grower (question 12, where N_i=1 if grower *i* responded "Yes" and N_i=0 if grower *i* responded "No"). The last term is an error term, which we assume is independently and identically distributed. The central reason that we use the logistic regression is because the dependent variable, C_i, is a binary variable. Choosing logistic regression rather than probit (the main alternative when the dependent variable is categorical), is predominately dictated by preference for interpretation.

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Our sample size was small (n=38; not all surveys were complete), and given asymptotic inference is often unreliable in small samples, we bootstrapped parameter estimates and standard errors in R (Robert and Casella, 2004). We took a random sample with replacement from our original dataset equal to the number of observations to form a new sample. We stored the corresponding parameter estimates associated with this new random sample and the model we presented above. We repeated this process 1,000 times; therefore, we obtained 1,000 new randomly sampled datasets and corresponding sets of parameter estimates. From these, we found the mean of the parameter estimates and standard errors and used them to compute confidence intervals and *p*-values.

Results

Demographics. The survey was accessed by 57 growers, but not all completed all questions in the survey. Any presented statistical representation (i.e., percent of respondents), is related to the number of actual responses for that question. Growers mainly reside in Washington State (47.4%, n=18) followed by Georgia (18.42%, n=7) and Oregon (15.8%, n=6). This demographic data is summarized in Supplemental Table 1. Pacific states (California, Washington, Oregon) represent 98% of all grape acreage in the country, but we unfortunately did not receive any responses from California. While the survey was shared extensively with California growers through the avenues previously described, survey fatigue was likely occurring, as there were a number viticulture-related surveys being distributed at that time, which likely resulted in survey fatigue of this heavily-targeted audience. Additional demographic data is presented in Supplemental Table 1.

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Important factors for designing a fungicide program. Growers were mainly concerned about quality (51.3%) and price (18.0%) of a fungicide brand (n=39). Respondents did not report a strong brand loyalty; only 2.0% have never changed fungicide brands. In fact, about 40% indicate that they change fungicide brands more than half of the time; 17.1% indicated they change brands about half of the time, 7.3% change brands most of the time, and 17.1% always change brands.

Management philosophies and fungicide program design. The primary management philosophy practiced by respondents was conventional management (42.1%, n=24) which permits the use of all crop-labeled fungicides. However, more than half of the surveyed growers (57.9%) adhered to a non-conventional management philosophy which includes: certified organic, biodynamic or sustainable (23.34%), intended (but not certified) organic/biodynamic/ sustainable (31.67%) and others (2.89%).

In the survey we asked whether growers applied fungicides preventatively or curatively. About 70% (n=28) indicated that they apply fungicides both preventively and curatively, while 27.5% apply fungicides only preventively and 2.5% apply only curatively. In general, growers followed the fungicide's label; 93% carefully read instructions. The most common resourced used by growers for designing spray programs was Extension pest management guides (39.7%, n=31), followed by Extension specialists or farm advisors (24.4%, n=19) and local crop consultants (20.5%, n=16)

Awareness of fungicide resistance and neighbors' fungicide use practices. About 80.5% (n=33) of respondents indicated that they had at least one neighboring farm, and 87.9% (n=33) claim that closest neighboring farm was within 1.6 km. Growers indicated that their neighbors mainly grew wine grapes (48.5%) and apples (24.2%).

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We also asked how much they know about their neighbor's fungicide use practices (Fig. 1). Approximately half of the growers (51.5%, n=17) indicated they know when their neighbor is applying a fungicide most of the time to always. Unfortunately, 15.2% (n=5) of the respondents indicated they are never aware, and 27.3% are only sometimes aware.

Respondents were generally aware of the causes and consequences of fungicide resistance, (97.6%, n=40). However, 39.0% indicated they have encountered fungicide resistance on their own farm (either through direct detection of a resistant fungus or assumed resistance due to a disease control failure). Among the responding growers, there remained a high degree of uncertainty about whether their neighbors' choices affected their own disease control efforts; 63.6% of respondents had not considered how their neighbors' fungicide uses could affect their own disease control efforts.

However, knowing what practices one's neighbors are using for both disease management and fungicide resistance mitigation may directly impact the approach of another. Approximately one third (36.4%) of the growers indicated that they considered how their neighbor's use of fungicides may affect their own control efficacy (Fig. 2), whereas 45.5% indicated that they have not considered how their neighbor's use of fungicides could be impacting their disease control efforts.

Willingness-to-change practices (cooperate). In our respondents, 90.5% (n=38) were willing to make changes to their fungicide use practices (e.g., completely stop using fungicides) if they knew fungicide resistance was a problem for that fungicide (Fig. 3). When asked if they would be willing to stop using a problematic fungicide if they knew it negatively affected their neighbor, 76.2% (n=32) were willing to do so. When asked whether they would alternate FRAC groups in

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their fungicide rotations, 88.1% were willing to cooperate to help their neighbor. When asked about changing the frequency of their applications, only 69.0% were willing to cooperate, and 26.0% were unsure about changing their frequency of applications to help their neighbor. When growers were not willing to cooperate (no = 7.1%, or unsure= 4.8%), their reasons were: 1) they adhered to a specific production standard (certification), and therefore could not adjust their own program; 2) they were concerned that there were too many other more important variables that ultimately dictate how a fungicide should be used; 3) they thought their practices associated with drift mitigation of spray meant that there was very little risk of cross-contamination of fungicides, and thus, their fungicide use would not impact their neighbor; or 4) they believed that the fungicides (FRAC groups) they were using were not impacted by fungicide resistance development.

To identify their willingness to cooperate (Table 1), defined as adjusting their fungicide use to mitigate fungicide resistance development when it impacts their or their neighbors' profits, growers were generally willing to consider changes as long as their profits were not affected (97.4%). If adjusting fungicide use harmed their profits, but could improve fungicide resistance management, only 35.9% were willing to adjust, while 41.0% are unsure. If the situation changed to where their adjustments in fungicide use practices improved their profits, but hurt their neighbor's profits, more respondents became unsure if whether or not they would make the change (61.5%).

We also evaluated the respondents' willingness to adjust their fungicide use if there was monetary compensation for profit loss. In the face of their own farm profit loss, 79.5% of the growers indicated they would be willing to adjust their fungicide use to help their neighbor and

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mitigate fungicide resistance if they are compensated to do so. Among this group, 37.9% are willing to cooperate if they were exactly compensated for their loss in profits, 41.4% would cooperate if they are mostly compensated (75% of lost profits returned) and 20.7% would cooperate in adjusting their fungicide use practices if they are partly compensated (25% to 50% of lost profits returned). In this situation, 15.4% of respondents were unsure if they would make an adjustment even if they were compensated for their profit loss.

The estimated coefficient for our baseline willingness-to-adjust index was statistically different than zero (Table 2). This estimate indicates that a one-unit increase in a grower's baseline willingness-to-adjust index (reflecting that a grower responds "Yes" to one of the included questions composing the index) is correlated with a 0.0697 increase in the log-odds of a grower being willing to adjust fungicide use to mitigate fungicide resistance when offered compensation.

We can also use this estimate to determine the range of probabilities that a grower in our study would be willing to adjust fungicide use when offered compensation. The probability that a grower would adjust their use if they were compensated for profit loss ("Yes" on Question 37, **Supplemental Information**) ranged from approximately 50-65%. The lowest end of the range is the probability associated with a grower who also chose "No" or "Unsure" for all of the questions included in the baseline willingness-to-adjust index. In contrast, the highest probability is associated with a grower who chose "Yes" for all the included questions. This indicates that the grower has a very high baseline willingness-to-adjust their fungicide use practices to mitigate the causes and/or consequences of fungicide resistance.

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Discussion

We assessed grape growers' self-reported knowledge of fungicide resistance, as well as their current practices of GPM management and willingness to cooperate to mitigate fungicide resistance. Similar to Oliver et al. (2021), we find that the majority of grape growers are aware of the causes and consequences of fungicide resistance to their vineyard operation. It is important to highlight the small size of our sample and the spatial distribution of the growers mainly concentrated on the state of Washington, which limits the scope of our findings.

Grape growers value fairness in regional management decisions. Our results suggest a preference among growers for fairness; a large proportion of respondents are willing to adjust their actions when their own and their neighbor's profits are unaffected, and when they both suffer decreases, but when one grower benefits while the other suffers losses the proportion that are willing to cooperate is greatly reduced. This behavior has been previously reported in the behavioral economics literature (Ferh and Schmidt 1999).

Compensation is likely needed to truly influence choices. We found that growers' baseline willingness-to-adjust fungicide use is positively correlated with their odds of indicating they are willing to do so for compensation (Table 2). Based on our estimation, if growers indicated that they were willing to cooperate on all questions that compose the index, then the probability that they are willing to cooperate with compensation was 65% percent. This is an increase of 15 percentage points compared to growers who indicated that they were unwilling or uncertain about changing a fungicide use practice. Because growers are willing to cooperate to achieve a common goal, we could improve the likelihood that they cooperate by offering compensation. One potential mode of compensation could be through local, state, or federal policies relating to fungicide

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stewardship and general use. Monetary transfers have been previously examined for the control of mammal population and transboundary species invasions (Bhat and Huffaker 2007, Liu and Sims 2016). Additional incentives could come through the various third-party vineyard sustainability certification standards, that would encourage the use of certain practices; while this would likely not be direct financial compensation, it would potentially be compensation offered in the scoring of points necessary for recertification that are common in these standards.

Can better educational programs increase willingness to cooperate / adjust fungicide use practices? In our survey, growers were presented with different scenarios where they could alter one aspect of their fungicide use practice to prevent their neighbors' profits from being negatively impacted (in the situation where fungicide resistance was the cause of that negative impact). Fungicide quality was a primary driver for the choice of that fungicide by growers. Hence, if more educational language is focused on how fungicide performance is lost due to fungicide resistance, that might help influence fungicide choice. This focus is different than primarily focusing on disease control failures. Focusing on fungicide quality forces the dual focus on money lost on using a product that doesn't work (product costs), and the money lost due to subsequent crop failures (yield loss). The fundamental key to many adult educational programming is hands-on learning, and practical application (Prell et al. 2009, Franz et al. 2010, Hoffman et al. 2015, Leach et al. 2019). This is also critical to the development of successful grower educational networks (Cooper et al. 2014, Hoffman et al. 2015, Oliver et al. 2021). Given that many of our respondents indicated they were generally aware of what their neighbors were spraying (Fig. 1), but they were not always sure if those sprays might impact their operation (Fig. 2), further organization of regional

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297 cooperative grower groups focused on mitigation fungicide resistance might benefit their baseline
298 education and willingness to cooperate.

299 Finally, the survey provides valuable insights about how monetary compensation can
300 induce grape growers to adjust their use of fungicides to mitigation of fungicide resistance, even
301 when their own or their neighbors' profits are affected. We found that different levels of
302 compensation triggered different responses towards cooperation among grape growers. This
303 observed strategic behavior is the key to a successful tool that achieves cooperation on fungicide
304 used designed to mitigate fungicide resistance.

305 ## Conclusion

306 This study examined grape growers' willingness to adjust their fungicide use practices
307 when facing fungicide resistance. We developed a survey to explore the possible ways and
308 motivations growers would be willing to cooperate (adjust a fungicide use practice) to mitigate
309 fungicide resistance. While our sample size was small, and limited in regional scope, we found
310 that 35.6% of the respondents were willing to adjust their practices if there was a loss in profit. We
311 found that they were also willing to cooperate (reduction of fungicide use and compensation of
312 neighboring growers), in an effort to solve regional challenges associated with fungicide
313 resistance. Given that our study focused on a small sample of grape growers, more would be
314 needed to truly understand the U.S. grape grower as a whole.

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Table 1: It shows the percent of respondents (n=39) who indicated would cooperate if they knew that such cooperation reduces fungicide resistance, considering the effect on their profits and neighbor's profits.

		How their decision impacted their neighbor's profits		
		Increased neighbor profits	**Decreased neighbor profits**	**Did not affect neighbor profits**
How their decision impacted their own profits	**Increased their profits**	-	30.8%	-
	Decrease their profits	35.9%	33.3%	-
	Did not affect their profits	94.87%	-	97.4%

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Table 2: Results for the logistic regression analysis.

Model Parameters	**Estimates[a]**	**Std. error**
Intercept, $ß_0$	0.2063	0.2958
Baseline willingness-to-adjust (cooperate) index, $ß_1$	0.0697*	0.0438
Neighbor, $ß_2$	0.1553	0.1929
[a] Significance codes: '*' indicates P = 0.01		

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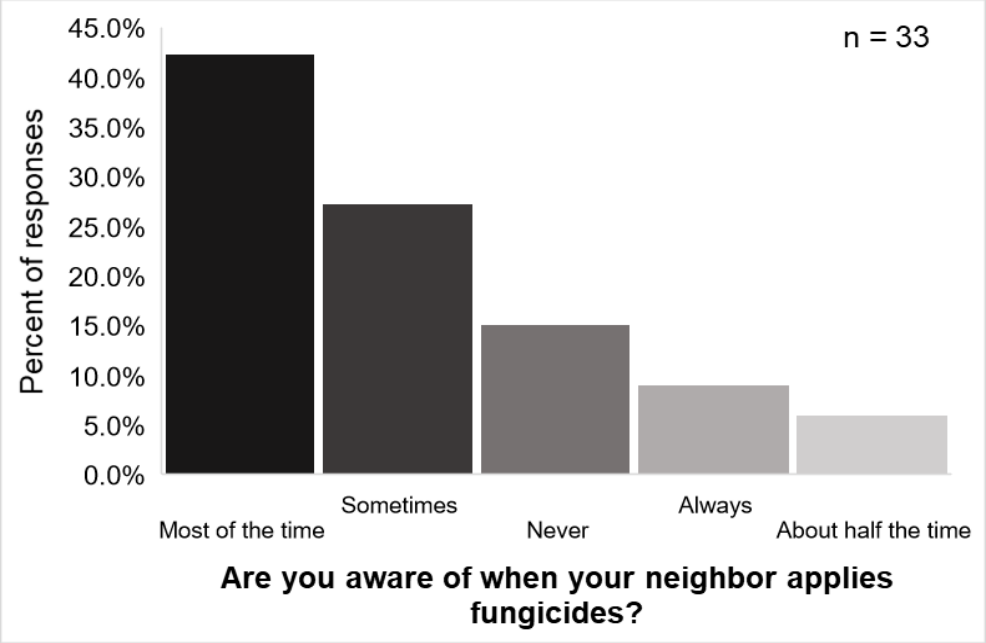

Figure 1: Frequency of grape growers' responses to the question on whether they were aware of when their neighbor applied fungicides.

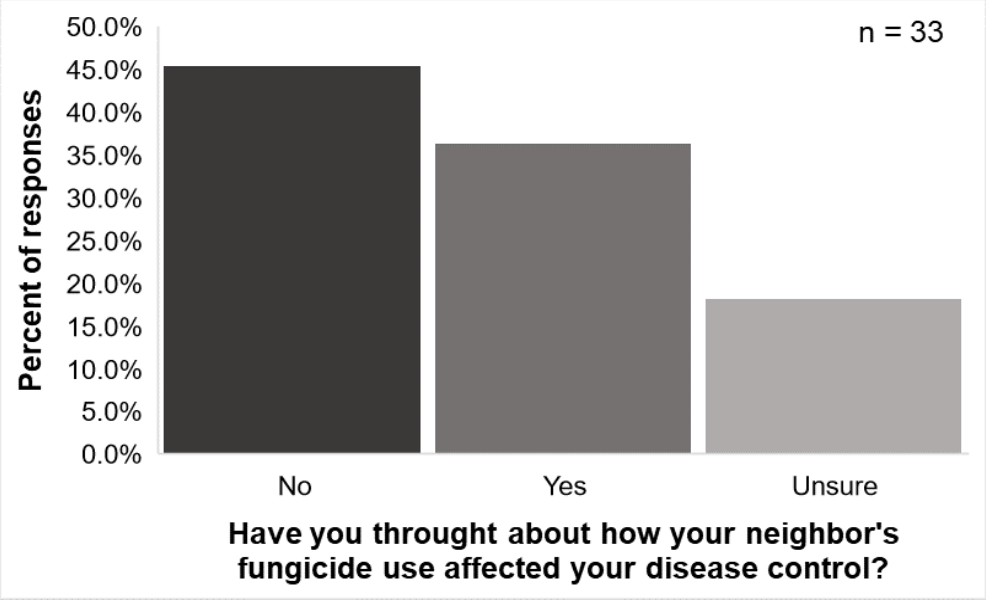

Figure 2: How grape growers responded to the question of whether they thought about, or noticed, if their neighboring farm's fungicide use practices affected their ability to maintain disease control in their own vineyard.

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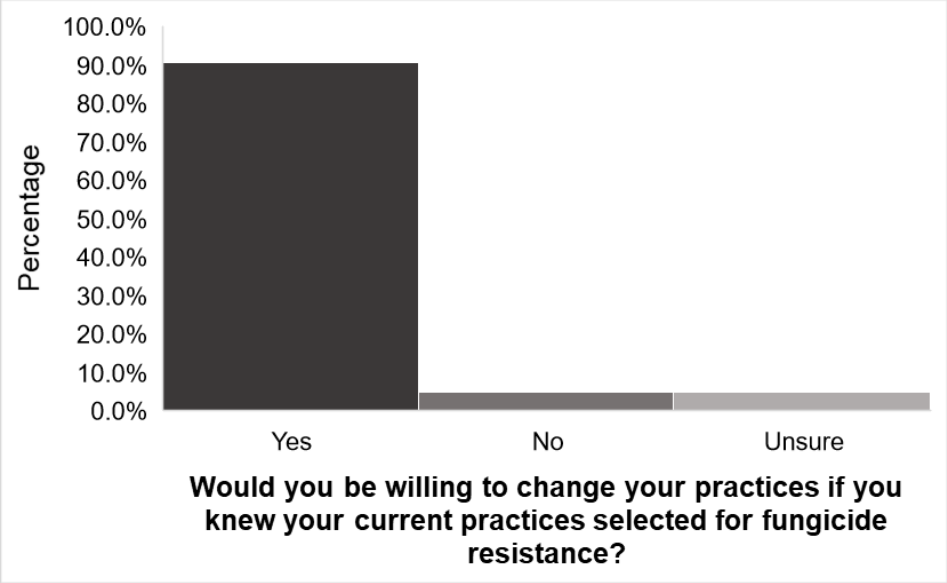

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390 Figure 3: Grape grower's willingness to adjust fungicide use practices, if they became aware that

391 their practices resulted in selection for fungicide resistance (*n*=42).

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Supplemental Document
Survey Instrument

Section 1 - Identification of fungicide-use practices.

1. From the list below, please select the various specialty crops you grow.

Grapes

_ Wine grapes
_ Raisin grapes
_ Juice grapes
_ Table grapes

Small Fruits

_ Blueberries
_ Raspberries and/or blackberries
_ Strawberries
_ Other berries: Please specify

Tree fruits

_ Apples
_ Pears
_ Sweet cherries
_ Sour cherries
_ Plums
_ Apricots
_ Nectarines and/or peaches
_ Other Tree Fruits (avocado, pomegranate, quince) Please specify

Nuts

_ Hazelnuts
_ Walnut
_ Almonds
_ Other nuts (please specify)

Other Vine crops

_ Hops
_ Melon
_ Other (please specify)

If the crop you grow is not listed above, please specify here:

1. Do you use fungicides? Fungicides are defined as any product applied to a plant for the intention of controlling a fungus-based disease. It can include both synthetic or natural products.
   _ YES
   _ NO

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2. For your grape production, select from the list below the brand names of fungicides you have used in the past year.
   - _ Abound
   - _ Actinovate-AG
   - _ Aim
   - _ Alion
   - _ Aprovia
   - _ Botran 75 W
   - _ Casoron
   - _ Chateu
   - _ Devrinol
   - _ Dithane, Manzate, Penncozeb
   - _ Elevate
   - _ Endura
   - _ Flint
   - _ Fusilade
   - _ Gallery
   - _ Gramoxone
   - _ Goal
   - _ Inspire Super
   - _ JMS Stylet Oil, Neem Oil, PureSpray Green
   - _ Kaligreen
   - _ Karmex
   - _ Kerb
   - _ Luna Experience
   - _ M-Pede
   - _ Matrix
   - _ Mission
   - _ Mettle
   - _ Orius 20AQ, Tebuzol 45DF
   - _ Ph-D
   - _ Poast
   - _ Princep
   - _ Pristine
   - _ Procure 480SC
   - _ Prolivo 300 SC
   - _ Prowl
   - _ Quadris Top
   - _ Quintec
   - _ Rally 40WSP
   - _ Regalia
   - _ Rely
   - _ Roundup

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_ Rovral, Nevado
_ Scala SC
_ Select
_ Serenade Max
_ Several formulations
_ Solicam
_ Sonata
_ Sovran
_ Surflan
_ Switch 62.5 WG
_ Treflan
_ Torino
_ Unicorn
_ Vangard WG
_ Venue
_ Vivando
_ Zeus XC
_ Zeus Prime XC
_ Ziram

3. If the fungicide you have used in the past year is not listed above, please specify here:

4. What is the *most* important attribute in your choice of fungicide brand? A fungicide brand is defined as the specific marketing name associated with the product. For example, Venue is the brand for pyraflufen-ethyl.
   _ PRICE
   _ QUALITY
   _ CUSTOMER SERVICE
   _ OTHER

5. How often do you change fungicide brand?
   _ NEVER
   _ SOMETIMES
   _ ABOUT HALF OF THE TIME
   _ MOST OF THE TIME
   _ ALWAYS

6. When designing a fungicide program for your grape production, do you rotate your fungicides between different modes of action (e.g., rotating between different FRAC groups).
   _ YES
   _ NO

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7. Do you use any of the following resources to assist in designing your fungicide programs in your grape production?
   - _ Extension Pest Management Guide (e.g., UC-Davis Grape Pest Management Guide, WSU Annual Grape Pest Management Guide, WSU Annual Treefruit Pest Management Guide)
   - _ Local crop consultant
   - _ Extension Specialist or Farm advisor (face-to-face, email, or phone consultations)
   - _ Third party certification recommendations (e.g., Oregon LIVE, Lodi Wine Rules)

8. What management philosophies do you follow in your grape production? Please select all that apply.
   - _ GENERAL/CONVENTIONAL
   - _ CERTIFIED ORGANIC
   - _ CERTIFIED BIODYNAMIC
   - _ CERTIFIED SUSTAINABLE (E.G., LODI RULES, LIVE)
   - _ INTENDED (BUT NOT CERTIFIED) ORGANIC
   - _ INTENDED (BUT NOT CERTIFIED) BIODYNAMIC
   - _ INTENDED (BUT NOT CERTIFIED) SUSTAINABLE
   - _ OTHER: _____

9. Do you typically apply fungicides preventatively (before you notice a disease problem in your crop) or curatively (to treat an existing problem) in your vineyards?
   - _ ONLY PREVENTATIVELY
   - _ BOTH PREVENTATIVELY AND CURATIVELY
   - _ ONLY CURATIVELY

10. How often do you carefully read the instructions and follow the recommended application procedure(s) for the fungicide(s) you use? This is in reference to reading and following the fungicide label.
    - _ NEVER
    - _ SOMETIMES
    - _ ABOUT HALF OF THE TIME
    - _ MOST OF THE TIME
    - _ ALWAYS

11. Do you have at least one neighboring farm?
    - _ YES
    - _ NO

12. If you selected YES in the above question, then what is the approximate distance of the closest neighboring farm from your property?
    - _ Less than 1 mile

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_ 1-2 miles
_ 3-5 miles
_ 6-10 miles
_ 11 miles and over

13. If you have a neighboring farm,, please select the various specialty crops your neighboring farm(s) grow (to the best of your knowledge)?

Grapes

_ Wine grapes
_ Raisin grapes
_ Juice grapes
_ Table grapes

Small Fruits

_ Blueberries
_ Raspberries and/or blackberries
_ Strawberries
_ Other berries: Please specify

Tree fruits

_ Apples
_ Pears
_ Sweet cherries
_ Sour cherries
_ Plums
_ Apricots
_ Nectarines and/or peaches
_ Other Tree Fruits (avocado, pomegranate, quince) Please specify

Nuts

_ Hazelnuts
_ Walnut
_ Almonds
_ Other nuts (please specify)

Other Vine crops

_ Hops
_ Melon
_ Other

14. If the crop your neighboring farm(s) grow is not listed above, please specify here:

15. How frequently are you aware of when your neighbors apply fungicide?

_ NEVER
_ SOMETIMES

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_ ABOUT HALF OF THE TIME
_ MOST OF THE TIME
_ ALWAYS

16. How often do you know which particular fungicides your neighbors use when they apply?
    _ NEVER
    _ SOMETIMES
    _ ABOUT HALF OF THE TIME
    _ MOST OF THE TIME
    _ ALWAYS

17. How often do you know which FRAC groups the fungicides belong to that your neighbors use when they apply?
    _ NEVER
    _ SOMETIMES
    _ ABOUT HALF OF THE TIME
    _ MOST OF THE TIME
    _ ALWAYS

18. Have you ever heard of fungicide resistance?
    _ YES
    _ NO

19. Are you aware of the causes and consequences of fungicide resistance?
    _ YES
    _ NO
    _ UNSURE

20. To the best of your knowledge, have you ever encountered fungicide resistance on your own farm?
    _ YES
    _ NO
    _ UNSURE

21. How often do you apply fungicide to your grape production? If the frequency that you apply fungicide to your crops varies, please explain (e.g., if you apply fungicide at a certain rate for blueberries and another for grapes, please describe that clearly and label the description with the crop).

22. Do you adjust the timing of your fungicide applications based on the weather (more than is required by the legal restrictions)?
    _ YES

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650 _ NO
651 _ UNSURE
652
653 23. If you selected YES in the above question, then please explain your reasoning in the
654 space provided below.
655
656 24. Have you ever noticed that neighboring farms' use of fungicide affects you?
657 _ YES
658 _ NO
659 _ UNSURE
660
661 **Section 2 - Growers' willingness to cooperate.**
662 25. When you had (If you have) just become aware of the causes and consequences of
663 fungicide resistance, did you (will you) make changes to your fungicide application
664 practices?
665 _ YES
666 _ NO
667 _ UNSURE
668
669 26. If you learned that your method of fungicide usage was negatively affecting
670 neighboring farms (e.g., by contributing to fungicide resistance), would you be willing
671 to *stop using fungicide altogether*?
672 _ YES
673 _ NO
674 _ UNSURE
675
676 27. If you learned that your method of fungicide usage was found to be negatively
677 affecting neighboring farms (e.g., by contributing to fungicide resistance), would you
678 be willing to *change the frequency* of your applications?
679 _ YES
680 _ NO
681 _ UNSURE
682
683 28. If you learned that your method of fungicide usage was found to be negatively affecting
684 neighboring farms (e.g., by contributing to fungicide resistance), would you be willing
685 to *change the timing* of your applications?
686 _ YES
687 _ NO
688 _ UNSURE
689
690 29. If you learned that your method of fungicide usage was found to be negatively affecting
691 neighboring farms (e.g., by contributing to fungicide resistance), would you be willing
692 to *alternate the FRAC group of fungicide* used in your applications?
693 _ YES

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_ NO
_ UNSURE

30. If you choose NO or UNSURE in the above question, please explain why in the space provided.

31. Would you adjust your fungicide use if you knew it would help to prevent fungicide resistance, but would otherwise *not affect your profits for the next 5 years or those of other growers*?
    _ YES
    _ NO
    _ UNSURE

32. Would you adjust your fungicide use if you knew it would help to prevent fungicide resistance, would help other growers get better profits, but would otherwise *not affect your profits for the next 5 years*?
    _ YES
    _ NO
    _ UNSURE

33. Would you adjust your fungicide use if you knew it would help to prevent fungicide resistance, would help other growers get better profits, but would otherwise *negatively affect your profits for the next 5 years*?
    _ YES
    _ NO
    _ UNSURE

34. Would you adjust your fungicide use if you knew it would help to prevent fungicide resistance, but would otherwise *negatively affect your profits for the next 5 years and those of other growers*?
    _ YES
    _ NO
    _ UNSURE

35. Would you adjust your fungicide use if you knew it would help to prevent fungicide resistance, would otherwise *negatively affect other growers' profits*, but would otherwise *increase your profits for the next 5 years*?
    _ YES
    _ NO
    _ UNSURE

36. If adjusting the use of fungicide negatively affected your profits for the next 5 years, would you be willing to adjust your fungicide use if you were compensated to do so?
    _ YES

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_ NO
_ UNSURE

37. If you selected YES in the above question, how much would you need to be compensated in order for you to be willing to adjust your fungicide use?
    _ Exactly Compensated (100% Of Lost Profits Returned)
    _ Mostly Compensated (75% Of Lost Profits Returned)
    _ Partly Compensated (25-50% Of Lost Profits Returned)

38. If the amount you wish to be compensated is not present in the above question, please specify the exact amount.

Section 3 - Demographics.

a. What is your age in years?
   _ Under 18 years old
   _ 18-24 years old
   _ 25-34 years old
   _ 35-44 years old
   _ 45-54 years old
   _ 55-64 years old
   _ 65-74 years old
   _ 75 years or older

b. What is your gender?
   _ Female
   _ Male
   _ Prefer not to answer

c. What is your marital status?
   _ Single, never married
   _ Married or domestic partnership
   _ Widowed
   _ Divorced
   _ Separated

d. Please specify your ethnicity.
   _ White
   _ Hispanic or Latino
   _ Black or African American
   _ Native American or Alaska Native
   _ Asian / Pacific Islander
   _ Other

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e. Which of the following educational attainment categories best describe you currently (please check all that apply)?

_ No schooling completed
_ Nursery school to 8th grade
_ Some high school, no diploma
_ High school graduate, diploma or the equivalent (e.g., GED)
_ Some college credit, no degree
_ Trade/technical/vocational training
_ Associate degree (e.g. AA, AS)
_ Bachelor's degree (e.g. BA, BS)
_ Master's degree (e.g. MA, MS, MEd)
_ Professional degree (e.g. MD, DDS, DVM)
_ Doctorate degree (e.g. PhD, EdD)

f. How much total combined money did all members of your household earn in 2018?

_ $0 – $9,999
_ $10,000 – $19,999
_ $20,000 – $29,999
_ $30,000 – $39,999
_ $40,000 – $49,999
_ $50,000 – $59,999
_ $60,000 – $69,999
_ $70,000 – $79,999
_ $80,000 – $89,999
_ $90,000 – $99,999
_ $100,000 or more

g. In which state do you currently reside?

_ Alabama	_ New Hampshire
_ Alaska	_ New Jersey
_ Arizona	_ New Mexico
_ Arkansas	_ New York
_ California	_ North Carolina
_ Colorado	_ North Dakota
_ Connecticut	_ Ohio
_ Delaware	_ Oklahoma
_ District of Columbia	_ Oregon
_ Florida	_ Pennsylvania
_ Georgia	_ Rhode Island
_ Hawaii	_ South Carolina
_ Idaho	_ South Dakota
_ Illinois	_ Tennessee
_ Indiana	_ Texas
_ Iowa	_ Utah

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_ Kansas _ Kentucky _ Louisiana _ Maine _ Maryland _ Massachusetts _ Michigan _ Minnesota _ Mississippi _ Missouri _ Montana _ Nebraska _ Nevada	_ Vermont _ Virginia _ Washington _ West Virginia _ Wisconsin _ Wyoming

h. In which county do you currently reside? Please specify:

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813 Supplemental Table 1 - Descriptive statistics on respondent demographics.

	Count (%)
Age	
18-24 years old	0 (0%)
25-34 years old	6 (15.8%)
35-44 years old	4 (10.5%)
45-54 years old	5 (13.2%)
55-64 years old	7 (18.4%)
65-74 years old	13 (34.2%)
75 years or older	3 (7.9%)
Sex	
Male	33 (84.62%)
Female	3 (7.69%)
Prefer not to answer	3 (7.69%)
Highest Degree Earned	
High school graduate,	2 (5.26%)
Some college credit, no degree	7 (18.42%)
Trade/technical/vocational	2 (5.26%)
Professional degree	1 (2.63%)
Bachelor's degree	11 (28.95%)
Master's degree	8 (21.05%)
Doctorate degree	7 (18.42%)
Household Income	
$30,000 – $39,999	3 (7.69%)
$40,000 – $49,999	2 (5.13%)
$50,000 – $59,999	1 (2.56%)
$60,000 – $69,999	0 (0.0%)
$70,000 – $79,999	6 (15.38%)
$80,000 – $89,999	6 (15.38%)
$90,000 - $99,000	0 (0%)
$100,000 or more	16 (41.03%)
Prefer not to answer	5 (12.82%)

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Neighbor	
Has a Neighbor	33 (80.49%)
Does Not Have a Neighbor	8 (19.51%)

814