Health, Safety and Disaster Preparedness in the Washington State Wine Industry

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Abstract

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The wine industry in Washington state is a high-hazard industry that exposes workers to a variety of physical, chemical, psychosocial, and natural hazards. However, literature on the impact of these hazards on this worker population is limited. This thesis presents a narrative literature review of hazards, exposures, health effects, and controls that impact the industry's workers. Findings reveal that winery and vineyard workers experience work-related musculoskeletal disorders (WMSDs), accidents, injuries, and fatalities. Workers are exposed to pesticides, heavy metals, noise, hazardous atmospheres, and heat. Administrative and engineering controls are recommended for many of these hazards. There is limited information available on the impact of natural hazards and disasters on wine industry workers, but the industry has been impacted by earthquakes, fires, and heat events in the past. Factors for improving emergency preparedness and industry resilience include stakeholder engagement, written emergency plans, organizational safety culture, resources, and knowledge sharing. Future occupational safety and health (OSH) research in this industry should focus on the interaction of OSH and natural hazards, natural hazard risk perceptions, and production of emergency preparedness materials based on industry needs. This thesis also characterizes wine industry OSH in Washington state using workplace inspection data from the Department of Labor and Industries (L&I) Division of Occupational Safety and Health (DOSH). Findings reveal that vineyards had frequent citations related to accident prevention programs (APPs), eye protection, pesticide application records, and safety meetings. Wineries also had frequent citations related to APPs and safety meetings. Wineries had other frequent citations related to medical evaluations and programs for respirators, heat-related illness training that is available in a language that employees understand, portable fire extinguisher testing, emergency washing facilities, confined space programs, and chemical hazard communication programs. These OSH violations highlight critical points for intervention and educational materials for the Washington state wine industry. These critical points also suggest a lack of preparedness for natural hazard events that could result in negative health outcomes for workers.

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Aim 1: Review of OSH Wine Industry Literature

The purpose of this aim is to conduct a narrative literature review, synthesizing known occupational health and safety hazards and controls specific to the wine industry's primary components of vineyards and wineries. Further, the review includes OSH literature specific to natural hazards within the industry. For this thesis, the definition of wine industry includes vineyards and wineries and excludes any other worksite involved in the production and distribution of wine products. Vineyard and winery workers perform distinct tasks that expose workers to a variety of hazards. Because they are performing different tasks, workers at each component of the industry are exposed to hazards in distinct ways and require different types of training and controls for those hazards. At a vineyard, workers maintain crops and primarily work outdoors, making them agricultural workers.[1] On the other hand, winery workers manufacture alcoholic beverages using fermentation, making them beverage manufacturing workers.[2] The background of this aim provides context for the narrative literature review and describes common work tasks and processes within the wine industry's distinct sectors: vineyards and wineries.

Background

Vineyard Process Overview

The winemaking process has multiple phases. First, wine grapes are grown in a vineyard. The processes of wine grape growing, vineyard management, and wine grape harvesting are called viniculture. In Washington state, the growing season typically runs from April 1st to October 31st,[3] but vineyards are maintained year-round. The variety of grape grown depends on the final wine product, which is often selected based on market demand and environmental conditions. Most grapes grown in Washington state are varieties of a single species.[4] Environmental factors that influence what grapes are suitable to be grown are climate, topography, soil type and quality, water availability, and nearby use of herbicides containing phenoxy-type active ingredients, as pesticide drift is a concern as grapes are extremely sensitive to this herbicide type.[3] Prior to planting, trellis systems must be identified and erected for training grape vines. There are a variety of systems for grape trellising and selection is based on the relationship between mechanical pruning and harvesting, irrigation systems, grape type, vine vigor, and the market.[5] Trellis systems vary in terms of overall height, number and location of wires, use of horizontal wire spreaders, and use of extendable flexible arms, made of metal or wood.[6] These trellises are erected in rows in order to accommodate mechanical and manual pruning and harvesting.[7] While grapes are growing, canopy management and pruning are important steps to achieve maximum vine production and quality.[5,6,8] Canopy management and pruning are necessary to eliminate damaged, diseased, or unproductive vines, open the canopy to sunlight, air, and pesticides.[9] It also facilitates ease of vine management for pruning, thinning and harvest.[9] Grape vines can be pruned and managed either mechanically or manually, and most vineyards in Washington use a combination of the two.[10] The type of trellis and canopy influences the type of pruning and harvesting possible and therefore changes how the worker interacts with tools and machinery. Depending on the location of the vineyard, concerns regarding canopy management vary depending on the environment. In Washington, vineyards in maritime climates are concerned with controlling vegetative growth and increasing exposure to sunlight, while those inland may need to protect their vines from too much sunlight exposure.[9] In addition to canopy management, the vineyard floor, irrigation and water, pests, and vine diseases must be managed.[4,11] Soil health in vineyards describes the soil's ability to resist disturbances such as large rain or wind events, improve nutrient efficiency, minimize soil losses, and grow a healthy crop.[12]

Diseases, weeds, and pests in the vineyard are usually controlled with integrated pest management strategies, including biological and chemical tools.[4] These strategies are similar for all grape varieties; however strategies may vary based on geographic location, such as Western vs. Eastern Washington.[4] Common diseases in the vineyard are botrytis bunch rot, powdery mildew, sour rots, armillaria root rot, crown gall, Phomopsis cane and leaf spot, grapevine leafroll disease, and trunk viruses.[13] Common pests include cutworms, mealybugs, mites, cane borers, scale, thrips, stink bugs, light brown apple moths, and nematodes.[13] The order of severity of the economic impact of pests in Washington state are diseases, insects and mites, nematodes, weeds, and vertebrates.[4] Some chemical pesticides and herbicides used to eliminate these pests and weeds include spirotetramat, glyphosate, glufosinate ammonium, paraquat, thiamethoxam, spinosad, cyprodinil and fluazifop.[4] When a chemical pesticide is required, vineyard workers choose a dose that both manages the target pest while minimizing environmental and worker health impacts.[4] The type of pesticide used depends on the target pest and the crop stage of the wine grape. Chemical pesticides are most commonly applied by spraying.[14(p25)] Sprayers can be manual and held by hand or on a backpack worn by a worker, or they can be mechanical and attached to a tractor or trailer. Before spraying, the pesticide must be mixed and loaded into the sprayer tank. Pesticides are commonly mixed with water and adjuvants,[15] which are additives that reduce drift, reduce foaming, increase deposit, control acidity, or improve penetration.[16] In general, the industry in Washington state is moving away from chemical pesticides in the vineyard and natural pest management methods are becoming more common. One reason to eliminate dependency on chemical pesticides is the intensive health monitoring required for use of cholinesterase-inhibiting pesticides due to their high level of toxicity.[17] Another reason is to conserve natural predators and beneficial organisms present in vineyards. Some methods that do not rely on synthetic chemicals include flame weeding, where a propane tank generates heat to destroy weeds.[18] Other methods include the use of cover crops, mulches, mechanical cultivation, and organic herbicides.[19] Cover crops, for example, can contribute to habitat for beneficial organisms and reduce or eliminate the need for chemical pesticides altogether.[20]

Once wine grapes have achieved the desired ripeness, they are harvested. Close monitoring is critical for a successful and quality wine grape harvest.[21] Harvest season in Washington state can last for up to two months, typically between the months of August and October.[22] In 2022, the harvest season was just getting started in some areas by September 14, which is about 2 weeks later than average.[23] The timing of harvest is determined by the ripeness of the grape fruit. Ripening is driven by temperature as it controls the conversion of acids into sugars.[21] There are desired sugar levels, also called Brix, and pH thresholds for different wine grape and wine varieties. The Brix measures the potential alcohol content of a wine.[24] Most Washington wine grapes are mechanically harvested and are immediately transported from the field to a processing facility.[4] Mechanical harvesting involves large tractors that follow the trellis rows hitting grapes from their vines into bins. Manual harvesting involves a worker holding shears, usually pneumatic or electrically powered, and clipping wine grape bunches into bins that the worker carries. Mechanical harvesting reduces manpower and time required for harvesting, but can lead to excess damage to the grapes and canopy, which makes canopy management difficult later on.[10,25] For this reason, higher quality wines may be picked by hand so only the healthiest and ripest grapes are harvested, however the difference in quality is debated by some industry professionals as technology has advanced.[26] Some wine types require grapes to be harvested manually. Manual pruning and harvesting also drives up the price of a wine. Small vineyard operations may also depend on handpicking over mechanized harvesting. After wine grapes are picked, they are sorted to remove rotten or unripe fruit.[25] Some mechanical harvesters have built in sorting and destemming systems,[26,27] eliminating those steps in later winemaking processes. Finally, the harvested grapes are weighed and sampled before delivery to the winery for wine production.[21] This step can also help growers determine their yield per vine and make decisions about vineyard management.[21]

Winery Process Overview

The next phase of winemaking takes place at the winery, where grapes harvested from a vineyard are processed into wine via fermentation.

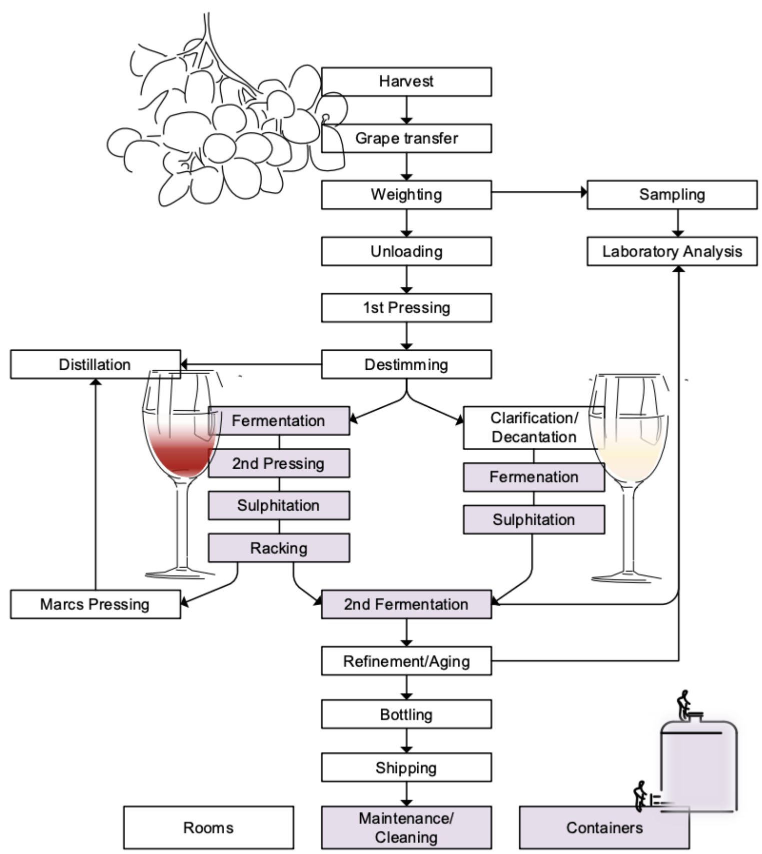

Figure 1. Winemaking process diagram from harvest to distribution. Processes highlighted in purple are where confined space hazards are introduced. Figure taken directly from Mosconi, S et al. (2022). A structured approach to support the definition of confined space entry and working procedures in the wine industry. Transportation Research Procedia, 67, 109–117. https://doi.org/10.1016/j.trpro.2022.12.041. Creative Commons CC-BY-NC-ND.

The following steps do not always occur in the order presented in Figure 1. The order of steps presented in this section are to illustrate a simplified overview of the red winemaking process, but the steps are highly dependent on the final wine product, the state of the grapes when they arrive at the winery, and the equipment and machinery present at the winery. For example, most white wines are never destemmed.[28]

After harvest and sorting, wine grapes are transferred from the vineyard to a winery for production into bottled wine.[28] Usually, the grapes come from vineyards not owned by the winery. A winemaker will often visit the vineyard throughout the growing process to monitor grapes and assist with sampling to ensure the desired Brix and quality.[29] Boutique wineries may have estate vineyards where they grow their own grapes.[29] Agricultural trucks with trailers transport the grapes where they are typically received in a reception area.[30] The reception area has many moving parts and vehicles and the expectation is that equipment used in this area is safe, decreases physical discomfort for the worker, and has the expected processing capacity without damaging the wine grapes.[30] Wineries often purchase a specific tonnage of a grape variety from a vineyard.[29] Similar to sampling at the vineyard to determine harvest time, sampling at the winery helps winemakers determine the Brix of the grape.[28] Wine grapes are then unloaded using forklifts and bins or gondolas and dumped into conveyors or hoppers for the next steps of the process.[28,30] Hoppers usually have augers built into the bottom for gently moving grapes into destemmers, pressers and crushers.[31]

Depending on the type of wine, wine grape destemming, pressing, and/or crushing often occur at the same time.[28] These processes are mechanical, using specialized heavy machinery, and usually occur outdoors.[32] To eliminate these steps, sometimes wineries will purchase just the juice for further processing. Mechanical harvesters can also eliminate the need for destemming. Destemming is the process of removing branches and leaves from the grape cluster and separating the grapes, which affects flavoring, color intensity, and alcohol and acid content.[33] Some wine varieties skip the destemming step altogether, keeping stems and clusters intact. Crushing breaks down the grape to allow the juice, pulp, and seeds to mix with the grape skins, while pressing separates the grape juice from fiber and other solids from the grape fruit.[34] Destemming, crushing and pressing can occur at the same time, or be separated by hours or days depending on the wine variety.[34] Crushing and pressing can be done in batches or continuously, where grapes are fed endlessly into the machine. The main difference between crushing and pressing is that crushed grapes ferment with the solids intact, while pressed grapes ferment only with the grape juice, but sometimes these processes are done simultaneously.[34] Leaving the skins in-tact during fermentation contributes to the color of red wines.[34] The juice and other solids left after destemming, crushing, and pressing is called grape must[35] and the leftover solid skins, seeds, and stems is called pomace.[36] A second pressing may occur again at later stages of the winemaking process, usually with some additives and using the leftover pomace.[36]

For red wine, the next step is fermentation. Wine fermentation is the process of converting the grape must into an alcoholic beverage using different types of yeast. With the help of oxygen, yeast transforms the sugars into ethanol and carbon dioxide (CO_2).[28] Grape must is transferred from the last step into stainless steel tanks or an open wooden vat. Yeast is added, the ideal temperature is reached, and the must is left to ferment for days to weeks.[28] Because the pomace tends to rise to the surface during red wine fermentation, punch downs are necessary. A punch down is when a winemaker breaks up the cap of pomace that forms over the fermenting wine, requiring a worker to orient themselves over an open tank and use a large paddle to punch down and break through the cap.[37] This allows the grape juice and skins to stay in contact. The worker will use a ladder or catwalk to get above the tank. A punch down happens 1 to 3 times a day. Larger tanks may use mesh screens that push down through the cap.[37] The fermenting must is continuously sampled throughout this process. Finally, the fermented must may be pressed a second time to separate the pomace from the liquid, producing a lower quality product than the first press.[38]

Sulfitation occurs after the second pressing. Sulfites are naturally produced by yeast during fermentation and additional sulfur dioxide (SO_2) can be added to protect and preserve wine by inhibiting bacterial growth and oxidation.[39] It can be added in gas or liquid form or in powder form as potassium-metabisulphite or potassium-bifulphite.[39] Other additives may be added at this stage to influence flavor. Next, the fermented juice is racked. The fermented juice is transferred to another container via siphoning or pumping to remove sediment and dead yeast.[40] This is an essential step because it improves flavor and may be performed up to 3-times to ensure full removal of sediment.[40] When racking, wine is transferred to a clean container, such as an oak barrel or carboy.[40] Sometimes the racked wine will also be passed through a filter.[41] After the first racking, a secondary fermentation takes place and the leftover sugars from the first fermentation are transformed into alcohol.[41] This is distinct from the first fermentation as the wine will remain in oak barrels or carboys rather than be transferred back to a tank or vat.[42] Secondary fermentation can also include malolactic fermentation where malic acid is transformed into lactic acid using bacteria, affecting the flavor.[43] Racking usually occurs after each fermentation.[44]

Once all stages of fermentation and racking are complete, the final step in winemaking is aging and refinement. Not all wine varieties are suitable for aging, but for some it improves a wines flavor and longevity.[45(p101)] This can take anywhere from 6 to 30 months and usually occurs in barrels.[45(p101)] Barrels are often racked and stacked by groups of 2 or 4 in a storage area. They are stacked vertically, up to 8 barrels high, using a forklift to provide easy access for topping off, degassing and sulfur adjustments.[46] Some wine in the container will evaporate, creating a headspace, and the container will need to be topped off with more wine or water to prevent oxidation and spoilage.[47] Degassing removes trapped CO_2 from the headspace.[48] There is a hole on top of each barrel so a winemaker can access the wine and make the necessary additions. An inert gas such as argon or nitrogen is used to move the wine through a hose[49] and the gasses are stored on-site in cylinders.[29] Proper humidity and temperature control limits the amount of evaporation that occurs.[49] Refinement in the final step before bottling, removing the remaining insoluble matter and can include filtration to mechanically remove unwanted particles.[50]

Before wine reaches the final customer, it is bottled in a bottling line. Operators control the different phases of the process.[51] This process varies depending on the bottling line equipment at the winery. Fully automating this process prevents contamination of the wine and reduces labor. The process starts with rinsing or blowing compressed air into the empty bottles to remove dust before loading them into a conveyor.[51,52] Then wine bottles are filled with wine, capped with corks, and labelled before being cartooned, placed on pallets, and finally wrapped for shipping.[51] The bottled wine is then transported to its destination before reaching the customer, which could be a tasting room, restaurant, warehouse, or store.

An ongoing process during winemaking is the maintenance and cleaning of storage tanks and other winery equipment. Proper sanitation is important for food safety and wine quality.[53] The level of cleaning necessary depends on the amount of grime leftover after the juice is transferred for racking. Regular cleaning using a pressure washer and warm water doesn't require a worker to enter the tank, they can stand above the tank and wash remaining pomace. However, if pomace remains on the tank walls after this mild cleaning, a worker will need to enter the tank to scrub the walls with a cleaner, phosphoric acid, or nitric acid, followed by an ammonia and hot water rinse, introducing a confined space and the hazards associated with use of chemicals in a confined space.[53] With proper maintenance cleaning, this level of cleaning only needs to occur once or twice a harvest season. Common cleaners are caustic soda (NaOH), soda ash (Na_2CO_3), trisodium phosphate (TSP), and sodium metasilicate.[53] Common sanitizers include hot water at 180 F or quaternary ammonium compounds combined with peroxyacetic acid.[53] Barrel and bottling room equipment also require cleaning and sanitizing, but this can be performed without entering the space or machinery.[29]

Due to the tasks wine industry workers perform using chemicals and tools, the way workers interact with a variety heavy machinery and industrial vehicles, the natural gaseous byproducts generated by the fermentation process, workers in outdoor environments or indoor confined spaces, there are clear worker health intersections in both vineyards and wineries. The industry also relies on temporary and volunteer workers, although it is unclear to what extent. The tasks performed by workers introduce a wide variety of occupational hazards, from physical to biological to chemical, and even psychosocial. These worksites are considered separately because despite their similar hazards, the way workers at each site interact with the hazard is distinct, resulting in different types and severities of exposures, health outcomes, and control needs. Despite the highly hazardous nature of the industry, there is a lack of systematic and comprehensive review of OSH literature pertaining to the impact of hazards on these worker populations. In order to address this gap, this thesis presents a narrative literature review synthesizing known occupational health and safety hazards and natural hazards specific to the wine industry's primary components of vineyards and wineries.

Methods

A narrative literature review was conducted to summarize prior research and grey literature covering occupational health and safety hazards and controls in the wine industry. Based on this research objective, a series of search terms were generated to identify relevant grey and peer-reviewed literature in Google Scholar and the UW library search. The search terms were refined based on preliminary searches, field experience, and guidance from UW librarians. Final search terms were placed into 4 categories (Table 1). Searches always incorporated one term from categories 1 and 2, and usually incorporated one term from either category 3 or 4, to identify articles for review.

Table 1. Search terms by category			
Category 1: industry component	**Category 2: study audience**	**Category 3: occupational hazard**	**Category 4: natural hazard**
Vineyard	Worker	Confined space	Wildfire
Winery	Occupational health	Heat	Flood
	Occupational safety	Noise	Emergency
	Health and safety	Pesticide	Climate change
		Chemical	Smoke
		Psychosocial	Disaster
		Ergonomic	Earthquake

Table 1. Search terms for wine industry OSH and natural hazard literature review.

Inclusion and Exclusion Criteria

Articles were included if they were available in English and explored occupational safety and health (OSH) at wineries or vineyards. Both international and national articles and grey literature were included due to the limited availability of research on this topic. Articles were included if they focused on occupational hazards, worker health outcomes, or the impact of natural hazards on vineyard or winery workers. Articles were excluded if they focused on food safety, sensitization to grapes, the health effects of drinking or tasting wine, soil or wine quality, environmental or community exposure to industry occupational or natural hazards (such as pesticide drift), the economic and structural impacts of natural hazards, or if they focused on a related or more generalized industry. Articles were initially identified by reviewing titles against the inclusion and exclusion criteria. Selected articles' abstracts were then reviewed against the inclusion and exclusion criteria before reviewing the article in its entirety. In an additional snowball sampling approach, the reference lists of included articles were compared against the inclusion criteria to determine additional relevant articles.

The following elements were abstracted from the included articles:

- Study location
- Occupational or natural hazard
- Control/intervention
- Results
- Discussion
- Limitations
- Future research recommendations

Abstracted information was synthesized by occupational and natural hazards and key findings were summarized.

Table 2.	**Number of search results**		**Number of included articles**	
Database	**Total**	**Pages reviewed**	**After title review**	**After abstract review**
Google scholar	1231400	First 5	45	11
UW library search tool	365	All	103	33
Snowballed			25	8
Total included			**173**	**53**

Table 2. Number of search results and articles resulting from literature review search terms.

Searches were conducted in January 2023. In total, 173 articles were identified as meeting the inclusion criteria during the title review (Table 2). After reviewing those article's abstracts, 103 were excluded. 53 articles were reviewed in their entirety and included in the final literature review. From the reviewed papers, key findings were identified from the discussion, key finding, and conclusion sections, and were summarized.

Results

The results of this narrative literature review describe general occupational hazards in wineries and vineyards and the impact of natural hazards on the industry's workers. A summary of the key findings from the collected literature is presented in Table 3.

Table 3. Summary table of narrative literature review results.

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
Wakula et al.[54]	2000	Germany	Study	Ergonomic	Vineyard	• Cutting grapevines requires postures that can cause WMSDs in the trunk and wrist • Results varied by tool and task characteristics
Çakmak and Ergül[8]	2018	Turkey	Study	Ergonomic	Vineyard	• Grip strength decreases with age • Type of pruning shear affects the grip strength of the dominant hand • Grip strength is negatively correlated with ambient temperature in both hands
Balaguier et al.[55]	2017	France	Study	Ergonomic	Vineyard	• Worksite adapted physical activity programs are a promising approach to prevent low back pain
Duraj et al.[56]	2000	California	Study	Ergonomic	Vineyard	• Smaller picking tubs with grip attachments, lightweight picking tub frames, and alternative picking-knife handles reduce pain symptoms, slightly reduce productivity, and are favored by workers
Grimbuhler and Viel[57]	2018	France	Study	Other physical or ergonomic	Vineyard	• Coveralls used for pesticide exposure control cause additional physiological burden in humid conditions depending on the task • Recommends compromises for PPE selection considering physiological costs and protection, the crop grown, and the environmental conditions encountered
Bernard et al.[58]	2011	France	Study	Ergonomic	Vineyard	• Pruning tasks are repetitive and cause strain on the hand-wrist system

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						• Ergonomic shears lower force exertion and reduce the frequency of awkward wrist postures
Roquelaure et al.[59]	2001	France	Study	Ergonomic	Vineyard	• 1/3 of employees develop hand paresthesia (HP) and most recover without medical treatment after the pruning season • Risk factors include being female, overweight, payment on a piecework basis, and using traditional blade sharpening methods • Use of electric shears prevents HP
Copper at al.[60]	2021	Australia	Study	Ergonomic	Vineyard and winery	• Workers report experiencing lower back pain (56%), foot pain (36.7%), knee pain (24.6%), leg pain (21.3%), ankle pain (17.9%), hip pain (15.5%), toe pain (13%), and heel pain (11.1%) • The most popular footwear are elastic sided safety boots followed by high lace up safety boots with a side zip
Brumitt et al.[61]	2011	Oregon	Study	Ergonomic	Vineyard	• Half of migratory Latino workers experienced musculoskeletal symptoms (MSS) in at least one region of the body, primarily back • Workers who reported MSS were older than those who didn't
Vallone and Catania[51]	2014	Italy	Study	Noise	Winery	• Noise levels increase as the capacity of a bottling line increases • Legal noise exceedances occurred in all bottle capacity conditions – requiring use of PPE

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
Catania and Vallone[62]	2013	Italy	Study	Noise	Vineyard	• Highest noise levels were obtained by flail mowers and rototillers • Action level noise exceedances occurred in all incline conditions and all tractor tools – requiring use of PPE
OSHA News Release – Region 5[63]	2012	Wisconsin	Grey literature	Multi-hazard	Vineyard and winery	• Wisconsin winery received OSHA citations with a total monetary penalty of $71,280 • Citations covered fall hazards, LOTO, machine guarding, forklifts, lack of PPE and PPE assessment, SDS, and hazard communication programs
Grimbuhler and Viel[64]	2019	France	Study	Multi-hazard	Vineyard	• Developed a safety climate scale questionnaire • Influential dimensions of safety climate are management commitment, communication and feedback, rules and practices, and knowledge
Firstenfeld[65]	2005	California	Grey literature	Multi-hazard	Vineyard	• Leadership, commitment, and training important for safety • Safety bonuses encourage teamwork
WorkSafeBC[66]	n.d.	British Columbia	Grey literature	Multi-hazard	Vineyard and winery	• Provides guidance for identifying and managing hazards for small- and medium-size wineries • Emergency evacuation plans allow workplaces to make quick decisions to minimize injuries and damage
Gubiani et al.[67]	2009	Italy	Study	Multi-hazard	Vineyard and winery	• Developed a check list for assessing safety levels at a workplace based on risk frequency and seriousness of damage

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						• Machinery poses a high risk due to lack of guarding or unsuitable use • High risk areas include fuel tank and exhaust oil storage rooms, grape unloading area, and the workshop
Gubiani et al.[68]	2008	Italy	Study	Multi-hazard	Vineyard and winery	• Development of tool for assessing risk at a workplace • Identified emergency management as a problem area for worker safety
Youakim[69]	2006	British Columbia	Grey literature	Multi-hazard	Vineyard and winery	• Vineyard workers are exposed to work-related musculoskeletal disorders (WMSD) risk factors, pests, and pesticides with various health outcomes • Winery workers are exposed to hazardous atmospheres, and acidic wines with various health outcomes • Crude data indicates injuries are more common than illnesses
Anaya-Aguilar et al.[70]	2018	Spain	Study	Multi-hazard	Winery	• High risk areas include production areas and workshop • Highest risk task is machine operation • Highest accident risk is slip, trips, and falls • All workers should be trained for workplace emergencies and evacuations
Anaya-Aguilar et al.[71]	2022	Spain	Study	Multi-hazard	Winery	• Highest ranked OSH determinants include control of personal and collective protective equipment and training • Factors associated with these determinants are accident investigation,

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						coordinated health and safety measures, and signage
Sirio et al.[72]	2010	Italy	Study	Multi-hazard	Winery	• Safety should be incorporated in the design phase of a winery • Important design considerations include rules and equipment for fire prevention, workflow ergonomics and comfort, chemical storage, forklift access, anti-slip floor treatment, maintenance access, visiting personnel, and lighting
Gilinsky et al.[73]	2020	California	Study	Disaster	Winery	• Proximity to a recent disaster influences preparedness more than the age or size of a winery • Location, stakeholder involvement, and company culture contribute resilience
Gilinsky[74]	2020	US	Study	Disaster	Vineyard and winery	• Four concepts for organizational resilience: realizing a need for preparedness, building stakeholder support, securing resources and capabilities, and exemplifying best practices
Gilinsky Jr. et al.[75]	2020	US	Study	Disaster	Winery	• Wineries with larger annual case production perceive greater resilience than smaller production operations • Significant differences among managerial level preparedness perceptions
Cradock-Henry and Fountain[76]	2019	New Zealand	Study	Disaster	Vineyard and winery	• New Zealand earthquake caused damage to infrastructure • Resilience influenced by size, scale, and ownership structure of operation

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						• Developed framework to identify system-critical vulnerabilities to inform resilience development in the face of multiple stressors
Stimmell[77]	2010	Chile	Grey literature	Earthquake	Winery	• Chilean earthquake caused damage to storage tanks, wine barrels, and glass bottles • Earthquake striking before harvest minimized wine lost • No workers lost their lives due to time of earthquake
Brenner-Ambramovitch[78]	n.d.	California	Study	Earthquake	Winery	• After the 2014 Napa earthquake, winery management spoke to their employees about earthquake preparedness, changed the way they stacked barrels, and obtained additional first aid and medical supplies • Management was most worried about the loss of life or effect on employees and guests • Larger wineries had more preparedness measures
Anderson[79]	2022	California	Grey literature	Wildfire	Vineyard	• Vineyard workers continue to work during nearby wildfires
Chavez[80]	2022	California	Grey literature	Wildfire	Vineyard	• Vineyard workers lack hazard pay and disaster insurance • Request for community safety observers to monitor whether employers are meeting state and health safety regulations

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
Chavez and Swindell[81]	2022	California	Grey literature	Wildfire	Vineyard	• New program being considered to offer disaster insurance and hazard pay to farmworkers who work on evacuated land • Workers report working in wildfire smoke and in the vicinity of active fires
Digitale[82]	2015	California	Grey literature	Wildfire	Vineyard	• 15% of vineyards in Lake County were impacted by the Valley fire • Industry disrupted by workers who lose their homes and cannot find temporary housing
Jordan[83]	2017	California	Grey literature	Wildfire	Vineyard	• Foreign-born workers do not qualify for disaster aid and fires impact their ability to find temporary housing, causing these workers to leave the industry
Editor[84]	2017	California	Grey literature	Wildfire	Vineyard and winery	• Power outages impact production and tasting rooms but many wineries have generators • Employees' ability to come to work impacted • Vineyard land destroyed
St John and Boyles[85]	2008	California	Grey literature	Heat	Vineyard	• A 17-year-old pregnant worker died after collapsing from heat exposure • Employer had been cited in the past for not having a heat illness prevention program
Firstenfeld[86]	2008	California	Grey literature	Heat	Vineyard	• Combination of poor air quality from wildfires and high heat • Two vineyard worker deaths found to be heat-related

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						• Company stated they followed requirements for heat-illness prevention – including stopping work early, providing water and shade breaks, and emergency plans for heat exhaustion
Cox[87]	2010	California	Grey literature	Heat	Vineyard	• Heat-related death while loading crates of grapes • Cal-OSHA has increased heat safety workplace inspections and launched multilingual campaigns
Grimbuhler and Viel[57]	2021	France	Study	Heat	Vineyard	• Canopy management causes cardiac and thermal strain • An instrument should be developed to simultaneously evaluate work intensity, work quality, and productivity to raise awareness of the need for prevention
Firstenfeld[88]	2014	US	Grey literature	Heat	Vineyard	• Training and regular meetings reminding employees to drink small quantities of water throughout the day are important • Heat illness prevention requires employers to train employees and supervisors, provide and encourage drinking water, provide and encourage shade breaks, and develop and implement written procedures
Hare[89]	2023	British Columbia	Grey literature	Confined Space	Winery	• One worker died standing on a ladder above a tank and falling in • Another worker died trying to rescue the first worker
Caputo[90]	2004	British Columbia	Grey literature	Confined Space	Winery	• Series of deaths in confined spaces – including drownings and asphyxiation

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						• Impact on surviving employees • Controls include atmospheric testing, sloped tank bottoms, automatic tanks washers, catwalks, and preventing employees from entering confined spaces
Wastradowski[91]	2016	US	Grey literature	Confined Space	Winery	• Deaths in confined spaces due to hazardous atmospheres • Oregon OSHA Hazard Alert warns that employees who clean, empty tanks, or check on the fermentation product may enter tanks • Controls include evaluation of confined spaces, labelling, written procedures, and training
Mosconi et al.[28]	2022	US	Study	Confined Space	Winery	• Lack of awareness about current and potential risks leads to high fatality rates in confined spaces • Confined spaces are hazards during multiple tasks and gases contribute to hazardous atmospheres • Developed 12 step procedure for interventions in confined spaces
Guillemin and Horisberger[92]	1994	US	Study	Confined Space	Winery	• Worker fatality due to the unexpected presence of carbon dioxide and lack of oxygen in a wine tank • Risk management deficiencies contributed to the death
Madrid et al.[93]	2017	California	Study	Indoor Air Quality	Winery	• Development of air monitoring system that measures and logs concentrations of CO_2, ethanol, VOCs, particles, other

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
						chemicals, and temperature and humidity levels necessary for winemaking
Tsakirakis et al.[94]	2014	Greece	Study	Pesticides	Vineyard	• 89% of exposure came from body (dermal) exposure • Application technique impacted exposure • Coveralls provided satisfactory protection
Fustinoni et al.[95]	2014	Italy	Study	Pesticides	Vineyard	• Head contamination significant • Coveralls protected from dermal exposure • Contaminated work environments and PPE contributed to exposure
Mandic-Rajcevic et al.[96]	2018	Italy	Study	Pesticides	Vineyard	• Exposure to mancozeb low with control procedures • Majority of exposure came from hand contamination • Type of equipment and type of PPE influenced exposure • Biological monitoring is suitable for mancozeb exposure
Lee et al.[97]	2022	Korea	Study	Pesticides	Vineyard	• Workers applying and mixing and loading pesticides had negligible exposure to thiamethoxam • Biological monitoring is suitable for thiamethoxam exposure
Rocha et al.[98]	2015	Brazil	Study	Pesticides	Vineyard	• Heavy metals found in blood serum of workers exposed to pesticides • Seasonal conditions influenced exposure due to differences in frequency of pesticide use

Citation	Year	Location	Article Type	Hazard	Component	Key Findings
Lini et al.[99]	2021	Brazil	Study	Pesticides	Vineyard	• Trace elements found in plasma and urinary excretions of workers exposed to pesticides • Factors positively associated with trace elements were exposure time, age, and lower education level
Baldi et al.[100]	2006	France	Study	Pesticides	Vineyard	• Most contamination on hands • Inhalation exposure minimally contributed to exposure • Farm owners experience higher exposures • Type of equipment significantly influenced exposure • PPE provided limited protection
Pimentel and Marques[101]	1969	Portugal	Study	Pesticides	Vineyard	• Characterizes an occupational illness resulting from inhalation of Bordeaux Mixture • Morphologically similar to silicosis nodules
Regel et al.[102]	2020	Austria	Study	Psychosocial	Vineyard	• Positive image of the wine product, the wine sector, and the profession contributes to high job satisfaction • Worker's personal interest in wine reduces dissatisfaction with pay, monotonous work, and long working hours • Problems concerning work-life balance and physical strain leading to job changes

Ergonomics

In total, 8 of the reviewed articles explored ergonomic hazards, risk factors, and potential controls. Ergonomic hazards are likely present at many steps of the wine production process, however most identified literature reviewed ergonomic hazards in the vineyard. Only one survey[60] included winery workers.

Vineyard workers are at risk of work-related musculoskeletal disorders (WMSDs), especially of the wrists, hands[69] and trunk.[54] However, information on this worker population is sparse overall.[59] In general, agricultural work is extremely labor-intensive and working conditions can be challenging. A vineyard's yield and product quality depend on the organization's capabilities and the vineyard worker's ability to operate various agricultural tools.[8]

Tasks associated with WMSD risk factors are manual pruning and harvesting,[54] as workers use hand tools and carry bins to complete these tasks. Hand tools such as pruning shears can be either electrical or manual and a variety of designs are available. These vineyard tasks are highly repetitive, require static positioning of the shoulders, put stress on the upper extremities, trunk, and head, have varied physical load intensities, and require undesirable postures, extreme positions such as stooping, and forceful exertions.[8,54,56,58] These are all risk factors for WMSDs and injury.[103] One study found when harvesting, vineyard workers fill 20 tubs that average 57 pounds and have an average working heart rate of 125 beats per minute.[56] While many vineyard tasks are seasonal and not occurring year-round, they require forceful manual work over consecutive months.[8] Tasks such as pruning also occur outside of the growing season when vines are dormant.

The WMSDs prevalent for vineyard workers include but are not limited to upper limb pain, muscle strength disorders, hand-wrist disorders, forearm injuries, upper extremity disorders, low back disorders,[8,59] and lower limb pain.[60] Nearly half of Latino vineyard workers in one study reported experiencing symptoms of WMSDs.[61] One disorder, hand paresthesia, primarily affected the dominant hand.[104] Grip strength was also found to be stronger in the dominant hand of pruners.[8] Grip strength is an indicator of hand muscle strength. In one survey of vineyard and winery workers, worker's reported moderate lower limb pain, but it did not impact workers ability to perform their work duties and they rarely received treatment for this problem.[60]

Factors that influence the presence of WMSD risk factors include tool characteristics, work and task characteristics, personal characteristics, environmental characteristics, and PPE characteristics. Tool characteristics include whether or not the tool was designed ergonomically, as non-ergonomic hand tools cause the worker to apply unnecessary force and/or adopt an awkward posture in the upper extremities.[8] Manual tools require more force exertion than electrical tools.[59] Task characteristics include the specific task's demands of force, precision, duration,[54] and time constraints due to the seasonality of vineyard work.[60] Work characteristics also include pay structure as piecework pay, or pay based on the amount of fruit harvested as opposed to time spent working.[59] This characteristic was associated with hand paresthesias.[59] The use of traditional blade sharpening methods is a risk factor associated with hand paresthesias.[59] It's suggested that the high level of skill necessary for traditional blade sharpening may leave blades inadequately sharpened, which increases the amount of force used for pruning.[59] Personal characteristics include gender, age, weight,[8] lack of trunk muscle endurance and flexibility,[55] and culture.[56,61] Being female or overweight was associated with hand paresthias.[59] Grip strength decreases with age in both the dominant and nondominant hand of vineyard workers[8] and prevalence of reported back pain increases for both genders.[61] Lack of trunk muscle endurance and flexibility contributes to low back pain.[55] PPE characteristics that contribute to WMSD risk factors are heavy footwear[60] and coveralls with thin and breathable fabrics.[57] Latino workers were less likely to recognize early discomfort as WMSD symptoms [56], were more reluctant to report symptoms, and more likely to work through symptoms.[61] This may have been due to fear of job loss, strong work ethic, and differences in interpretations of words related to symptoms such as "painful" and "bothersome" related to Latino culture.[56] Environmental characteristics include temperature[8] and humidity.[57] Higher ambient temperatures and rapid temperature changes throughout the day were associated with lower grip strength.[8] Humidity contributed to physiological strain.[57]

Various engineering controls have been designed and tested to reduce exposure to ergonomic risk factors during hand harvest and pruning. One engineering control is the use of electric or ergonomic hand pruning shears, which reduce exertion, awkward postures,[58] and hand paresthesias.[59] Grip strength was found to be highest in worker's using pruning shears with an anvil blade and lowest for shears with a rotating lower handle.[8] Other engineering controls include a smaller picking tub with grip attachments, a light weight frame to keep the picking tub 10 inches off the ground, and an alternative picking-knife handle with smaller dimension near the blade and improved main body contour.[56] The tub controls had widespread adoption and resulted in significant reduction in pain symptoms and minor reductions to productivity.[56] Handcarts for moving tubs along the vine were found to be too costly for the number necessary for widespread implementation, but reduced repetitive gripping and lifting.[56] Safety boot design features such as light weight and comfort can help reduce lower limb discomfort,[60] however these features may not be optimal if they compromise safety from heavy machinery and agricultural vehicles. These minor adjustments in tool design and tasks have the potential to have significant impacts on MSD risk factor reduction.[8,56] These engineering controls should be combined with administrative controls such as work adaptation.[58]

Administrative controls such as work adaptation and WMSD programs are also suggested. Vineyard workers avoid extreme wrist positions by implementing working strategies such as adjusting the location of their hand in relation to branches and moving their body to reduce reach distance.[58] A control for WMSDs affecting the trunk is a workplace supervised program designed to improve flexibility and muscle endurance.[8] It is important for these programs to take place at the workplace and be supervised because it contributes to program adherence and individualization of exercises that improve worker outcomes.[8]

Controls are a necessary workplace health and safety component for all hazards, but at times controls for one hazard may introduce or exacerbate other hazards. For example, PPE controls for pesticide exposure in the vineyard contribute to the physiological burden for vineyard workers involved in canopy management.[57] PPE selection has a larger effect on cardiac strain than vineyard characteristics, environmental conditions, work conditions, and sociodemographic characteristics.[57] This highlights the complexity and importance of proper PPE selection.

Noise

Only 1 article evaluating vineyard noise and 1 evaluating winery noise were reviewed, indicating limited research on this topic in the wine industry. Noise is a hazard present at multiple steps of the wine production process due to the use of heavy agricultural machinery and electrical tools in wine grape production and automated machinery systems in wine production. Occupational exposure to loud noise can lead to irreparable hearing loss that impacts a person's ability to hear high frequency sounds and understand speech.[105]

Noise was ranked with a medium risk-level in the wine industry in both the vineyard and winery due to tractors and bottling machinery.[67] One study evaluated noise at an Italian vineyard during processes that use a tractor with different types of tool attachments in various slope conditions.[62] Regardless of slope conditions, the highest noise pressure level was obtained during the use of flail mowers, followed by rototillers.[62] In fact, all tractor tool attachments resulted in higher noise pressure values when tested at steeper slope conditions compared to no slope.[62] On the production side, the wine bottling phase results in high noise due to repeatedly colliding bottles.

A study at an Italian winery evaluated noise produced by an automated bottling line at different working capacities, ranging from 4,000 to 6,000 bottles an hour.[106] It was found that increasing a bottling plant's capacity increases the level of noise.[106] The study measured noise at numerous points along the automated process, which involves different machines that move empty bottles, wash the inside and outside of bottles, fill bottles with wine, cap bottles, apply labels, and move full bottles into cartons before finally closing and wrapping them. Two specific areas resulted in the highest noise pressure values, before the capping machine and immediately after the closing machine.[106] In the vineyard, the highest measured noise levels exceeded Italy's legal daily exposure limit value of 87 dB(A) and all noise levels were higher than the upper action level of 85 dB(A).[62] In the winery, most noise measurements exceeded Italy's upper action limit and all exceeded the lower action limit of 80 dB(A).[106] Italy's peak exposure limit value of 140 dB(C) was not exceeded in either the vineyard or winery.[62,106] Clearly, noise overexposures occur both in the vineyard and winery. Overexposures indicate that noise PPE is required legally for tasks and processes involving tractors and automated bottling[62,106] and hearing conservation programs throughout the wine industry. No literature assessed the impact of PPE or other controls on noise exposures.

Accidents, Injuries, and Safety

There is a lack of literature exploring the prevalence and severity of accidents and injuries in the wine industry. There were 9 articles that discussed vineyard safety and 10 that discussed winery safety. However, in 2021, the agriculture industry experienced one of the highest fatal injury rates compared to all United States (US) industries.[107] In 2020, there were 11,800 injuries in US agricultural production that required days away from work and there is well-known underreporting of injuries in the industry.[107] Specific to the wine industry, crude data available in British Columbia, Canada indicates that between 1997 and 2005 nearly 500 injury claims were made, mostly related to traumatic injury.[69] These statistics indicate the potential risk of accidents and injury in the wine industry, particularly in the vineyard. Despite the lack of available data for both vineyards and wineries, the risk in both agricultural and production processes cannot be ignored. Not only do injuries and accidents directly harm employees, but there are costs to the business as well, such as increased claim costs and insurance premiums, and fines.[66] These costs can be particularly devastating to small wineries.[66]

Vineyard workers are at risk of the same accidental injuries faced by all agricultural workers[69] and the agricultural aspects of the wine industry are considered one of the highest risk by industry experts.[70] In general, agricultural workers are at high risk of injury and fatalities due to their use of hazardous equipment, sharp tools, machinery, ladders,[65,108] and employees working at heights.[72] The industry also relies heavily on temporary workers, who often do not receive proper training and ultimately experience a high frequency of accidents.[68] Hazardous equipment and machinery expose workers to fall hazards and serious injuries such as amputations, entrapments, lacerations, eye injuries, electrical shocks, and punctures.

In the winery, many of the machines needed for wine production are mobile and crushers and augers are used constantly.[67] This introduces the risk of struck-by and crush hazards. In small wineries, ladders are used to enter tanks which can slide off and cause serious injury or death.[90] The use of certain boot and footwear styles in the wine industry can also contribute to slip events that result in injury, especially when the shoe tread is worn and traction is compromised.[60] Wet surfaces contribute to slips, trips and falls.[70] Workers can be buried beneath harvested grapes, run over by vehicles, and fall into vats.[71]

One way to explore safety concerns in the industry is looking at OSHA violations. Employers are responsible for identifying and controlling safety hazards present at their workplace. A 2012 newspaper article explored 12 OSHA violations given to a vineyard and winery company in Wisconsin, resulting in fines totaling $71,280.[63] The company received 7 repeat violations for failing to provide fall protection on wine tanks and catwalks, failing to implement and train on lockout/tagout (LOTO) procedures for the control of hazardous energy, lacking proper machine guarding on bottling machinery, failing to provide forklift training, and allowing workers to use damaged electrical cords.[63] Repeat violations occur when an employer has received the same citation within the last 5 years, indicating a lack of remediation of a known hazard. The company received additional serious safety citations for improper forklift operation and lack of eye protection.[63] Serious violations occur when there is a high probability that death or serious harm could result from a hazard. This article not only highlights national legal safety requirements for wineries and vineyards, but also potential critical points that companies within the industry may be failing to address and a lack of commitment to safety from some leaders in the industry. One vineyard labor consultant argued that lack of eye protection is one of the most difficult to solve, year-round safety issues in the industry due to lack of compliance from workers and lack of encouragement and action from leadership.[65]

Another look into wine industry safety is through safety assessments and development of assessment tools, such as checklists and questionnaires. One study assessed wine industry safety levels, based on risk frequency and seriousness of damage,[67] another conducted telephone surveys with industry experts.[70] The highest levels of risk were assigned the following areas and topics: tractors, machinery, farm workshops, processing and production, the unloading area, and storage.[67,70] Tractors are considered high risk because they are often not equipped with a roll-over protective structure and due to uncovered rotating parts and fast movement.[65,67] Machines cause accidents especially when they are used for an unsuitable task, poorly maintained, and because machine guarding and anchoring was removed or never present.[67,70] This is especially true during grape pressing and the separation of must, seeds, and stems, as it is a highly mechanized and automated process.[70] Risk was also associated with high work volume and concentration of machinery.[70] In a farm workshop, trip and hand or eye injury risk was related to inadequate lighting, the use of hand tools and air powered tools, cluttered floors, and obstructed areas.[67,70] In the unloading area, it can become very busy creating significant tripping hazards.[67] In fuel storage rooms, there are often a lack of fire prevention systems, smoke detectors, and lack of firefighting equipment and emergency planning.[67] Pruning can also be dangerous because shortcuts such as worker's carrying shears on their shoulders, stowing shears in their waistbands, and tossing knives to each other can cause serious injuries.[65] An identified weak point is the lack of emergency management, mainly due to the characteristics of wine cellars located in old buildings, lack of emergency signage, and insufficient training.[68] The topic of emergency preparedness will be explored in more detail in the natural hazard section of this literature review.

For accident and injury control, vineyard management can use a checklist or a safety climate scale tool to help identify critical points.[64,67,68] Such assessment tools allow a vineyard to strategize to reduce or eliminate these critical points that can result in serious physical harm. This is important because risk prevention measures should be specific. Other important tools include risk assessment, planning in the face of operational changes, execution and coordination of procedures, and safety and health audits. Commitment from wine industry leadership to addressing these critical points is a key factor in managing risks and maintaining safety,[65,66] as management practices were found to have more influence on organizational safety climate than individual behaviors[64] and workers' health and safety representatives.[71] However, the need for health and safety to come from internal management depends on the size of the workplace, as many experts believe having in-house health and safety management was more appropriate for large businesses, while smaller companies should rely on external health and safety management.[71] In addition to safety benefits, these management commitments can create a better work environment, boost morale, help retain good workers, increase worker participation in decision making, improve productivity, and enhance customer service.[66] One form of commitment from leadership is investment into safe equipment and supervisor training, as many supervisors in the field move into the positions through seniority and do not have backgrounds in health or safety.[65] Other action from leadership includes inspection of serious incidents, review of near misses, discipline of safety violations even if no accident occurred, safety program bonuses such as prizes,[65] and evaluating safety performance.[64] Management should also create channels for communication and feedback.[64] In addition to management commitment, all employees have an individual responsibility for OSH.[71]

Lack of training for employees was identified by industry experts as a safety weak point due to the industries reliance on temporary workers[68] and training activities are considered to be one of the most important OSH factors.[71] Training for workers and supervisors should include injury prevention and education on the importance of safety from both an individual and company perspective.[65] To reduce the risk of injury from machinery, workers should be provided adequate warning of risks and employers should ensure that machinery is functioning correctly, and install protective equipment.[70]

Worker-friendly improvements in vineyard machinery and equipment also contribute to industry safety.[65] A possible safety engineering control happens at the initial or upgrade design phase of a winery, such as forklift runways and a safety path for visiting tourists.[72] When small and medium-sized wineries are designed with safety in mind, there is better control of process flow and safety management costs are reduced.[72] Recommendations for design factors to keep in mind are rules and equipment for fire prevention, workflow ergonomics and comfort, chemical storage, forklift access, anti-slip floor treatment, maintenance access, visiting personnel and lighting.[72] Specific areas to invest design planning into are the grape receiving and unloading area, and the crushing and pressing areas due to high movement of people and materials.[72]

Confined Space

Confined spaces are primarily a hazard in the winery rather than the vineyard, which is reflected in the literature. 5 of the reviewed articles discussed confined spaces and their associated hazards in wineries. The products of wine production are stored in different containers depending on their stage in production, including wine tanks, autoclaves, de-stemmers, crushers and fermenting vats and workers periodically enter these spaces to perform maintenance and cleaning.[28,71] Confined spaces are spaces that are large enough and arranged so an employee can fully enter the space, have limited entry or exit, and are not designed for continuous human occupancy.[109] Hazardous atmospheric conditions within the confined space are generated by byproducts of the wine-making process, additives, and residual cleaning agents and can result in entrapment, asphyxiation, poisoning, or engulfment that have the potential to be fatal.[28] Exposure to accumulated gasses can also cause irritation and obstruction of the upper respiratory tract.[70]

Confined spaces are one of the deadliest hazards present in the industry. There are many examples throughout the industry of workers dying due to exposure to hazardous atmospheres in wine tanks, both empty and full of liquid.[69,92] The hazardous atmospheres that have led to fatalities are high levels of CO_2, CO, ammonia, and oxygen deprivation caused by displacement.[89–92] Other hazardous atmospheres include exposure to SO_2 and alcohol.[28] These deaths often happen during tasks involving the transfer of liquids, checking on fermentation status, cleaning and maintenance of tanks.[71,91] Workers may also access confined spaces during second pressing, suphitation, and racking.[28] Contributing factors to these accidents are the lack of natural or mechanical ventilation, lack of measuring oxygen and gas levels before entry,[71] lack of records and investigation into past incidents,[92] attempted rescue of coworkers,[89] lack of safety culture, supervisory and operational violations, and organizational process vulnerability.[28] Workers die due to toxicity, oxygen deprivation, engulfment, or drowning.[89,90] Workers have also died by being crushed by an unconscious, falling coworker[91] and falling materials. In addition to the loss of life, these confined space incidents result in mental health impacts for surviving workers.[90]

Controls for confined space exposures are primarily administrative. A confined space program, warning signs, training, pre-entry atmospheric testing for gasses and oxygen levels, LOTO and ventilation procedures, providing adequate PPE and rescue equipment, and verifying qualifications of confined space entrants and attendance are all essential controls.[71,90,91] Procedures should include an initial assessment of equipment used for entry, elimination of obstacles inside or in proximity to the space, preparation of legal permits, and a closing meeting where an intervention report is generated.[28] Performing cleaning as soon as possible can prevent the buildup of hazardous atmospheres in a wine tank.[92] Attendants should maintain communication with the entrant, guard the space from unauthorized entry, warn the entrant of unusual conditions, and call properly trained emergency response if necessary.[28] These procedures should also include effective techniques that prevent additional risks for rescuers and aid rescue time.[28]

Engineering controls are also possible in conjunction with administrative controls. These include doors and a sloped tank bottom so pomace can be scraped or pressure washed from outside so tank entry is eliminated.[90] However, deaths have occurred due to exposures outside of wine tanks as well,[89] so removing the worker from the confined space may not be an adequate control without the addition of other controls. Portable gas detectors have been designed to be worn by the entrant with acoustical and optical signaling.[28] Real-time remote monitoring systems have also been designed to assess indoor air quality (IAQ). These systems can measure and data log concentrations of CO_2, ethanol, VOCs, particles, and other chemicals for health and safety purposes at the same time as measuring temperature and humidity levels necessary for winemaking.[93] This allows winemakers to make informed decisions, monitor overtime and assess seasonality of gas production, and investigate problems before an accident occurs.

Pesticides

Pesticide hazards and exposures are more thoroughly researched in the literature than many of the other industry hazards. All the literature reviewed focuses on pesticide exposures in the vineyard during wine grape growing, though some pesticides and preservatives are wine additives introduced during winemaking.[111] In total, 8 articles evaluated vineyard worker pesticide exposure.

Like many agricultural workers, vineyard workers are regularly exposed to a variety of pesticides. Pesticides are chemicals used for preventing, destroying, repelling or mitigating pests including insects, plants, rodents, and fungi.[112] Grapevines are considered one of the most demanding crops due to its plant protection needs[94] and susceptibility to many diseases, fungi, and pests that reduce crop yields.[64,96] In the vineyard, pesticide application is seasonal and occurs up to 15 times per year.[113] This is comparable to other intensively treated crops, such as corn and soybeans,[114] which are sprayed an average of 10 to 20 times per year.[115] However, the frequency varies greatly within and between sectors,[115] emphasizing the importance of risk assessment specific to an industry and workplace.

The vineyard workers most at risk of pesticide exposure are operators who apply the pesticides,[94] workers who mix and load pesticides into applicators,[97] and workers who clean pesticide applicators.[100] Workers who mix and load may have the highest exposures because they handle the pesticide in its most highly concentrated form.[15]. Workers can be exposed through ingestion, dermal, or inhalation exposure, however dermal and inhalation exposures are often considered the main routes due to handling and application methods.[116] The type and severity of health effects experienced by a worker depend on the type of pesticide they are exposed to, as some active ingredients are more toxic to humans than others. Some minor health effects include headaches, dizziness and nausea, and more severe health effects include convulsions, coma, and even death.[116] The severity is also affected by the duration (single exposure, multiple exposures over days or weeks, multiple exposures over months or years) and type of exposure, with the most severe health effects typically resulting from ingestion, followed by inhalation, and finally dermal exposure.[116]

Multiple studies quantified dermal exposure to various pesticides in the vineyard, via biological monitoring, and dermal and inhalation sampling methods. However, it can be difficult to study agricultural exposure to pesticides due to many factors.[95] The majority of exposures for applicators came from body contamination, followed by hand contamination, and head contamination was a minor contributor.[94] Potential dermal exposure considers both exposures within and outside of worn PPE so it can capture the maximum potential exposure if a worker is not adequately protected by PPE or clothing. When compared to actual dermal exposure, head contamination was the major contributor due to the lack of head PPE and effective protection from coveralls and gloves.[94] Actual dermal exposure was 6% of the potential dermal exposure.[94] During mixing and loading, the major contributor was hand contamination followed by body contamination.[97]

Determinants of pesticide exposures are application technique such as low crop application and handheld spraying,[94,95] the type of tractor[96] or equipment[100] used for spraying, the use and type of coveralls and gloves,[95,96] contamination of machinery and PPE,[95] season,[98] and duration or number of times of spraying.[100] Older workers had higher exposures to heavy metals[99] and workers at large farms had lower exposures to pesticides.[100] Individual and task differences, the presence of pesticides in the diet,[95] and smoking[99] also contribute to exposure variability.

A variety of pesticides were included in the exposure assessments. It is important to note that the amount and active ingredients used in US pesticides have changed drastically through 1960 to now[114], indicating a need for regular exposure assessments. Tebuconazole is a common vineyard fungicide used to treat leaf spot diseases. It is classified as a suspected human teratogen and possible carcinogen.[117] Exposure to TEB was found to be highly variable and via dermal absorption.[95] Mancozeb is a pesticide used to fight molds such as powdery mildew in grapes and contains manganese and zinc. Exposure to mancozeb can negatively affect the thyroid,[118] however it is generally characterized by its low acute toxicity and short environmental persistence.[119] Mancozeb exposures were found to be low with the proper adoption of safe OSH procedures.[119] Thiamethoxam is another insecticide used at the vineyard, but inhalation and dermal exposures were ultimately found to negligible.[97] Thiamethoxam is a likely carcinogen but the toxicological effects of exposure to workers are minimal.[120] An additional exposure resulting from contact with pesticides is exposure to heavy metals. Vineyard workers had significant exposures to lead, arsenic, nickel, zinc, manganese, copper,[98,99] and noticeable exposures to selenium, chromium, and cobalt.[99] Exposure to heavy metals in pesticides can cause health effects such as vineyard sprayer's lung.[101]

Properly used PPE is an effective control for reducing exposure to pesticides. To reduce dermal exposure to pesticides, workers can wear coveralls[94–96] and gloves.[96,97] However, it's important to note that significant exposures came from hand contamination likely due to contamination of personal gloves from previous uses.[95] Also, gloves were found to increase exposure for workers in closed tractors.[96] A component of proper PPE use is its maintenance in a clean and reliable fashion[121] or it's replacement when necessary. One study evaluated the effectiveness of two types of coveralls, one 50% cotton and 50% polyester, and the other 100% cotton.[94] It was found that the 50% cotton 50% polyester coveralls resulted in slightly lower potential body exposures due to spray liquid run off from the water repellant material.[94] For actual body exposures, the two types of coveralls performed similarly and provided satisfactory levels of protection.[94] It's important to note that the PPE performance success may depend on the application conditions and technique, and that in higher exposure scenarios the difference in PPE performance may be more apparent.[94] Two studies found that fungicide contamination of the head was significant,[94,95] indicating a potential need for head covering PPE that was not reported in the literature as commonly used in practice. However, one study found there was a lower absorption rate for pesticides that contact head hair compared to body skin,[95] indicating a lower contribution to total exposure than other dermal exposures. Only one study found that PPE only provided a limited decrease of pesticide exposure.[100] As mentioned in the ergonomics section, PPE controls for pesticide exposure in the vineyard also contribute to the physiological burden for vineyard workers,[57] indicating the potential introduction of additional hazards from reliance solely on pesticide PPE controls.

In addition, administrative controls could reduce pesticide exposures. An unexpected finding from one study was the presence of TEB metabolites in samples taken prior to the work-shift, indicating additional TEB exposures from contamination of the work environment which were confirmed by wipe samples of machinery.[95] Proper cleaning of the work environment and disposal or decontamination of contaminated PPE could prevent these additional exposures. Control banding is another useful tool for chemical exposures.[71] Exposure assessment tools such as biological monitoring of urine for pesticide metabolites can be used to assess individual exposures, as dermal exposure assessments can be difficult and expensive in the agricultural field.[95,97] One benefit of using biomonitoring as an exposure assessment tool is it allows the measurement of the amount of a substance absorbed by the body through all exposure routes; however it is difficult for these measurements to be actionable at the workplace as only lead, cadmium, and benzene have Occupational Safety and Health Administration (OSHA) regulations that require biological monitoring.[122] There are also no recommended exposure limits (RELs) tied to biological monitoring set by the National Institute for Occupational Safety and Health (NIOSH).[122] In Washington state, workers using organophosphate or N-methyl-carbamate pesticides may be monitored for depressed cholinesterase.[123] The proper selection of metabolites and timing of urine sample collection are important for biological monitoring.[95] These methods of exposure assessment are likely not accessible for most workplaces. The fact that pesticide application methods and tasks impact pesticide exposure also indicate that adjusting these could also reduce control, but it is important to acknowledge that not every adjustment is appropriate depending on the characteristics of the vineyard – such as canopy height. Other controls, such as elimination, substitution, and engineering controls were not discussed or assessed in the literature, though these controls exist for pesticide exposures.

Psychosocial Hazards

Only one study directly explored psychosocial hazards in the wine industry, specifically how psychosocial hazards impact job satisfaction for workers in the vineyard. The study examined how aspects of work impacted employee job satisfaction, defined as whether work met the employees' needs.[102] The main contributors to job satisfaction were the positive public image of wine, the wine industry, and professions within the industry and personal interest in the product.[102] These factors were found to reduce dissatisfaction with pay, monotonous work processes and long hours, which are considered negative psychosocial work hazards.[102] However, vineyard workers expressed concerns with work-life balance and physical injuries or strains resulting in job or position changes.[102]

Natural Hazards

Disasters and Emergencies

In total, 4 articles discussed winery disasters and disaster preparedness generally, rather than focusing on a specific disaster or emergency. Disasters are serious disruptions to the functioning of a community that exceed its capacity and can be caused by natural, human-caused, or technological hazards.[124] Climate change is expected to increase the complexity, frequency, and severity of disaster impacts and severe weather events such as floods, wildfires, and heat events,[125] the impacts of which are already being seen today. The wine industry is considered one of the most vulnerable industries to natural hazards and is expected to be severely impacted by climate change[126] and risks are becoming increasingly complex.[76] This is partially dependent on the location of an individual winery, as some geographical locations are more vulnerable to specific natural hazards and disasters than others.

Research exploring the economic, product, and structural impacts of disaster on the industry is better established[127–129] than health and safety impacts on management and employees of the industry. However, an emergency plan was identified by industry experts as one of the most important factors involved in industry OSH.[71] The development of emergency plans includes the following steps: list all possible events (such as fires, explosions, and natural hazard events), identify major consequences associated with each event, determine necessary measures to deal with those consequences, determine required resources, store emergency equipment in an accessible location, ensure workers are trained in emergency procedures, hold periodic drills, and communicate the plan to all involved parties.[66] From a sample of 25 wineries assessing safety strengths and weaknesses with a checklist, emergency management was identified as an OSH critical point due partially to the location of wine cellars in old buildings and a lack of prevention culture.[68]

Organizational resilience is defined as the ability of an organization to anticipate, prepare for, and respond to sudden disruptions.[130] In some cases, a workplace's ability to adapt may be more important than a comprehensive plan due to the occurrence of unexpected events.[74] After an event, managers may not have access to up-to-date information that makes following a plan difficult.[74] The roadmap to organizational resilience to disasters is built on four concepts: "realizing a need (for preparedness), building stakeholder support, securing resources and capabilities, and exemplifying best practices."[74] Resilience in this industry is related to communication between stakeholders,[76] company culture, company location, and proximity to a recent disaster rather than a company's size or age.[74] However, wineries with larger case productions perceived more resilience to disasters than those with smaller operations.[75] Involving stakeholders in resilience assessments can lead to more effective industry interventions for disasters.[76] Industry stakeholders include vineyard workers, tourism operators, and emergency management.[76] This may be especially true for stakeholders who have been involved in past crises. Developing resources, sharing knowledge, and planning anticipatory and adaptative responses all contribute to successful event preparedness.[74] The following sections consider specific natural hazards separately, but resilience assessments can improve resilience for all workplace stressors through the identification of system-critical vulnerabilities that can lead to improved resilience.[76]

Wildfires

Only grey literature explored the impacts of wildfires on winery workers, all focusing on the vineyard. There were 6 articles discussing wildfires. Occupational exposure to wildfires can lead to burns and death if evacuation measures are not taken, but this is rare.[131] Workers are more often exposed to wildfire smoke from a fire in a nearby area and may experience symptoms such as eye irritation, respiratory irritation, exacerbation of pulmonary diseases, and cardiovascular outcomes.[131] Workers may experience greater exposures than the general public due to physical demands of work that increase breathing rates, and need to be outside for longer periods of time.[131]

Over the last several years, vineyard workers in California have been forced by employers to harvest grapes during wildfires, exposing them to hazardous smoke[79,81] and putting their bodies on the front lines of climate change.[80] Multiple fires have impacted vineyard land directly, [82,84] but efforts from fire crews can prevent delays in grape harvest.[82] Vineyard employers suggested there were significant business disruptions due to the loss of employee homes, power outages,[84] available temporary housing[82] that drive the workforce away.[83] It is also common for farmworkers to not receive hazard pay or disaster insurance that would help them recover lost wages, although there are movements to improve these conditions.[80,83] A suggested intervention for preventing vineyard worker wildfire smoke exposure is the establishment of community safety officers who can observe if employers are meeting OSH regulations.[80]

Heat

Identified literature related to outdoor heat was limited to exposures in the vineyard. Overall, the literature was sparse, only 5 articles were reviewed. Due to the physical demands of work and working outside without temperature control, outdoor workers are at risk of thermal stress.[132] Exposure to heat can lead to heat-related illness and death.

Vineyard workers working on canopy management in hot weather experience cardiac and thermal strain.[133] These effects can be exacerbated by use of PPE such as coveralls.[57] There have also been multiple cases of vineyard workers dying as a result of exposure to outdoor heat.[85–87] Two deaths in California occurred despite implementation of controls such as drinking water, shade breaks, emergency plans for heat exhaustion, and adjusting the timing of shifts to avoid the hottest hours of the day.[85]

Suggested controls for vineyard worker exposure are primarily administrative. They include training, provision of drinking water, shade breaks, meetings, and implementation of heat illness plans.[88] Important elements of a heat illness plan include identifying who will provide oversight, how new workers will be acclimatized to heat, provide adequate medical assistance when needed, identify measurement tools for heat stress, and training plans.[134] Meetings should occur regularly and include reminders to workers to drink small quantities of water throughout the day.[88] Development of instruments for evaluating work intensity, work quality, and productivity are also suggested to raise awareness of the need for prevention in the industry.[133]

Earthquakes

Literature exploring the impact of earthquakes on wine industry workers is extremely limited, as most focuses on the economic, tourism, and structural impacts.[76] Most reviewed literature focused on the winery rather than the vineyard. 6 articles discussed winery earthquakes and their impacts on the workplace and workers. Examples of earthquakes impacting the industry are the 2016 Kaikoura Earthquake in New Zealand,[127] the 2014 Napa earthquake in California,[129] the 2010 Maule earthquake in Chile.[128] These earthquakes damaged winery infrastructure such as old buildings, roofs, wine storage tanks and areas, barrels, irrigation systems, and barrel racks.[76,127–129] Transportation routes for materials and tourism were also impacted.[76] Wine leaked from tanks, and barrels fell from their racks, resulting in loss of product and economic stress. Due to the timing of the earthquakes being outside of normal working hours,[77] the direct impact on the health and safety of workers was minimal. The seasonal timing of an earthquake also impacts how much wine is released from storage tanks, for example, the Chilean earthquake experienced minimal liquid releases because it occurred just before harvest season.[77] Despite minimal impacts to workers, under different circumstances the potential for physical harm or death is severe. Response capabilities were also impacted by damages to critical infrastructure such as transportation networks,[76] which could have serious implications if a worker is injured in an earthquake. Earthquakes are unique from other natural hazards discussed because their timing is unpredictable and only information about earthquake risk based on geographic location is available.[135]

Industry stakeholders in Italy and California emphasized their primary concern during an earthquake is the safety and wellbeing of their staff.[76,78] One sample of Italian wineries identified strong relationships with other organizations in the wine industry as contributing to resilience due to their ability to provide assistance.[76] Coordination with local government agencies was also reported to contribute to an effective response.[76] Temporal proximity to an earthquake contributes to swift implementation of lessons learned.[76] After nearby earthquakes, some wineries installed new earthquake-resistant tanks, retrofitted old tanks, and improved other systems like piping and catwalks.[76,77] Other wineries spoke to their employees about earthquake preparedness, changed the way they stacked barrels, and obtained additional first aid and medical supplies.[78] Cost can be a major barrier to these upgrades, especially for small operations.[76] This is because there is a trade-off between these costs and their benefits in the short term relative to the long term.[130] Larger wineries in Napa Valley reported having more preparedness measures in place.[78]

Discussion

The findings of this literature review reveal significant gaps in academic research related to OSH hazards, exposures, and controls in vineyards and wineries. A limited number of studies have examined crucial OSH aspects, such as cleaning agent exposures, organic pesticide exposure, wine additive exposures (e.g., gaseous or liquid SO2), and biological hazards. Furthermore, there was only 1 study investigating psychosocial hazards in the industry. There is also a lack of literature investigating the wine industry in the US. For example, all the studies investigating pesticide exposure in vineyard workers were conducted outside of the US, where different formulations and regulations around pesticides may exist. This indicates a need for exposure assessments specific to pesticides and work practices used by national and state wine industries. Another notable gap is the lack of assessment of elimination and substitution controls, which are recognized as the most effective forms of hazard control. However, it is important to acknowledge the potential challenges associated with implementing these controls in the wine industry. Pesticides are an example of a hazard that has the potential for elimination and substitution controls as there are organic and non-chemical pest control methods available,[13,20,29] however the level of control and introduction of additional hazards needs to be assessed in this industry.

There is also insufficient literature investigating the impacts of natural hazards on workers within the vineyard and winery industry. While existing literature primarily focuses on the effects of natural hazard events on industry production, economics, and structures, the safety and well-being of workers have been identified by industry experts as the priority during an event. Studies on climate change and the changing frequency and intensity of natural hazards, such as heat and wildfire smoke, primarily investigate changes in vineyard management, wine grapes, and in turn, wine products.[136–139] Most of the literature reviewed exploring the impacts of natural hazards on industry workers was grey literature rather than academic studies. To address this gap, future research should prioritize studying the potential impacts of natural hazards on the industry's workforce. Conducting interviews or surveys with both employers, management, and employees can provide a more comprehensive understanding of risk perception and industry needs in relation to natural hazards and disasters. Stakeholders outside of the industry, such as local government agencies and emergency responders, could assist in the development of materials to improve industry resilience to these events. There is an opportunity to learn from other related agricultural industries, such as other fruit farms or orchards as the impacts of natural hazards on these workers are likely similar. Related industries may be able to share strategies for resilience that have been successful.

In addition, there is a lack of literature exploring the potential interactions of OSH hazards and natural hazards in this industry. For instance, heat and wildfire smoke exposure could exacerbate injuries, chemical exposures (via inhalation and dermal exposure), and the presence of hazardous atmospheres in confined spaces, both indoors and outdoors. It is also crucial to recognize how heat can interact with PPE to introduce additional hazards. Understanding these interactions is essential for developing effective interventions and tools. Therefore, conducting interviews or focus groups with industry professionals and employees can yield valuable insights into risk perception, industry needs, and guide the prioritization of interventions. To address these needs, it is crucial to develop materials and tools for emergency preparedness within the industry. These materials should be catered to the natural hazards related to the geographic location, capabilities, and culture of the winery or vineyard. Such resources can assist employers in selecting appropriate PPE that accounts for multiple environmental stressors, the development of written emergency plans, and regulations regarding workplace disaster preparedness.

The identified gaps emphasize the need for further research focusing on this specific worker population, particularly regarding disaster preparedness, vulnerability, and the interactions between occupational hazards, natural hazards, and PPE. However, it is important to acknowledge that this literature review has its own limitations. The scope of the review may not have captured all available studies, and language or publication biases could be present. Future research should aim to overcome these limitations by conducting comprehensive systematic reviews or meta-analyses. Being an occupational health researcher from outside of the wine industry and emergency management industry may have limited identification of certain sources of information. Additionally, including literature from a more generalized workforce component (such as agricultural OSH or beverage manufacturing OSH) or from related industries (tree fruit farming or breweries) may provide insight on hazards and controls relevant to the wine industry.

In conclusion, there is a need for further research in the field of OSH in vineyards and wineries. By addressing the identified gaps and limitations, future studies can contribute to a more comprehensive understanding of the hazards, exposures, and controls in this industry, and ultimately improve the safety and well-being of its workers.

Aim 2: Characterizing Wine Industry Health and Safety Inspections in Washington State

Background

Wine Industry in Washington State

In 2020, 63,820 people worked in wine industry nationally.[140] While wine in the US is often associated with the state of California, wineries are a significant and growing agricultural and economic industry in Washington state. Employment in the wine industry and the number of wineries in the US have been steadily increasing since 2001 and the state has the second most winery employees and wineries behind California.[140] According to 2020 data from the US Bureau of Labor Statistics, there were 435 wineries and 4,190 winery jobs in Washington State.[140] There were an estimated additional 10,900 employees working in sales and distribution of Washington wines, which includes warehouse, restaurant, bar and retail workers and 3,000 employees in wine tourism.[4] In 2018, the total business revenue for the wine industry in Washington state was $4.1 billion.[141] Washington also has 14 different American Viticulture Areas, which are wine-growing areas with distinct environmental features that result in unique wine.[141] Wine grape production in the state occurs primarily in Central and Eastern Washington and most wine grape production acreage are in the counties of Benton, Grant, Klickitat, Yakima, and Walla Walla.[4] Some vineyard workers are unionized under the United Farm Workers in America,[142] however data was not available for the total number of unionized workers in the state's industry. The wine industry in King County is less involved with wine grape production but contributes to wine production and tourism and is home to corporate offices for large wineries.[141] Businesses included in the state's winery industry are involved in at least one step of the winemaking process, but often they participate in multiple steps. Their operations range from agricultural work at vineyards, such as wine grape growing and harvesting, to wine production, distribution, sales, tasting, and tourism. As stated previously, for the purpose of this thesis, the term wine industry includes winery and vineyards only. Beverage Manufacturing and Fruit and Tree Nut Farming industries, of which the components of the wine industry are a part, have been identified as two of the top 100 most hazardous industries in Washington state based on injury, fatality, and illness rates.[143]

DOSH Inspections

In Washington state, the regulatory agency responsible for workplace health and safety is the Division of Occupational Safety and Health (DOSH) within the Department of Labor and Industries (LNI).[144] Chapter 49.17 RCW is the Washington Industrial Safety and Health Act (WISHA) that gives LNI the authority and responsibility of administrating the state program. State programs must enact standards that are at least as protective as or more protective than the federal Occupational Safety and Health Administration (OSHA). One of these responsibilities is enforcing compliance with WISHA standards.[144] Employers are responsible for complying with WISHA standards in Title 296 of the Washington Administrative Code (WAC).

The DOSH Compliance Manual[144] provides guidance on internal compliance operations. One step of the process for enforcement includes workplace compliance inspections carried out by

Compliance Safety and Health Officers (CSHOs). There are multiple types of workplace inspections. Unprogrammed inspections are investigations in response to fatalities, complaints, and referrals.[144] Both complaints and referrals are notices of alleged workplace hazard. Complaints are filed by a current employee, past employee, an employee representative or attorney, or an employee at another company exposed to hazards at the identified workplace. Referrals are filed by a CSHO based on an observation, another safety and health or government agency, a media report, or any other public person.[144] Follow-up and monitoring inspections are also unprogrammed. These inspections re-inspect a previous citation for abatement evaluation. An abatement is an action to comply with a cited standard or eliminate a recognized hazard. On the other hand, programmed or planned inspections are scheduled from lists that are generated by worker's compensation data for individual employers, as well as industry, hazards, claims, and employer history data to identify high hazard employers and industries.[144]

Inspections are categorized as either comprehensive or partial. Comprehensive inspections thoroughly inspect all potentially hazardous areas while partial inspections are limited to certain hazardous areas or operations.[144] Partial inspections can be expanded under certain conditions, such as when a workplace is lacking a comprehensive safety and health program. Programmed inspections are always comprehensive. Inspections are also categorized as either health or safety depending on the hazards present.[144] CSHOs are either Health and Safety Specialists or Industrial Hygienists and specialize in either safety or health hazards. For example, safety inspections include fall, forklift, or electrical hazards and health inspections include chemical or biological hazards. Employers are not given advance notice of inspections and they occur during a workplace's normal working hours.[144] The exception is in the case of monitoring inspections, which take place after the initial walkaround. A CHSO will do a walkaround with an employer, interview employees, and review written documents and records to determine if a workplace is out of compliance with any WISHA standards.

When an inspection results in identification of a hazard and exposure in violation of a safety and health rule, a citation is issued.[144] There are multiple categories of violations. General violations are granted when an injury, illness, or disease resulting from a hazard cannot reasonably be predicted to cause serious harm to exposed employees, but still has an impact on that employee's safety or health. Serious violations are granted when there is a substantial probability that serious harm or death could result from a hazard.[144] Willful violations are granted when there is evidence that an employer intentionally violated or acted with plain indifference of a WISHA standard. Repeat violations are granted when an employer has been previously cited in the last 3 years of the same standard or a related hazard. This can be a result of a lack of abatement or a reoccurrence of the hazard.[144] Serious, repeat, and willful violations may come with a monetary penalty. A violation is assigned a severity of 1-3 based on the severity of the potential injury, from temporary and reversible injuries to disability or death. A violation is also assigned a probability based on the likelihood of an injury or illness occurring.[144] The severity and probability of a violation are multiplied to establish a gravity, which determines the base monetary penalty. The penalties are adjusted based on a workplace's size, violation history, quick abatement, and faith (demonstrated effort towards compliance with WISHA standards).[144]

Methods

A data query of DOSH inspection data was conducted to characterize wine industry inspection health and safety trends in Washington state. The data was queried by a research and development specialist from LNI. Data came from their internal inspection management system, called the WISHA Information Network (WIN). WIN system data is pulled from LNIs data warehouse. CSHOs manually enter inspection information into this system when closing an inspection. The query date was November 15, 2022.

Industries in WIN are categorized by their North American Industry Classification System (NAICS) code. NAICS are the Federal code used to classify business establishments for data collection, analysis, and publication of US business economy data.[145] Industries are distinct from occupations. Industry is the type of activity at a place of work while occupation is the kind of work being done.[146]

Data Clean-up and Analysis

Data was exported from WIN to excel for data cleaning and analysis of descriptive statistics. Data was initially separated into two spreadsheets, one containing vineyard (111332) inspections and the other winery (312130) inspections. Data clean-up included removing sections and subsections from the "WAC Cited" category (for example, "296-307-59805-3" was cleaned to "296-307-59805") and removing data outside of the April 2004 and October 2022 timeframe. Data clean-up of inspection type was also performed for consistency. Inspection types categorized as "Targeted" and "Planned" were re-categorized as "Programmed", as the language input in WIN did not match the language in the DOSH Compliance Manual.[144]

First, a separate worksheet was created for individual inspections for both vineyard and winery data. This involved adding a column for unique inspection numbers, not including repeat inspection numbers. This column was then counted to determine the total number of inspections at each worksite. The same process was performed but stratified by safety or health to determine the number of total health inspections vs. total safety inspections. Other columns counted after removal of repeat inspection numbers include the inspection type, inspection scope, and violation type. Descriptive statistics including the minimum, maximum, and average were calculated for the column of employee quantity.

In a worksheet preserving all violations attached to their inspection numbers, the descriptive statistics minimum, maximum, and average were calculated for the monetary penalty column. Finally, all cleaned WAC citations were counted by WAC and compiled into a table displaying the number of times the WAC was cited. The table was then sorted by number of citations from high to low, and the top 25% of citations were used to create a figure displaying the frequency of each citation.

Inclusion and Exclusion Criteria

Inspections were included if they were categorized under the NAICS code 312130 for wineries and 111332 for grape vineyards. All other NAICS codes were excluded. Both health and safety inspections were included. Inspections from the date range April 12, 2004 to October 6, 2022 were included. Inspections prior to April 2004 were excluded because this is when the WIN system went live. Data prior to this date was migrated from a previous system and is considered unreliable.

The following information was included in the data query:

- Inspection number
- Site NAICS
- Safety or health inspection
- LNI region
- Citation date
- Business type
- Complaint severity
- Referral severity
- Hospitalization
- Inspection type
- Inspection scope
- Inspection description (whether the inspection resulted in a violation)
- Violation item number
- Violation type
- WAC cited
- WAC text
- Original assessed penalty
- Employee quantity
- Union
- Original violation description
- Site city
- Site ZIP code

Limitations

Workplaces classified under NAICS code 312130 and 111312 for wineries and vineyards offer an incomplete representation of the wine industry. Winery operations such as wholesalers, restaurants, warehouses, and other non-winery and non-vineyard operations involved in the industry are not captured in this data query. Additionally, some vineyards included in the query may be growing grapes not used in winemaking. Also, because data is input into the WIN system manually by different CSHOs, there may be inconsistency in the data over time and between CSHOs that leads to miscategorization of data. For example, some businesses under the vineyard NAICS were categorized as “Dairy/Agriculture”, “Hop Farms”, or “Greenhouse”. This partially represents the fact that not all vineyards are solely used for wine grape growing, taking up a portion of an orchard or another agricultural operation growing other fruits. Because of this, business type was not able to be verified and some inspections may not have occurred at a vineyard. Some of the cited WACs are also no longer active and have been repealed and replaced by new WACs or eliminated completely.

Results

Table 4.	Vineyard	Winery
Inspections		
Safety	110	105
Health	28	48
Total	138	153
Inspection Type		
Unprogrammed		
Referrals	42	44
Complaints	20	15
Unrelated	0	1
Programmed	62	74
Follow-up	11	18
Monitoring	0	1
Scope		
Partial	92	79
Comprehensive	46	74
Violations		
General	165	295
Serious	97	125
Repeat serious	3	2
Total	265	422
Monetary Penalties		
Average	$359	$378
Maximum	$3,600	$3,000
WACs Cited		
Total	111	159

Table 4. Demographic summary of vineyard and winery inspection data.

Vineyard

The average number of employees at inspected vineyards was 25, with a minimum of 1 employee and maximum of 600. Only 2 inspected vineyards had union employees. The city with the most vineyard inspections was Prosser, Washington.

In total, there were 138 vineyard inspections (110 safety and 28 health). There were 62 programmed inspections, 42 unprogrammed in response to referrals, 20 unprogrammed in response to complaints, 11 follow-up inspections, and 3 inspections were missing data for inspection type. 92 inspections were partial and 46 were comprehensive.

83 of those inspections resulted in violations, representing 267 citations. There were 165 general violations, 97 serious violations, and 3 repeat serious violations. The average original monetary penalty was $359, with a maximum of $3600. In total, 111 WAC codes were cited. Figure 2 displays the top 25% of cited WACs for vineyards. These citations are all under WAC chapter 307, dedicated to safety standards for the agricultural industry.[i]

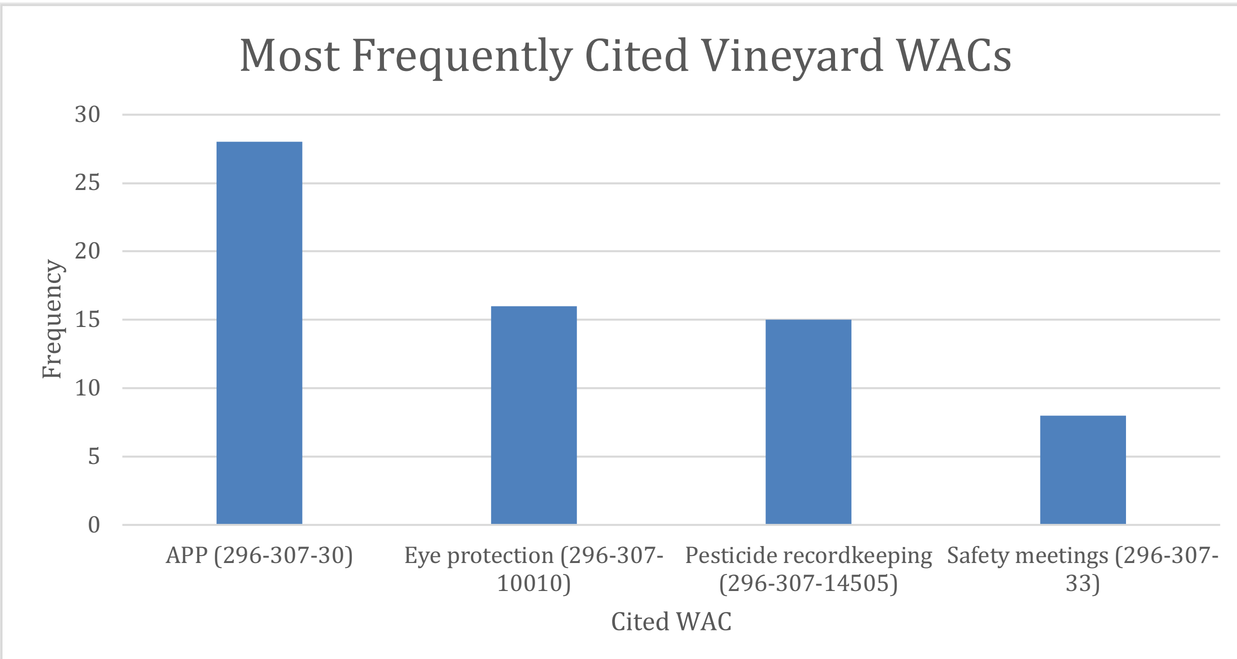

Figure 2. Most frequently cited vineyard WACs. Top 25% of violations.

Winery

The average number of employees at inspected wineries was 19, with a minimum of 1 employee and a maximum of 500. Only 6 inspected wineries had union employees. The city with the most vineyard inspections was Mattawa, Washington.

In total, there were 153 winery inspections (105 safety and 48 health). There were 74 programmed inspections, 44 unprogrammed in response to referrals, 15 unprogrammed in response to complaints, 18 follow-up inspections, 1 monitoring inspection, and 1 unprogrammed inspection at a multi-employer worksite that was initiated due to an observed hazard during an unrelated inspection. 79 inspections were partial and 74 were comprehensive.

106 of the inspections resulted in violations, representing 422 citations. There were 295 general violations, 125 serious violations, and 2 repeat violations. The average monetary penalty was $378, with a maximum of $3000. In total, 159 WAC codes were cited. Figure 3 displays the top 25% of cited WACs for wineries. These citations are from the WAC chapters for core safety and health rules (chapter 800), safety standards for the agricultural industry (chapter 307), safety standards for respirator use (chapter 842), and confined space rules (chapter 809). WAC 296-800-17005 was repealed due to the adoption of WAC 296-901, which is the standard for the globally harmonized system for hazard communication.[151,152]

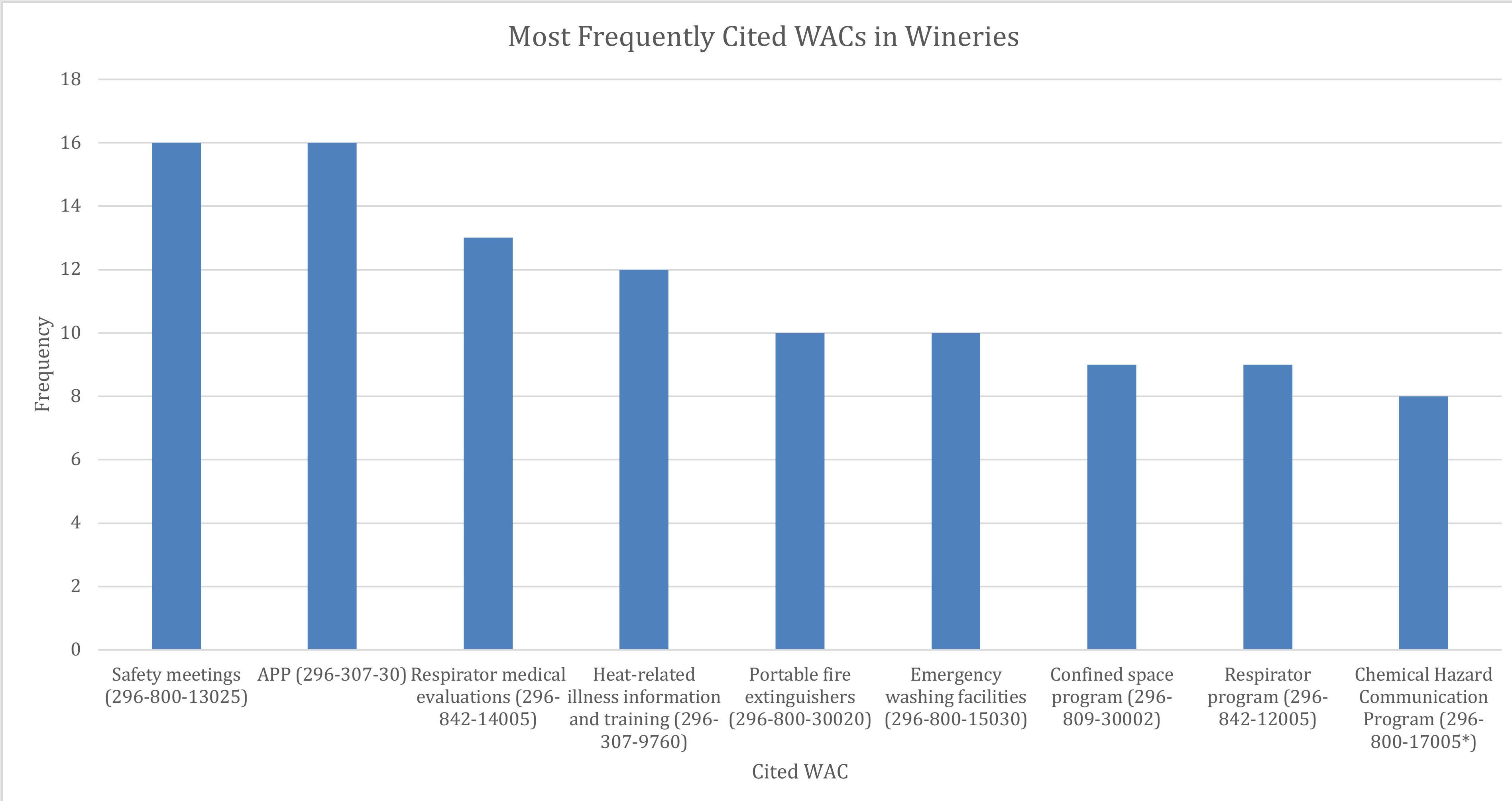

Figure 3. Most frequently cited winery WACs. Top 25% of violations. * This WAC was repealed by WSR 17-02-066 February 3, 2017, due to the adoption of WAC 296-901, the Globally Harmonized System for Hazard Communication (effective June 1, 2016).

Discussion

Inspection data provides valuable insight into the workforce size, union representation, inspection types, violations, and associated citations. These findings shed light on the regulatory compliance status and potential areas of improvement within the inspected wineries. It is noteworthy that only 6 out of the inspected wineries and 2 of the vineyards had union employees, indicating a relatively low prevalence of union representation of inspected workplaces in the industry. Multiple factors may influence the lack of union representation in this inspection data. First, research shows that union workplaces are safer due to collective bargaining for safety clauses, access to PPE, and additional safety training.[55,153,154] Employees with union involvement may also be more empowered to contact L&I with a complaint, but the higher level of safety at their workplace may reduce their need for filing complaints. The influence of union presence on the wine industry's health and safety and compliance needs to be further investigated.

There are also limitations to the view of the industry presented by this data since not every workplace receives an inspection. The programmed list assists in prioritization of these inspections. Another limitation is that this data does not capture the proportion of Washington state wine industry workers that are volunteers or temporary workers. That data was also unavailable from other sources. There is value to investigating the level of health and safety at workplaces with a small vs. large number of permanent employees, temporary employees, and volunteer workers. These different workplace qualities may influence needs for L&I compliance and resilience to natural hazards.

Inspection data illustrates only a portion of the OSH issues within the industry. Partial inspections focus on specific hazards or groups of hazards, potentially overlooking other hazardous conditions. Nevertheless, given the classification of the industry as high-hazard,[143] there were a significant number of programmed and comprehensive inspections, particularly in wineries. In addition, not all industry hazards have WISH standards and may not be citable by CSHOs. For instance, the absence of an ergonomic standard in Washington state is concerning, considering the prevalence of work-related musculoskeletal disorder (WMSD) risk factors experienced by vineyard workers. Furthermore, there are only temporary, emergency rules for natural hazards such as wildfire smoke and outdoor heat in Washington state. These rules are more recently implemented than many of the cited standards. This may explain the limited representation of these hazards in citations, despite the occurrence of multiple heatwaves and wildfire smoke events in recent years. Further analysis of this data should investigate the effective date of cited WACs. The data could also be analyzed for themes in the specific reason identified for the issued citation.

The inspection data reveals citations that indicate a lack of preparedness for natural hazard events within the industry. Safety meetings,[150] accident prevention programs (APPs),[147] respirator programs,[155] respirator medical evaluations,[155] fire extinguishers,[156] confined spaces,[109] and eye protection[148] are areas that could contribute to negative health outcomes for industry workers during natural hazard events. APPs and safety meetings should incorporate information specific to natural hazards in Washington state, such as earthquakes. Respirators play a crucial role in preventing wildfire smoke exposure, and their safe use is dependent on adequate medical evaluations. Fire extinguishers are essential for preventing the spread of fires and mitigating additional hazards introduced by the ignition of chemicals or gases. Of particular concern is the violation of standards related to heat-related illness training and information, considering the anticipated increase in frequency and severity of heat events. The availability of information in a language understandable to workers, as outlined in WAC 296-307-9760, raises potential health equity concerns. One potential intervention is to create a consortium or trade alliance of small vineyards to address these preparedness gaps by designing resources and trainings to aid employers with meeting L&I requirements.

The results of this inspection analysis can inform interview guides investigating Washington state wine resource needs and industry risk perceptions, regarding OSH and natural hazards. It also can aid in the development of materials for what to include in safety meetings and APPs.

In conclusion, the results of the winery inspections highlight areas of concern in terms of regulatory compliance and worker safety. The findings indicate the need for targeted interventions and corrective actions to address the violations identified during the inspections. By addressing these issues and promoting a culture of safety and compliance, wineries can create safer working environments for their employees and reduce the potential for workplace incidents and injuries. There is an additional need to identify differences in small vs. large employers, as they may have different needs and access to resources for compliance with L&I standards.

Conclusion

This thesis emphasizes several key findings and areas of concern regarding the wine industry in terms of OSH hazards, compliance, and natural hazard preparedness. The inspection data identifies areas of concern related to natural hazard preparedness within the Washington wine industry. Violations in safety meetings, accident prevention programs, respiratory programs, medical evaluations, fire extinguishers, confined spaces, eye protection, and heat-related illness training indicate a lack of readiness for natural hazard events. Ensuring the inclusion of specific emergency plans for natural hazards, providing adequate PPE, training for natural hazards, and addressing the availability of information in workers' language are important steps for promoting worker safety during such events. In conjunction with the key hazards identified in the literature review, this information can guide the development of interview guides for future research exploring risk perceptions and industry needs regarding the interaction of OSH, climate change, and natural hazards and the impact on workers. There is a pressing need to conduct this research both before and after an event as disaster data is considered perishable. Perishable data degrades in quality, is altered, or permanently lost if it is not collected soon after it is generated.[157] The loss of this data could lead to a missed opportunity for effective interventions for disaster prevention and response, specific to the needs of the wine industry in Washington state. Identifying these specific needs can guide the development of materials that address OSH and natural hazard critical points. Involving interdisciplinary stakeholders from outside of the industry such as local government agencies and emergency responders could improve emergency plans. Future research should also prioritize representation from management, health and safety staff, and employees within the industry for a holistic perspective on industry needs and concerns. It is crucial to develop tailored materials and resources for emergency preparedness that account for geographic location, capabilities, and the culture of wineries and vineyards. These efforts can enhance the resilience of the industry and promote safer working environments for employees, reducing the potential for workplace incidents and injuries.

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[i] Required elements of an accident prevention program (APP) include instruction in safe workplace practices, a written APP, a monthly walk around safety inspection with an employee

representative, and information on incident reporting, hazards, PPE, and emergency action plans.[147] Requirements for eye protection include requiring American National Standards Institute (ANSI) certified eye protection when workers are exposed to hazards such as flying objects, injurious liquids or radiation, or welding or cutting glare.[148] Recordkeeping for pesticide applications requires information such as when an application occurred, the pesticide product name, the site and total area to which it was applied, the amount and concentration of the pesticide, the wind direction and velocity at the time of application, and the personal information of the licensed applicator.[149] Safety meetings must be held at least monthly or when there are significant job changes, the meetings must be tailored to specific operations or activities, minutes and records must be recorded.[150] There is an exception for operations that last less than a month, such as harvesting, in which case only an initial safety orientation is required.[150]