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Cover Page Footnote

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Growers' Perceptions and Strategies to Mitigate Spring Frost Injury in Grapevines

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Abstract. Uncertain weather patterns raise concerns about frequent spring frosts and injury in grapevines. This article quantifies growers' perceptions of susceptibility to spring frosts and examines their satisfaction with existing mitigation strategies. Results from a survey with grape growers show that over 80% of sampled growers have experienced damage due to frosts. Over-vine sprinklers, proper site selection, and adoption of late budding cultivars are the practices with the highest satisfaction levels. None of the strategies examined reached the highest satisfaction score. In addition, 61% of respondents showed interest in sprayable products to delay budbreak and circumvent grapevine damage.

INTRODUCTION

Grape is a significant specialty crop with an annual production of approximately 76 million metric tons and a gross production value of $79 billion worldwide (FAOStat, 2023). One of its most cultivated species, *Vitis vinifera*, is a fruit of global importance with a historical connection to human culture (Shecori et al., 2022). Advanced production management practices include assessing the number of accumulated chilling hours and growing degree days to monitor crop growth and development (Martínez-Lüscher et al., 2016). Of recent concern, climate change and uncertain weather patterns have triggered grapevine injuries as cold temperatures are estimated to negatively affect the global production quantity by 5 to 15% annually (Evans, 2000). Grape growers have expressed concerns about the effectiveness of existing practices and products available for protecting their vineyards against spring frost injuries (Poling, 2008). To the best of our knowledge there are no risk and perception assessment studies conducted with U.S. grape growers that quantify these concerns. This article aims to fill this gap by informing Extension agents as well as practitioners with a stake in grape production. Grapes are most susceptible to significant frost damage during the post-budbreak stage of shoot development (Warmund et al., 2007). If a freeze happens after budbreak, untreated or unprotected vineyards tend to incur significant crop losses and harm to the vines. Crop losses occur with damage to the grapevines' primary buds, which are the most fruitful (Zabadal et al., 2017). Cold injury can occur during autumn, causing early leaf abscission; in winter, causing damage to buds and/or vascular tissue; or in spring, causing harm to young shoots (Wang & Dami, 2020). Young green tissues are susceptible to damage at relatively high temperatures (just below 32°F), while perennial structures may experience vascular damage only below subzero temperatures. Regardless of whether a production region is typically considered cold, spring frost damage is the most prevalent form of cold injury requiring validated techniques for vineyard management. The appropriate selection of grape genotype is an important factor that determines susceptibility to cold damage. According to Londo & Johnson (2014), *Vitis riparia* and related interspecific cultivars are widely grown in the eastern and midwestern United States due to their cold hardiness trait. However, some of these cultivars tend to initiate budbreak early in the spring, making them more vulnerable to frost damage.

Various methods have been studied to reduce exposure to spring frost. Active approaches involve raising the temperature in vineyards during frost using costly equipment like wind machines, heaters, and helicopters. While these methods may be used in large vineyards, they are frequently unfeasible for small-scale growers due to their high capital cost (Poling, 2008), operational costs, environmental concerns (Jorgensen et al., 1996), and resulting externalities such as noise complaints filed by adjacent neighbors. Trought et al. (1999) discussed several methods to protect vineyards against frost damage and concluded that preventative actions such as selecting a farm site with low propensity for frost occurrence are the most effective practices. Active frost protection methods were studied further by Poling (2008) in North Carolina. The author concluded that wind machines tend to be the most cost-effective investment in areas prone to white frosts and over-vine sprinkling systems are more effective against black frosts.

More recently, research initiatives have focused on the development of and experimentation with natural or chemical components. The exogenous application of abscisic acid (ABA) at appropriate times preceding the occurrence of spring frosts, for example, has been studied as a practice to delay budbreak (Hellman et al., 2006; Li & Dami, 2016). Promising results show that foliar applications of ABA at a concentration of 400 mg/L increase freezing tolerance in 'Pinot gris' grapevines. Abscisic acid is involved in the dormancy of grapevines as it is metabolized upon endodormancy release (Kovaleski & Londo, 2019; Noriega & Pérez, 2017; Vergara et al., 2017; Zheng et al., 2015). Nevertheless, these results and others from the plant science community are not conclusive regarding the role of ABA in dormancy maintenance, dormancy release, and budbreak (Zhang et al., 2015). The development and application of chemical components such as surface and systemic cryoprotectants have also been considered for grapes (Dami & Beam, 2004) and other crops (Howell & Dennis, 1981). Examples of cryoprotectants are solutions enriched with potassium ions, proline, glycerol, and antifreeze proteins—potentially affordable products capable of mitigating cold stress (Fuller et al., 2003; Jahed et al., 2023).

A range of other sprayable products also have been tested on a trial-and-error basis by practitioners and through controlled experiments at research institutions. While growers seem to be trying to adapt existing products formulated for other purposes to reduce cold stress in grapevines, researchers are meticulously attempting to design sprayable formulas based on a refined understanding of plant physiology. Due to the absence of definitions applied to product categories, sprayable products aimed to mitigate frost damage may encompass hormone-based, cryoprotectant, chemical, and mineral solutions.

The present article uses a small but representative sample of U.S. grape growers to assess their perceptions regarding regional susceptibility to spring frosts and production loss, as well as their adoption rate and satisfaction levels toward existing management practices. This article characterizes the sample of respondents based on their location, types of grapes grown, operation size, production value, application of the harvested fruit, and basic sociodemographics. Extension agents may use our model to characterize growers in different production hubs across the country, measure how the risk associated with spring frosts is perceived, raise awareness for alternative mitigation strategies, and assess the feasibility and acceptance of certain practices with regional growers.

MATERIALS AND METHODS

We distributed a survey on growers' perceptions towards existing mitigation strategies via email using a network of Extension agents and through DTN, a reputable marketing research company that maintains a panel of growers interested in engaging in survey studies. The target population was commercial grape growers with existing operations in the United States. Two selection criteria needed to be met by interested respondents before accessing the survey. Besides consenting to participate in a research study, recipients of the survey had to indicate that they were adults over the age of 18 years old and responsible for production and use decisions. In total, 66 growers met the selection criteria and provided valid and usable answers. The data collection happened between March 13 and April 28, 2023.

For data collection, we relied on survey research methodology (Fowler, 2014) to ask U.S. growers about their views and beliefs about spring frost and mitigation strategies. Survey research methods comprise data collection from answers provided by a sample of individuals (Check & Shutt, 2012). We used a Qualtrics online survey instrument that was pre-tested and validated by industry stakeholders. This study was reviewed by the Office of Responsible Research Practices at Ohio State University and determined exempt from regulatory provisions concerning the protection of human subjects (study number 2023E0195). The complete survey instrument is available from the researchers upon request.

We built our analytical model using strategic marketing concepts related to the buying decision process (Kotler & Keller, 2016). The process postulates that buyers typically pass through five stages when in the market: (a) problem recognition, (b) information search, (c) evaluation of alternatives, (d) purchase decision, and (e) post-purchase decision. We used the buying decision process as a framework for guiding our analytical approach.

In the case at hand, the buying decision process suggests that only grape growers who recognize spring frost as an issue will search for methods to mitigate the negative impact on production. Once they become educated on alternative strategies to reduce cold stress in grapevines, growers will turn to self-evaluations or guided evaluations and will prioritize the strategies according to constrained resources and to the best of their evaluation capabilities. Sequentially, the buying decision occurs. Experiences accumulate over time through use, leading to an implicit satisfaction level.

Post-purchase decisions are conditional on accumulated satisfaction. Low satisfaction levels with a given mitigation strategy may trigger a new round of information search and evaluation of alternatives. High satisfaction levels lead to recurring purchases and prevent the entry of new mitigation strategies.

Using the buying decision process as a conceptual framework, we queried growers on their perceptions of *susceptibility* to spring frosts and the *frequency* and *severity* of occurrences. Answers to these questions led to variables treated as proxies for problem recognition. Participants were also asked whether they were aware of nine alternative mitigation strategies. In our model, *awareness* serves as an indicator for information search. Our approach unfolded with the estimation of adoption rates for each mitigation strategy examined. *Adoption* is assumed to reflect purchase decisions, with the chosen strategy ranked first in the growers' evaluation stage. Finally, the survey instrument and posterior analysis turned to growers' *satisfaction* with the mitigation strategies they adopted. We use satisfaction levels and growers' interest in learning more about certain strategies to discuss development opportunities for promising technologies.

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS

Recognizing the limitations that small samples impose on survey-based studies, we focus on reporting descriptive statistics, perception trends, correlations, and multiple regression results. Advanced statistical methods measuring causal effect relationships aiming to explain the probability of mitigation strategy adoption, for instance, require a more robust dataset. Nevertheless, the results obtained from the present effort may be useful to inform Extension agents and practitioners interested in grape growers' perceptions of spring frosts and mitigation strategies.

Table 1 summarizes the operations' characteristics and business information reported. Most respondents operate in California (84.4%) and dedicate themselves to producing *V. vinifera* grapes (73%). In addition to those in California, growers from the states of Washington, Oregon, Michigan, Ohio, Pennsylvania, and New York provided valid and usable responses. Native (*V. labrusca*) and table cultivars ranked second and third in sample participation and acreage, respectively. Interspecific hybrid cultivars were the least represented in the sample. Compared to national statistics, our sample marginally underrepresents the importance of the Californian grape industry, which accounts for over 95% of the national production in volume (U.S. Department of Agriculture (USDA), 2022).

The size of operations included in the sample ranges from small (< 4 acres) to large (>100 acres), with a relatively uniform representation. Operations of 12 acres or less account for 38% of the sample, whereas operations with 50 acres or more represent 30%. As expected, the same applies to production value. While the production value mode lies above $200,001 annually, operations with production value below $20,000 represent 23% of the sample. Operations with production value between $20,001 and $200,000 per year add to 40% of the sample. Sampled operations have been in uninterrupted activity for 21 years, on average. They employ on average four full-time workers and 21 seasonal workers in a regular year.

Most growers report selling their harvest (85%, n=56). Winemakers represent the most common type of buyer, followed at a distance by packers and brokers. On average, 76.9% of the sold production is processed into wine at a place other than where the grapes were grown. Other processing accounts for 8.1% of the production sold, whereas packers and brokers take approximately 13.2% of the sales. Our sample does not include operations that run direct sales (e.g., farmers markets, pick-your-own) or sell directly to retailers or institutional buyers. The second most common destination for harvested grapes is internal processing. A share of 29% (n = 19) report using their production for fermentation and manufacture of food items (e.g., raisins). A few respondents report personal consumption or sharing fruit with friends and acquaintances (17%, n = 11).

SUSCEPTIBILITY, FREQUENCY, AND SEVERITY

Initial results indicate that most operations have experienced vineyard damage caused by spring frost (53 out of 66 valid responses, or 80.3%). Without further investigation, one may infer that there is demand and a potential market for management practices and agricultural inputs to mitigate the adverse effects of spring frosts. Our survey results, nevertheless, allow for a more comprehensive understanding of the potential demand. Over one-third of the sample (34.8%, n = 23) considers their regions highly susceptible to spring frost, suggesting that growers foresee additional challenges in the future. When asked about frequency and severity, 45% of the sample (n = 30) indicated that spring frosts occur once a year or more frequently. When frosts happen, 36.4% of growers (n = 24) perceive the impact as highly or critically severe, with the potential to cause a 50% or more crop loss.

Combining growers' answers to the susceptibility, frequency, and severity questions yields useful insights. Positive correlations are observed between susceptibility and frequency ($\rho_s = 0.46$), susceptibility and severity ($\rho_s = 0.59$), and frequency and severity ($\rho_s = 0.13$). The coefficients for the Spearman correlation analysis between susceptibility and frequency and susceptibility and severity are statistically significant at a 5% level. These results indicate that growers' perception of regional susceptibility to spring frosts increases

Table 1. Operations' Characteristics and Descriptive Business Information

Discrete Variables	Sample share	Count	Acreage share
+ Location of operation			
- CA	86.4%	57	
- Elsewhere	13.6%	9	
+ Grape type			
- vinifera	73%	48	72.5%
- native	20%	13	18.8%
- table	8%	5	6.4%
- hybrid	6%	4	2.3%
+ Operation size			
- Less than 4 acres	14%	9	
- Between 4.1 and 12 acres	24%	16	
- Between 12.1 and 25 acres	9%	6	
- Between 25.1 and 50 acres	23%	15	
- Between 50.1 and 100 acres	9%	6	
- More than 100 acres	21%	14	
+ Production value			
- Less than $8,000	6%	4	
- Between $8,001 and $20,000	17%	11	
- Between $20,001 and $50,000	17%	11	
- Between $50,001 and $100,000	8%	5	
- Between $100,001 and $200,000	15%	10	
- More than $200,000	38%	25	
+ Application of harvested fruit			
- Sell	85%	56	
- Transfer internally for processing	29%	19	
- Share with friends	8%	5	
- Personal consumption	9%	6	
Continuous variables	**Average**	**Unit**	**5 and 95 percentiles**
+ Years in business			
- Uninterrupted activity	21.4	years	[6; 30]
+ Number of employees			
- Full-time	4	workers	[1; 12]
- Seasonal	21	workers	[1; 80]

with greater frequency of occurrences and greater severity of frosts. The Spearman's coefficient for frequency and severity is not statistically significant, indicating that frequent spring frosts do not imply severe crop losses or vineyard damage.

Furthermore, a multiple ordinary least squares regression of frequency and severity on perceived regional susceptibility returns statistically significant estimates for both parameters (see Table 2). The severity effect on susceptibility ($\beta_{sev} = 1.25$) is greater in magnitude compared to the frequency effect ($\beta_{fre} = 0.86$), suggesting that growers' perception of susceptibility to spring frost injury and yield loss is influenced by the severity more so than the frequency of occurrences. From a behavioral perspective, these results corroborate the growing post-traumatic stress disorder (PTSD) literature. In the psychology field, PTSD symptoms are clinically assessed in terms of severity and frequency of experiences (Foa et al., 1993; Foa et al., 1997) using a protocol that resembles our questions. Our results suggest that growers' experiences with

Table 2. Multiple Regression Results—Coefficients, Standard Errors, and Statistical Significance

Parameter	Coefficient (standard errors)	P value
Severity	1.248 (0.192)	0.00
Frequency	0.859 (0.178)	0.00
Constant	omitted	

Note. Standard errors in parentheses. N = 66. $R^2 = 0.896$.

severe spring frosts impact their perceptions of regional susceptibility with more emphasis than frequent spring frosts.

Among growers who experienced grapevine injuries in the past due to spring frost (53 out of 66 respondents), 22.7% of the sample ($n = 15$) perceive their regions as highly susceptible to severe frosts (causing 50% crop loss or more). Growers perceiving high susceptibility to spring frost and medium severity (crop loss between 25% and 50%) represent 10.6% ($n = 7$) of the sample. Growers who assign medium susceptibility to their locations but consider that spring frosts are of medium or high severity combined add to 24.2% of the sample ($n = 16$). Together, these three segments of growers (57.6% $n = 38$) may be interpreted as an immediately accessible market for management practices and agricultural inputs capable of reducing the negative effects of spring frosts in vineyards.

GROWERS' AWARENESS AND USE OF MITIGATION STRATEGIES

In addition to asking grape growers to estimate the risk of spring frost damage, the survey asked grape growers about their awareness of and previous experience with mitigation strategies and their level of satisfaction with the strategies implemented. Table 3 summarizes the findings and organizes the strategies according to the overall market awareness, adoption, and satisfaction. The color codes distinguish how the strategies rank within each parameter analyzed, ranging from the highest (green) to the lowest level (red).

The use of over-vine sprinklers ranked first in the satisfaction analysis. It ranked second in growers' awareness and second in terms of adoption rate. Considering that this technique has the highest satisfaction average score among the strategies analyzed, one may infer that growers employing it to mitigate injuries to vineyards are likely to keep doing so instead of adopting a different strategy. U.S. growers also seem to agree with results from Trought et al. (1999), which conclude that preventative measures are most effective against vineyard frost damage. Properly selecting farm sites that are less prone to frosts ranks second in growers' satisfaction and first in share of adopters. Proper cultivar selection ranks third in growers' satisfaction score and fourth in terms of growers' awareness and adoption.

It is worth noting, nevertheless, that the top three mitigation strategies on average ranked below optimal satisfaction scores (6 or 7). This indicates that over-vine sprinklers, vineyard site selection, and cultivar selection are strategies that can still be refined to better serve the needs of growers in reducing crop losses caused by spring frosts. Alternatively, new inputs can be developed to meet the needs of growers and reach higher satisfaction levels.

Results on the use of wind machines, heaters, and helicopters deserve attention. While representative shares of growers seem to know of these mitigation strategies, adoption and satisfaction scores are low, disconnected from the relatively high levels of awareness. Factors such as capital costs, technical effectiveness, and the presence of suitable providers in the region could be investigated further as plausible reasons preventing adoption.

Survey results further suggest that two mitigation strategies are in the incipient stages of market development. Sprayable products and cryoprotectants rank last in growers' awareness. This is most likely because few (or no) products are available commercially or have been positioned by developers to mitigate spring frost damage. A second possibility is that growers are failing to access resources and information regarding the products that are commercially available within these categories.

Although sample size prevents us from testing whether accessing technical information is a significant factor in explaining growers' adoption of sprayable products, answers to two closing questions shed light on the matter. A substantial share of growers (61%, $n = 40$) indicated an interest in reading the results of a study conducted at Ohio State University, where researchers compared the efficacy of budbreak-delaying products. The same proportion of the sample (61%, $n = 40$) stated interest in learning more and considering new sprayable products to delay budbreak . Together, these results suggest that access to technical information may be critical to motivate the adoption of techniques and products about which there is currently little awareness. The apparent knowledge gap and desire to learn may represent an opportunity for developers and agricultural input companies to explore new products capable of reducing vineyards' susceptibility and exposure to spring frosts.

CONCLUSION

A high share of sampled growers reported facing crop losses due to spring frosts (80.3%, $n = 53$) in the past. Of those, 38 growers (57.3% of the sample) perceive their regions as highly or moderately susceptible to spring frosts capable of causing at least 25% production loss. In addition, 45% of

Table 3. Growers' Awareness of, Adoption of and Satisfaction with Spring Frost Mitigation Strategies

Mitigation strategies	Awareness level		Previously or currently adopting		Satisfaction, average
	Share of aware growers	Count (n)	Share of adopters	Count (n)	score (1-7 rating scale)
Use of over-vine sprinklers	61%	40	26%	17	5.25
Site selection	45%	30	29%	19	5.11
Growing late budding cultivars	41%	27	17%	11	4.82
Double-pruning sensitive cultivars	36%	24	24%	16	4.38
Use of wind machines	67%	44	18%	12	4.17
Use of sprayable products	11%	7	3%	2	3.5
Application of cryoprotectants	15%	10	5%	3	2.67
Use of heaters	39%	26	2%	1	1
Use of helicopters	33%	22	-	-	-

growers report spring frosts occurring at least once a year in their region.

Growers reported varying degrees of familiarity, experience, and satisfaction with vineyard management strategies to mitigate the negative impact of frosts. Over-vine sprinklers, proper farm site selection, and adoption of late budding cultivars stand as the three strategies with the highest satisfaction scores. The computed average scores, however, are consistently below optimal scores in our rating scale (e.g., 1 [*ineffective strategy*] to 7 [*highly effective strategy*], suggesting the opportunity for improvement of existing practices or the emergence of new methods. This is a critical finding. The results obtained from this study can motivate further engagement between Extension agents and product development groups to refine existing technologies, test new practices, or elaborate new protection methods.

The results allow us to conjecture that new technology categories, such as sprayable products and cryoprotectants, can potentially fill the satisfaction gap. The low level of awareness and small number of adopters in these technology categories, relative to all other mitigation strategies examined, serve as indications that sprayable products and cryoprotectants are developing technologies. Low satisfaction rates demonstrate that existing products in these categories perform below established methods to mitigate cold stress. Nevertheless, a significant share of sampled growers is interested in learning more about new sprayable products to delay budbreak (61%, n = 40), reflecting the need for continued research and development efforts from agricultural input suppliers in this category. These results highlight the opportunity for Extension agents and growers to design on-farm research protocols for experimenting with prototype products under development through land grant universities, research institutes, and private corporations.

Although survey answers were sufficient to draw patterns in grape growers' opinions and behaviors, the small sample size prevented us from studying causal-effect relationships among important variables. Therefore, the results of this work must be used with discretion.

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