Rural R&D for Profit Program

Mitigation of climate change impacts on the national wine industry by reduction in losses from controlled burns and wildfires and improvement in public land management

Final Report

Wine Australia
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Plain English summary

The exposure of vineyards and grapes to smoke from bushfires and/or controlled burn events may result in 'smoke-tainted' wine, which can cause serious economic losses to industry. Between 2003 and 2015, major fire events in Australia resulted in over $400 million worth of grapes being lost or downgraded due to smoke taint. As bushfire frequency and severity are only expected to increase under climate change scenarios, it is important that the Australian wine industry develops novel tools to manage smoke-affected grapes and wine.

The key objectives of the project were to:

1. Develop an improved early warning system for smoke exposure in vineyards
2. Understand how smoke dose and composition link to levels of smoke taint compounds in grapes and wine and to sensory outcomes in wine
3. Investigate practical options to prevent or limit smoke taint compounds being absorbed by grapes in the vineyard
4. Improve analytical methods of assessing the risk of smoke taint in both grapes and wine
5. Evaluate remedial management options for dealing with smoke-affected grapes and wine in the winery.

A network of seven remotely accessible smoke detectors was set up across wine regions of Victoria and was operational from the controlled burning period of autumn 2017 onwards. The network proved to be effective for monitoring widespread smoke events during the growing season. In addition, roving detectors were used to take smoke dose measurements at and around controlled burns in Victoria and during bushfires in three states from 2018-2020, along with smoke composition data and grape uptake of smoke taint compounds. Wines were produced from smoke-exposed grapes to assist with developing thresholds for smoke taint.

Together, this data allowed the establishment of some key relationships between smoke measurements and levels of smoke taint compounds in grapes and wine. Development of smoke taint is site-specific and depends on the proximity of a vineyard to a burn or bushfire, the intensity of the fire, the age of the smoke and the prevailing weather conditions. Smoke haze from old smoke from controlled burns was not shown to be sufficient to cause smoke taint.

Since smoke taint compounds occur naturally in grapes at low concentrations, it is important to know background concentrations when assessing whether grapes have been exposed to smoke. Extensive sampling across the country allowed for the expansion of baseline concentration data of smoke taint compounds in both grapes and wine to be extended to 12 of the main winegrape varieties grown in Australia.

A total of 21 different barrier-type materials were tested for their ability to protect grapes from smoke taint compounds in the vineyard. Treatments typically did not provide any significant protection and often increased the uptake of smoke taint compounds by grapes. Only one product — chitosan — a biopolymer extracted from fungi and shellfish, was effective as a protective coating on grapes. Adsorption of smoke taint compounds onto the berry skin was found to be rapid and generally complete within a day of smoke exposure.

This project also evaluated a range of remedial treatments for dealing with smoke-affected grapes and wine. Fifteen commercially available activated carbons were tested, along with five commercially available enzyme treatments. Chemical and sensory evaluation showed that carbon

treatment was able to reduce smoke taint in wine, especially when added to grape juice prior to fermentation. Results were dependent on the type of carbon product used, the matrix (juice versus wine; red versus white wine) and the dose applied, and desirable aroma and flavour compounds were often also removed. Enzymes only removed certain classes of smoke compounds but may be effective for certain wine styles when combined with carbon treatment.

Blending was shown to be an effective option for remediation of smoke-affected wine. A blend of 25% or less of smoke-affected Pinot Noir with unaffected wine was sufficient to reduce sensory perception of smoke taint to the same as the control wines. Consumer tasting studies showed that wine preferences are highly variable. Some people are either not sensitive to smoke or enjoy the sensory characteristics it provides and for others, even a small proportion of smoke-affected wine in a blend can significantly affect liking.

Recommendations arising from the project are that:

- Future projects place heavy emphasis on sensory testing to link all data collected from smoke events to smoke taint, to define smoke thresholds to predict the risk of smoke taint and to define sensory thresholds for a range of varieties and wine styles
- A smoke taint risk assessment tool be developed for the wine industry. This would involve establishment of a national network of smoke detectors, which provides real-time measurement of smoke compounds in the air, is readily accessible to industry and can convert smoke exposure levels into smoke taint risk
- Field testing of chitosan be carried out to develop it as a product which could be practically and economically applied as a spray to protect crops in the event of smoke
- Evaluation of commercially available enzymes, activated carbons and other emerging mitigation technologies be continued for use by winemakers.

The significant benefits for the wine sector which arose from this project have already been realised, particularly in the context of the 2019/20 bushfires. The research teams provided extensive on-the-ground support and information to the sector during and after the fire events in SA, NSW and Victoria this season and following the Tasmanian bushfires of 2018/19. Uptake of findings, especially regarding testing of grapes for exposure to smoke and treatment of smoke-affected wine with activated carbon or by dilution, has been significant. Wine made for this project is being used in regional training workshops, to aid winemakers with the detection and mitigation of smoke taint. Grapes and wine sourced during the 2019/20 season are a valuable resource for future studies.

The success of this project was made possible through many collaborations with researchers at Agriculture Victoria, La Trobe University, the Australian Wine Research Institute, University of South Australia, University of Adelaide, University of Melbourne, Metabolomics Australia, the University of Nottingham and the Cooperative Research Centre for Polymers. Grape growers and wine industry partners across wine regions of Australia were key to provision of access to vineyards for smoke monitoring and collection of grape samples and commercial winemaking, as were wine industry suppliers in Australia and overseas. The project also relied heavily on partnership with public land management agencies throughout Victoria, including the Country Fire Authority Victoria, VicForests and the Department of Environment, Land, Water and Planning (DELWP).

This project was funded by the Australian Government Department of Agriculture Water and the Environment Rural R&D for Profit program with co-investment from Wine Australia, La Trobe University, the Australian Wine Research Institute and the Department of Jobs, Precincts and Regions in Victoria.

Abbreviations and glossary

CrPG - Cresol pentosylglucosides

CrRG - Cresol rutinoside

AWRI - Australian Wine Research Institute

DAWE – Federal Department of Agriculture, Water and the Environment (formerly DAWR – Department of Agriculture and Water Resources)

DJPR - Department of Jobs, Precincts and Regions in the Victorian Government (formerly DEDJTR - Department of Economic Development, Jobs, Transport and Resources)

GCMS - Gas Chromatography Mass Spectrometry

GuGG - Guaiacol gentiobioside

GuPG - Guaiacol pentosylglucosides

GuRG - Guaiacol rutinoside

LCMS - Liquid Chromatography - Mass Spectrometry

MGuRG - Methylguaiacol rutinoside

MSyGG - Methylsyringol gentiobioside

PhPG - Phenol pentosylglucosides

PhRG - Phenol rutinoside

SyGG - Syringol gentiobioside

VESDA – Very Early Smoke Detection Apparatus

VPs – volatile phenols

1 Project rationale and objectives

Smoke taint occurs when ripening grapes are exposed to smoke from a fire. Chemical compounds present in the smoke enter the grapes through the skin and undergo a conversion to more stable forms which cannot be detected by smell or taste. During winemaking, the fermentation process converts the molecules back to their original forms, releasing the smokiness, which is experienced as undesirable 'ashy' and 'burnt' flavours in wine. These flavours can intensify when the wine is tasted, due to enzymes in the mouth, and can continue to develop during wine storage in bottle.

In the past decade, major bushfire events have resulted in more than $400M worth of grapes and wine being rendered worthless, or products being downgraded, as a result of smoke taint in Australia. Early estimates suggest that economic loss to the sector from the bushfires in SA, NSW and Victoria this season could be up to $200M. Under various climate change scenarios, the frequency of days with very high and extreme forest fire danger is predicted to increase by up to 70% by 2050, and this will increase the risk of forest fires and the need for fuel reduction burning on public land. The risk of smoke drift into vineyards will increase as a consequence.

Many wine companies rate smoke taint as their greatest environmental risk. Grapes and wine from an entire region or state can come under suspicion of smoke taint in the event of localised fires. Wine marketing companies avoid buying wine from regions where smoke has occurred for fear of taint developing in wine during storage. Actual and perceived smoke taint is threatening the well-being of Australia's wine growers and producers and severely affecting the prosperity of some of the best wine production regions in Australia.

Prior to this project, the Australian wine sector had a very limited number of unselective, generally ineffective remediation technologies available. These included carbon fining, reverse osmosis and winemaking techniques such as minimising skin contact and use of oak and tannin addition for masking low-level smoke taint. At-risk wines could also be targeted for quick consumption. In addition, grape purchasing and wine processing decisions were made by the sector based on exposed/not-exposed criteria alone, leading to rejection of significant quantities of grapes and wines due to perceived, rather than actual, defects.

It is therefore important that the Australian wine industry develop strategies to manage the major financial and reputational risk resulting from smoke taint. The specific project objectives were to:

- Understand the links between smoke composition, exposure and risk of smoke taint in grapes and to use this as a basis to provide an early warning system for smoke exposure
- Enable grape producers to pro-actively 'immunise', through protective sprays, vineyards threatened by approaching smoke fronts from wildfires or controlled burns
- Provide wineries with processing options and materials to remediate smoke-affected wines and minimise losses in final wine quality
- Establish sensory and compositional thresholds for smoke taint compounds in both red and white wine and evaluate consumer preferences for smoke-affected and treated wine

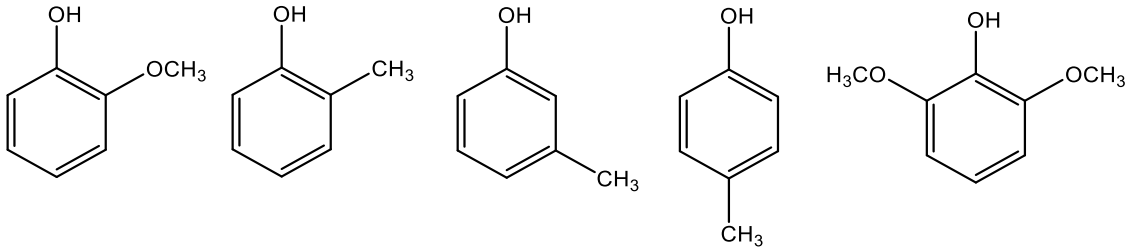
- Enable better planning by land managers and fire controllers to manage controlled burns, thereby reducing the frequency of large-scale wildfires, their environmental impacts and adverse financial impacts on winegrape growers and winemakers
- Conduct an economic evaluation of vineyard and winery remediation strategies
- Improve certainty of supply and reduce the financial risk and economic losses from rejected grapes and wine quality downgrades, with associated economic and social benefits for rural communities.

2 Method and project locations

2.1 Background information

When grapes are exposed to smoke, chemical compounds from the smoke diffuse passively into the skins of the grapes. These compounds are gases called volatile phenols, and there are a few which are thought to be important in the development of smoke taint (Figure 1).

Figure 1. Volatile phenols from smoke



Guaiacol o-Cresol m-Cresol p-Cresol Syringol

Once absorbed into the berry, the plant reacts by converting the volatile phenols to a range of non-volatile glycosides (also called glycoconjugates), by adding sugar molecules. The smoke glycosides cannot be detected by smell. However, during winemaking, sugar unit(s) from the glycosides can be cleaved, releasing the volatile phenols back into the wine. The volatile phenols emit 'smoky' aromas and their corresponding glycosides can cause an unpleasant 'ashy' and 'smoky' taste in the wine. Overall, these sensory characteristics are commonly described as 'smoke taint'.

2.2 Methods

2.2.1 Smoke detection and measurements

Smoke methods involved the measurement of smoke density (particulates) and smoke chemical composition (concentrations of each smoke taint compound within the smoke) and relating these to the uptake of smoke taint compounds by grapes, the concentrations of the smoke taint compounds in wine, and the degree of sensory smoke taint in those wines.

Smoke particulates were measured using a Very Early Smoke Detection Apparatus (VESDA®) — an aspirated smoke detector based on a nephelometer (which measures the deflection of a laser beam by smoke particles). The smoke 'dose' at each measurement site was calculated as the area under the VESDA® plot, giving a cumulative measure of the smoke exposure at each site.

The VESDA network consisted of seven static units across Victoria (Figure 1) all of which were accessible remotely, and five roving VESDA®s which could be deployed to take smoke measurements directly above the fire at controlled burns (fresh smoke) and at various distances from controlled burns and bushfires (Figure 2). Weather stations attached to each unit provide data including wind direction and speed, relative humidity, temperature and atmospheric pressure.

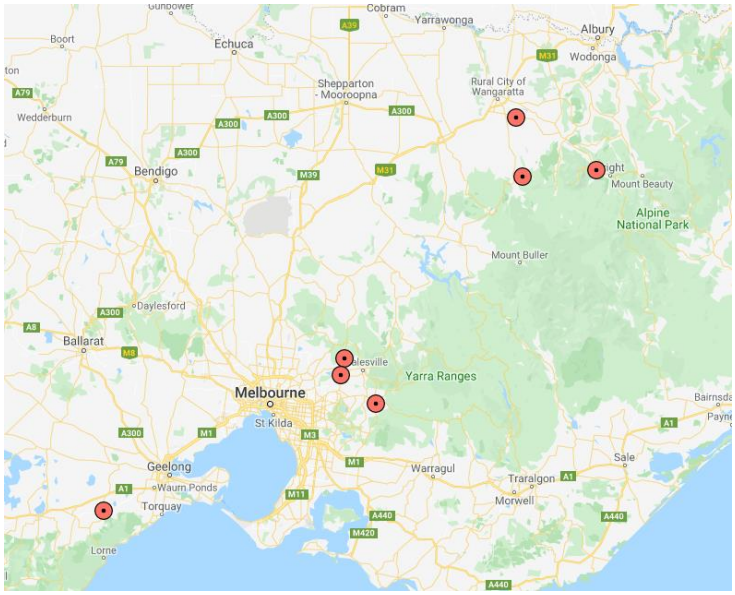


Figure 1. Locations of static VESDA® smoke detection units across wine regions of Victoria



Figure 2: Sampling of smoke at controlled burn sites using roving VESDA® units

Smoke chemical composition was determined at all roving VESDA® sites, and whenever possible during smoke events at static VESDA® sites, using sampling tubes containing Tenax® resin. These tubes captured the smoke taint compounds from the air. The tubes were subsequently returned to the laboratory and the smoke chemical composition determined by gas chromatography–mass spectrometry (GC-MS).

In most cases, roving smoke measurements were also accompanied by 'sentinel' grape bunches — excised bunches of grapes exposed to the exact same smoke as was measured by the smoke detector and sampled on Tenax® tubes. The use of these sentinel bunches was to provide a mechanism which would simulate similar uptake by grapes in a vineyard.

Smoke measurements (smoke dose from VESDA®s, smoke composition from Tenax® tubes) were collected from around 40 controlled burns and 6 bushfire events during the course of the project. Multiple smoke sampling occurred at different distances from the fire at each site. Grape samples

were collected both from excised bunches placed around burn sites and from commercial vineyards, and small-scale and commercial wines made from the grapes. All samples were analysed for 23 phenols in both free and bound (glycoconjugated) forms using the standard method for the laboratory (Allen *et al.*, 2013). Linkage of smoke compound levels across corresponding smoke, grape and wine samples provides a basis for determinations of threshold levels for smoke taint. Linear regression analysis was used to determine the extent of the relationship between variables.

2.2.2 Evaluation of barrier compounds to prevent the uptake of smoke taint compounds by grapes

One way of tackling smoke taint is to prevent or reduce the entry of volatile phenols into the grape berries, which will in turn limit the formation of glycosides. A number of options were investigated. These included washing, to remove smoke taint compounds from the surface of the grapes, and coating the grapes with a potentially protective barrier to reduce or prevent the smoke taint compounds from entering the grapes.

A total of 21 different agrochemicals and biopolymers were tested for their ability to reduce the uptake of smoke compounds by grapes and are listed in Table 1. These included commercial products already in use in viticulture (oily/hydrophobic materials, pest control products, sunscreen protectants), other materials that might provide a physical barrier (such as silicon oil, titanium oxide) and biopolymers (such as various chitosan products).

Table 1. List of agrochemicals/coatings investigated for their ability to prevent uptake of gaseous phenols by winegrapes

Product	Typical application	Other information
BioFlora 4-9-4	Crop fertiliser	Bio-organic fertiliser designed for steady nitrogen release with essential nutrients
BioFlora Sea Isolates	Crop fertiliser	Blend of microbes and seaweed designed to modify soil to enhance plant growth and suppress pathogens
Biopest	Pest management	Used as a broad-range fungicide and/or insecticide, active ingredient is paraffinic oil
Chitosan (Aspergillus)	Biopolymer	A modified glucose polymer made from chitin, which is sourced from the cell walls of the fungus *Aspergillus niger*
Chitosan (mushroom)	Biopolymer	A modified glucose polymer made from chitin, which is water soluble and sourced from the cell walls of mushrooms
Chitosan (crustacean)	Biopolymer	A modified glucose polymer made from chitin, which is sourced from the cell walls of crab shells
Deccoshield	Sunburn protectant	Liquid calcium carbonate formulation that protects fruits and vegetables from sunburn and heat stress
Dextran	Biopolymer	High molecular-weight glucose polymer produced by bacteria
Ecoprotector	Pest management	Fungicide used in horticultural crops, particularly *Botrytis* in grapes, potassium soap (potassium salts of fatty acids)
Envy	Anti-transpirant	A water emulsifiable polymer concentrate; forms a semi-permeable biodegradable film, which reduces transpiration
FPS Carbon (in Raynox)	Salvage chemical compounds	Activated carbon, used as a positive control due to its ability to scavenge volatile phenols; Raynox used as wetting agent
Fruit drying oil	Vine fruit drying	An emusifiable concentrate; ethyl and methyl esters of fatty acids produced from food grade canola oil; modifies surface waxes

Fulvex	Crop fertiliser	Carbon-based product composed of humic and fulvic organic acids
Oenobrett	Wine stabilisation	Chitosan and enzyme-based preparation for the control of *Brettanomyces* spoilage
ParkaPlus	Cuticle supplement	Composition of food-grade phospholipids supplements the plant's cuticle and forms a protective shield necessary to maintain the integrity of fruit and foliage
Peratec	Pest management	Applied as a fungicide to a range of tree, broadacre and vegetable crops
Raynox	Sunburn protectant	Wax-based, forms a particle film, applied as a sunscreen to a range of horticultural crops
Silicone oil	Lubricant	Polymer of silicon and oxygen which is able to form a thin coating, often used as a lubricant in industrial applications
Surround	Sunburn protectant	A processed and refined kaolin in the form of a wettable powder, forms a particle film
Titanium dioxide	Colourant in a wide array of common products	White, inorganic compound. In the presence of light activation can break down phenols. Raynox used as wetting agent
VaporGard	Anti-transpirant	Terpene polymer derived from pine resin, forms a semi-permeable biodegradable film which reduces transpiration

Excised grape bunches were coated with the product and exposed to smoke compounds either in glass tanks containing an aqueous phenol mixture or in a purpose-built smoking chamber. Grapes were then analysed for smoke taint compounds following standard laboratory procedures (La Trobe: Allen *et al.*, 2013; AWRI: Pollnitz *et al.*, 2004; Hayasaka *et al.*, 2013). In-field evaluation of the only barrier compound showing any promise, fungal chitosan, was carried out in 2018 and 2019 using excised grape bunches either in close proximity to a controlled burn or in a large-scale controlled smoking tent experiment.

2.2.3 Baseline concentrations of smoke taint compounds in winegrapes

During 2016 and 2017, 325 non-smoke-exposed grape samples were collected from 23 regions across Western Australia, South Australia, Victoria, New South Wales and Tasmania. Grapes were analysed for the seven volatile phenol and six phenolic glycoside smoke marker compounds targeted as part of the AWRI Commercial Services' Smoke Panel Analysis. These are the compounds which previous research suggest are responsible for smoke taint in wine. Specifically, the volatile phenols are methylguaiacol, guaiacol, methyl syringol, *o*-cresol, *p*-cresol, *m*-cresol and syringol and the glycosides are syringol gentiobioside, methylsyringol gentiobioside, phenol rutinoside, cresol rutinoside, guaiacol rutinoside and methylguaiacol rutinoside. Small-lot wines were made from the 325 non-smoke-exposed grape samples and also analysed for smoke marker compounds.

This data was combined with that from previous surveys conducted during 2010 and 2011. The background survey now contains data for 12 varieties, with volatile phenol and glycoside results for 531 and 529 grape samples respectively, and 494 wine samples. A summary of the varieties and sample numbers in the combined background concentrations database for grapes and wine is provided in Table 2.

Table 2. Summary of grape varieties and sample numbers in the baseline concentrations database

	Number of samples			
	Volatile phenols		Phenolic glycosides	
Variety	**Grapes**	**Wine**	**Grapes**	**Wine**
Cabernet Sauvignon	44	35	44	35
Chardonnay	47	41	45	41
Pinot Noir	52	39	52	39
Riesling	38	30	38	30
Shiraz	62	61	62	61
Grenache	44	44	44	44
Merlot	56	56	56	56
Pinot Gris	55	55	55	55
Sauvignon Blanc	39	39	39	39
Semillon	39	39	39	39
Mataro	25	25	25	25
Sangiovese	30	30	30	30
Total	**531**	**494**	**529**	**494**

2.2.4 Remedial management options for smoke-affected grapes and wine

In the event that a vineyard is exposed to smoke and the uptake of volatile phenols by grapes cannot be avoided, then a 'curative' approach must be undertaken on the resulting grape juice, must or wine. In smoke-exposed grape berries, much higher concentrations of smoke glycosides than volatile phenols are typically observed. Therefore, mitigation approaches applied to grape juice should mainly focus on removing the glycosides. In wine, there is typically a mixture of both glycosides and volatile phenols (see section 2.1) and therefore the removal of both classes should be considered.

2.2.4.1 Evaluation of activated carbon

Carbon can be used as a fining agent during winemaking to remove off-flavours and odours from wine, to decrease browning or pinking in white wines and to remove colour from red wines. A total of 15 commercially available activated carbon products (Table 3) were evaluated in the laboratory for their abilities to remove smoke taint compounds from grape juice and wine, as compared to untreated controls. Grape varieties included were Merlot, Cabernet Sauvignon, Pinot Noir, Mataro, Sauvignon Blanc, Riesling and Chardonnay.

Table 3. List of activated carbon products evaluated for their abilities to remove smoke taint compounds from grape juice and wine

Product	Manufacturer/ supplier	Other information
Acticarb PC1000	Activated Carbon Technologies	Ex coconut – steam-activated; used in water filtration for removal of very low molecular weight pollutants
Acticarb PS1000	Activated Carbon Technologies	Ex coal - steam-activated; used in water filtration for removal of algal toxins and taste and odour compounds
Acticarb PS1300	Activated Carbon Technologies	Ex coal - steam-activated; used in water filtration for removal of algal toxins and taste and odour compounds

CA-50	CarboChem	Mesh 325; for decolourising
P-1000	CarboChem	No information available
PC-900	CarboChem	Ex coconut, mesh 325; for food processing
Carbocromos	Vason/IMCD Australia Ltd	Active vegetal carbon with a high level of purity, activated with phosphoric acid; has a strong decolourising power; used for stabilising white wines
FPS	Vason/IMCD Australia Ltd	A vegetal powder carbon – steam-activated; characterised by a remarkable specific adsorption surface; can selectively adsorb pigments and small molecules; efficient removal of ethyl phenols in wines; used for stabilising white wines
Smartvin Carb	Vason/IMCD Australia Ltd	Vegetal carbon in pellets
Toxical	Laffort	Combination of silica sol and activated carbon; special product for removing ochratoxin by adsorption then clarification of wines
Norit D10	Cabot/IMCD Australia Ltd	Steam-activated; high phenolic value that can remove taste and odour in food applications.
Norit SX Plus	Cabot/IMCD Australia Ltd	Acid-washed activated carbon; suitable for a large range of applications such as decolourisation and purification of pharmaceuticals, food products and organic chemicals, where the use of high purity additives is required.
Bentonorit DX	Cabot/IMCD Australia Ltd	Combination of activated carbon and calcium bentonite; can adsorb undesired contaminants such as taste and odour compounds without affecting the desired natural character of the treated product
Norit CASPF	Cabot/IMCD Australia Ltd	Activated using the phosphoric acid process; used in the food and beverage industry for purification of highly coloured and/or foaming liquids; combines a superior adsorptive capacity with good filtration characteristics at low carbon dosage rates.
Deobrett	EnolTech	No information available

Treatment was carried out in the laboratory on small (50ml) samples of pressings, juice or wine. Variables included matrix (juice/wine/variety) dose rate, contact time, contact temperature, stirring or not stirring and batch of activated carbon product. Following treatment, the carbon was removed and sub-samples analysed for volatile phenol and/or phenolic glycosides.

2.2.4.2 Evaluation of commercially available glucosidases

As an alternative treatment option, a range of glucosidase enzymes were tested for their ability to cleave smoke glycosides in juice or wine (Table 4). Glucosidase enzymes break down complex molecules by cleaving sugar molecules. They can be during winemaking to liberate aroma compounds from their sugar-bound forms, thereby enhancing the aroma profile of the wine. The idea behind this work was to use enzymes to break down the glycosides in smoke-affected juice or wine, allowing the volatile phenols released to be removed by subsequent reverse osmosis or membrane technology.

Table 4. Enzymes investigated for their ability to cleave smoke glycosides, including manufacturer/supplier information and enzyme activity data

Product	**Manufacturer/ supplier**	**Other information**
Lafazym	Laffort	Recommended for use at end of fermentation; β-glucosidase
Zimarom	VASON/IMCD	Pectinase, β-glucosidase and polygalacturonase activities
Rapidase Revelation Aroma	DSM/Vintessential	Polygalacuronase (pectinase), β-glucosidase

Lallzyme Beta	Lallemand	Polygalacuronase (pectinase), β -D-glucosidase
Trenolin Bouquet Plus	Erbsloh	No information available on product label or product information sheet

Briefly, samples of juice or wine (50 mL) were treated with the glycosidase at a given rate, typically the highest recommended dose or multiples of that (i.e. x2; x5), with contact times ranging from a few days to up to three weeks and at temperatures of either 17°C, 22°C (ambient laboratory temperature) or 28°C. Following treatment, the glycosidase was removed and sub-samples analysed for volatile phenol and/or phenolic glycosides.

2.2.4.3 Other materials and methods for the remediation of smoke-affected juice and wine

Other materials tested for their ability to scavenge phenolic glycosides from grape juice included XAD resins, zeolites, grape seed oil, cream and full cream milk. These experiments were performed as described for the activated carbon experiments, where 50 mL of juice was treated with the material being evaluated for a contact time of 24 hours before the required volumes were taken for chemical analysis. In addition, hyperoxidation (via bubbling of oxygen through the juice) or UV light in the presence of titanium dioxide (a method used to purify water) were also trialled.

2.2.4.4 Winemaking trials with grape juice after fining with activated carbon

The most promising activated carbon treatment options were subject to winery-scale testing. Smoke-affected Chardonnay and Pinot Noir juices (in 50L batches) were used in winemaking trials to test the performance of Acticarb PS1300 and Norit CASPF at differing dose rates. Standard winemaking and bottling procedures were followed.

The AWRI's Technical Quality sensory panel was used to determine the overall impact of the commercial-scale treatments of juice and wine on sensory perception of wine. This panel offers an independent evaluation of a wine's attributes, indication of quality level and presence of off-flavours. There were 14 wines for each variety: seven treatments (one control and six carbon treatments) x two fermentation replicates, for a total of 28 wines. The sensory descriptive analysis method was used by the panel to evaluate the wines made from smoke-affected Pinot Noir and Chardonnay juices treated with activated carbon prior to fermentation. Descriptive analysis is the most well-known and regularly used method of sensory analysis and provides a comprehensive description of a product. Sensory characteristics are identified and their intensities scored, producing numerical data as well as descriptive data. In this case, wines were assessed by appearance, aroma and palate, against reference standards where feasible. The performance of the panel was assessed using standard software and the data subject to comprehensive statistical analysis.

2.2.4.5 Commercial-scale testing of combined glycosidase and carbon treatment of wine

Winery-scale remediation trials were also carried out using Trenolin Bouquet Plus, the most effective glucosidase in laboratory trials, to treat a smoke-affected Pinot Noir wine. Enzyme treatment was combined with subsequent carbon fining to 'mop up' the volatile phenols produced. Two different activated carbons were used (Acticarb PS1300 and FPS) both individually and in combination with the glucosidase and at different dose rates.

The ten wines produced were assessed by the AWRI's Technical Quality sensory panel, as described above, to provide an indication of sensory characteristics and the effectiveness of carbon and/or enzyme treatments at removing smoke-related aromas and flavours. The tasters were asked to write detailed comments for appearance, aroma and palate, and asked to give an intensity score (0-9) for smoke, and any additional taints or faults present.

2.2.4.6 Dilution studies

A 2016 moderate-highly smoke-affected Pinot Noir wine from Victoria and a moderate-highly 2019 smoke-affected Pinot Noir rosé from Tasmania were sequentially diluted with unaffected Pinot Noir wines of a similar style sourced from the same vintage. The dilution series, resulting in six samples, was as follows: 0% (i.e. 100% smoke-affected wine); 50% (50:50 blend with the unaffected wine); 75% (25:75 blend with the unaffected wine); 87.5% (12.5:87.5) blend with the unaffected wine); 93.75% (6.25:93.75 blend with the unaffected wine) and 100% (i.e. 0% smoke-affected wine).

The sensory effects of the dilution studies on the above wines were determined by two highly qualified and experienced panels, with members chosen based on their ability to perceive smoke flavour. For this investigation, the judges were asked to rate 'smoke aroma', 'smoke flavour', 'overall fruit aroma' and 'overall fruit flavour'. Results were subject to statistical analysis.

In addition to expert evaluation, the rosé dilutions were the subject of a consumer study (n=82) in which each wine was rated on a numerical scale for overall liking. The aim here was to gauge the difference between consumer perception of smoke taint in wines and that of the expert tasting panel. Five of the six dilutions were included in the consumer study, namely the 0%, 75%, 87.5%, 93.75% and 100% dilution wines. Consumers rated each wine for overall liking on a nine-point hedonic scale from 'like extremely' to 'dislike extremely'. Prior to tasting the wine samples, consumers were asked to complete an entrance questionnaire to obtain demographic information, and an exit survey exploring spending behaviour, attitudes to food and wine, and likelihood of ordering a rosé at various drinking occasions was completed following the tasting. Data was subject to statistical analysis, including correlation with demographic information.

2.2.5 Economic analysis of mitigation options for smoke taint

2.2.5.1 Smoke detector network and application of protective spray

An analysis was performed by a DJPR economist, estimating the benefit/cost ratio of implementing an industry-wide smoke detector network, with application of a protective spray where smoke levels pose a sufficiently high risk of smoke taint. The benefit/cost analysis was calculated for the farm-gate value of premium wine grapes, over a 30-year period, with results expressed in present value terms. The analysis assumed that the protective grape coating tested in this project could be further developed to enable effective implementation by spraying in-field. All other assumptions are as detailed in the analysis spreadsheet (Section 7).

2.2.5.2 Application of mitigation options at the winery

Economic analysis of implementing mitigation options at the winery, in the event that smoke exposure leads to tainted wine, explored three main scenarios. This is because fining of tainted wine with a low dose of a suitable activated carbon can reduce smoke taint, but might not always fully eliminate quality defects from wine. The scenarios were: A) quality improvements to a wine that is

otherwise unfit for sale leading to production of a dry bulk wine that can be sold at a 30% discount; B) quality improvements to a wine that is otherwise unfit for sale leading to a varietal bulk wine that can be sold at a 30% discount; C) quality improvements to a tainted dry wine leading to a wine that can be used for blending bulk dry wine; D) quality improvements to a tainted dry wine leading to a varietal bulk wine that can be sold at a 30% discount; E) blending of improved wine made under B) or D) with clean varietal bulk wine. All other assumptions and parameters are detailed in the analysis spreadsheet (Section 7).

2.3 Project locations

Research was based at the following locations:

Facility/Location	Activity
La Trobe University Bundoora, Victoria	Controlled smoking studies with barrier compounds for vineyard mitigation VESDA® validation Storage of museum wines derived from project Analytical facilities for extraction and measurement of smoke taint compounds from smoke, grapes and wine (joint laboratory with DJPR)
Organic Chemistry Unit Department of Jobs, Precincts and Regions (DJPR) Bundoora, Victoria	Analytical facilities for extraction and measurement of smoke taint compounds from smoke, grapes and wine (joint laboratory with La Trobe University)
DJPR Research unit and farm Mildura, Victoria	Commercial vineyard for trials and fully equipped winery facilities for commercial wine preparation (year 1)
Christmont King Valley, Victoria	Fully equipped winery facilities for commercial wine preparation (year 2-3), wines made from unsmoked and smoked grapes from bushfires, controlled burns and controlled smoking experiments
Australian Wine Research Institute Urrbrae, South Australia	Analytical chemistry facilities for extraction and measurement of smoke taint compounds from grapes, juice and wine and basic chemical analysis of juice and wine samples Laboratory-based research for evaluation of winery mitigation options Benchtop studies with barrier compounds for vineyard mitigation Wine sensory testing by professional panels and consumer tasting panels Winemaking facilities
WIC Winemaking Services Hickinbotham-Roseworthy Wine Science Laboratory Urrbrae, South Australia	Winery mitigation trials
Commercial vineyards across Victoria, NSW and Tasmania	Opportunistic sourcing of smoke-affected grapes and wine. Specific locations included Ballarat (Victoria), Orange (NSW) and Huon Valley (Tasmania)
Vineyards in 23 regions across Western Australia, South Australia, Victoria, New South Wales and Tasmania	Collection of over 300 non-smoke-exposed grape samples for the baseline analysis of smoke taint compounds

Smoke monitoring locations were as follows:

- Seven static VESDA® units were located strategically across Victoria, where controlled burns are mandatory. Three were located in the Ovens and King Valleys in north-east Victoria, three in the

Yarra Valley, and one in the Otways region (Figure 1). Roving VESDA units were deployed at various locations across South-eastern Australia in response to bushfires or controlled burn events near vineyards (Figure 3)

- In response to bushfires, permanent VESDA® units were added in Tasmania in 2018/19 and the Hunter Valley, NSW in 2019/20.

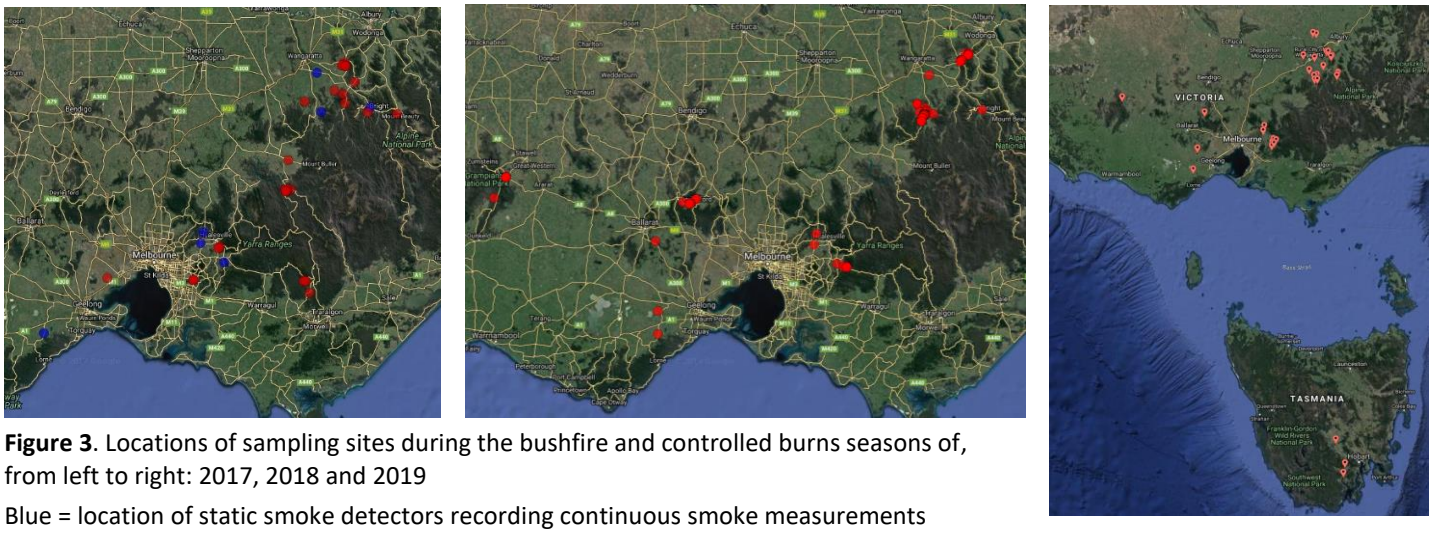


Figure 3. Locations of sampling sites during the bushfire and controlled burns seasons of, from left to right: 2017, 2018 and 2019

Blue = location of static smoke detectors recording continuous smoke measurements
Red = additional sampling sites using roving smoke detectors

The research findings are applicable to all wine-producing regions of Australia which can be impacted by smoke generated from bushfires, forest or stubble fires and prescribed burns. All the major grape-growing areas are close to public land, national parks and mountainous regions where bushfires are predicted to increase in intensity (Figure 4). Outcomes from the project will also particularly benefit grape growers in regions close to areas in which regular controlled burns are conducted to meet the requirements of state legislation for reducing risk from bushfires.

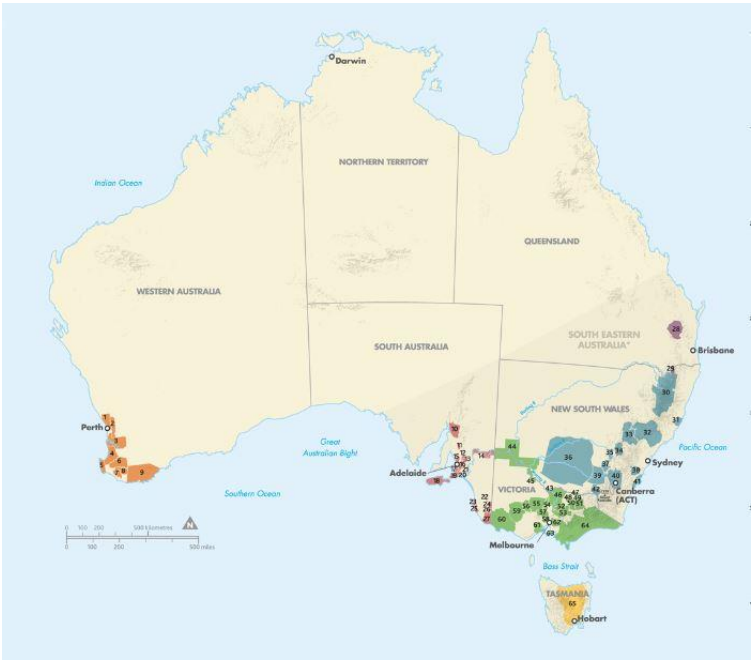


Figure 4. Location of Australia's wine regions

2.4 References

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Pollnitz, A.P., Pardon, K.H., Sykes, M., Sefton, M.A. (2004) The effects of sample preparation and gas chromatograph injection techniques on the accuracy of measuring guaiacol, 4-methylguaiacol and other volatile oak compounds in oak extracts by stable isotope dilution analyses. *J. Agric. Food Chem.* 52(11): 3244−3252.

3 Project Outcomes

3.1 Project level achievements

Overall, the project achieved or exceeded the activities, KPIs and outputs as specified in the agreement. Further detail is provided below and in the project evaluation report.

Activity B1. Project initiation

Output 1(a) – Engage a project manager for the duration of the Activity.
Output 1(b) – Establish a project steering committee responsible for oversight of the Activity. The project steering committee will agree its terms of reference which will set out its membership, governance arrangements and responsibilities.

The Funding Deed was executed between Wine Australia and the Commonwealth on 20/6/2016, for project commencement on 1/7/2016. Project initiation outputs included engagement of a project manager (Dr Sharon Harvey, Wine Australia) and establishment of an Industry Reference Group (IRG) with agreed terms of reference. Membership included a number of viticulturists and winemakers from both Victoria and South Australia, and representatives from Wine Australia, the state wine associations of Victoria, Tasmania, Western Australia and South Australia, AWRI, DJPR and La Trobe University.

Output 1(c) – Execute agreements with partner organisations.

Execution of individual Project Agreements with La Trobe University and the Australian Wine Research Institute (AWRI) were complete in April and May 2017, respectively. A Program Management Agreement, detailing the project collaboration terms and co-investment commitments, was signed by all parties in August 2017. Despite contracts taking longer to finalise than anticipated, the research partners (La Trobe University, DJPR and the AWRI) proceeded in good faith with experimental work to enable capture of data from the 2016-17 growing season and 2017 controlled burns season.

Output 1(d) – Advise the yearly breakdown of the cash and in-kind contributions to be provided by partner organisations for the duration of the Activity.

The yearly breakdown of the cash and in-kind contributions to be provided by partner organisations across the entire period of the Grant was provided with Milestone Report 1.

Activity B2. Project planning and management

Output 2(a) – Prepare a project plan, setting out the schedule for activities, and the human resources and financial resources required. Prepare a risk management plan as part of the project management plan.

A detailed project plan was developed and provided with Milestone Report 2. It included a schedule for activities, human and financial resources required and a risk management plan to be implemented during the project if necessary. The lack of bushfire events in the first two years of the

project meant that smoke-affected wine for mitigation studies and establishment of sensory thresholds was in short supply. Although this was a risk not forseen, the project team responded quickly to access smoke-tainted wine from the previous season and from overseas collaborators and progress other areas of the project.

Output 2(b) – Prepare a communication and extension plan, setting out the schedule for communication and extension activities, and the human resources and financial resources required.

Smoke taint issues have, in the past, been an emotive topic for the grape and wine industry and public land management agencies. Communication between the parties involved and to the general public requires careful management to avoid the negative impacts of misinformation. The communication and extension plan (submitted with Milestone Report 2) therefore included a risk management plan in order to manage these risks. The plan was implemented around major fire events in grape-growing regions in NSW and Tasmania (2018-19) and SA, Vic and NSW (2019-20).

Output 2(c) – Prepare a monitoring and evaluation plan, setting out timeframes for activities to be delivered, and the human resources and financial resources required.
Output 2(d) – Provide a progress report on the evaluation of the project, delivered at the mid-point of the project.

A monitoring and evaluation plan was developed and submitted with Milestone Report 2. A progress report on the evaluation of the project was delivered at its mid-point.

Activity B3. Communication and extension activities

Output 3(a) – Identify target audiences and establish appropriate contacts with land/fire managers, vineyard managers and extension networks and platforms.

This objective was met. Target audiences were identified and engaged early in the project, enabled by existing and new relationships. Contact points included public land management agencies (e.g. DELWP, other State environmental departments), winery producers, grape growers, grape and wine industry service providers, regional grape and wine industry associations, wine industry media, Agriculture Victoria (DPJR), LaTrobe University, the AWRI Board, Wine Australia and DAWE. Extension via Wine Australia networks occurred through existing platforms such as AWRI Roadshows and the Regional Program.

The strategy for communication with each of these groups is outlined in the communication and extension plan (submitted with Milestone Report 2) and specific activities throughout the project are detailed in Section 5. The extent of communication and extension activities attests to the strength of the relationships developed in this project between researchers, land management agencies and the wine sector.

Output 3(b) – Implement communication and extension plan, and promote project activities and outcomes through existing extension networks and platforms, including regional AWRI Roadshows/seminars, regional workshops, conference workshops, electronic information and communication platforms (such as e-news bulletins, webinars, website and social media),

professional education, helpdesk advice, industry emergency response capability and specific publications .

Communication and extension opportunities were actively pursued throughout the project. Industry interest and engagement was strong from the outset of the project and increased following the major bushfires in 2019 (Tasmania, NSW) and 2020 (NSW, Victoria and SA). In addition to more formal events such as workshops, the research team provided significant on-the-ground support to affected wine regions during and after bushfires and provided valuable practical advice, based on the outcomes of this project, for dealing with the consequence of the fires. All communication and extension activities for the term of the project are detailed in Section 5.

Output 3(c) – Provide planning and management protocols for land/fire managers. Protocols will include summaries of data from trials which identify whether smoke of particular ages has the potential to damage grapes and wine, and advice on probable safe distances for controlled burns.

The planning and management factsheet developed for land/fire managers is attached in Section 7. The primary aim was to raise awareness and improve communication between grape growers and land/fire managers. The protocol informs fire managers of the risk that grapes can be damaged as a result of prescribed burn activities and of the essential steps involved in working with the wine industry in planning prescribed burns to reduce that risk. Important factors are defined by research results from this project. Potential impact on vineyards is now a consideration in controlled burn activities by land managers and fire controllers, reducing adverse impacts on winegrape growers and winemakers.

Output 3(d) – Provide planning and management protocols for vineyard managers. Protocols will include advice on remote sensor networks and the use of any effective barrier treatments identified in the project.

Following grower feedback, the planning and management protocol factsheet for grape growers takes the form of an action plan (Section 7). It provides information on testing grapes and some factors which influence smoke taint. It informs growers of the essential steps involved in planning and communicating with fire managers by liaising with a local member of Forest Fire Management Victoria (FFMV) and registering on the FFMV website to receive prompts to their phone for any burn scheduled in their region during growing season. The protocols also assist grape growers to take more control in scheduling controlled burns. None of these options were available prior to the project. The protocol will be updated when the remote sensor network is rolled out more widely and when mitigation treatments shown to be effective in small scale trials in the project have been shown effective in vineyards against burns.

Output 3(e) – Identify the costs of implementing the technologies and techniques identified by the project and conduct farm economic analyses to ascertain costs/benefits for growers.

An analysis was carried out to determine the cost/benefit of implementing an industry-wide smoke detector network, with application of a protective spray where smoke levels pose a sufficiently high risk of smoke taint. The result of the cost-benefit analysis is attached in Section 7, and indicates a potential cost-benefit ratio across 30 years of 3.6. In other words, for every $1.00 invested, this component of the project would return $3.60 of value to the sector by reducing the incidence of smoke taint.

Economic analysis was also carried on application of carbon fining as a treatment for smoke taint at the winery. The analysis, as detailed in Section 2.2.5 and Section 7, explores five main scenarios based on probability of success and outcomes of treatment, and was carried out for both red and white wine. This is because price and quality considerations vary between reds and whites, as does the success of carbon fining as a treatment option. The cost of materials for treating smoke tainted wine with carbon is very low ($3.70 to $17.00/1,000L wine, depending on dose rate and choice of product) and the impact of wine volume losses (typically 2%) is also marginal, given the low value of the wine prior to carbon fining. Addition of fining agents and their removal are standard operations in winery, not requiring specialised equipment or significant extra labour inputs. These factors make carbon fining an attractive value-add proposition for producers facing otherwise unusable grapes or wine. The relative reduction in losses (or value recovered) was found to be in the range of 38 to 96% when compared to wine which is otherwise not fit for sale.

The outcomes of this project, if implemented by producers, would clearly have a significant long-term benefit and allow continuity of business for the portions of the sector facing a smoke damage scenario.

Activity B4. Early warning remote sensing network

Output 4(a) – Develop an early warning remote sensing network for monitoring real-time levels of smoke across several key regions of the wine industry, and calibrate and validate sensors against reference methods.

The network of seven fixed VESDA®s was operational across Victoria from the summer of 2017/18. They provided continuous, real-time data on smoke density which was downloaded remotely by researchers and proved to be effective for monitoring widespread smoke events during the grape-growing season.

Smoke dose data from the static network of VESDA®s and the five mobile VESDA® units, collected at controlled burns and bushfires, was used to calibrate the sensors against the output from Tenax® tubes, which measure chemical composition of the smoke (Section 2.2.1). Good correlation between the measurements (Figure 5) suggests that VESDA® outputs can be used as an indicator of the total concentrations of key smoke taint compounds in smoke. Poorer correlation was obtained closer to fires (not shown), due to high variability and high levels of gaseous compounds in fresh smoke which have yet to be converted to a form which is detectable by VESDA®s. The data indicates that vineyards within 500m of a burn may experience much higher concentrations of smoke taint compounds than would be predicted from VESDA® measurements, a factor to be taken into account when interpreting VESDA® outputs.

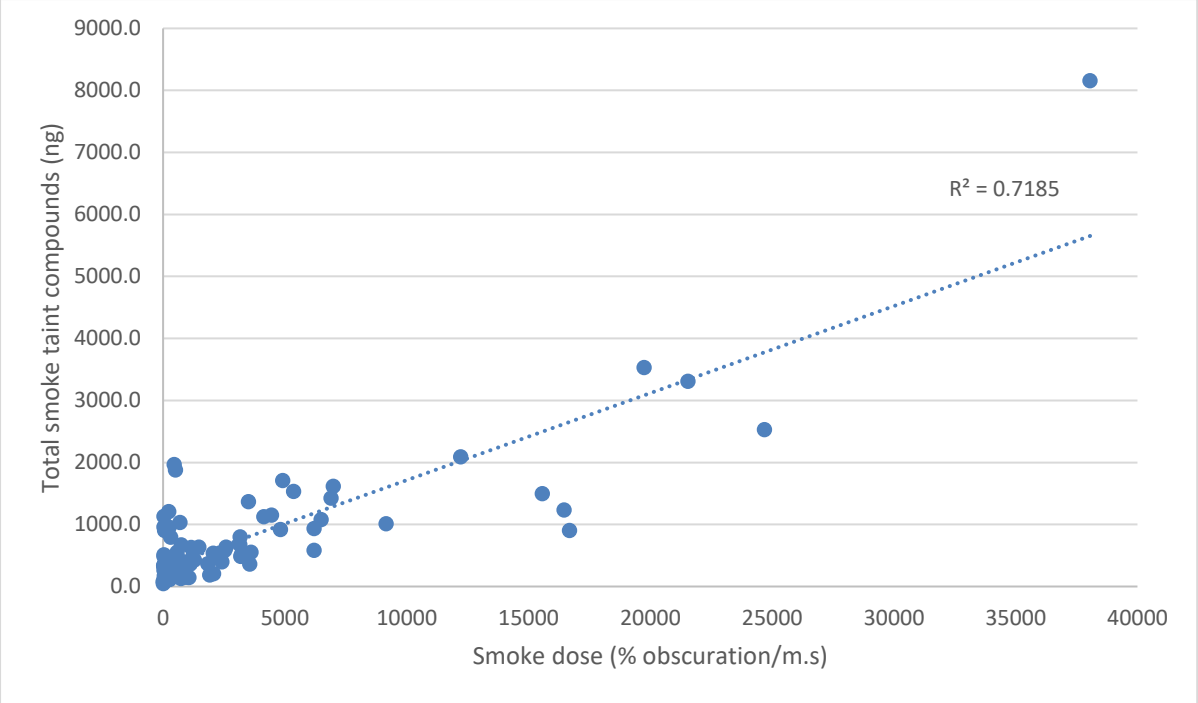


Figure 5. Correlation between total smoke taint compounds (sum of amounts of phenol, o-cresol, m-cresol, p-cresol, guaiacol, 4-methylguaiacol, syringol and 4-methylsyringol recovered from Tenax® tubes) versus area under curve of VESDA® measurements during sampling period. Measurements taken less than 500 m from fires have been excluded

This important result allows the VESDA® outputs to be used as an indicator of smoke taint risk around vineyards in real time. The establishment of a field-based smoke detection network in a key wine region is a world first and gives producers the ability to make informed decisions regarding their crop from a much earlier stage than if they had to wait for grape testing results.

Activity B5. Vineyard mitigation options

Output 5(a) – Conduct experiments to establish the composition of smoke taint in vineyards and determine the impact of smoke age, environmental parameters and distance on the profile of taint compounds.

A large volume of smoke information and grape samples were collected around prescribed burns and bushfires during the project, allowing a comparison of the levels of smoke compounds in smoke, grapes and wine. Smoke sampling at different distances from the fire allowed measurement of changes in smoke composition as smoke ages and travels away from a fire. Wind conditions and whether the burn was a bushfire or a controlled burn were also taken into account. Around 2000 data points were generated which contain analytical data from corresponding smoke-grape-wine samples. An example of data collection is presented in Table 5.

Table 5: Example of data collection: wines made from smoke-exposed grapes in autumn 2018

Fire type	Wind	Distance from burn (km)	Downwind	Tenax sample	Vesda reading	Variety	Type	Grape chemical composition	Wine made	Wine chemical composition	Wine sensory testing	Taste score (0-5 scale)	Comment
Bushfire	Still - inversion	0.47	Yes	Yes	Yes	Semillon	On-vine	Yes	Small-scale	Yes	Basic	?	Unsure
Bushfire	Still - inversion	0.51	Yes	Yes	Yes	Pinot Noir	On-vine	Yes	Small-scale	Yes	Basic	1	Low taint
Bushfire	Still - inversion	0.63	Yes	Yes	Yes	Prosecco	On-vine	Yes	Small-scale	Yes	Basic	?	Unsure
Bushfire	Still - inversion	0.57	Yes	Nearby	Nearby	Chardonnay	On-vine	Yes	Small-scale	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.58	Yes	Nearby	Nearby	Pinot Gris	On-vine	Yes	Small-scale	Yes	Basic	0	No taint
Bushfire	Still - inversion	1.07	Yes	No	No	Pinot Noir	On-vine	Yes	Small-scale	Yes	Basic	0	No taint
Bushfire	Still - inversion	1.40	Yes	No	No	Pinot Gris	On-vine	Yes	Small-scale	Yes	Basic	0	No taint
Bushfire	Still - inversion	1.39	Yes	No	No	Prosecco	On-vine	Yes	Small-scale	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.55	Yes	Yes	Yes	Fiano	On-vine	No	Commercial	Yes	Basic	1	Slight taint
Bushfire	Still - inversion	0.79	No	No	No	Riesling	On-vine	No	Commercial	Yes	Basic	<1	Very slight taint
Bushfire	Still - inversion	0.76	Yes	No	No	Sauvignon Blanc	On-vine	No	Commercial	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.72	Yes?	Nearby	Nearby	Chardonnay	On-vine	No	Commercial	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.93	No	Nearby	Nearby	Pinot Gris	On-vine	No	Commercial	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.72	Yes	Nearby	Nearby	Pinot Gris	On-vine	No	Commercial	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.58	Yes	Yes?	Yes?	Prosecco	On-vine	No	Commercial	Yes	Basic	0	No taint
Bushfire	Still - inversion	0.53	Yes?	Yes?	Yes?	Pinot Noir	On-vine	No	Commercial	Yes	Basic	<1	Very slight taint
Controlled burn	Low	0.01	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	1	Slight taint
Controlled burn	Low	0.15	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	2	Low taint
Controlled burn	Low	0.15	Yes	Yes	Yes	Chardonnay	Excised bunches	Yes	Small-scale	Yes	Basic	1	Slight taint
Controlled burn	Low	0.01	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	3	Medium taint
Controlled burn	Low	0.01	Yes	Yes	Yes	Chardonnay	Excised bunches	Yes	Small-scale	Yes	Basic	2	Low taint
Controlled burn	Moderate	0.01	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	1	Slight taint
Controlled burn	Moderate	0.01	Yes	Yes	Yes	Chardonnay	Excised bunches	Yes	Small-scale	Yes	Basic	<1	Very slight taint
Controlled burn	Moderate	0.09	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	0	No taint
Controlled burn	Moderate	0.09	Yes	Yes	Yes	Chardonnay	Excised bunches	Yes	Small-scale	Yes	Basic	0	No taint
Controlled burn	Moderate	0.05	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	?	Unsure
Controlled burn	Moderate	0.02	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	3	Medium taint
Controlled burn	Moderate	0.02	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	2.5	Medium taint
Controlled burn	High	0.005	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	0	No taint
Controlled burn	High	0.25	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	0	No taint
Controlled burn	High	0.125	Yes	Yes	Yes	Shiraz	Excised bunches	Yes	Small-scale	Yes	Basic	0	No taint

This data allowed key relationships to be determined between smoke composition (Tenax®) and grape composition, smoke composition (Tenax®) and wine composition, smoke dose (VESDA®) and wine composition, smoke composition (Tenax®) and fuel type and smoke composition (Tenax®) and distance from a fire. An example of the regression analysis performed in all cases is in Figure 6. Another example, which shows the decrease in all smoke taint compounds with distance from fire, is shown in Figure 7. The exponential decrease is due mainly to dilution with clean air but also chemical degradation. Degradation rates differed between compounds, with some degrading more quickly than others.

Key outcomes are:

- Development of smoke taint is site-specific and depends on the proximity of a vineyard to a burn or bushfire, the intensity of the fire, the age of the smoke and the prevailing weather conditions
- The profile of smoke taint compounds changes substantially with distance from controlled burns
- The risk of smoke taint decreases rapidly as the smoke ages (travels further from a fire)
- It appears that 5 km may be a safe distance for vineyards downwind from typical controlled burns, conducted in reasonably still climatic conditions in autumn
- Bushfires present a much higher risk of smoke taint in grapes and wine than controlled burns, due to the potentially much larger volume of smoke and atmospheric conditions such as high winds, which may carry compounds further before they degrade
- Smoke haze from old smoke from controlled burns is not sufficient to cause smoke taint

Although the aim was to conduct professional sensory studies to link with the smoke-grape-wine chemical data, this aspect of the work proved difficult. Levels of smoke taint in the wines produced from the above studies were considered too low to be definitive or too high to be informative. The former is apparent in the example data from 2018 (Table 5). Sufficient wines for formal sensory analysis were only obtained following this year's bushfires, too late to include in the project. This is the only element of the project which was not achieved. The wines from the 2018 and 2019 bushfires and controlled study samples were instead used to conduct industry consumer studies and for valuable training of regional tasting panels in the sensory perception of smoke taint.

A new project between La Trobe University and Charles Sturt University aims to add the sensory analysis to the smoke-grape-wine data collected in this project for smoke taint compounds. The new work will allow threshold levels for the risk of smoke taint to be defined, the first time this has been done globally.

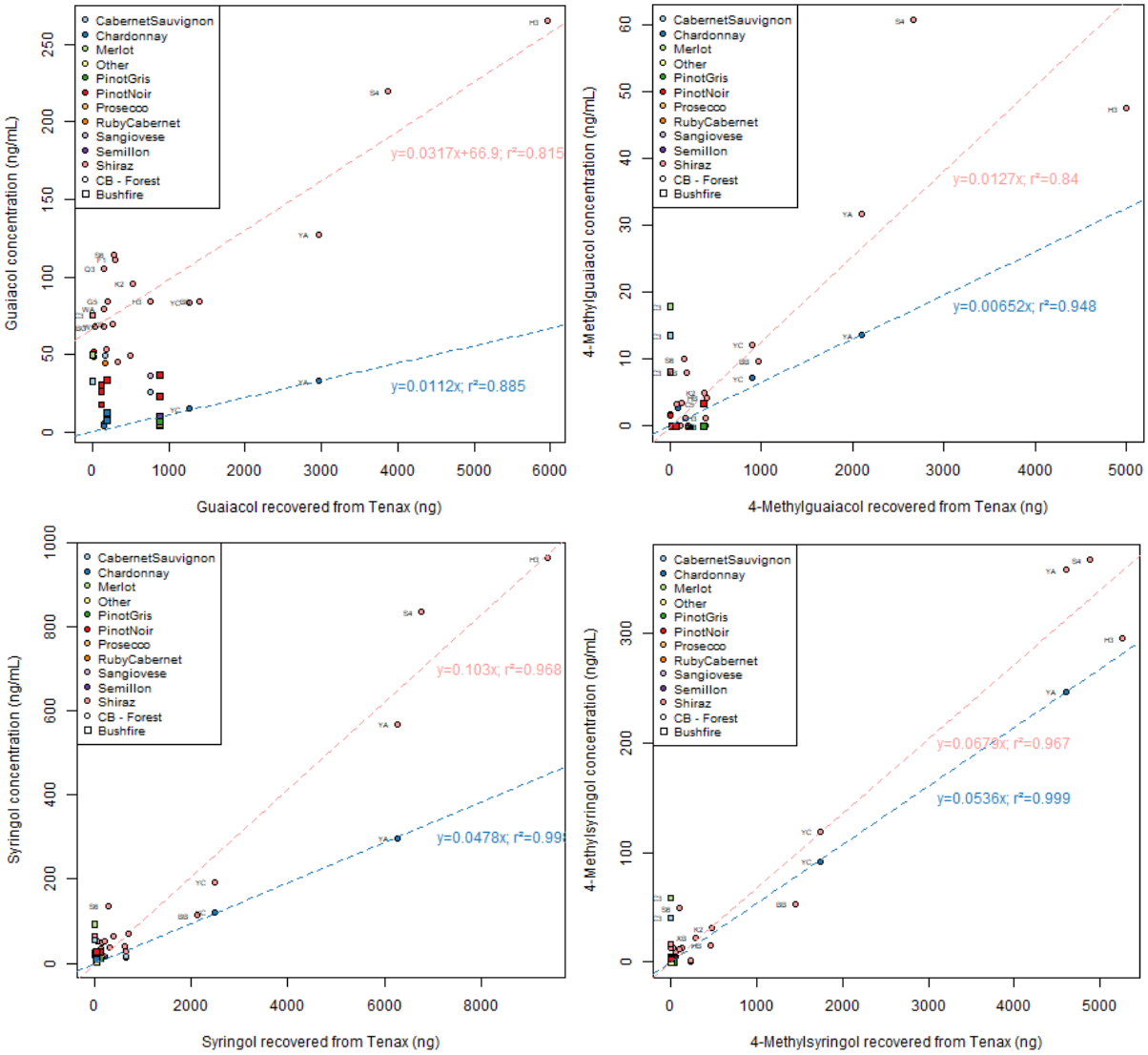


Figure 6: Relationship between the concentration of smoke taint compounds in wine (ng/ml) and the amount of compound captured on Tenax® tubes (ng) for all wines. Linear regression lines for Chardonnay (blue) and Shiraz (orange) shown.

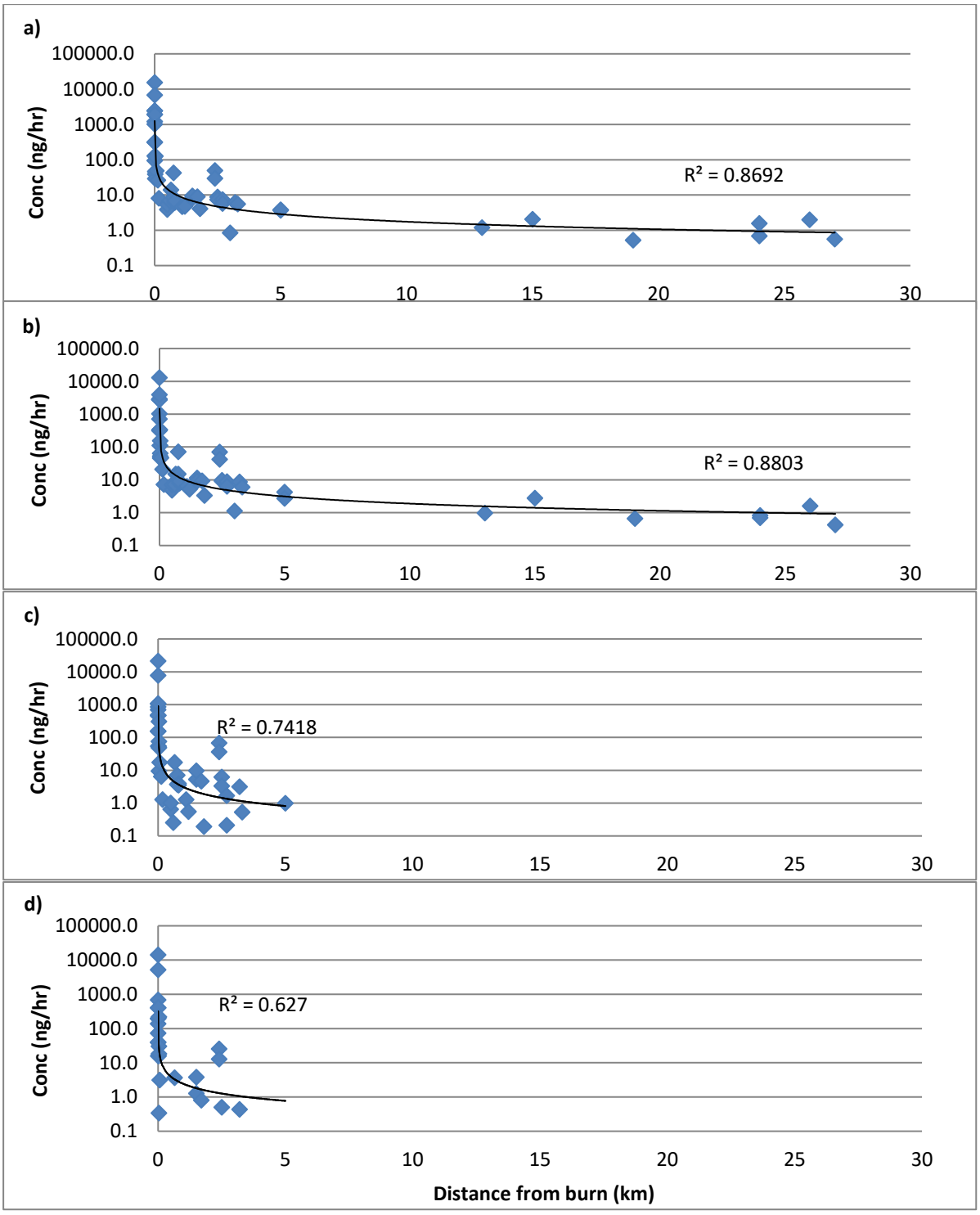


Figure 7: Changes in concentration (log scale) of four major taint compounds; (a) cresols, (b) guaiacol, (c) syringol and (d) 4-methylsyringol in smoke with distance from controlled burns. Data presented from 53 sites sampled in 2017. Syringol and 4-methylsyringol were not detected beyond 5 km from controlled burns and are not included here.

Output 5(b) – Assess practical ways to prevent the entry of taint compounds into grapes. This will include trials with anti-transpirants and barrier-type compounds, and exploring options for limiting the conversion of volatile taint compounds into their glycosylated grape metabolites.

Early warning, provided by the network of sensors, can allow preventive measures to be applied in vineyards and minimise economic losses from smoke taint in grapes and wine. To this end, the project team screened over 21 products for their potential as protective barriers (Section 2.2.2). Many were agrochemicals already used in viticulture, which we know are safe to use and which can be sprayed onto grapes (sunscreens, oily/hydrophobic materials, pest control products). Others were selected on the basis that they might provide a physical barrier (biopolymers, silicon oil) and/or are known to break down phenols (Titanium oxide).

Many of the coating products, including commercially available anti-transpirants and sunburn protectants, had the effect of increasing the uptake of smoke taint compounds by grapes. It may be important that growers avoid using these products when there is the risk of smoke exposure. However, controlled smoke chamber experiments showed that chitosan, a biopolymer present in crab shells, reduced the entry of smoke taint compounds in grapes by up to 60%. Several chitosan products were trialled, with a fungal-derived chitosan showing similar efficacy to the crab chitosan. As fungal chitosan is already in use in the industry as a processing aid in wine production, it may not require additional approvals for commercial use in a new application.

A field experiment was conducted in March 2019 in collaboration with AWRI using excised bunches of Shiraz grapes in a smoking tent (Figure 8). Both uncoated and chitosan-coated bunches were smoked, and the grapes were made into wine. The chitosan again had a protective effect on the grapes, with approximately 35% less total phenolic glycosides present in the wine produced from chitosan-coated grapes. Sensory analysis carried out by the AWRI Technical Quality panel rated the chitosan-treated Shiraz significantly lower in 'smoke' flavour intensity than the non-treated Shiraz.



Figure 8. Smoking trials (a) Chitosan-coated grapes on a drying rack (foreground) and the smoke tent and smoke generator (background) at Great Western; (b) Chardonnay grapes inside the smoking tent at Faraday; (c) Shiraz grapes being placed inside the smoking tent at Great Western; (d) the application of chitosan to Shiraz grapes at Great Western; and (e) smoking of Shiraz grapes within the smoking tent at 20% obscuration at Faraday.

These results suggest that fungal-derived chitosan has significant potential as a spray which could be applied in a vineyard to protect grapes against smoke taint. Field trials are required in future to test the practicality of applying the product in commercial vineyards.

Investigations also showed that grapes are able to rapidly convert smoke taint phenols to glycosides, with this process generally complete within a day of smoking. Since the compounds must first be absorbed by the grapes before conversion to glycosides can take place, this implies the bulk of the smoke taint compounds have been absorbed within a day. Laboratory experiments confirmed that washing of the grapes did not have any significant effect on phenol and glycoside levels in smoke-exposed grapes.

Activity B6. Sensory thresholds

Output 6(a) – Determine critical concentrations of taint compounds in wine through sensory threshold and consumer response studies.

Determination of threshold concentrations of smoke taint compounds in wine was approached using the wines generated in the dilution experiment, as described in Activity B7 (below). A 2016 smoke-affected Pinot Noir wine from Victoria and a 2019 smoke-affected Pinot Noir rosé from Tasmania were serially diluted (Section 2.2.4) and assessed by highly qualified and experienced tasting panels, with members chosen based on their ability to perceive smoke flavour. Based on chemical analysis and knowledge of the smoke characteristics, the wines were classified as moderately to highly smoke tainted.

Results for the two wines were similar. Analysis of variance demonstrated significant differences among wine blends for all four attributes: overall fruit aroma, smoke aroma, ‘overall fruit’ flavour and ‘smoke’ flavour. The 100% smoke-affected wine was scored significantly higher in ‘smoke’ aroma and flavour than the unaffected wine and was the lowest scoring wine for ‘overall fruit’ aroma and flavour. The blends with 75% or greater unaffected wine were not significantly different from the unaffected wine for any of the attributes. This suggests that a blend of 3:1 unaffected:affected wine is sufficient to remove the perception of smoke taint in a moderate-highly smoke tainted wine in a full-bodied and light red wine style.

Further sample sets should be investigated to assess whether this result might be applicable more generally. The intensity of smoke taint, as well as the sensory properties of the unaffected wine used as the blending wine, will both influence the amount of unaffected wine required to dilute the perception of smoke taint sufficiently.

Results of sensory analysis were compared with chemical composition of the wines in order to establish sensory thresholds for smoke taint compounds. The parallel relationship of chemical (measurement of smoke taint-related phenols and glycosides) and sensory data (Figure 9) shows that there was good correlation between chemical and sensory data. Importantly, this strongly reinforces

the link between the measured compounds as indicators of smoke taint. That is, these compounds are the appropriate markers to test in chemical analysis of grapes or wine which may be smoke-damaged. The plateauing of sensory scores at the lower end of the trendlines (after 87.5% of the blend contained unaffected wine), reinforce that there were no significant sensory differences between these blends and the unaffected wine.

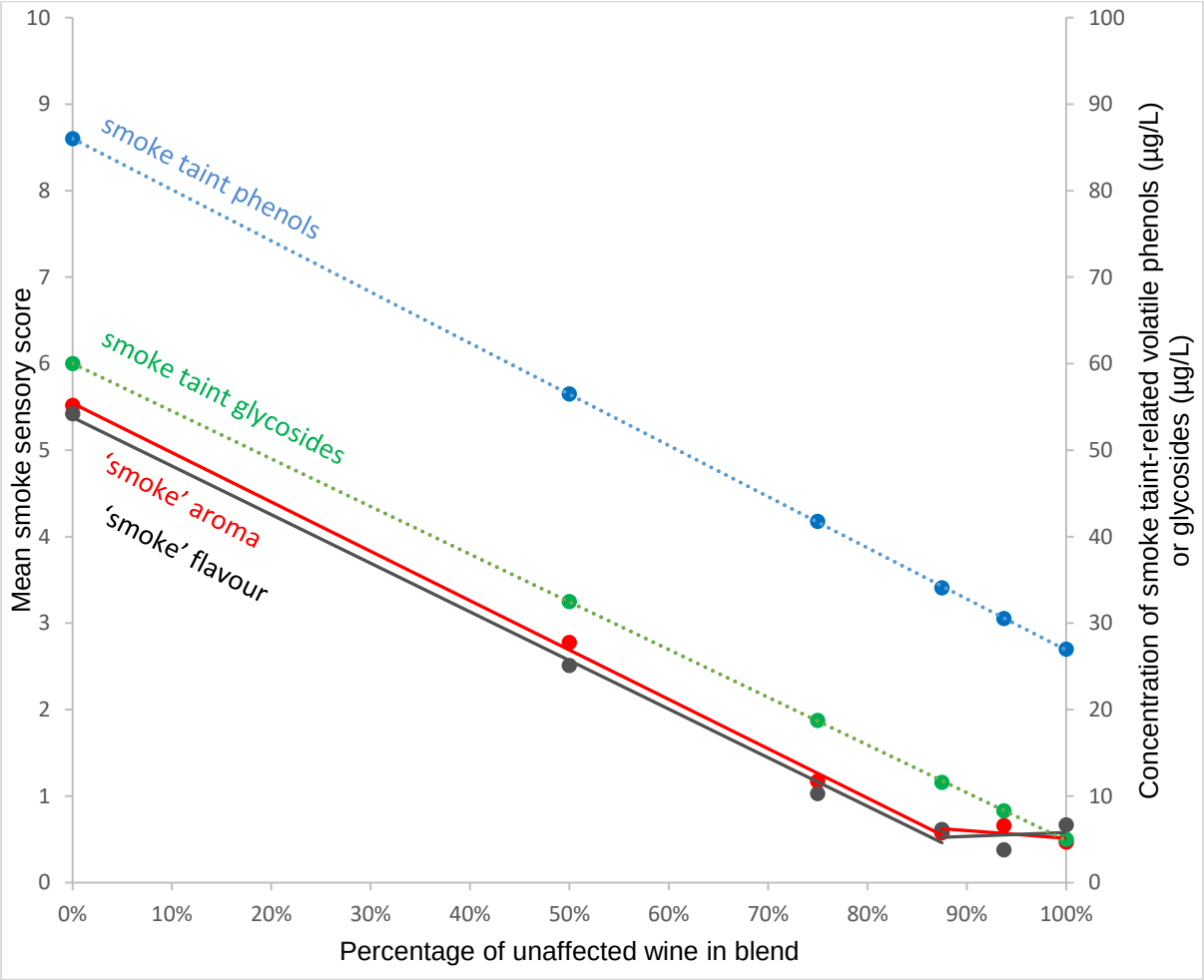


Figure 9. The relationship between the percentage of unaffected Pinot Noir wine added to the smoke-affected wine and the mean 'smoke' sensory aroma (●) and flavour (●) scores together with the concentration of smoke taint-related phenols (●) and glycosides (●) within each wine. Bivariate fit lines for 'smoke' aroma (—) upper concentration range [y = -5.70x + 5.54, R^2 = 0.9988] and lower concentration range [y = -0.89x + 1.40, R^2 = 0.3243]. 'Smoke' flavour (—) upper concentration range [y = -5.62x + 5.38, R^2 = 0.9968] and lower concentration range [y = -0.44x + 0.14, R^2 = 0.0328]. Linear trends for smoke taint-related phenols (·····) and glycosides (·····) [y = -59x + 86] and [y = -55x + 60], respectively.

In addition to expert evaluation, the rosé dilutions were the subject of a consumer study (n=82) in which each wine was rated on a numerical scale for overall liking. The aim here was to gauge the difference between consumer perception of smoke taint in wines and that of the expert tasting panel. Five of the six dilutions (the 50% one was omitted) were rated for overall liking on a nine-point hedonic scale from 'like extremely' to 'dislike extremely'.

Overall, liking scores decreased with increasing proportion of smoke-affected wine. The consumers formed three clusters with respect to wine preferences. Half the consumers grouped into a cluster who most liked the clean wine, with progressively lower liking scores for the wines with a greater percentage of smoke-affected wine. One cluster preferred the middle three dilutions to either the 0% or the 100% blend and the remaining cluster liked all the wines, suggesting that they were either not sensitive to smoke or enjoy the sensory characteristics it provides. On the other hand, even a small proportion of smoke-affected wine in a blend can affect liking for some consumers.

What became apparent during this work is that to set specific and widely applicable thresholds for concentrations of smoke taint compounds will be difficult. The critical concentrations will vary between varieties and wine styles and, as we have seen, there is wide variation in how consumers perceive smoke taint in wine. The results obtained here are specific for this particular wine variety, wine style and severity of smoke taint. Definition of even loose thresholds would require a much wider study with many more examples of smoke-tainted fruit and wine than were available in this project. As outlined in Activity B5, appropriate material for sensory analysis was in short supply. However, this season's bushfires provided a unique opportunity to source many smoke-affected grape samples, with a range of low to high exposure, and current work is using them to understand more about the threshold levels of smoke taint compounds for each particular variety.

Activity B7. Remediation technologies and techniques

Output 7(a) – Evaluate readily available remediation technologies and techniques with trials in white juice, Chardonnay, Shiraz and Pinot Noir.

Evaluation of activated carbon

Activated carbon is a highly porous, carbonaceous material used in a variety of applications, including winemaking, for removal of contaminants. They vary widely in their properties. A total of 15 commercially-available activated carbon products (Section 2.2.4) were evaluated in benchtop studies for their ability to remove smoke taint compounds (both volatile phenols and phenolic glycosides) from grape juice and wine. A total of 14 grape juice, pressing samples and wine (including Merlot, Cabernet Sauvignon, Pinot Noir, Mataro, Sauvignon Blanc, Riesling and Chardonnay) were tested, from grapes which had been artificially smoked or exposed to bushfire. Dose rate and treatment time was varied to determine optimal conditions for removal of smoke compounds.

Key outcomes were:

- The removal efficiency of phenolic glycosides and volatile phenols from smoke-affected juice and wine was dependent on the activated carbon product. The best performers were PS1300, CA50, Smartvin and CASPF, regardless of the juice matrix treated. On the other hand, Carbocromos and FPS were the best performers for removing volatile phenols. An example of a dataset from this extensive study is shown in Figure 10.

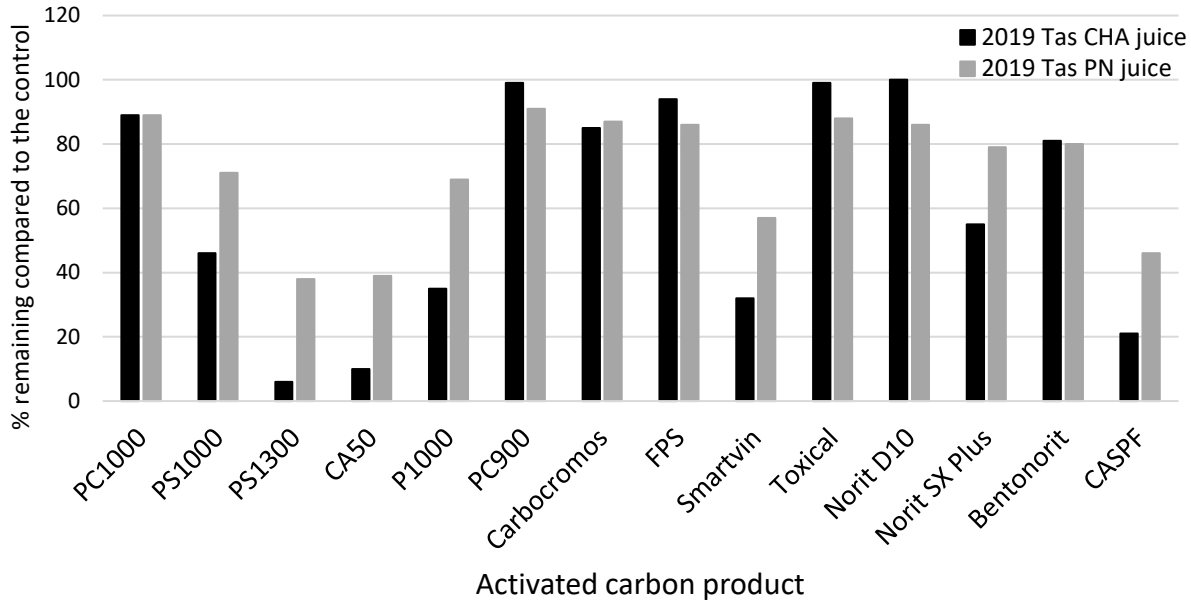


Figure 10. Comparison of the ability of several activated carbon products (dose rate 2 g/L, contact time 24 hours) to remove total phenolic glycosides from two 2019 smoke-affected Tasmanian juices (CHA = Chardonnay; PN = Pinot Noir). Results are presented as percentage of phenolic glycosides remaining compared to the control (i.e. juice without carbon treatment).

- In general, the products were not very effective at removing phenolic glycosides from wine, and performed particularly poorly in red wine (possibly because other compounds in red wine - anthocyanins, tannins - compete for binding sites in the carbon). For two full-bodied Pinot Noir wines, the reduction in phenolic glycosides was less than 20%, even at a high dose rate of 2 g/L.
- The activated carbon products fared slightly better in white and rosé wines, with some removing between 50 and 60% of the phenolic glycosides.
- Overall extraction of phenolic glycosides was better in juice than wine, with up to 8-fold difference for the better performers, even when used at low concentrations. Certain carbons could reduce the concentration of phenolic glycosides in juice by 90% or more. Again, the products performed better in white juice than red juice.
- There is a linear relationship between the amount of activated carbon added and removal of phenolic glycosides from juice and wine
- Some activated carbons are effective at removing volatile phenols from red wine, with effectiveness being dependent on dose and carbon used.

Winemaking trials with grape juice after fining with activated carbon

Trials were scaled up to assess the performance of two of the most promising activated carbons, PS1300 and CASPF, on smoke-affected Pinot Noir and Chardonnay juice. Results were:

- Grape processing at the winery can significantly affect the concentrations of smoke taint marker compounds, with substantially lower concentrations of volatile phenols and phenolic glycosides in free run juice compared to grapes, and the highest concentrations in pressings. Skin contact should be minimised if grapes are suspected or known to be smoke tainted.

- Confirming benchtop studies, removal of phenolic glycosides depended on dose of activated carbon and was more effective in Chardonnay than Pinot Noir juice. Treatment of Chardonnay juice by either carbon at 4 g/L removed 99% of the total phenolic glycosides.
- Colour was reduced in the Pinot Noir juice following treatment.
- The two carbons were similar in their removal efficacy of phenolic glycosides from juice.
- Sensory analysis on treated Pinot Noir and Chardonnay wines was extensive and used the quantitative sensory descriptive analysis method. For both wines, the highest carbon dose treatments were able to reduce the severity of 'smoke' aromas and flavours in the wine, but many of the pleasant 'fruit/floral' attributes also decreased (Figure 11; Figure 12). Results varied across panel members.

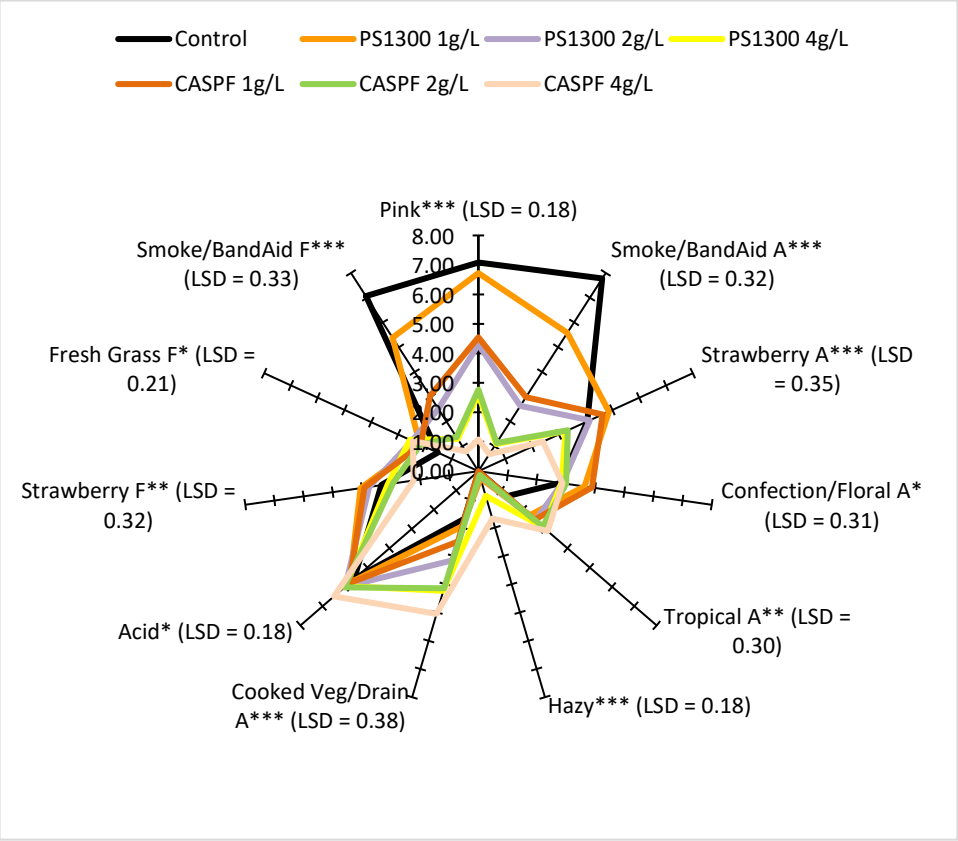


Figure 11. Spider plot of sensory ratings for significant (*P<0.05; **P<0.01; ***P<0.001) and approaching significance (ǂ P< 0.10) attributes for seven treatments of Pinot Noir wines. LSD (P=0.05) values included for the significant attributes (P<0.05)

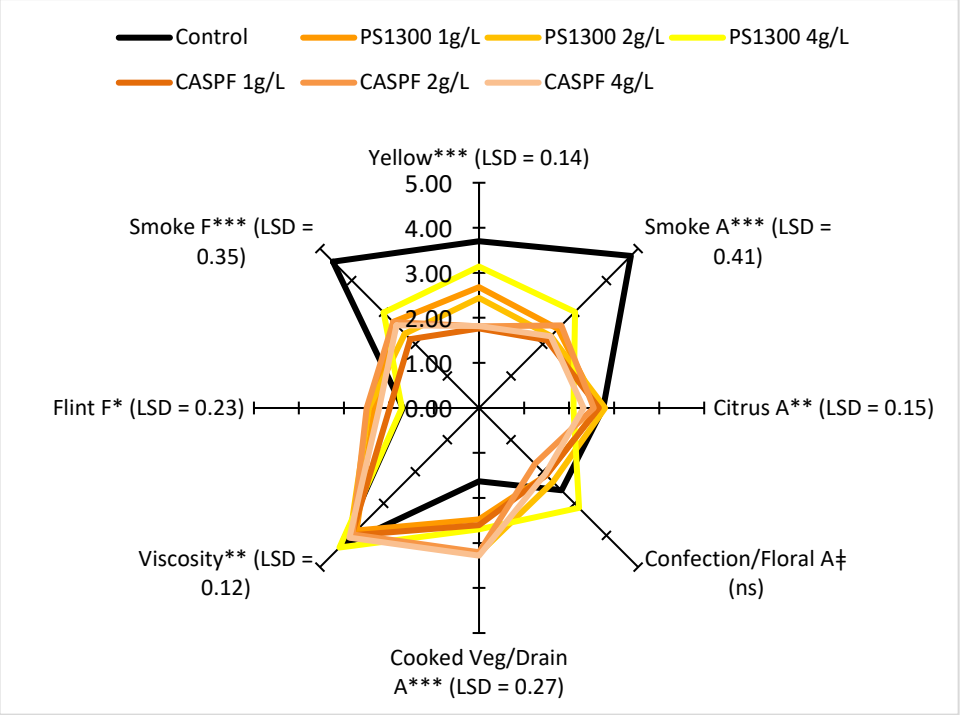


Figure 12. Spider plot of sensory ratings for significant (*P<0.05; **P<0.01; ***P<0.001) and approaching significance (‡ P< 0.10) attributes for the seven treatments in the Chardonnay samples. LSD (P=0.05) values included for the significant attributes (P<0.05). ns = not significant

Evaluation of commercially available glycosidases

Glucosidase enzymes were also explored as a mitigation option for smoke taint at the winery (Section 2.2.4). The premise was to use enzymes to break down the glycosides in smoke-affected juice or wine, allowing the volatile phenols which were released to be removed by subsequent reverse osmosis or membrane technology. The ability of five commercially available glycosidases to cleave smoke glycosides in 13 different wines and pressings was investigated under various temperatures, contact times and dosage rates. Smoke-affected wines were a mixture of red and white varietals including Pinot Noir, Cabernet Sauvignon, Sauvignon Blanc and Chardonnay.

Glycosidases were ineffective in the treatment of juice (probably due to high sugar inhibiting enzyme activity). This is in line with manufacturer recommendations for glycosidase addition at the end of fermentation when sugar concentrations are low. The focus was therefore on evaluating glycosidases as a remediation treatment for wine. All enzymes gave similar results. That is, they were efficient in their ability to cleave a certain class of glycosides but not others (Figure 13). Longer contact time, higher additions of enzymes and treatment at higher temperature influenced their effectiveness. Not surprisingly, levels of volatile phenols increased significantly following treatment. Trenolin Bouquet Plus was the only enzyme evaluated which demonstrated an ability to cleave rutinosides (Figure 14) and was therefore chosen for winemaking trials.

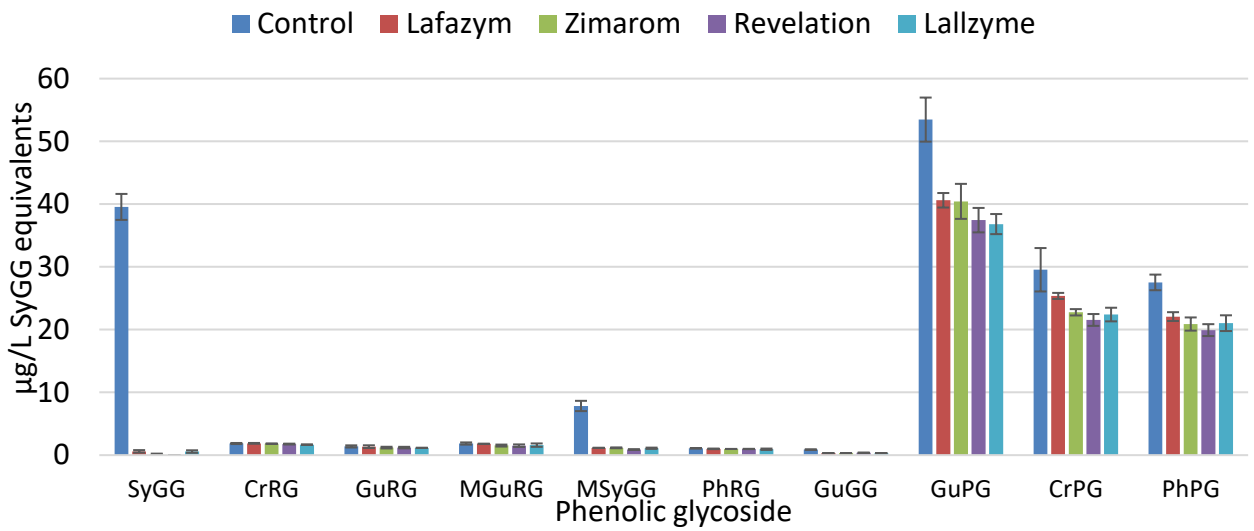


Figure 13. Concentrations of phenolic glycosides remaining in a 2016 smoke-affected Pinot Noir wine after treatment with various glycosidases at their highest recommended doses for three weeks at 17°C. Trenolin Bouquet Plus was sourced subsequent to this experiment.

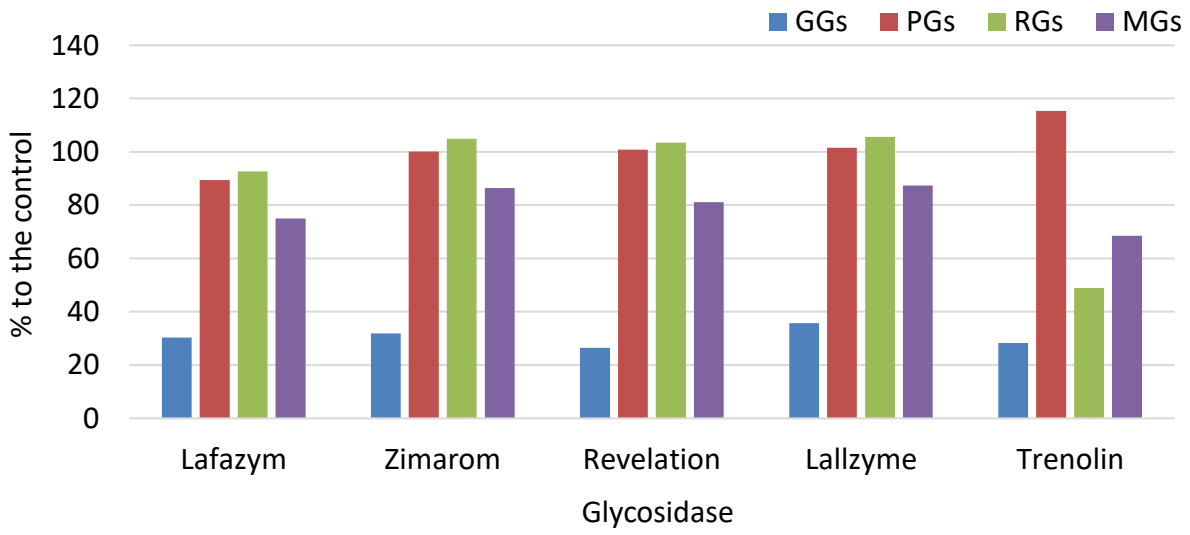


Figure 14. Classes of glycosides (total gentiobiosides (GGs), pentosylglucosides (PGs), monoglucosides (MGs) and rutinosides (RGs)) remaining in a smoke-affected Cabernet Sauvignon wine after treatment with various glycosidase enzymes at their highest recommended dose rates for 96 hours at 28°C

Other potential materials and methods for the remediation of smoke-affected juice and wine

A range of other materials and methods were evaluated for the remediation of smoke-affected juice and wine through removing volatile phenols and/or phenolic glycosides. However, none were shown to effectively reduce the concentrations of smoke compounds. Treating juice samples with XAD resins, zeolites, grape seed oil, cream or full cream milk did not reduce phenolic glycosides. In addition, juice samples spiked with volatile phenols were subjected to hyperoxidation (via bubbling of oxygen through the juice) or UV light in the presence of titanium dioxide (a method used to purify water) but neither method reduced the volatile phenols in these model experiments.

Commercial-scale testing of combined glycosidase and carbon treatment of wine

To validate the laboratory-based experiments for glucosidase treatment, winery-scale remediation trials were carried out using Trenolin Bouquet Plus to treat smoke-affected Pinot Noir and Chardonnay wines. Enzyme treatment was combined with subsequent carbon fining to 'mop up' the volatile phenols produced. Two different activated carbons were used (PS1300 and FPS) both individually and in combination and at different dose rates.

Results mirrored the laboratory studies. That is, activated carbons failed to remove phenolic glycosides from wine and enzyme treatment alone reduced phenolic glycosides to approximately half the concentration in the control wine and increased the levels of volatile phenols in the wine. Whilst carbon was able to reduce the levels of phenols in the combined treatment, they were still above levels when carbon fining was used alone.

This result was reflected in sensory panel evaluation which showed that the carbon treatments (with or without prior glycosidase enzyme addition) were more effective in reducing smoke taint ratings than the enzyme treatment alone. However, use of carbon to improve the performance of enzyme treatment resulted in wines that were also described as appearing very stripped and lacking positive characters ('fruit' aroma/flavours), which is consistent with previous knowledge about sensory effects of carbon fining when used on wine.

These results suggest that, in this scenario, treatment of smoke-affected wines with glycosidase enzymes alone may worsen the perception of smoky flavours, and using carbon fining in combination with enzyme treatment tended to strip desirable characters and colour from the wine. In practical terms, using carbon fining as a remediation method on smoke-affected juice appears to be a better option than in combination with enzyme treatment on wine.

Dilution studies

A further remediation option for dealing with wine made from smoke-affected grapes is to dilute the affected wine with enough 'clean' wine to reduce or eliminate the sensory impacts of smoke taint. A 2016 smoke-affected Pinot Noir wine from Victoria and a 2019 smoke-affected Pinot Noir rosé from Tasmania were sequentially diluted with unaffected Pinot Noir wines of a similar style, sourced from the same vintage. The unaffected wine was selected after a preliminary sensory assessment of several candidate wines, together with consideration of basic chemical composition.

Sensory analysis was carried out by experienced panels, convened for the study and a consumer group. Results are summarised in Activity B6 (above).

3.2 Contribution to program objectives

Many wine companies in Australia rate smoke taint as the primary environmental and economic risk to their business. As a result of this project, Australian grape growers and winemakers now have access to an expanded array of knowledge, tools and techniques which, when applied, will allow the industry to better manage and recover from the effects of fires in the future.

Grape growers are now able to assess the risk, extent and seriousness of smoke damage as never before. The characteristics of a fire and the weather conditions which influence the risk of smoke taint have been defined. Relationships established between smoke measurements and levels of

smoke taint compounds in grapes and wine provide a basis for an early-warning system across viticultural regions, provided by a network of smoke monitors. This will enable growers to quickly make informed decisions following smoke events, will make marketing of grapes from areas where low level smoke events have occurred easier and more objective, and will enable informed decisions by winemakers at harvest, where the smoke taint status of grapes may be pending the results from grape analysis. In addition, fire/land managers will be able to monitor the spread of smoke and risk of smoke taint from controlled burns in real-time.

In addition, early warning provides growers the option of applying a protective spray to grapes, with the potential to eliminate the risk posed by smoke from a nearby fire. Chitosan, identified in the project, may provide that option. Setting of baseline data for smoke compounds in the most commonly-grown varieties has increased the accuracy of analytical tests for smoke taint. All these factors mean that fruit which was previously thought to be unfit for commercial use can be processed, which has significant economic benefit to growers and to the sector overall.

In the event that smoke exposure is unavoidable, winemakers can apply treatments at the winery to reduce the effects of smoke taint and predict the sensory outcomes on the wine. Carbon fining proved to be valid and cost-effective option for dealing directly with smoke-tainted wine or juice, potentially rendering unusable wines usable. Dilution with 'clean' wine is also an effective option for businesses with an adequate volume of blending wine. Having mitigation options at the winery will also assist grape growers, because fruit which is smoke-affected has a pathway to market rather than being rejected by the wine company. This will clearly lower crop losses and reduce the economic impact of a smoke event across the wine sector.

The relationships developed in the project between researchers and wine industry stakeholders provided a pathway to adoption for outcomes from this project. Across three states from 2018-2020 Australian grape growers and wine companies were heavily involved with, and engaged in, this project, contributing significantly to its success. Findings from the project have already been used to manage the consequences of the 2019 bushfires in Tasmania and the 2020 bushfires in SA, NSW and Victoria.

Taken together, the project's findings will improve certainty of supply and resilience of the Australian wine sector to bushfire impacts, protect Australia's wine reputation, enhance grower, business and industry profitability and Australia's competitiveness in global markets and contribute to the profitability of grape growers and wine producers, with associated economic and social benefits for rural communities.

3.3 Productivity and profitability

This project utilised key capabilities in Australia to, for the first time either nationally or internationally, develop a risk management protocol which links smoke composition and smoke intensity to the levels of taint compounds and grapes and wine and provide a range of mitigation practices to reduce the likelihood of smoke taint. Whilst not directly measurable, all Australian grape growers and wine producers will benefit from this project. Its outcomes will enhance the reputation of Australian wine both nationally and internationally by minimising the chance of any wine containing smoke taint entering the market.

Two cost-benefit analyses were carried out in an attempt to quantify the potential benefits to the sector that have emerged or are likely to emerge from investment in this project.

An analysis was performed by a DJPR economist, estimating the benefit/cost ratio of **implementing an industry-wide smoke detector network, with the application of a protective spray** where smoke levels pose a sufficiently high risk of smoke taint. The benefit/cost analysis was calculated for the farm-gate value of premium wine grapes, over a 30-year period, with results expressed in present value terms. The benefit/cost analysis is attached in the Appendix, Section 7, and indicates a potential benefit/cost ratio of 3.6. In other words, for every $1.00 invested, this component of the project would return $3.60 of value to the grape and wine community by reducing the incidence of smoke taint. This analysis has assumed that the protective grape coating tested in this project could be further developed to enable effective implementation by spraying in-field. All other assumptions are documented in the report attached.

The economic evaluation of **remediation solutions for wine** focused on the application of activated carbon for fining of grape juice, as the other treatment strategy (use of enzymes to degrade smoke taint compounds in wine) did not result in obvious improvements. Overall, the increase in value, reduction in losses and improvements to profitability that are achievable will be a function of many variables including: severity of smoke exposure; grape varieties and wine styles produced; and distribution of grape and wine prices. At the same time any value recoverable through fining of grape juice or wine (or through other mitigation techniques) may be offset by money spent on buying or producing grapes and other sunk costs prior to the mitigation treatment.

As demonstrated in the sensory studies described in Activity B7, fining of tainted wine with a low dose of a suitable activated carbon can reduce smoke taint, but might not always fully eliminate quality defects from wine. Hence economic analysis explored five main scenarios, based on producing wines destined for the bulk wine market rather than a premium category, and starting with wines which can't be sold. Essentially the aim here is to minimise losses. Full detail is provided in the workbook included in the Appendix, Section 7. The scenarios were:

A) treat a wine that is otherwise unfit for sale with carbon, leading to production of a dry bulk wine (the lowest quality category) that can be sold at a 30% discount on dry bulk wine prices
B) treat a wine that is otherwise unfit for sale with carbon, leading to a better quality outcome than in above: varietal bulk wine that can be sold at a 30% discount on varietal bulk wine prices
C) treat a wine that is otherwise unfit for sale with carbon and use as a blending wine for bulk dry wine
D) treat with carbon and improve quality from a tainted dry wine to a varietal bulk wine that can be sold at a 30% discount
E) blend improved wine made under B) or D) with clean varietal bulk wine. Note the blending option requires large volumes of blending wine and may not be suitable for many producers and styles.

As the cost of carbon required for fining is very low, the opportunity cost of turning something unusable into something usable is also low. Where there is a sufficient market for bulk wine, wine made after carbon fining of grape juice will at least contribute to cashflow and assist in regaining some of the value otherwise lost. The relative reduction in losses (or value recovered) can be in the range of 38 to 96% when based on the cost of wine which is otherwise not fit for sale. In other words, a loss is still being made but it is a better prospect than writing off the wine. For both red and white wines, the best-case scenario was E): carbon fining and dilution with clean wine to produce a

varietal bulk wine. Depending on costs, it may be possible for producers to break even or make a small profit under this scenario.

Knowledge, innovative technologies and processes were generated in this project that will directly benefit grape growers and wine companies. The outcomes of this project, if implemented by producers, would have a significant long-term benefit, help industry implement cost-effective solutions in their businesses and provide a vast improvement on the options currently available for managing smoke taint. A specific example of this already occurring is that the AWRI assisted a large winery during the 2019 vintage by providing some insights from laboratory-scale experiments, enabling the winery to treat 400,000L of juice made from grapes where there was concern about smoke impact. The resulting wine was not smoke tainted and was usable in the winery's larger blend.

The potential to improve productivity following a smoke event is much greater as a result of this research. Fewer grape growers will face the prospect of having their crop rejected on the basis of smoke taint. There is also an efficiency gain for winemakers. If large volumes of grapes are smoke-affected, grape yield across the sector will be lower than that projected, which not only reduces the total amount of wine which can be made but increases the price per tonne by wineries for fruit, impacting the income of wineries, affected regions and the entire wine sector.

More generally, results of the project will enhance Australia's wine reputation, industry profitability and Australia's competitiveness in global markets. Knowledge generated will contribute to the innovation of process and practices and aid public land management agencies to implement effective planned burn programs with reduced potential for damage for grape and wine producers.

4 Collaboration

The success of this project was made possible through the many collaborations established over the life of the research. Responsibility for project activities was essentially divided between two primary research parties, the AWRI and La Trobe University/DJPR. The solid partnership between the organisations was fundamental to delivery of the project and formed a foundation for all other relationships within it. Organised opportunities for information-sharing and collaboration were provided by yearly project update meetings, reference group meetings and industry forums. Informal interactions between partners occurred in the background throughout the project. Many relationships established in this project will continue beyond its life, as detailed below.

Collaborations between ***project partners*** were:

La Trobe University/DPJR

La Trobe University and DJPR (then DEDJTR) collaborated closely to carry out half the project activities, led by Dr Ian Porter. This collaboration covered all aspects of project delivery. All smoke-related studies, including VESDA® validation and maintenance of the early warning network, were carried out by La Trobe University researchers in collaboration with fire authorities and industry partners. Analysis of smoke taint compounds from smoke, grapes and wine was performed in a joint laboratory by the two organisations. Dr Porter performed the vast majority of extension duties, with significant input from DJPR in terms of analytical results and interpretation of results.

DPJR was sub-contracted by La Trobe University to address certain project deliverables. DPJR researchers, together with AWRI, carried out controlled smoking studies with barrier compounds for vineyard mitigation. This included smoking tent studies at Great Western to test chitosan on a larger scale and to generate smoked wine for AWRI's winery mitigation experiments. Commercial wine preparation in the first year of the project was carried out at the DJPR Research unit and farm at Mildura, on samples collected by La Trobe University during field studies.

AWRI

The remaining project activities were largely carried out by the Australian Wine Research Institute (AWRI), under the leadership of Dr Mark Krstic. Collaborative activities included evaluation of suitable grape coatings to prevent or reduce the uptake of smoke taint compounds, which DJPR/La Trobe would then trial in-field. The wine sensory testing laboratory at AWRI was used by all research partners to relate sensory thresholds to levels of smoke compounds in smoke, grapes and wine. Dr Krstic's facilitation skills and stature within the wine industry made him a valuable collaborator throughout this project, particularly in extension.

CRC for Polymers

The CRC for Polymers provided advice to the AWRI and La Trobe/DJTR research teams on innovative, commercially available synthetic or biopolymers and formulations which would be suitable for trialling as smoke barrier products, including consideration of environmental and end-use constraints. The collaboration concluded in June 2017 when the CRC concluded its funding term.

Wine Victoria

Partnership and buy-in from industry was crucial to this project. From the outset, growers in Victoria, through their representative body, Wine Victoria, confirmed their support for the goals of the work and their willingness to engage with the project by allowing smoke detection sensors and other research on their properties. The costs incurred by growers to assist with setting up and running smoke detection units and sampling involved in research experiments on commercial sites were underwritten by Wine Victoria.

Formal collaborations between the project partners, in terms of cash and in-kind contributions, are summarised in the table below. In-kind contributions by research partners was significant and symbolic of the overall goodwill which pervaded the project from beginning to end.

	Contribution to project		
Party or Partner	**Cash**	**In-kind**	**Total**
Wine Australia	$250,000	$30,000	**$280,000**
Agriculture Victoria (DJPR)	$840,000	$343,000	**$1,183,000**
AWRI	$250,000	$306,106	**$556,106**
La Trobe University	$126,000	$23,050	**$149,050**
CRC Polymers	-	$4,500	**$4,500**
Wine Victoria	-	$16,500	**$16,500**
	$1,466,000	$723,156	**$2,189,156**

A large number of ***informal partnerships*** were also established during the project. These included other research organisations, state government departments and industry partners across which information-sharing and coordination occurred as detailed below.

Forest Fire Management Victoria

This project relied heavily on partnership with public land management agencies throughout Victoria, including the Country Fire Authority Victoria, VicForests and the Department of Environment, Land, Water and Planning (DELWP). The project networked with staff in all key controlled burn regions daily during the season. Incident controllers at planned burns were always notified and allowed the research team into controlled burn sites for collection of smoke data. In the first two years of the project, when bushfires were few, controlled burns allowed data collection for calibrating smoke sensors, setting thresholds of smoke compounds in grapes and wine and determining the impact of smoke characteristics on risk of smoke taint.
40 burns new project.

University of Melbourne

Following the closure of the CRC for Polymers, the La Trobe/DJPR research team commenced conversations with the Polymer Science Group in the Department of Chemical Engineering at the University of Melbourne. They provided the suggestion to trial biopolymers, leading to the identification of chitosan as an effective coating compound.

The Department of Primary Industries NSW (DPI NSW)

A case study opportunity on vineyard mitigation was provided when a DPI NSW field trial of sunscreen products in a vineyard planted with Pinot Noir unexpectedly experienced smoke exposure from a nearby bushfire. DPI NSW provided grape samples to the AWRI from the field trial, allowing the effects of smoke exposure on grapes that had been treated with the horticultural protectants VaporGard or Surround to be assessed.

UniSA

A range of zeolites were supplied the AWRI by Professor Krasimir Vasilev, School of Engineering, University of South Australia. These zeolites were evaluated for their ability to remove smoke phenolic glycosides from grape juices.

The University of Adelaide

The AWRI collaborates with the University of Adelaide's Industrial Transformation Training Centre on smoke taint research. Assistance was provided for two PhD projects which augment the studies carried out in this project. One was investigating whether in-canopy misting can reduce the uptake of smoke molecules in grapes and a second investigated the use of cyclodextrins for mitigating smoke taint in juice and wine. In addition, researchers from the University of Adelaide assisted AWRI project staff with controlled smoking experiments in 2018 and 2019, and the model studies on excised grape bunches. A new collaboration between the AWRI, The University of Adelaide, PIRSA, Grains Producers SA, SA Grains Industry Trust and La Trobe University, built upon relationships developed in this project, commenced in 2019 with SA State Government funding to assess the potential impact of smoke from stubble burns on grapes and wine.

Metabolomics Australia

This project provided Dr Natoiya Lloyd (Metabolomics Australia) with a range of fruit, juice and wine samples for analysis using mass spectrometry and nuclear magnetic resonance (NMR) spectroscopy. Dr Lloyd's research was funded through the '2017 Science and Innovation Awards for Young People in Agriculture, Fisheries and Forestry' by Wine Australia, and aimed to explore metabolomics approaches for identifying additional unknown components that might be contributing to smoke taint.

University of Nottingham

A visiting student from the University of Nottingham spent 4.5 months at the AWRI. As part of her PhD research, two novel glycosidases, (i) *Halothermothrix orenii* (Hal) β-glycosidase; and (ii) *Alicyclobecillun Acidiphilas* (Aci) β-glycosidase were evaluated for their abilities to cleave smoke glycosides in two smoke-affected Pinot Noir wines.

Industry partners

In general terms, the project relied heavily on partnership and engagement with industry for access to vineyard sites and valuable research material. The project leads, Dr Ian Porter and Dr Mark Krstic, have long associations with the wine sector, and their relationships drove the sector's significant engagement with the project. An enduring legacy of this project will be the improved openness of the relationship between the wine industry and fire authorities, which has traditionally been strained, at best. The change is due in no small part to the on-the-ground efforts of the researchers in this project.

A number of industry partners participated in the projects's industry reference group, contributed grape and wine samples for analysis and testing, and provided contract winemaking services to the project. Christmont commercial winery in King Valley, Victoria, contributed significantly to the project by making wines from unsmoked and smoked grapes from bushfires, controlled burns and controlled smoking experiments carried out by La Trobe/DJPR in years 2 and 3 of the project. The collaboration has continued, with Christmont making at least 70 wines from smoke-affected grapes in February and March for a new La Trobe/DJPR project which will make use of the opportunities provided by bushfire events this season.

Wine industry suppliers in Australia and overseas

Suppliers provided access to commercially available activated carbon materials, glycosidase enzymes and other commercial products for vineyard and winery mitigation studies. Two wine companies in the USA, E&J Gallo and Constellation Brands, provided the AWRI with a set of smoke-affected wines for use in wine mitigation studies. These were used early in the project when lack of bushfire events in Australia made smoke-affected wine difficult to source. The AWRI formed a new collaboration with ETS Laboratories, a wine analysis laboratory in the USA, to streamline analytical testing protocols for smoke taint compounds in grapes and wine. Both laboratories now test levels of glycosides as well as glycols.

5 Extension and adoption activities

The extension activities over the life of the project are captured in the tables below summarising (i) presentations, workshops and talks; and (ii) industry reference group meetings.

In brief, presentations were given in regions affected by smoke events, such as those in NSW during vintage 2018, Tasmania during vintage 2019 and the most recent bushfires affecting multiple grapegrowing regions throughout Australia in 2020. Workshops were also presented to educate wine industry personnel on smoke taint (what is it and how to identify it). Many of these educational workshops involved tasting smoke tainted wines sourced or produced from this project. These workshops also provided a forum to disseminate information on options for remediating smoke taint in juice and wine.

Dissemination of information to industry was also achieved via the industry reference group, consisting of representatives from major wine companies, who met annually with the research team. The AWRI's helpdesk has also received a large number of queries about smoke taint, particularly in regard to remediation of smoke tainted juice and wine using activated carbon. Information generated from the project has been relayed to industry personnel via the helpdesk.

Further adoption of project outcomes will be facilitated via publication in peer-reviewed journals, industry journals and additional AWRI Roadshows and workshops.

External presentations, workshops and talks

Staff	Title of presentation or event	Participants and Location	Date
Ian Porter		Victorian statewide stakeholders for Fire and Land Management	2 June 2016
Ian Porter		Yarra Valley growers	15 Sept2016
Ian Porter		Northeast Victoria growers	29 Nov 2016
Ian Porter Tim Plozza Pei Zhang Janna Bui	Overview of smoke taint project	National DAWR project planning meeting	13 Dec 2016
Mark Krstic Ian Porter	Impact of smoke exposure to vineyards	Wine Victoria/Department of Environment, Land, Water and Planning (DELWP) Annual Planned Burning Forum, Melbourne, Vic	14 Dec 2016
Mark Krstic	Smoke taint industry sessions	Tasmania Fire Service, Parks and Wildlife, Forestry Tasmania and local wine industry members Coal River Valley, Tasmania Swansea, Tasmania Tamar Valley	16-17 Jan 2017
Ian Porter		Victorian Wine Industry and Fire Planning Officers Brown Brothers, Milawa Vineyard, Vic	9 Feb 2017
Tim Plozza	Overview of the smoke taint program	DEDJTR Deputy Secretary, Macleod, Vic	March 2017
Ian Porter	Overview of smoke taint project	Industry representatives from all wine regions and Wine Australia	July 2017

Staff	Title of presentation or event	Participants and Location	Date
		(Regional Program Partners meeting) Yarra Valley, Vic	
Ian Porter		DELWP senior management including Deputy Chief Fire Officer Melbourne, Vic	4 Dec 2017
Mark Krstic Ian Porter	Insights into vineyard and winery smoke taint mitigation options	Yarra Valley Wine Growers Association smoke forum, Yarra Valley, Vic	8 Dec 2017
Mark Krstic Ian Porter	Outline of smoke taint project	Wine Victoria/Department of Environment, Land, Water and Planning (DELWP) Annual Planned Burning Forum, presented to 25 industry personnel and Victorian Government/DELWP managers, Melbourne, Vic	14 Dec 2017
Julie Culbert Geoff Cowey	Smoke taint Q&A workshop including sensory training to assist in detecting smoke taint	Wine industry personnel Orange, NSW	20 Feb 2018
		Wine industry personnel Mudgee, NSW	21 Feb 2018
Ian Porter Tim Plozza		DELWP Forest Fire Management north east Victoria Senior Fuel Management officers Benalla, Vic	26 Feb 2018
Mark Krstic Geoff Cowey Con Simos Katie Dunne Ian Porter Tim Plozza	Smoke taint Q&A	Local wine producers and DELWP regional planned burn managers Lancefield, Vic	27 Jun 2018
Ian Porter		Victorian Fire Management and Wine Industry Forum Melbourne, Vic	31 Oct 2018
Ian Porter	Information session	Environmental Protection Authority air monitoring group Macleod, Vic	22 Nov 2018
Julie Culbert Eleanor Bilogrevic Damian Espinase Nandorfy Desiree Likos Leigh Francis	Summary of outcomes of R&D4P smoke taint project followed by a sensory evaluation session on smoke tainted wines	Group of 13 winemakers AWRI, Urrbrae, SA	13 Jan 2019
AWRI helpdesk and research teams	Impact of bushfires on vineyards and co-ordination of grape analysis	Wine industry personnel in Tasmania (Wine Tasmania, TIA, Tourism Tasmania) Conference call	4 Feb 2019
Con Simos Mark Krstic Ian Porter	Smoke taint Q&A	Winemaking Tasmania Smoke taint Q&A workshop Cambridge, Tas	13 Feb 2019
		Wine Tasmania Smoke taint Q&A workshop Hobart, Tas	
Ian Porter		DELWP Fuel Management Steering Committee Melbourne, Vic	9 May 2019
Ian Porter		DELWP/Wine Victoria Planned Burn Forum	17 Oct 2019

Staff	Title of presentation or event	Participants and Location	Date
		Melbourne, Vic	
Ian Porter	Smoke taint Q&A	Hunter Valley wine industry personnel Pokolbin, NSW	19 Nov 2019
Markus Herderich	Adelaide Hills bushfire recovery meeting	Grape growers and winemakers Adelaide Hills, SA	8 Jan 2020
Ian Porter	Smoke taint Q&A	Wine Industry personnel North East Victoria	15 Jan 2020
Ian Porter	Smoke taint Q&A	Wine Industry personnel Mornington, Vic	17 Jan 2020
Markus Herderich Mark Krstic	Smoke taint Q&A	Pernod Ricard Winemakers, SA	22 Jan 2020
Markus Herderich Mark Krstic Eric Wilkes Con Simos	Smoke taint and testing Q&A	Wine Australia, SA	23 Jan 2020
Markus Herderich Mark Krstic	Smoke taint Q&A	Accolade Wines, SA	24 Jan 2020
AWRI Roadshow team	Smoke taint screening tasting – wines obtained or produced during the R&D4P smoke taint project were used for training purposes	Wine industry personnel Pokolbin, NSW	24 Jan 2020
		Wine industry personnel Adelaide Hills, SA	29 Jan 2020
		Treasury Wine Estates, SA	31 Jan 2020
		Wine industry personnel Mudgee, NSW	4 Feb 2020
		Wine industry personnel Orange, NSW	5 Feb 2020
Julie Culbert	Smoke taint remediation in the winery (major findings from the smoke taint R&D4P project)	Managing Bushfire Risk 2020 Forum held by Wine Tasmania Hobart, Tas	11 Feb 2020
		Managing Bushfire Risk 2020 Forum held by Wine Tasmania Launceston, Tas	12 Feb 2020
AWRI Roadshow team	Smoke taint screening tasting – wines obtained or produced during the R&D4P smoke taint project were used for training purposes	Wine industry personnel Yarra Valley, Vic	14 Feb 2020
		Wine industry personnel Canberra, ACT	19 Feb 2020

Internal presentations and industry reference group meetings

Title of event	Location	Date
Project review meeting and site visit with researchers, Wine Australia Program Managers (Keith Hayes and Sharon Harvey), DAWR staff (Kerrie McMahon) and industry participants	Yarra Valley, Vic	7-8 Feb 2017
Smoke taint project team meeting: review of progress with Wine Australia	Adelaide, SA	13 Sept 2017
IRG meeting: Project update to industry representatives on project progress and future directions	Teleconference – multiple locations	6 Dec 2017
Smoke taint project team meeting: review of progress with Wine Australia	Adelaide, SA	22 Oct 2018
IRG meeting: Project update to industry representatives on project progress and future directions	Teleconference – multiple locations	29 Oct 2018
IRG meeting: Final update on smoke taint project outcomes	Teleconference – multiple locations	10 Dec 2019

Project researcher attendees at IRG meetings: Julie Culbert, WenWen Jiang, Mark Krstic, Markus Herderich, Ian Porter, Tim Plozza
Industry representatives on the IRG: Paul Smart (Wine Tasmania); Alex Sas (Accolade Wines); Louisa Rose (Yalumba); Brett McClen (Brown Brothers); Adrian Coulter (AWRI); Gioia Small (TWE); Sharon Harvey (Wine Australia); Damien Sheehan (Mt Langi/Wine Victoria); Larry Jorgensen (Wines of WA); Mandy Gerhardy (TWE); Warren Birchmore (Accolade) and Matt Holdstock (AWRI helpdesk).

A large number of extension and adoption activities were ad hoc and not necessarily formally recognised or recorded. Such activities included:

- Contribution by Ian Porter to an article for an internal DELWP newsletter, distributed throughout the Department and showing how the improved communication/interaction with this project was already changing the way planned burns are conducted, June 2018
- Ad hoc presentations by Ian Porter and DJPR staff to regional DELWP staff at controlled burns
- Ad hoc liaison between Mark Krstic, Katie Dunne and Wine Victoria, DELWP Forest Fire Management and growers who were likely to be affected by smoke from planned burns, to discuss management options, June 2018
- The project team responded to a number of smoke taint queries from wine producers in the USA and Canada following wildfires in 2018. They also supported extension queries and assisted producers in the USA on the analysis and diagnosis of potentially smoke-tainted wines
- The research teams provided extensive on-the-ground support and information to support winemakers and regions managing the consequences of bushfire events which occurred during the project. These included bushfires in NSW in 2018, in the Huon region of Tasmania in 2019 and following the severe bushfires in SA, NSW and Victoria this season. Assistance took the form of formal workshops as described in the table above but also many ad hoc conversations which assisted the decision-making of grape growers and winemakers
- A specific example is that the AWRI assisted a large winery during the 2019 vintage by providing some insights from laboratory-scale experiments, enabling the winery to treat 400,000L of juice, made from grapes where there was concern about smoke impact. The resulting wine was not smoke tainted and was usable in the winery's larger blend.

6 Lessons learnt

There were significant delays to the contracting at the initiation of this project. This placed pressure on the project team, especially during the first year of the project. Despite the delay in the start phase it was not possible to extend the project end date beyond January 2020; this meant that no field work and only a small number of extension activities could be conducted within the project in the 2019/2020 bushfire season.

Lack of natural smoke events during the 2017 vintage made sourcing smoke-affected juice and wine a considerable challenge early in the project, particularly for winery-scale remediation trials. This was overcome by artificially smoking Merlot, Shiraz and Cabernet Sauvignon grapes in a purpose-built smoke tent and sourcing smoke-affected wine from California, USA. Bushfires later in the project provided an opportunity to source 'real' smoke-affected grapes, but the severe bushfires this season occurred too late to be fully capitalised upon in this project.

Linking smoke dose and composition to grape and wine data was very effective, but obtaining wines which exhibited suitable levels of sensory taint was challenging early in the project. This was because:

- It took a much greater smoke dose from controlled burns and bushfires than we initially thought to cause sensory detectable smoke taint in wines, even though elevation in smoke taint compounds in the wines was easily detectable by chemical analysis
- The first season's wines were made from grapes exposed to smoke from controlled burns up to several kilometres away, as the effect of distance on the concentration of smoke taint compounds in smoke was not fully understood at that stage. Whilst these experiments were very successful at showing how low smoke dose (combined with the dynamic nature of the smoke plume) does not produce taint, the early resultant wines had little or no smoke taint. In subsequent seasons, we became more adept at choosing locations to smoke grapes, which were much closer to burns or bushfires to ensure a sufficient dose of smoke to cause sensory taint.
- Issues with storing excised bunches for longer periods than anticipated (up to two months prior to smoking meant that, even though the grapes were still able to take up taint compounds after this period, they had often begun to degrade, resulting in inferior quality wine which made the wines unsuitable for sensory testing.

It became apparent during this project that to set specific and widely applicable thresholds for concentrations of smoke taint compounds will be difficult. There are many variables, including grape variety, wine style, winemaking technique, storage time and condition of wine being tasted and variation in consumers perception of smoke taint in wine. As outlined above, appropriate material for sensory analysis was in short supply and many more examples of smoke-tainted fruit and wine would be required to set even loose thresholds for a particular variety. However, this season's bushfires provided a unique opportunity to source many smoke-affected grape samples, with a range of low to high exposure to smoke, and current work is using them to understand more about threshold levels of smoke taint compounds.

There were also considerable logistical issues throughout the project relating to the need to be sampling at fires in several places concurrently, and the often large distances between sampling locations. Obtaining smoke data to match with samples of grapes and wine from bushfire-affected

vineyards was also a difficult task due to the delay between a fire starting and the time we could respond to be on site, resulting in the early smoke being missed in some cases. These issues would be resolved or reduced with the implementation of a more extensive smoke detector network, which may reduce the need to always attend such unplanned smoke events.

Whilst the fixed network of VESDA®s effectively monitored large-scale fire events, they were not suitable for more localised smaller bushfires and controlled burns. A more extensive network of detectors would be required for fire monitoring across a viticultural region or state. In addition, as an expensive research tool, the cost of VESDA®s rules them out for most producers. A new project is underway which aims to engage with an AgTech company to produce inexpensive smoke monitors which can be validated against the VESDA®s as an early warning sytem for smoke taint. The system will be rolled out nationally across all viticultural areas.

7 Appendix - additional project information

7.1 Project, media and communications material and intellectual property

Media interviews

16 Jan 2017	Ian Porter ABC Radio interview – Tasmanian Country Hour
17 Jan 2017	M.P. Krstic, C.A. Simos Smoke taint and the sensory impact on wine Sally Davies, ABC Country Hour, Tas
19 April 2017	Ian Porter "Wine smoke taint experiments" Mansfield Courier https://www.pressreader.com/australia/mansfield-courier/20170419/281655369947649
29 Sep 2017	M.J. Herderich Glucosylation of smoke-derived volatiles in grapevine (Vitis vinifera) by a promiscuous resveratrol/guaiacol glucosyltransferase Doug Main, Scientific American
14 Oct 2017	M.P. Krstic Smoke taint in wine Jancis Robinson, Financial Times and JancisRobinson.com
18 Oct 2017	M.J. Herderich Smoke taint threat of wildfires to California wineries Jesse B. Staniforth, Food Quality & Safety, USA
30 Oct 2017	M.P. Krstic Smoke taint in wine Lexi Williams, Wine Spectator; Amanda Gallagher, Western Fruit Grower, USA
7 Dec 2017	M.P. Krstic Smoke taint in wine Danielle Beurteaux, NPR 'The Salt' blog, USA
20 Mar 2018	Ian Porter Interview at Community Briefing Meeting/Bushfire Control Centre during major King Valley bushfire, Whitfield, Victoria All major television channels
21 Mar 2018	M.J. Herderich Smoke taint management Lauren Wolf, ACS C&EN news
5 Feb 2019	Ian Porter Impact of bushfires on the Tasmanian wine industry ABC Radio Hobart
13 Feb 2019	Ian Porter 'Smoke taint a hot topic for vineyards' Interview by Mark Smith (ed), Tasmanian Times
13 Feb 2019	M.P. Krstic, C.A. Simos Smoke taint Hugh Hogan, ABC Tasmania; Mark Smith, TasmanianTimes.com
20 Feb 2019	M.P. Krstic Smoke taint in Tasmania Emily Jarvie, Australian Community Media
22 Feb 2019	M.P. Krstic Smoke in Tasmania Huon Hooke, huonhooke.com
6 Mar 2019	M.P. Krstic Stubble burning collaborative project Stuart Taverner, Barossa and Light Herald
8 Mar 2019	M.P. Krstic Smoke taint in Tasmania Amanda Ducker, News Corp Australia
22 Mar 2019	M.P. Krstic Smoke taint in Victorian wineries Sumeyya Ilanbey, The Age

26 Mar 2019	M.P. Krstic	Smoke taint/stubble burning project Richard Whitehead, Beverage Daily
23 Oct 2020	M.P. Krstic	Transfer of volatiles from plants near vineyards Kerana Todorov, Wine Business Monthly
14 Jan 2020	M.P. Krstic	Smoke research at the AWRI Mike Cherney, Wall Street Journal
16 Jan 2020	M.J. Herderich	New research on early-season smoke exposure with Adelaide Hills producers Andrew Spence, The Lead SA
22 Jan 2020	M.P. Krstic	Smoke research at the AWRI Mike Cherney, Wall Street Journal
22 Jan 2020	M.P. Krstic	Smoke research at the AWRI Richard Whitehead, Beverage Daily

Presentations, articles, posters and fact sheets

- Article: "Addressing knowledge gaps in smoke taint – the AWRI's new collaborative Rural R&D for Profit project" M Krstic, M Herderich, J Culbert (2017) AWRI Technical Review 227(4), 6-8
- Article: "Where there's smoke there's not necessarily taint". Wine Australia Research Newsletter, March 2017 https://www.wineaustralia.com/news/articles/where-there%e2%80%99s-smoke-there%e2%80%99s-not-necessarily-taint
- Article: "Addressing knowledge gaps in smoke taint – the AWRI's new collaborative Rural R&D for Profit project", AWRI Technical Note, April 2017. Technical Review No. 227
- Video: "Smoke taint", Grigg Media and DELWP as part of community engagement for the controlled burning program (content relates primarily to a previous project on smoke composition, but Dr Ian Porter and Tim Plozza provided input on the current project). June 2017 https://youtu.be/j0tv67OtLo0
- Presentation: "Seeing through the haze - insights into smoke taint impacts in wine", Mark Krstic, keynote presentation at the American Society of Enology and Viticulture Annual Conference, Seattle USA, 28 June 2017
- Presentation: "Outreach Seminar – Smoke Taint", Mark Krstic. Workshop presentation at the American Society of Enology and Viticulture Annual Conference, Seattle USA, 29 June 2017
- Article: "Smoke taint remediation", R&D update article in AWRI Technical Review No. 230, October 2017, pp7-9 https://www.awri.com.au/information_services/ebulletin/2017/11/18/technical-review-october-2017-issue-available/
- Article: "Smoke taint remediation", R&D update article in AWRI Technical Review No. 230, pages 7-9, Oct 2017
- Article: "Looking at smoke is making things clearer", Wine Australia RD&E Newsletter, November 2017 https://www.wineaustralia.com/news/articles/looking-at-smoke-is-making-things-clearer
- Article: "Smoke taint: analysis and interpretation", AWRI Technical Review No. 234, pages 511, Jun 2018
- Article: "Providing clarity on when smoke can cause taint", Wine Australia RD&E Newsletter, April 2019 https://www.wineaustralia.com/news/articles/providing-clarity-on-when-smoke-can-cause-taint
- Article: "Providing clarity on when smoke can cause taint", Ian Porter, Australian and New Zealand Grapegrower and Winemaker, April 2019

- Article: “Smoke taint concerns spark new smoke research in Tasmania”, Australian and New Zealand Grapegrower and Winemaker 663: 43-48, April 2019
- Presentation: Ian Porter conference dinner presentation by to CASANZ (Clean Air Society of Australia and New Zealand), 18 June 2019
- Presentation: “Evaluating activated carbons for removal of phenols and their glycoconjugates from smoke-affected juice and wine”. Julie Culbert,, Fresh Science session at the 17th Australian Wine Industry Technical Conference, Adelaide, 23 July 2019
- Poster: Does the application of horticultural products to grapes form a protective barrier against smoke taint?, 17th Australian Wine Industry Technical conference, Adelaide, 21-24 July 2019
- Poster: Evaluating activated carbons for removal of phenols and their glycoconjugates from smoke-affected juice and wine, 17th Australian Wine Industry Technical Conference, Adelaide, 21-24 July 2019
- Poster: New early warning system and vineyard mitigation of smoke taint in wine. Ian Porter, Tim Plozza, Pei Zhang, Joanne Bui, David Allen. 17th Australian Wine Industry Technical Conference, Adelaide, 21-24 July 2019
- Presentation: “Overcoming smoke taint, the biggest threat to the Australian wine industry”, Ian Porter, AgriBio Science Conference, DJPR Bundoora, Vic, 19 November 2019
- Article: “I can smell smoke – now what?”, Australian and New Zealand Grapegrower & Winemaker, Issue 672, 28-31, Jan 2020
- Fact sheet: “Treating smoke-tainted must or wine with activated carbon”, AWRI website, Feb 2020 https://www.awri.com.au/information_services/fact-sheets/
- Fact sheet (updated) “Sensory impact of smoke exposure”, AWRI website, Feb 2020 https://www.awri.com.au/information_services/fact-sheets/
- Fact sheet: “Protocols for fire managers to minimise smoke taint in wine” February 2020 http://www.hin.com.au/__data/assets/pdf_file/0003/164631/Protocols-for-Fire-managers.pdf
- Fact sheet: “Protocols for vineyard managers to minimise smoke taint from prescribed burns” February 2020 http://www.hin.com.au/__data/assets/pdf_file/0020/164630/Protocols-for-Vineyard-managers.pdf

7.2 Equipment and assets

Equipment or assets created or acquired during the period covered by the project were:

- 5 x SKC AirChek TOUCH air sampling pumps with low flow adaptors
- 6 x Xtralis VESDA® VLF-250 smoke detectors
- The project has produced a large number of museum wines which are being stored. Smoke-tainted and treated wine made for this project have already been used for industry sensory training purposes in regions affected by fire, to aid winemakers with the detection and mitigation of smoke taint.
- Although the bushfires this season could not be fully capitalised upon in this project, grapes and wine sourced during the 2019/20 season have been stored and are a valuable resource for future projects in the area.

7.3 Monitoring and evaluation

Has the project addressed the Rural R&D for Profit outcomes and measures?

This project addressed the objectives of the Rural R&D for Profit program through collaborative research, development and extension, in support of continued innovation in Australia's primary industries. Specifically, the project successfully addressed the following objectives:

Provide primary producers of wine grapes with a measurement of the risk of smoke exposure

Primary producers now have improved options for measurement of the risk of smoke exposure. This is due to deployment and validation of the world's first early warning system for smoke damage to vineyards, together with gains in knowledge during the project on:

- The levels of smoke compounds in smoke which are likely to cause taint in grapes and wine, and the features of smoke which increase that risk
- The baseline levels of smoke compounds in unexposed grapes from 12 of the most commonly grown grapevine varieties in Australia. This means that we have a standard which can be used to compare levels of smoke exposure markers in suspect grapes
- Improved analytical methods for determining the levels of smoke taint compounds in smoke, grapes, juice and wine
- The threshold levels of smoke exposure markers in grapes, juice and wine which are likely to give rise to perception of taint in wine and be unpalatable to consumers
- The influence of wine style and winemaking practices on these threshold values and the likelihood of wine being affected by smoke taint.

In the event that smoke exposure is unavoidable, provide growers with practical mitigation strategies to prevent smoke compounds from entering the grapes

- While no horticultural products could be identified in this project that provided effective protection to grapes, a biopolymer, chitosan, appeared to provide an effective barrier to smoke taint compounds in smoke. Chitosan is already approved for use in the wine sector. In addition, a detrimental role of some products in exacerbating uptake by grapes of taint compounds from smoke was identified. This knowledge will be used to reduce the use of potential problem products during periods of smoke exposure of vineyards, and in the long term might be applied in the re-formulation of essential plant protection products for spray application.
- Fining of grape juice or wine with activated carbon was found to provide a practical option for the remediation of smoke-affected juice (and wine to a lesser degree) at the winery, thereby minimising the need to reject smoke-affected fruit, increasing returns and lowering crop losses.
- The economic analysis identified which processing strategies and readily available products were most efficient and applicable.
- Together, the project's findings will improve certainty of supply and resilience of the Australian wine sector to bushfire impacts, protect Australia's wine reputation, enhance grower/business/industry profitability and Australia's competitiveness in global markets and contribute to the profitability of grapegrowers and wine producers, with associated economic and social benefits for rural communities.

Strengthening pathways to extend the results of rural R&D, including understanding the barriers to adoption

- The project team worked closely with industry partners from the start of the project and an Industry Reference group established at the beginning of the project was consulted regularly, to aid experimental design and guide project progress.
- Laboratory-based model studies were corroborated through field work in commercial vineyards (for example, in NSW in 2018), and grape, juice and wine samples were sourced from commercial producers (for example, in 2019 from Tasmania and Padthaway).
- Project findings have been shared with members of the Industry Reference Group, who acted as early adopters. In addition, key findings were communicated and discussed at industry briefing events in January 2020, for example with major producers such as Treasury Wine Estates, Accolade Wines and Pernod Ricard Winemakers. Wines made for this project have been used in multiple sensory training sessions, as part of the AWRI's extension efforts to support winemakers managing the consequences of the 2019/20 bushfire season.
- Well-established extension platforms have been effectively used, for example through a poster and short plenary presentation at the 17th Australian Wine Industry Conference in 2019, production of a fact sheet on carbon fining and publishing of associated articles in industry journals.
- The two protocols developed in the project are a significant output, providing benefit to both grape producers and fire managers. They reinforce the improved relationship and open lines of communication between fire/land managers and wine producers. The relationship was at best strained before the project, with a high level of distrust on both sides.
- Qualitative economic analyses assessed costs and benefits for growers, with reductions in costs following a smoke event achieved through the discontinuation of non-effective but costly practices (such as application of horticultural sprays in vineyards; enzyme application in grape juice) and an increased ability to reduce taint levels and reduce quality defects in wine.

Establishing and fostering industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture

- This project attracted significant industry support at the individual business level with commercial vineyards and wine businesses included in the project as partners and collaborators. These partnerships have significant potential to contribute to ongoing innovation.
- The success of this project was made possible through close collaboration between Wine Australia and researchers at the AWRI, Agriculture Victoria, La Trobe University, University of South Australia, University of Adelaide and grape and wine industry partners in Australia and wine industry suppliers in Australia and overseas.
- Many of these are new collaborations, with some organisations working together for the first time. Based on previous experience, it is expected that a number of productive collaborations initiated through this project with 'new' partners such as Metabolomics Australia will continue past the project end date.

7.4 Budget

Project funds were received and expended according to budget.
The final financial report will be tendered by the due date of 15th June 2020.

7.5 Attachments

7.5.1 Planning and management protocols for land/fire managers to minimise impact on vineyards

7.5.2 Planning and management protocols for vineyard managers to minimise smoke taint from prescribed burns

7.5.3 Cost/benefit analysis of early warning system and application of protective spray

7.5.4 Cost/benefit analysis of mitigation options for smoke taint at the winery

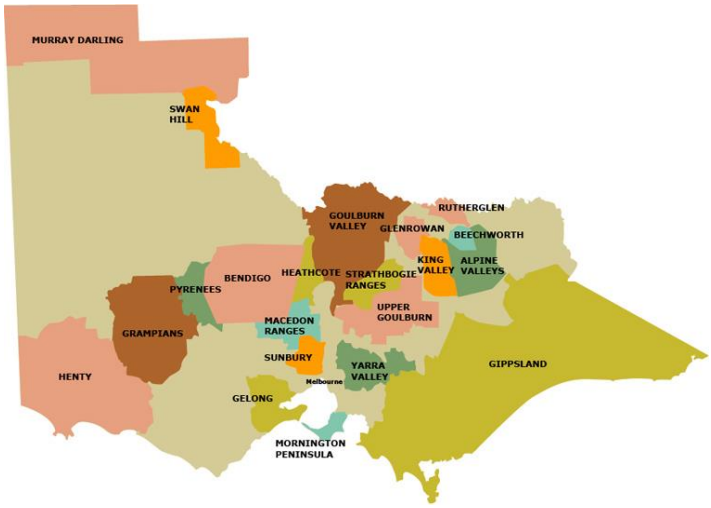
Protocols for fire managers to minimise smoke taint in wine



Controlled burns at any time during the grape growing season may result in the absorption of smoke taint compounds into berries and leaves. The optimum time for prescribed burning is in late summer or early autumn. This coincides with key berry development phases when most grape varieties are very susceptible to smoke taint.

Wine grape production is a valuable industry to Victoria. It provides local employment and supports many regional communities through tourism. The following protocols aim to provide advice to fire managers on how to reduce the risk of berries absorbing smoke from prescribed burns and how to minimize smoke taint compounds in wine.

- Identify and contact vineyards and wineries located close to land where FFMVic or CFA controlled burns are likely to occur.



- Conduct twice-yearly meetings with local and regional wine industry associations (see map) to discuss the current Joint Fuel Management Program (JFMP) for the region.
- Invite growers and industry to raise concerns to FFMVic and CFA over controlled burns when the JFMP is released.
- Encourage growers who are concerned about specific burns to use the Planned Burns Victoria System on the FFMVic website to see when burns are planned and if necessary to set up automatic notification about timing of specific burns.
- Update vineyards and wineries prior to burns so that FFMVic and CFA are informed of seasonal issues that may assist fire managers with planning and undertaking burns. Continued communication may give fire managers the opportunity to burn in other areas or to undertake extra burns due to an early grape harvest.
- Prioritise burns so they occur after harvest in areas considered to be at high risk of contaminating vineyards with smoke taint.
- Avoid conditions which prevent the smoke plume from rising, such as inversion layers and burning late in the day
- Plan to avoid burns creating smoke that immediately drifts into vineyards, as research has shown that fresh smoke poses a much greater risk than older smoke. Research to date has indicated that some smoke taint compounds do not travel more than 5 km from prescribed burns conducted under typical low-wind conditions. This indicates that vineyards >5 km from burns are at relatively low-risk of smoke taint.
- Avoid repeated exposure of a vineyard to smoke during the season as research has also shown that smoke taint has a cumulative effect over time.
- Conduct smoke modelling to estimate smoke dispersion during and after burns.

For more information, please contact, Agriculture Victoria Research on 136186 or Prof Ian Porter at La Trobe University on 1300 528 762

This document is also available in PDF format at http://www.hin.com.au/current-initiatives/smoke-taint-research

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AGRICULTURE VICTORIA

Protocols for vineyard managers to minimise smoke taint from prescribed burns



The optimum time for prescribed burning is in late summer or early autumn. This coincides with key berry development phases when many grape varieties are most susceptible to the absorption of smoke taint. Prescribed burning in winter or spring will reduce the impact on wine production but these burns are less effective and more expensive due to damp undergrowth and low ambient temperatures.

The following protocols aim to provide advice to vineyard managers on how to reduce the risk of berries absorbing smoke from prescribed burns and how to minimize smoke taint compounds in wine.

- Advise local and regional FFMVic and CFA fire management staff of your location, your enterprise, varieties (early and late ripening), anticipated harvest dates, size and contact details. This can be done as an individual or as a regional industry group.
- Conduct a twice-yearly meeting to discuss the current Joint Fuel Management Program (JFMP) for your region (see https://www.ffm.vic.gov.au/bushfire-fuel-and-risk-management/joint-fuel-management-program). The JFMP covers the next 3 years of burns to take place. Information can be given to fire managers to allow planning to take into account any burns near your location.
- Use the Planned Burns Victoria System on the FFMVic website (see https://plannedburns.ffm.vic.gov.au/) to determine when burns are planned and if necessary to set up automatic notification about timing of specific burns.
- Update local and regional FFMVic fire management staff prior to and during harvest to give fire managers the opportunity to burn in other areas or to undertake extra burns in your area due to an early harvest.
- Measure smoke density, timing, duration and composition to determine the risk of berries absorbing smoke taint compounds (see DJPR fact sheet “Measuring smoke intensity and smoke composition in vineyards”). The risk of smoke taint absorption by berries varies during the season (see DJPR fact sheet “Smoke taint risk and management in vineyards”).
- Test grapes for smoke taint compounds at an accredited laboratory within two weeks of harverst, such as the Australian Wine Research Institute or Vintessentials. Visit www.awri.com.au or https://www.vintessential.com.au/ for guidelines for assessing vineyards and grapes for smoke taint.
- Minimise the risk during the winemaking process of contamination with smoke taint compounds in leaf and woody tissue by hand harvesting and reducing Matter Other than Grapes (MOG) in the ferment.
- Minimise skin contact time in the fermentation and implement early press cutoff to reduce the extraction of smoke compounds from skins.
- Conduct a mini bench top ferment of smoke affected grapes to produce a small-scale wine when particularly concerned. Send grape and wine sample to the Australian Wine Research Institute or Vintessentials for analysis and interpretation.
- There is evidence that the perception of taint may increase during storage, so it may be wise to market smoke affected wines for earlier consumption.

For more information, please contact Agriculture Victoria Research on 136186, or Prof Ian Porter at La Trobe University on 1300 528 762

This document is also available in PDF format at http://www.hin.com.au/current-initiatives/smoke-taint-research

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AGRICULTURE VICTORIA

Smoke taint BCA for premium wine grapes in Victoria (cool climate regions)

North East, Central Victoria, Port Phillip and Gippsland wine growing regions
Benefits evaluated over 30 years
Evaluated at farm-gate

manual inputs
stochastic input (calculation)
stochastic output (calculation)

	Totals over 30 years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Research costs ($m)	1.38	1.38																														
Costs for early warning system (EWS) ($m)																																
Up-front investment in field-based smoke detection network		1.0																														
On-going network maintenance			0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total costs		1.0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
PV total EWS costs	5.1	1.00	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.17	0.16	0.16	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.07	0.07
Production volumes and values																																
Total area of plantings (ha)			11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400	11400
- Yield (t/ha)			5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
- Price ($/t)			1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Gross value ($m)			94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1	94.1
Total production (t)			62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700	62700
Assessed bushfire impact in each year																																
- Volumes above sensory threshold with quantitative evaluation (t)			11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74	11766.74
- Suspect volumes with subjective assessment (relatively high) (t)			1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177	1177
- Suspect volumes with quantitative evaluation (relatively low) (t)			588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588	588
Damages in each year with subjective assessment ($m)																																
- Discard grapes judged above sensory threshold			15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832
- Losses to higher volumes of suspect grapes (50% processed wine downgraded)			3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010
Total damages			18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841	18.841
PV damages without EWS and protective spray ($m)	310.9		18.049	17.290	16.563	15.866	15.199	14.560	13.947	13.361	12.799	12.261	11.745	11.251	10.778	10.325	9.890	9.474	9.076	8.694	8.329	7.978	7.643	7.321	7.014	6.719	6.436	6.165	5.906	5.658	5.420	5.192
Protective spray of 'boarder-line' grapes ($m)			0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
PV treatment costs	0.4		0.022	0.021	0.020	0.019	0.019	0.018	0.017	0.016	0.016	0.015	0.014	0.014	0.013	0.013	0.012	0.012	0.011	0.011	0.010	0.010	0.009	0.009	0.009	0.008	0.008	0.008	0.007	0.007	0.007	0.006
Damages in each year with EWS and protective sprays ($m)																																
- Discard grapes above sensory threshold (as above!)			15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832	15.832
- Losses to lower volumes of suspect grapes (spraying 50% effective)			1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505	1.505
Total damages			17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337	17.337
PV damages with EWS and protective spray ($m)	286.1		16.607	15.909	15.240	14.599	13.985	13.397	12.833	12.294	11.777	11.281	10.807	10.352	9.917	9.500	9.100	8.718	8.351	8.000	7.663	7.341	7.032	6.737	6.453	6.182	5.922	5.673	5.434	5.206	4.987	4.777
Net benefits to growers																																
- additional costs ($m)	6.9																															
- reduced damages ($m)	24.8																															
PV net benefits ($m)	31.7																															
B/C ratio	3.6																															

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ASSUMPTIONS & DATA ENTRY	**MEAN**	**MIN**	**MAX**	*Comments on assumptions*
Discount rate				
CPI (%)	2.5%			
Nominal discount rate (%)	7.0%			*https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/FlagPost/2018/October/Discount-rates*
Real discount rate (%)	4.4%			
Research costs ($m p.a for 3 years)	0.46			
Investment in field-based smoke detection network ($m)	1.000			*Early warning system adopted by whole industry in year zero*
On-going network maintenance ($m p.a.)	0.25			
Wine grape production				
Area under production (ha)	11400			*http://data.daff.gov.au/data/warehouse/9aas/2013/AustWineGrapesFinAndBusPerf/AustWineGrapesFinAndBusPerf_v1.0.0.pdf*
- Total production (t)	62700			*http://data.daff.gov.au/data/warehouse/9aas/2013/AustWineGrapesFinAndBusPerf/AustWineGrapesFinAndBusPerf_v1.0.0.pdf*
- Yield (t/ha)	5.5	4.0	7.0	*http://data.daff.gov.au/data/warehouse/9aas/2013/AustWineGrapesFinAndBusPerf/AustWineGrapesFinAndBusPerf_v1.0.0.pdf*
Orchard-gate price for premium wine grapes ($/t)	1500	1000	2000	*http://data.daff.gov.au/data/warehouse/9aas/2013/AustWineGrapesFinAndBusPerf/AustWineGrapesFinAndBusPerf_v1.0.0.pdf*
- Wine cost ($/l)	5116			
- multiple	3.4			*see 'value add' worksheet.*
Variable costs ($/ha)				
- Hand harvesting	800			*https://winesvinesanalytics.com/features/article/53452/Moving-Toward-Mechanical*
- Chemicals	50			
Likelihood of damages				*The risk of smoke exposure causing a perceptible taint in wine is a function of the stage of grapevine growth and development, the grapevine variety exposed, smoke concentration, duration of exposure and the volatile phenol concentration and composition of the actual smoke.*
- Portion of crop above threshold for damages in given year	19%			*Say the likelihood of a severe impact (i.e. all grapes above sensory threshold) is 20% in a given year (i.e. low likelihood event). This assumption is based on the frequency of extreme droughts and hence more severe and widespread bushfires*
- Portion of crop boarder-line for damages with quantitative evaluation	0.9%			*Assume 5% error in identifying grapes above threshold with quantitative evaluation*
- Portion of crop boarder-line for damages with subjective evaluation	1.9%			*Assume 10% error in identifying grapes above threshold with subjective evaluation*
Treatment costs (protective spray)				
- Cost (delivered) ($/ha)	1000			
- Application cost ($/ha)	40			
- Number of treatments (sprays)	2.0	1	3	

ECONOMIC ANALYSIS OF WINE REMEDIATION OPTIONS

Grape and wine value lost estimates, based on grape price; volumes of wine downgraded or lost ($0 value)

volumes & prices ex2019 Wine Australia National Vintage Report

	tonnes	price	grape value at 2% smoke exposed & tainted	L wine at 0.6 extraction rate		grape value at 10% smoke exposed & tainted	L wine at 0.6 extraction rate
grapes red 2019	941583	$ 845	$ 15,912,753	11,298,996		$ 79,563,764	56,494,980
grapes white 2019	786871	$ 462	$ 7,270,688	9,442,452		$ 36,353,440	47,212,260
totals	1728454		**$ 23,183,441** grape value lost at 2% of crush	**20,741,448** litres wine lost	(can't be sold)	$ 115,917,204	103,707,240

only attributes losses to losses in tainted grapes/wine, does not include additional winemaking cost and not including analytical testing of grapes or wine
0.6L/kg extraction rate based on typical range 500L - 750L (free run only - free run plus pressings)

For this evaluation it is estimated that exposure of vineyards to smoke could result in recognisable contamination of grapes and/or tainted wine that is unfit for sale and has an impact on approximately 2% to 10% of the national harvest in each year. This equates to approximately 34,570 to 172,845 tonnes of grapes which might not be harvested, cannot be sold or result in tainted wine (11.3 ML white wine and 9.4 ML red wine under the 2% exposure scenario). Based on average 2019 grape prices ($845/tonne red grapes, $462/tonne white grapes) economic losses from value of grapes that cannot be realised would range from $23.2 million pa to $115.9 million pa. These estimates exclude additional costs associated with analytical testing, winemaking steps needed when dealing with at risk grapes, damage to brand image etc. As such, total losses will very likely exceed the above estimates based on average grape prices.

Potential wine upgrade, based on minimisation of losses

Amelioration is not viable if value generated < cost of treatment

potential wine upgrades and associated value gains
bulk wine prices ex 2018 Austwine market update

red wine bulk	*value before/L*	*value after*		**value gain/L**	**value gain/1000L**	***value gain***	***notes***
carbon treat and sell into the lowest quality category	0	0.77	2018 dry red/rose bulk 1.10/L with 30% discount	**$ 0.77**	**$ 770**	***$ 754.60***	*corrected for volume losses during carbon treatment*
more optimistic, can sell into a low category	0	1.05	to bulk Shiraz/Rose with 30% discount	**$ 1.05**	**$ 1,050**	***$ 1,029.00***	
carbon treat and use as a blending wine	0	1.1	fining & blending cleaned up wine with bulk dry red/rose 1.1/L	**$ 1.10**	**$ 1,100**	***$ 1,078.00***	*
carbon treat and trade up from dry bulk to Shiraz	0.77	1.05	trade up from 2018 dry red bulk 1.10/L with 30% discount to bulk Shiraz/Rose with 30% discount	**$ 0.28**	**$ 280**	***$ 259.00***	#
carbon treat and dilute with clean Shiraz	1.05	1.5	fining & blending cleaned up Shiraz with bulk Shiraz 1.5/L	**$ 0.45**	**$ 450**	***$ 420.00***	*, #

** blending requires availability of 20-50x excess of clean base wine*
 # volume loss from carbon removal has a small impact, based on value of wine prior to fining

white wine bulk	*value before/L*	*value after*		**value gain/L**	**value gain/1000L**	***value gain***	*corrected for volume losses*
	0	0.63	2018 dry white bulk 0.90/L with 30% discount	**$ 0.63**	**$ 630**	***$ 617.40***	
	0	0.77	to bulk Chardonnay with 30% discount	**$ 0.77**	**$ 770**	***$ 754.60***	
	0	0.9	fining & blending cleaned up wine with bulk dry white 0.9/L	**$ 0.90**	**$ 900**	***$ 882.00***	*
	0.63	0.77	trade up from 2018 dry white bulk 0.9/L with 30% discount to bulk Chardonnay with 30% discount	**$ 0.14**	**$ 140**	***$ 124.60***	#
	0.77	1.1	fining & blending cleaned up Chardonnay with bulk Chardonnay 1.1/L	**$ 0.33**	**$ 330**	***$ 308.00***	*, #

Cost of carbon fining

	carbon/kg	cost @0.1g/1000l	cost 1g/1000l	cost additional bentonite 1kg/1000L
cheap cart	$7	$0.70	$7.00	$ 3
expensive	$14	$1.40	$14.00	$ 3

cost fining materials/1000L

low dose	***high dose***	
$3.70	$10.00	***cheap carbon***
$4.40	**$17.00**	***expensive carbon***

cost is excluding extra labor, analytical testing
wine losses after fining 2%; cost impact depends on value of starting wine

Notes:

The cost of the materials required for fining is very low ($3.70 to $17.00/1,000L wine, depending on dose rate and choice of product) and the impact of wine volume losses (typically 2%) is also marginal, given the low value of the wine prior to carbon fining. Addition of fining agents and their removal are standard operations in winery, do not require specialised equipment or significant extra labour inputs.

Summary of cost/benefit analysis for wine remediation of smoke taint

It's about minimising losses.

Amelioration is not viable, if value generated < cost of treatment

Potential wine upgrades and associated value gains

bulk wine prices ex 2018 Austwine market update

					value generated in fined wine corrected for volume losses	***value generated minus cost carbon high ($17)***	***grape to wine losses* per 1000L extraction rate 0.6*****	*doesn't include cost of winemaking ** conservative estimate; typical range 500L - 750L (free run only - free run plus pressings)	***benefit***	***% reduction in losses***	
red wine bulk	*value before/L*	*value after*		**value gain/L**	**value gain/1000L**							
	0	0.77	2018 dry red bulk 1.10/L with 30% discount	**$ 0.77**	**$ 770**	***$ 754.60***	*$ 737.60*	$ 1,408		***-$ 670.73***	**52%**	
	0	1.05	to bulk Shiraz with 30% discount	**$ 1.05**	**$ 1,050**	***$ 1,029.00***	*$ 1,012.00*	$ 1,408		***-$ 396.33***	**72%**	
	0	1.1	fining & blending cleaned up wine with bulk dry red 1.1/L	**$ 1.10**	**$ 1,100**	***$ 1,078.00***	*$ 1,061.00*	$ 1,408		***-$ 347.33***		blending with bulk dry red/rose
	0.77	1.05	trade up from 2018 dry red bulk 1.10/L with 30% discount to bulk Shiraz with 30% discount	**$ 0.28**	**$ 280**	***$ 259.00***	*$ 242.00*	$ 638	cost of grapes to make 1000L wine	***-$ 396.33***	**38%**	
	1.05	1.5	fining & blending cleaned up Shiraz with bulk Shiraz 1.5/L	**$ 0.45**	**$ 450**	***$ 420.00***	*$ 403.00*	$ 358	cost of grapes to make 1000L wine	***$ 44.67***		blending w bulk Shiraz[1]
white wine bulk	*value before/L*	*value after*		**value gain/L**	**value gain/1000L**							
	0	0.63	2018 dry white bulk 0.90/L with 30% discount	**$ 0.63**	**$ 630**	***$ 617.40***	*$ 600.40*	$ 770		***-$ 169.60***	**78%**	
	0	0.77	to bulk Chardonnay with 30% discount	**$ 0.77**	**$ 770**	***$ 754.60***	*$ 737.60*	$ 770		***-$ 32.40***	**96%**	
	0	0.9	fining & blending cleaned up wine with bulk dry white 0.9/L	**$ 0.90**	**$ 900**	***$ 882.00***	*$ 865.00*	$ 770		***$ 95.00***		blending w dry white[1]
	0.63	0.77	trade up from 2018 dry white bulk 0.9/L with 30% discount to bulk Chardonnay with 30% discount	**$ 0.14**	**$ 140**	***$ 124.60***	*$ 107.60*	$ 140	cost of grapes to make 1000L wine	***-$ 32.40***	**77%**	
	0.77	1.1	fining & blending cleaned up Chardonnay with bulk Chardonnay 1.1/L	**$ 0.33**	**$ 330**	***$ 308.00***	*$ 291.00*	$ -	cost of grapes to make 1000L wine	***$ 291.00***		blending w bulk Chardonnay[1]

cost of grapes

(they could be worth nothing but we make something by treating the wine)

[1] this is the best scenario: break even depending on costs

Definitions:

dry' is generic (non-varietal) commercial bulk wine

varietal' bulk is bulk wine with the variety stated

Notes:

Another key variable that impacts on value recovered is the extraction rate, or in other words the volume of wine produced from 1 kg of grapes. For this analysis the extraction rate was assumed to be 0.6 L wine/kg grapes, which is a conservative assumption for achievable extraction rates for smoke-tainted grapes and is positioned between extraction rates of 0.5 L wine/kg grapes (where free run juice only is used which may be lower in some taint compounds) and common extraction rates of 0.75 L wine/kg grapes (free run juice plus pressings which are likely to be higher in taint compounds and more difficult to improve).

Key risks to producers after carbon fining (as for any other mitigation option) include that the resulting wine cannot be sold - despite suitable quality attributes - because of damage to brand image and/or negative perception associate with smoke exposure, and a lack of market demand or pre-existing oversupply in the bulk market. There is therefore a risk that producers might incur additional costs which cannot be recovered and would further increase their losses.

Where there is a sufficient market for bulk wine, wine made after carbon fining of grape juice will contribute to cashflow and assist in regaining some of the value otherwise lost. The relative reduction in losses (or value recovered) can be in the range of 38 to 96% when based on the cost of wine which is otherwise not fit for sale.

Finally, the overall increase in value, reduction in losses and improvements to profitability that are achievable will also be a function of prize paid for grapes (or cost of producing grapes) which varies widely between < $300 to $2000+ for grapes from different varietals, for different quality brackets, and between warm and cool/temperate regions (Wine Australia, National Vintage Report 2019). Not surprisingly, the biggest gains can be anticipated from carbon fining of juice from white varietals, given that 71% of fruit from white varieties sold in 2019 was in the $300 to $600 category. Considering the overall higher grape prices for red varietals (62% in the $600 -$1500 category; 12% in the $1500-$2000+ category), together with the detrimental impact carbon fining has on red wine colour, it is estimated that the aggregate value recoverable from ameliorating smoke-tainted red wine would be similar to value recovered from smoke-exposed white grapes and smoke tainted white wine, but the relative reduction in losses is likely significantly smaller for most red wine compared to white wine.