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Small-scale wine production from bushfire smoke-affected wine regions in Victoria and NSW





FINAL REPORT TO WINE AUSTRALIA

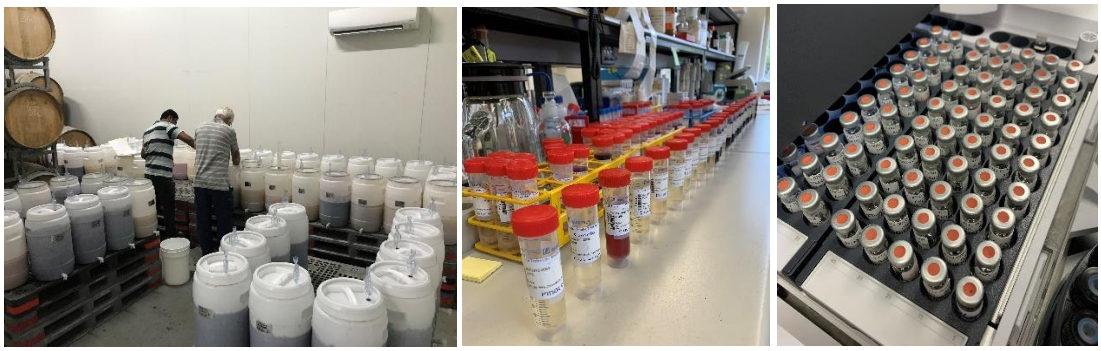
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Principal Investigators: **Ian Porter, Warren Proft, Prasad Patil, Stephen Lowe**

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Author details:

La Trobe University: Ian Porter

Chrismont Wines and Industry: Warren Proft, Prasad Patil, Stephen Lowe

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Confidentiality: This report contains confidential information which should not be released until the sensory studies are conducted. This will maintain the anonymity that is required for the future sensory studies. Additionally, it is important that the companies which donated fruit for the project are not penalized commercially from any findings in this program. Whilst this is unlikely, it is important to respect their participation.

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Contents

Executive Summary **4**

1 Background and Project Objectives **5**

2 Method and Project Locations **6**

2.1 General 6

2.2 Measurement of Smoke Intensity (ie. particulates) 7

2.3 Calculation of Cumulative Smoke Dose 7

2.4 Static VESDA® Network 7

2.5 Smoke Chemical Composition 8

2.6 Grape and Wine Analysis for Smoke Compounds 8

2.7 Microvinification Techniques 9

2.8 Sensory Analysis of Wines 10

3 Project Results and Discussion **11**

3.1 Smoke Distribution from Bushfire Smoke 11

3.2 Relationship between Smoke Dose and Smoke Chemical Composition 13

3.3 Relationship between Smoke Phenol Concentration and Grape Phenol Composition 16

3.4 Relationship between Smoke Dose and Grape and Wine Chemical Composition 17

3.5 Grape and Wine Chemical Composition at Harvest 19

3.6 Effect of Distance from the 2020 Bushfires 24

3.7 Effect of Grape Maturity on Smoke Taint Uptake and Final Levels in Grapes and Wine 24

4 Conclusions **26**

5 Recommendations **27**

6 Media and Communications **28**

7 References **29**

8 Appendices/Attachments **30**

8.1 Details of the site number, harvest date, location, company, variety for grape and wine samples evaluated in the small scale wine project from the 2020 bushfires in Vic and NSW 30

8.2 Grape and wine details and final winemaking characteristics 30

8.3 White wine micro-vinification procedure 2020 31

8.4 Red wine micro-vinification procedure 2020 32

8.5 Locations of grape sampling from wine regions of Victoria and NSW March 2020.. .32

Executive Summary

The summer of 2019-20 saw an unprecedented scale and intensity of bushfires across Australia, with severe impact on the grape and wine sector. This project aimed to capitalise on the important smoke, grape, wine and other air quality data resources from the catastrophic bushfires in Victoria and NSW in 2020, to aid in our understanding of smoke taint.

Through highly coordinated collaboration between industry (Chrismont Wines) and La Trobe University, 91 vintages of wines were made from fruit subjected to different levels of bushfire smoke. Wines were made in the King Valley using a standardised commercial winemaking process with minimal intervention, to ensure that wine composition can be characterised accurately against smoke taint in future sensory studies.

Cumulative smoke doses calculated from 13 smoke detectors placed in smoke zones from bushfires in December and January in Victoria were used to select the regions to access wines for this study. Where necessary, supplementary data was obtained from state air quality sensors used for public health. Results showed an excellent spread of cumulative smoke dose, which meant a consistent spread of phenols in the grapes and final wines across the eight key varieties in the study.

Of priority were smoke levels that would produce wines in the 'grey zone' for assessment of smoke taint, as it is this zone which provides the most uncertain outcomes for grapes and wine. Improving these thresholds for industry will support downstream decision-making and the development of an early warning system for smoke taint risk. This is the key task of a parallel project which is making use of all data from this project as well as data from bushfires and controlled burns which have occurred in Australia since 2016.

This project achieved its objective to correlate smoke, grape and wine data from 91 vintages of wines made from fruit subjected to different smoke levels. Analysis showed that smoke dose correlates well with smoke, grape and wine phenol composition. This augments previous studies which showed that the smoke dose to which the grapes are exposed is a reliable indicator of smoke taint in wine. Additionally, the project showed how the levels of specific phenolic marker compounds in smoke change with smoke movement and distance from fire.

Results also showed how traditional 'no skin' fermentation for whites and fermentation on skins for reds affects the levels of smoke taint compounds in wine. A Shiraz winemaking trial showed that increasing the amount of time on skins elevates the levels of smoke phenols in wine, which has a sensory impact when the wine is consumed.

Preliminary tasting of the wines produced in this project showed that the desired outcome of producing a reference set of wines for future studies in Australia was achieved. These wines are now in an optimum state to be rated by industry in professional sensory studies for smoke taint. The collaboration with industry has been the key success factor behind the outcomes to date and the completion of successful sensory studies should, for the first time globally, see a new smoke warning system and new risk thresholds established for smoke taint.

This project was funded by Wine Australia as part of emergency support provided in response to the catastrophic bushfires which occurred in south eastern Australia in 2019-20.

1 Background and Project Objectives

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. Since 2003, major fire events have affected over $500M worth of grapes and wine that were either rejected commercially or downgraded as a result of smoke taint. Smoke damage to fruit across NE Victoria during the 2020 bushfires resulted in an estimated $140 million lost to grape and wine businesses in that region alone. The frequency of bushfires and controlled burns is expected to increase under various climate change scenarios, thus it is important that the Australian wine industry develop cost-effective methods to manage grapes and wine affected by smoke.

The catastrophic bushfires in 2020 produced enough smoke to cause smoke taint in wine at a number of different levels across the Victorian and NSW wine sectors. This offered industry a unique opportunity to collect reference wines which can be used for future projects to set thresholds for smoke dose and composition, grape levels, wine levels and sensory outcomes for taint.

Levels of smoke in Victoria were up to 10 times those experienced in the main Hunter Valley production region in the same season but similar to those seen at Broke (Hunter Valley), Orange and Huon Valley in Tasmania in 2019. La Trobe University in the past has been monitoring these older sites for smoke dose and to a limited extent, smoke composition, but has had no coordinated grape and wine samples with which to compare all the data across a wide range of smoke levels in the same region. This is because growers generally discard fruit at risk of smoke taint to avoid the costs associated with harvest.

The 2020 fire events offered a unique chance to work directly with industry to improve the knowledge of smoke effects on development of smoke taint. The aim of this project was to produce a large number of wines from grapes affected by different levels of smoke. In all, 91 batches of grapes were processed. The grapes were harvested at optimum maturity levels and used to produce wine with minimal intervention so that they could, at a later date, be assessed for sensory outcomes for smoke taint.

The project was also tasked with correlating this data to smoke levels in the region and to provide data, which;

(i) Characterises a set of reference wines with varying exposure to bushfire smoke for future use by the Australian wine industry

(ii) Adds to previous data and is transferable to any region nationally

(iii) Provides information to help set thresholds for risk of smoke taint

(iv) Allows varieties which experienced the same level of smoke to be compared for assessment of their tolerance to smoke taint

(v) Demonstrates the influence of skin contact during winemaking on levels of smoke taint in wine.

2 Method and Project Locations

2.1 General

The 2020 bushfires occurred so widely throughout Australia that it was the first time that coordinated sampling could be conducted over large regions. In Victoria, data over the last five years had been collected from controlled burns and small bushfires and smoke detectors were set up to record in sensitive regions, but at only a limited number of sites. Fortunately, as soon as the fires started and developed to a threatening size, sampling units were set up in a wider area of Victoria subject to different levels of smoke. Without this quick action, data would have been limited from the bushfires in Australia.

In all, 91 batches of samples (25 or 35kg) were collected from grapes which had been subjected to either no smoke or a range of smoke from some of the highest levels of smoke in Australia. Samples were selected from several bushfire-affected regions in Victoria (e.g. NE Vic, Gippsland, Yarra Valley) and Western NSW (Appendix 5). Thanks to emergency funding from Wine Australia, growers were approached to supply grapes in March 2020 as harvest was upon them and all agreed to supply grapes for the study. In addition to measured smoke levels, preliminary grape samples at pea size onwards were also used to select sites to ensure a cross section of wines for the study. This selection process was vital for a small-scale study of this type to succeed.

At each of the sampling sites, smoke dose, smoke composition, phenol levels in grapes and wine were taken and this information allowed this project as much as possible to correlate this data with smoke taint.

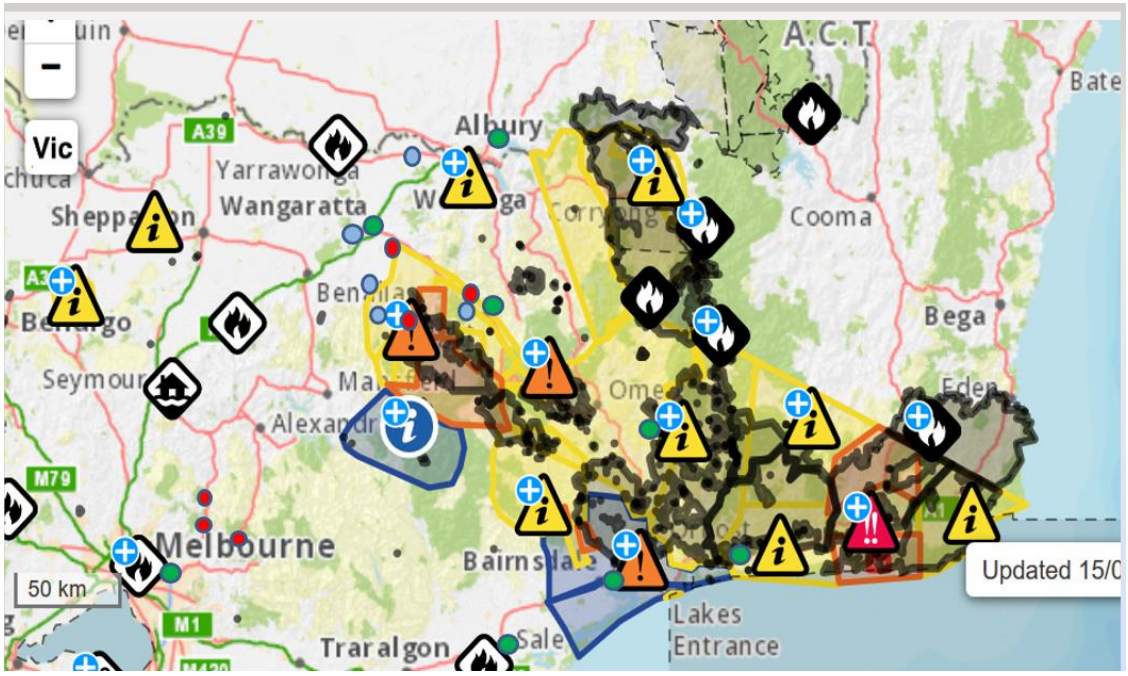


Figure 1. Location of smoke detectors operating continuously 24 hrs daily during the 2020 bushfires. Permanent smoke detectors (red dots); Supplementary smoke detectors placed into susceptible regions as fires occurred (blue dots); Other stakeholder (e.g. EPA) PM2.5 detectors used for air quality

studies where information was interpreted to smoke dose levels (green dots) Fire boundaries are shown as of 15th January 2020 before rain suppressed fires.

2.2 Measurement of Smoke Intensity (ie. particulates)

Smoke density of particulates (PM2.5) was measured using 'Very Early Smoke Detection Apparatus' (VESDA®) detectors during the bushfires until harvest of the crop. Fortunately, there were no controlled burns conducted after the fires to affect the cumulative volume of smoke taint compounds in the grapes. The VESDA®s are aspirated smoke detectors based on a nephelometer, which measures the deflection of a laser beam by smoke particles. Commercially available VESDA®s (VLF-300, Xtralis P/L, Victoria, Australia) were modified during past projects to allow data collection at suitable smoke intensities and sampling rates for this project. These VESDA®s recorded the smoke particulate matter concentration as obscuration values in units of percentage obscuration per metre (% obs/m).

2.3 Calculation of Cumulative Smoke Dose

The smoke 'dose' at each measurement site was calculated as the area under the VESDA® plot below a certain threshold for determining fresh and old smoke. Dose was calculated as the observed average level of smoke at each measurement multiplied by the duration of that measurement. To exclude the effect of the background reading of the smoke detector and the contribution of low-level smoke haze from old smoke, which was found not to contain significant levels of smoke taint compounds, the smoke dose was calculated using only smoke measurement above a specific obscuration reading (0.04% obs/m). This level can be varied if different thresholds are found to be more effective, but as the bushfire smoke was so intense during the bushfires in 2020, the smoke was mostly fresh smoke and this helped with correlation of data.

2.4 Static VESDA® Network

As stated above, a state-wide network of 7 VESDA® smoke detectors had been set up and operational from the 2017 autumn controlled burning period onwards. This network consisted of three smoke detectors in the Ovens and King Valleys in north east Victoria, three in the Yarra Valley, and one in the Otways region, as shown in Figure 1 and Figure 2. The smoke detectors were located in vineyards and encompassed the bulk of the production in each region, enabling a broad picture of the smoke experienced across a region from any particular fire. Each smoke detector was connected to a cellular IP gateway device, allowing remote communication with the smoke detector and download of the data to a server via the Telstra cellular network. The static network of VESDA®s recorded smoke from the major bushfires and, together with our own grape assessments, were useful for prediction of smoke taint for all zones in Eastern Victoria.

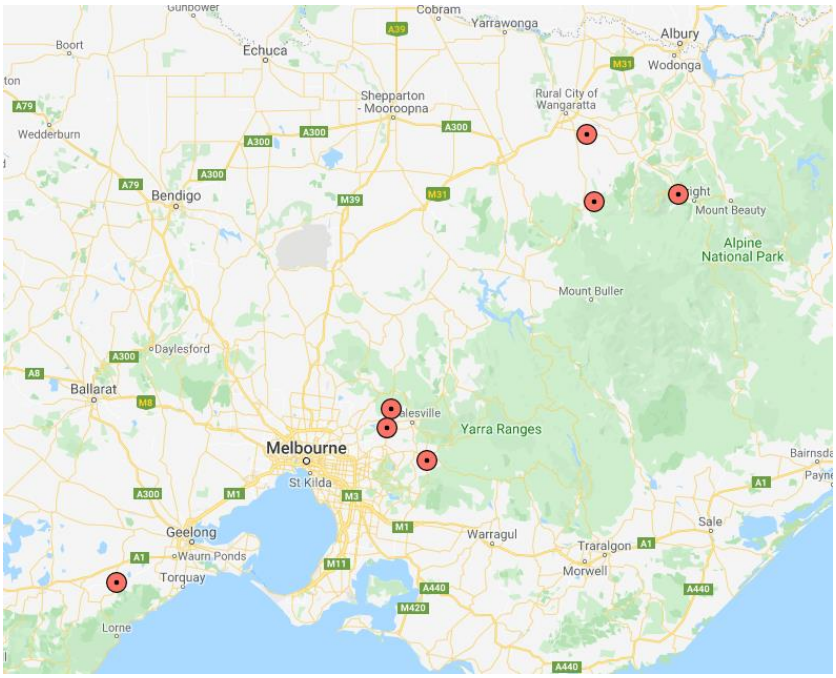


Figure 2: Locations of the remotely accessible, static network of VESDA® smoke detectors.

2.5 Smoke Chemical Composition

The smoke chemical composition was determined at all VESDA® sites if practical, using sampling tubes containing Tenax® resin. These tubes enabled the measurement of the smoke chemical composition by capturing the smoke taint compounds from the air, which was drawn through the tube at 100 ml/min using a calibrated vacuum pump. A constant flow rate of air was maintained across the tubes using air pump extraction methods designed in past projects (Porter *et al.*, 2020). The tubes were subsequently returned to the laboratory at Macleod, where the free phenols from the smoke were desorbed from the resin with ethyl acetate, derivatised with bis-silyltrifluoroacetamide/1 % trimethylchlorosilane (BSTFA/1 % TMCS) and analysed using an Agilent 7890A GC coupled to an Agilent 5975C mass selective detector (GC-MS).

Given the complexity of needing to deploy the sampling tubes remotely at the static VESDA® sites at specific times during fires, the Tenax® tubes were generally deployed by the vineyard manager at each location.

2.6 Grape and Wine Analysis for Smoke Compounds

Unsmoked and smoked batches of grapes (25 kg for red wines and 35 kg for white wines) from both bushfire-affected regions and a control region with very low smoke were collected from properties at maturity (Appendix 5). Grapes were processed into wine at a commercial winery (Chrismont, Cheshunt) in the King Valley. Wines were made using a standardised method without any exposure to oak barrels or chips to avoid artificially raising the levels of some taint compounds in the wine (see Appendices 3 and 4).

At a few sites, it was possible to sample grapes at several time points from pea size to maturity, to determine the change in concentration of free and bound phenols during grape ripening. At certain periods after the bushfires commenced, grapes were sealed in zip-lock plastic bags prior to transport to the laboratory for chemical analysis. Where measurements took place in a phylloxera-infested zone (PIZ), grapes were required to be frozen and permits obtained prior to removal of the grapes from the PIZ.

Grapes and wines were analysed for 23 phenols in both free and bound (glycoconjugated) forms using the method described by Allen *et al*. (2013). Briefly, the phenols were extracted from the grapes by homogenisation and centrifugation, followed by re-extraction of the tissue pellet with methanol. The grape extract or wine was then subjected to solid phase extraction to separate the free and bound phenols and clean up these fractions ready for derivatisation with BSTFA/1 % TMCS and GC-MS analysis.

2.7 Microvinification Techniques

As stated above, wines were made by commercial production methods at the Chrismont Winery, each from approximately 26 kg (reds) or 36kg (whites) of randomly selected bunches using the detailed procedure shown in the Appendix 3. These procedures involved storage in barrel shed to stabilise grapes at 18-20^{o}C before processing. After crushing and de-stemming, 30 mg of PMS and 30ppm Enartis RS enzyme was added to the crush. The crush was transferred to a small basket press and allowed to drain with light pressing to 500ml per kg juice being collected into fermenters (18L). Be, pH, temperature and FSO_2 and TA were assessed and TA was adjusted to 7.5 with H2T. pH was ideally under 3.4, and PMS added if necessary to achieve 10ppm of FSO_2. Following overnight settling, the juice was racked and rehydrated with 0.3g/kg yeast (Lafort VL1 (5 grams)) into another fermenter, sealed and stored at 18C. Once ferment was completed, wine was transferred to cool room for settling for 5 days, 0.1ppm Cu added and then analysed for RS, pH, TA, temp, VA, Alc. The gross lees was then racked off to a Cornelius keg, PMS and TA added and keg sealed and cooled. SO2, pH, TA were checked before bottling, further racking before bottling.

For red wines a similar procedure was followed however ferments were on skins. Ferments were held in a barrel room at 18C, 30mg/kg PMS and 40mg/kg enzyme (Enartis Arom MP) added. Skin contact was allowed for 7 days, although some samples of reds were prepared without skins or on skins for a shorter time (ie 3 days). The must was gently pressed to full extraction. At this time Be, pH, TA, Temp., extraction% was analysed and Tartaric Acid was added if necessary to achieve 7.5g/L TA pre MLF. Ferments were inoculated 0.3g LaFort Expure and 50ml of yeast. and stored in a cool room at 18C. They were mixed daily for 5 days, DAP added (200ppm)Post MLF pH, TA, H2M, VA, Alc, RS was analysed and TA was adjusted with Tartaric Acid to 6.4g/L if necessary and PMS 100ppm (1.5g) at day 3, with no plunging Day 6 and 7. Ferments pressed off on day 7 and placed in 30L fermenter and 0.1ppm CU added. Final analysis of RS, pH, TA, VA, Alc was conducted in conjunction with King Valley Wines. Before bottling 40ppm PMS (and Tartaric Acid to TA 6.0, if necessary) was added. The wine was siphoned into 750mL bottles and screw capped.

Bottled wines were subject to standard analysis by Chrismont and King Valley Wines and the data included in Appendix 2.

2.8 Sensory Analysis of Wines

Due to time limitations, this project was not tasked with conduct of formal wine sensory analysis However, initial sensory analysis was carried out by industry using a pivot-type test under the advice of Dr John Blackman (Charles Sturt University). Commercial wines were made appropriately and are available for future sensory analyses by methods selected by industry. Industry is tasked with leading the sensory analyses in conjunction with La Trobe University and Charles Sturt University. The details of the sensory studies will be included in future projects.

3 Project Results and Discussion

3.1 Smoke Distribution from Bushfire Smoke

The VESDA® network (Figure 3) proved to be effective for monitoring widespread smoke events during the bushfires and quickly providing industry with objective results. The current static network used over the past five years and the supplementary detectors were ideally placed to measure continuous smoke measurements from the extensive bushfires and captured the variability in smoke concentration of both dose and phenol loads caused by the widespread dispersal of smoke. These cumulative smoke dose measurements provided an early warning for growers as soon as the smoke occurred in both Victoria and New South Wales that smoke levels were very high and likely to cause smoke taint in some regions (Figure 4). Results from this project have added to previous data from past projects to validate that smoke dose can be used as a good predictor of levels in grapes and wine from both bushfires and prescribed burns.

In Victoria, where the bushfires abated rapidly after an intense period of rain in mid-January 2020, it was important to interpret levels of smoke compounds in grapes relative to growth stage. The bushfire smoke was observed much earlier in the growing season than in past major fires, with both white and red varieties approximately pea-sized, and it was important to ensure this can be taken into account in future predictive models. Results showed that levels of phenolic smoke taint compounds in grapes had reduced in the harvested grapes by 50% from original levels. This is suggested to be caused by berries filling with fluid after smoke had abated, resulting in dilution of the concentration of phenols in the grapes at harvest. This was not observed in past years during similar bushfires as smoke generally continued until later in the season. For instance, in the Hunter in NSW and during past major bushfire events in Tasmania and Victoria in 2018 and 2019 where the fires either started or continued burning later into the season (after version), a reduction did not occur.

The importance of this finding will be further explored in future research.

Growers have been given a best estimate of the potential for taint during previous Centre for Expertise in Smoke Taint Research (CESTR) and Rural R&D4P projects (Porter *et al.*, 2015, Porter *et al.,* 2020) based on measurements of smoke dose and the concentrations of smoke compounds in grape and wine. When combined with this data and the pending wine sensory analysis, results from this study will allow the development of a model relationship between smoke dose and risk of smoke taint development in wine.

Current work in conjunction with the Victorian Department of Environment, Land, Water and Planning (DELWP) aims to convert these relationships into a smoke taint risk assessment tool and phone app, which will be able to be used by industry to guide their decision-making process following smoke events. Sensory analysis of wines produced in the project described here will confirm these relationships through to sensory perception of taint in wine.



Figure 3: Location of grape sampling sites (red circles) in relation to the approximate perimeter of the bushfire boundary in Victoria and New South Wales (black outline) on 20 January 2020. Note: Fire boundaries did not expand much after this date.

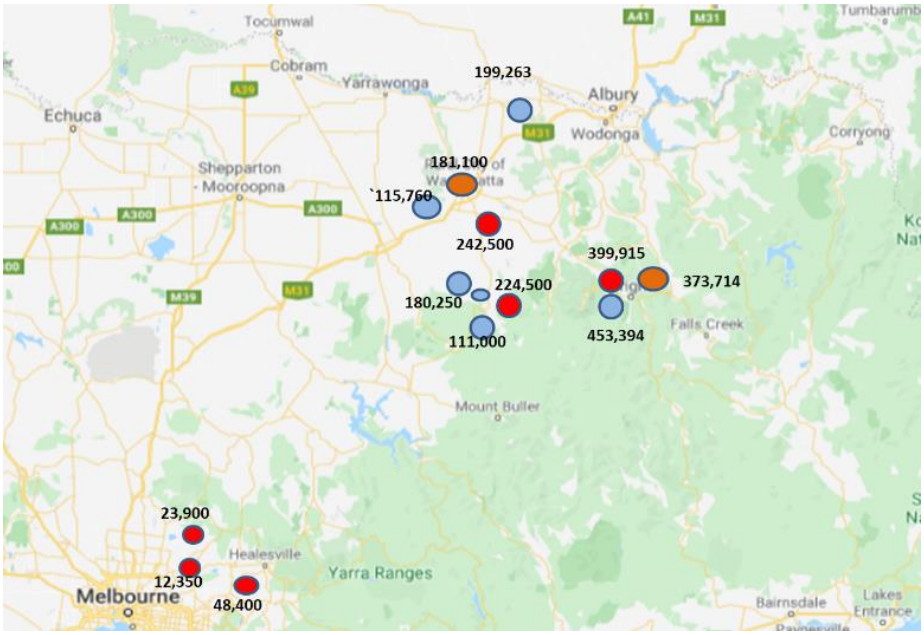


Figure 4: Cumulative smoke dose measured above 0.04% obscuration/m at sampling sites in Eastern Victoria. (Note: for some sites a small portion of the smoke dose that affected grapes was estimated by comparison to nearby sites as data was unavailable prior the VESDA smoke detector being set up). Red dots (Permanent VESDA sensors), Blue dots (Temporary VESDA sensors) Brown dots (EPA sensor sites)

3.2 Relationship between Smoke Dose and Smoke Chemical Composition

Our previous data showed a linear correlation between the total smoke dose recorded by VESDA®s with the total phenols recovered from Tenax® tubes, for samples taken greater than 500 metres from fires (Figure 5). In this study, smoke from the bushfires travelled more extensively and at much higher atmospheric concentrations than has occurred in our previous studies since 2014. This meant we obtained good data for monitoring individual species of phenols in the smoke and not just the total sum of key smoke taint phenols. It also allowed for the data to be modelled and the model used to validate data from previous bushfires. This information will also define relationships for the early warning system and inform of situations where, due to the intensity of the fire, higher smoke doses occur at longer distances away from a bushfire, ie. >50km.

As with previous studies, the total phenol concentration measured by Tenax® had a reasonably good linear relationship with smoke dose measured by the VESDA®s, at greater than 7km from the bushfires (Figure 6). Within 7 km, the phenol load varies because of the variable combustion which occurred during the catastrophic bushfire events and the impact that winds, air mixing and turbulence had close to the fire. Within this distance, phenol loads can be dramatically elevated.

This study, as with past studies, has confirmed wide variability in the way individual species of phenols are carried in the atmosphere and thus captured on the Tenax®. This is due to the

instability of particular phenols and degradation in the presence of hydroxy radicals and/or ultraviolet radiation. The phenols which proved to correlate well in air with smoke dose included methyl guaiacol and guaiacol, whilst the phenol which correlated either less well or poorly with smoke dose included syringol (Figure 7).

Results from this study appear to be consistent with the ability of specific phenols to react in the atmosphere and coalesce into secondary aerosol particles. Phenols are known to differ in the way they degrade in the atmosphere, with syringol derivatives (eg. Syringol and methyl syringol) degrading more quickly than guaiacol in controlled experiments simulating the atmospheric degradation of methoxylated phenols (Yee, 2013; Bejan *et al.*, 2015, Lauraguais *et al.*, 2015 and 2016; El Zein *et al.*, 2016). This is evident from Figure 7, in which guaiacol and methyl guaiacol are highly correlated with smoke dose (R^2= 0.84 and 0.92 respectively beyond 5 km from the bushfires studied), but syringol is correlated poorly (R^2 = 0.17). Also, syringol and methyl syringol concentrations fell much more dramatically with distance than a number of other phenols extracted, including guaiacol and methyl guaiacol (Figure 8 and 9).

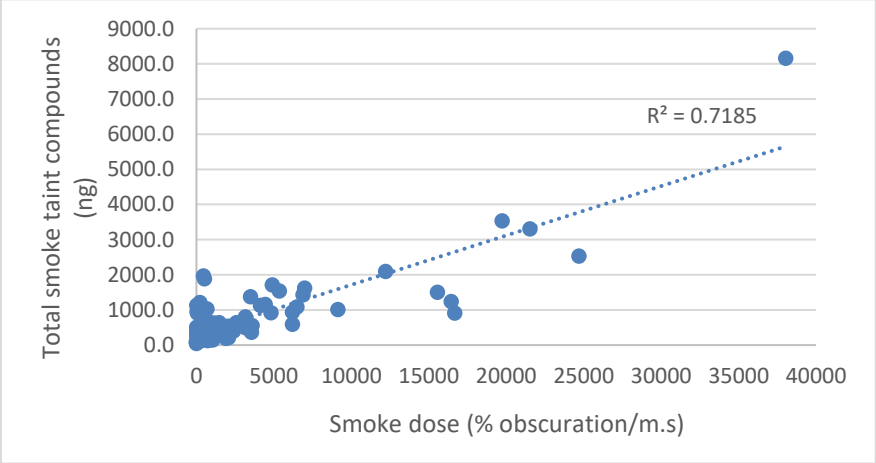


Figure 5: Total smoke taint compounds (sum of amounts of phenol, o-cresol, m-cresol, p-cresol, guaiacol, 4-methylguaiacol, syringol and 4-methylsyringol recovered from Tenax® tubes) versus cumulative smoke dose measured by a VESDA® during sampling period in a past Rural R&D4P project (Porter et al, 2020). Measurements taken less than 500 m from fires have been excluded.

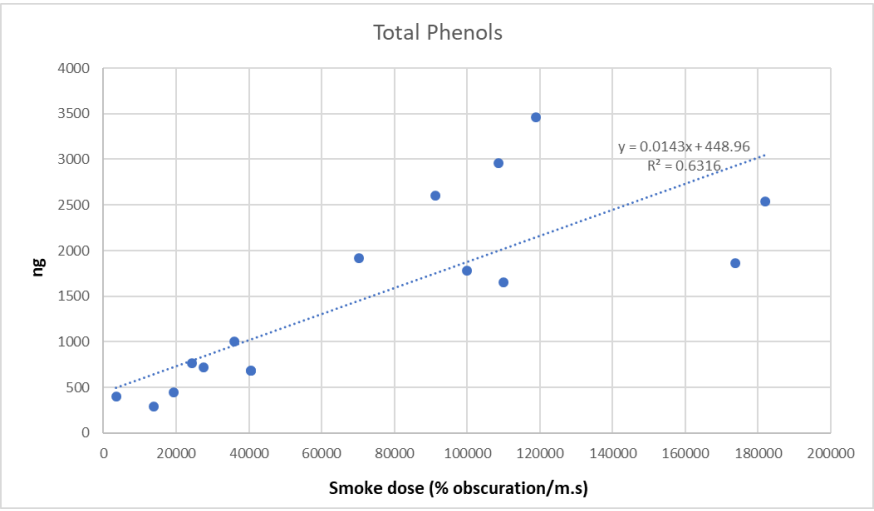


Figure 6: Total smoke taint compounds (sum of amounts of phenol, o-cresol, m-cresol, p-cresol, guaiacol, 4-methylguaiacol, syringol and 4-methylsyringol recovered from Tenax® tubes) correlated with the cumulative VESDA® dose (% obscuration/m.s)) during the bushfires in NE Victoria during 2020. All measurements taken from greater than 5km from bushfires.

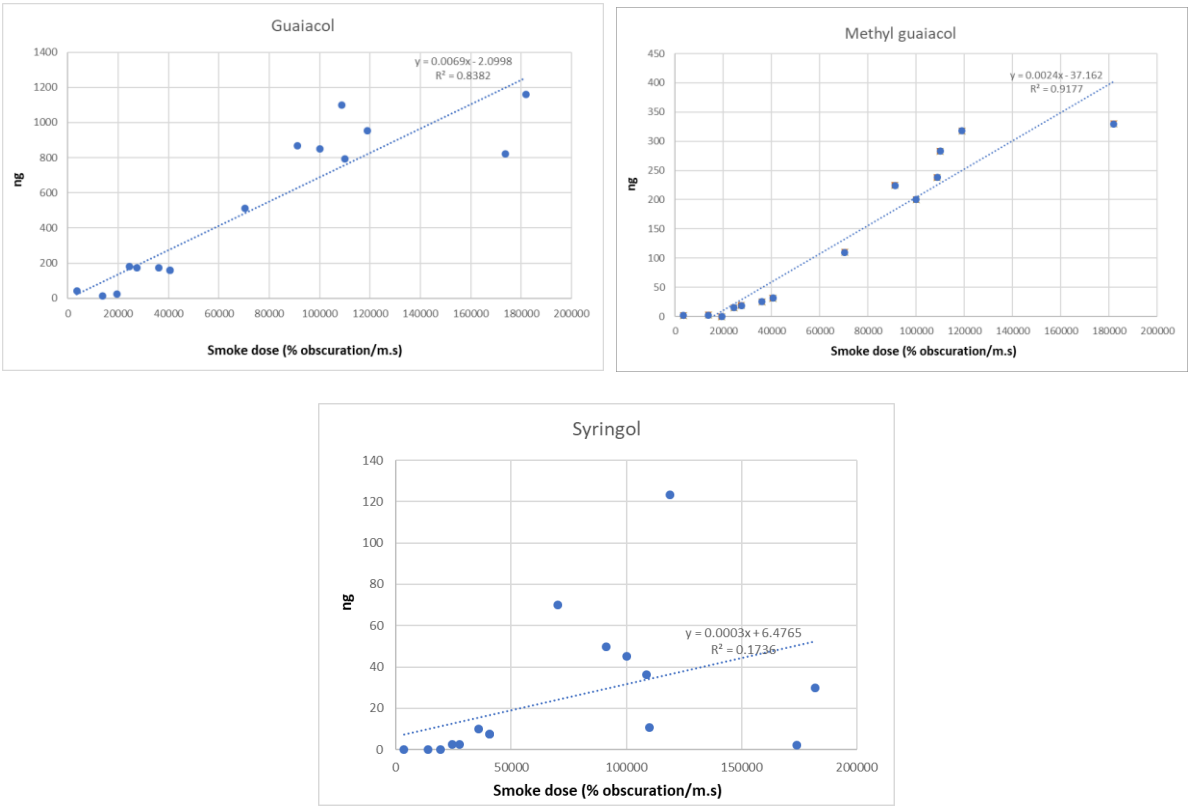


Figure 7: Amount (ng) of guaiacol, methyl guaiacol and syringol recovered from Tenax® tubes correlated with the cumulative VESDA dose (% obscuration/m.s) during the bushfires in NE Victoria during 2020.

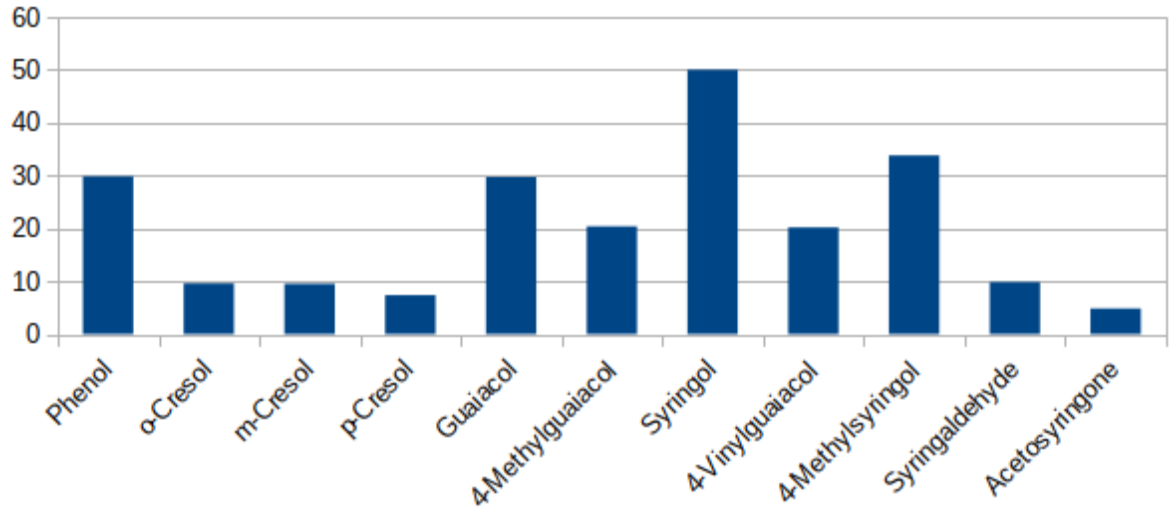


Figure 8. Average concentration (ng) of phenolic compounds in Tenax tubes from a site receiving very high fresh smoke levels (Dose of 2006 l/hr) from approximately 6 kms from the edge of the bushfires in NE Victoria in 2020

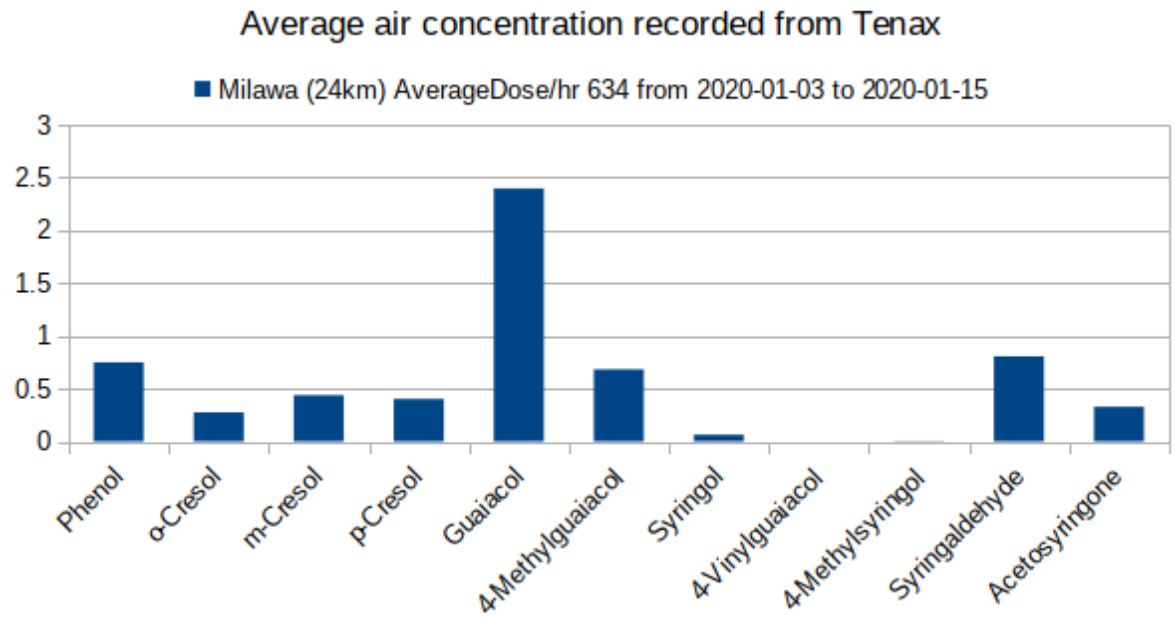


Figure 9. Average concentration (ng) of phenolic compounds in Tenax tubes from a site receiving very high fresh smoke levels (Dose of 634 l/hr) from approximately 24 kms from the edge of the bushfires in NE Victoria in 2020

3.3 Relationship between Smoke Phenol Concentration and Grape Phenol Composition

Past results have shown a high correlation between the concentration of some individual smoke taint compounds in grapes and the amount of each compound captured on Tenax® tubes, as shown in Figure 10. The recent study has shown that syringol and methyl syringol are not as well correlated with distance from a burn as guaiacol and methyl guaiacol (Figures 8 and 9). In the past study, similar relationships were found for the uptake of each smoke taint compound between Chardonnay and Shiraz grapes, suggesting grape variety does not influence uptake. Shiraz showed higher levels of guaiacol than Chardonnay due to the natural levels of guaiacol found in Shiraz grapes.

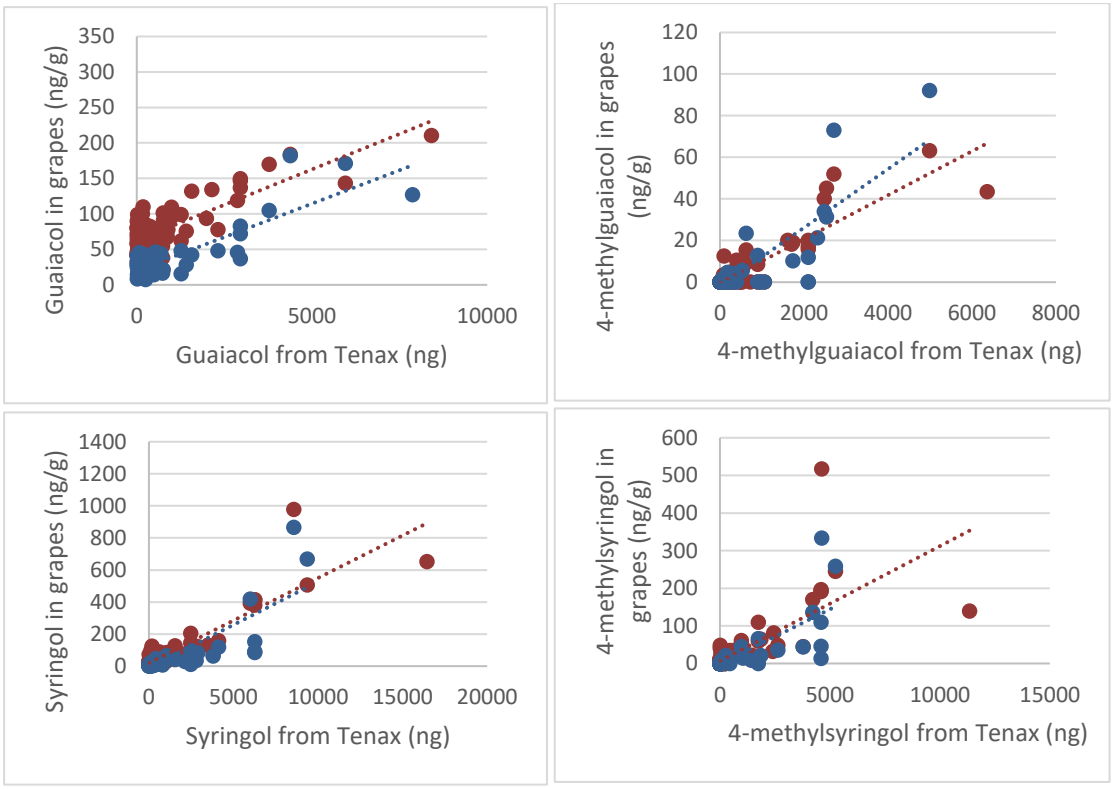


Figure 10: Relationship between the concentration of smoke taint compounds in grapes (ng/g) and the amount of compound captured on Tenax® tubes (ng). Linear regression lines for Chardonnay (blue) and Shiraz (red) shown.

3.4 Relationship between Smoke Dose and Grape and Wine Chemical Composition

A previous study showed that measurement of the cumulative amount of smoke taint compounds to which the grapes are exposed can allow an accurate prediction of the concentrations of these compounds in the resulting wine (Table 1; Porter *et al.*, 2020).

Table 1: Relationship between the concentration of smoke taint compounds in wine (ng/ml) and the smoke dose (measured by VESDA®) applied to Chardonnay and Shiraz grapes at controlled burns.

	Chardonnay		**Shiraz**	
Compound	**Equation**	**R^2**	**Equation**	**R^2**
Guaiacol	y=0.000353x	0.933	y=0.00112x + 82	0.24
4-Methyguaiacol	y=0.000147x	0.905	y=0.000561x	0.654
Syringol	y=0.00315x	0.969	y=0.00913x	0.628
4-Methylsyringol	y=0.00259x	0.98	y=0.0045x	0.836

The current study showed similar relationships for a wide variety of grapes (as indicated by the Shiraz and Pinot Grigio examples in Figure 11) and wine and support the use of smoke dose as a good predictor for smoke taint.

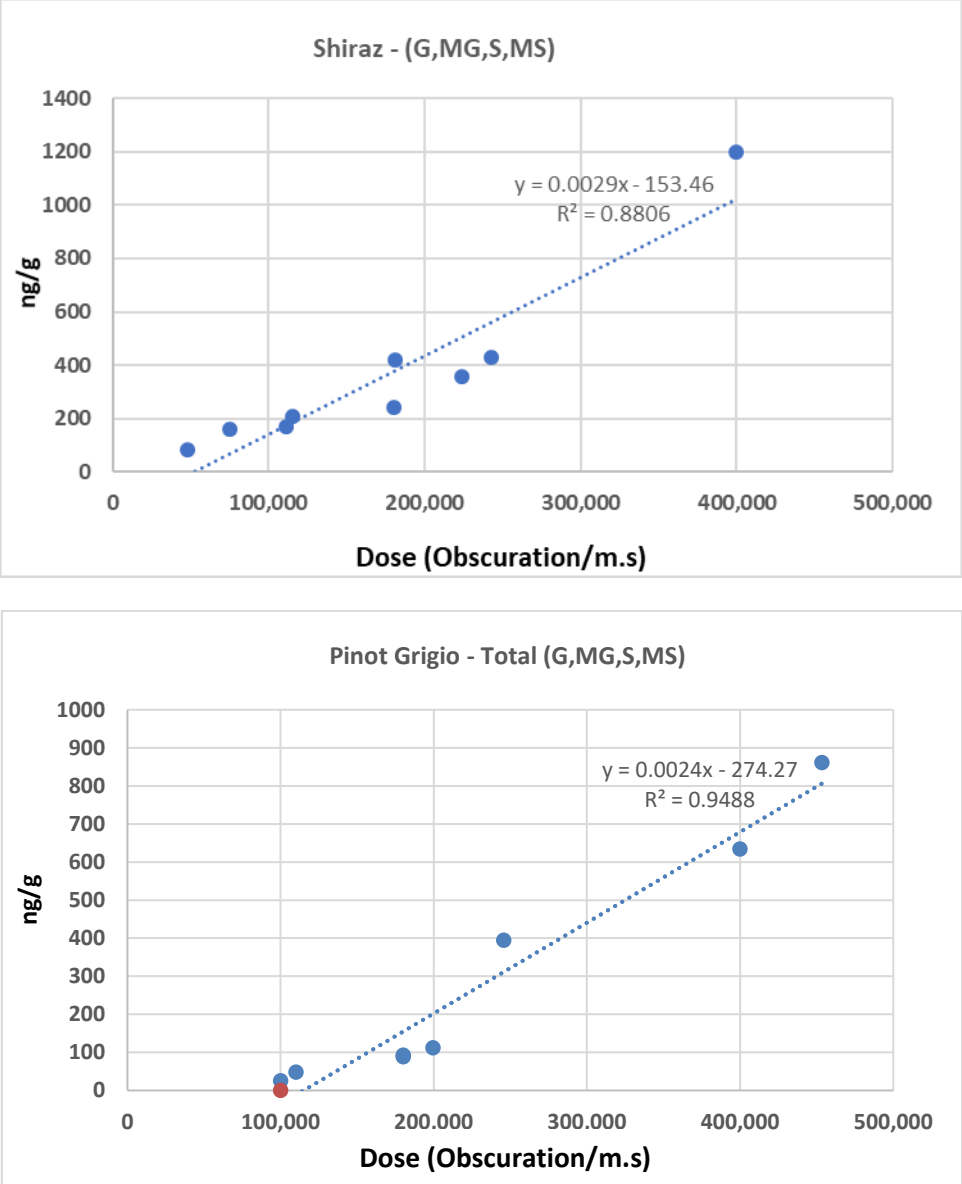


Figure 11: Correlation of **s**moke dose related to aggregate phenol concentration of key phenols (guaiacol, methyl guaiacol, syringol and methyl syringol) in two variety of grapes.

3.5 Grape and Wine Chemical Composition at Harvest

3.5.1 Correlation between phenol concentration in wine and smoke of different intensities and cumulative dose

Analysis of the 91 wines showed that concentrations of individual smoke taint compounds in wines correlated well with measurements of smoke compounds in grapes across a range of white (Figure 12) and red (Figure 13) varieties. In addition, concentrations of phenols in grapes and wine were highly correlated with the smoke dose measured at the site of sampling by VESDA®s.

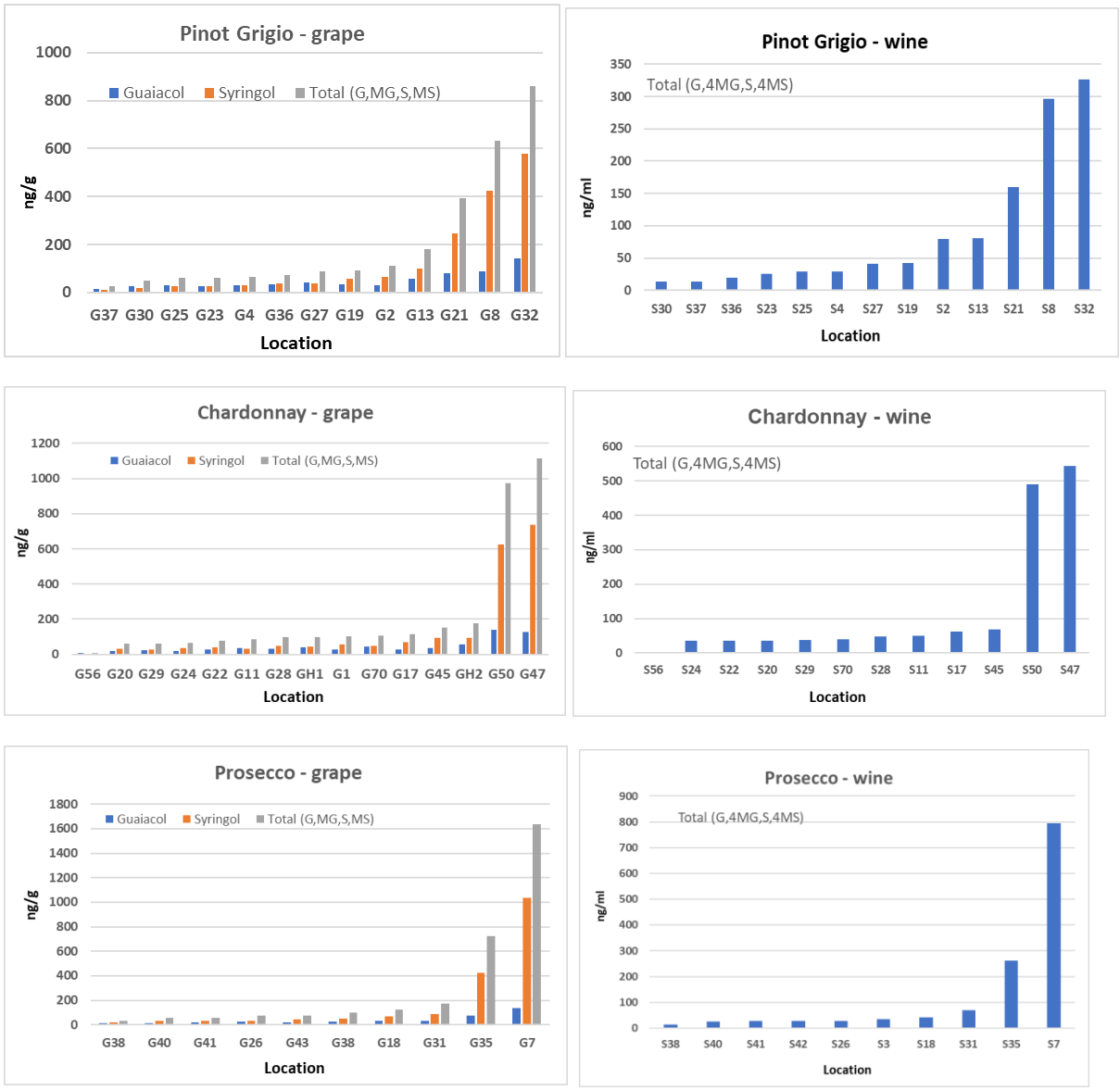
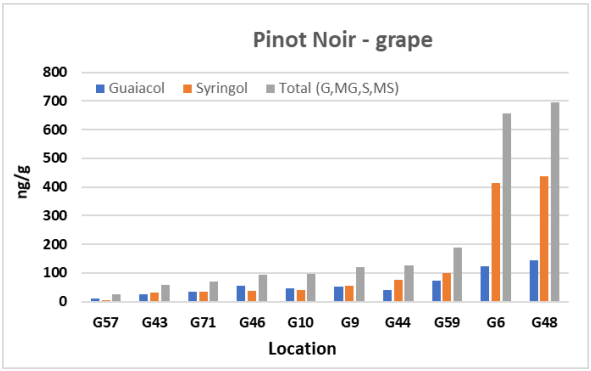
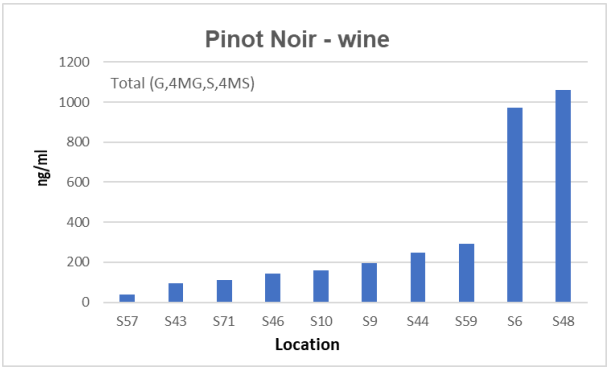
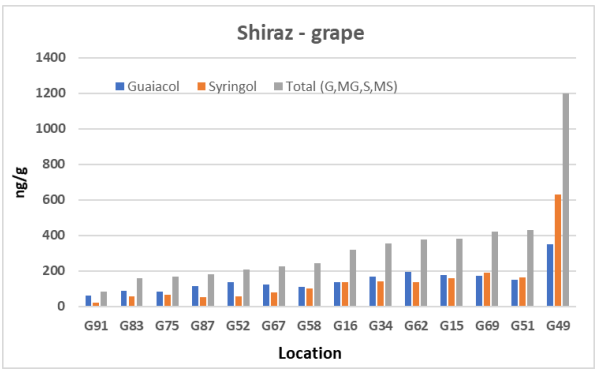
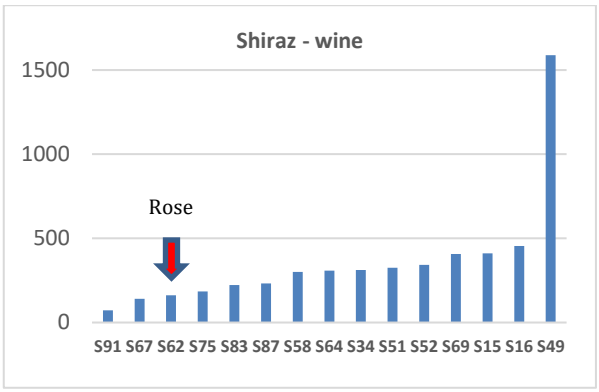


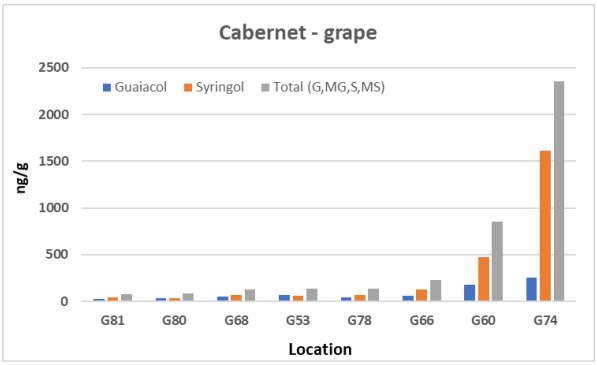
Figure 12: Relationship between the concentration of smoke taint compounds in grapes (ng/g) and white wines (ng/ml) from different locations. Data is arranged in increasing level of smoke dose at the site from left to right.

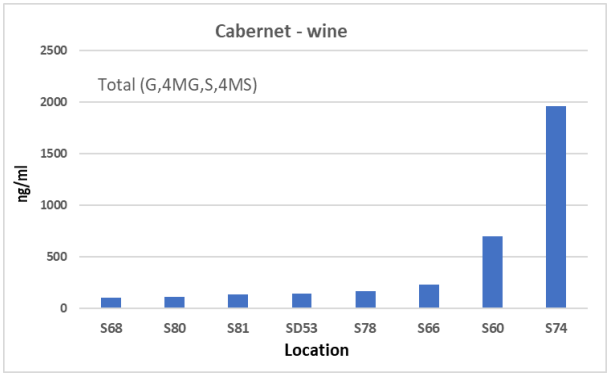

Pinot Noir - grape
Guaiacol
Syringol
Total (G,MG,S,MS)
ng/g
800
700
600
500
400
300
200
100
0
G57 G43 G71 G46 G10 G9 G44 G59 G6 G48
Location

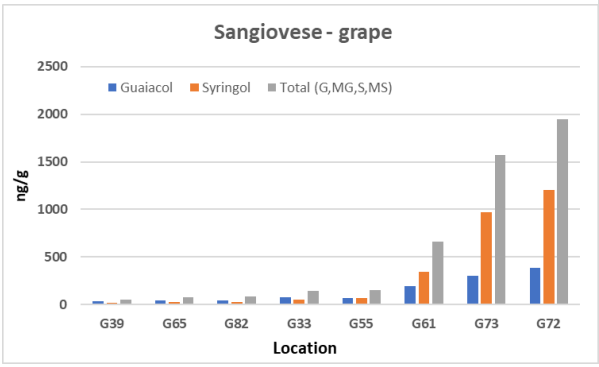

Pinot Noir - wine
Total (G,4MG,S,4MS)
ng/ml
1200
1000
800
600
400
200
0
S57 S43 S71 S46 S10 S9 S44 S59 S6 S48
Location

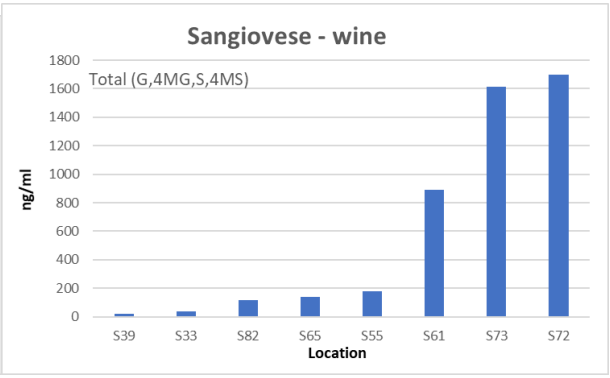

Shiraz - grape
Guaiacol
Syringol
Total (G,MG,S,MS)
ng/g
1400
1200
1000
800
600
400
200
0
G91 G83 G75 G87 G52 G67 G58 G16 G34 G62 G15 G69 G51 G49
Location


Shiraz - wine
1500
1000
500
0
Rose
S91 S67 S62 S75 S83 S87 S58 S64 S34 S51 S52 S69 S15 S16 S49


Cabernet - grape
Guaiacol
Syringol
Total (G,MG,S,MS)
ng/g
2500
2000
1500
1000
500
0
G81 G80 G68 G53 G78 G66 G60 G74
Location


Cabernet - wine
Total (G,4MG,S,4MS)
ng/ml
2500
2000
1500
1000
500
0
S68 S80 S81 SD53 S78 S66 S60 S74
Location


Sangiovese - grape
Guaiacol
Syringol
Total (G,MG,S,MS)
ng/g
2500
2000
1500
1000
500
0
G39 G65 G82 G33 G55 G61 G73 G72
Location


Sangiovese - wine
Total (G,4MG,S,4MS)
ng/ml
1800
1600
1400
1200
1000
800
600
400
200
0
S39 S33 S82 S65 S55 S61 S73 S72
Location

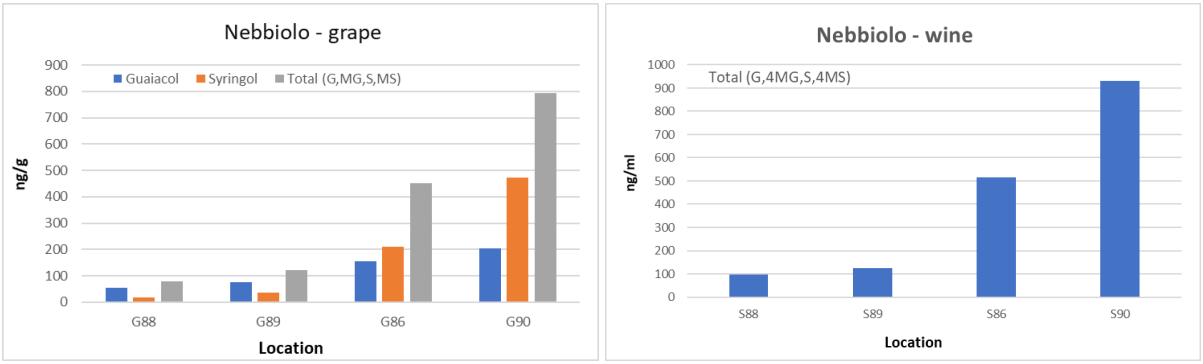


Figure 13: Relationship between the concentration of smoke taint compounds in grapes (ng/g) and red wines (ng/ml) and the smoke dose (measured by VESDA®) from bushfires in 2020. Data is arranged in increasing level of smoke dose at the site from left to right.

Whilst the trends in phenol concentrations and smoke dose were similar across all wine varieties, absolute concentrations differed between varieties grown at the same location, and therefore exposed to the same smoke dose (Figure 12, 13, and 14). Red wines had higher phenol levels in wine because of fermentation on skins, which typically contain a high proportion (approx. 60%) of the smoke taint compounds present in a grape. Absolute values of phenol levels in grapes also varied between varieties, which may relate to differing susceptibility to smoke uptake (see below).

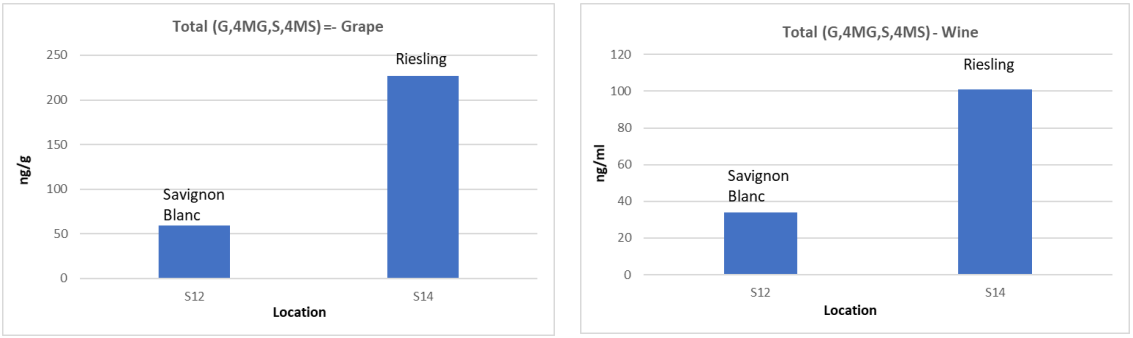


Figure 14: Relationship between the concentration of smoke taint compounds for grapes and wine (ng/ml) made from grapes at two specific sites in NSW and subjected to moderate smoke levels.

The data for Shiraz wines (Figure 13) did not correlate as well as for other varieties, possibly due to these wines being made 'on-skins' and the extra variability introduced through extraction of smoke taint compounds from the skins during fermentation. The higher and more variable levels of guaiacol naturally present in Shiraz grapes may be an additional factor causing the lower correlation for guaiacol in Shiraz.

Taken together, these results show that measurement of the smoke dose to which the grapes are exposed can allow an excellent prediction of the concentration of smoke taint compounds in wine made from seven key varieties grown in Australia. Measurement of smoke dose will also provide a reasonable prediction for some smoke taint compounds in Shiraz.

3.5.2 Effect of grapevine variety on uptake of smoke taint phenols

The absolute concentration of the phenolic smoke taint compounds in grapes and wine differed between varieties located in close proximity to one another and exposed to similar levels of smoke. This is related to the berry physiology and other characteristics which differ between varieties, i.e., size, skin thickness and potentially differences in the type of sugars. At one site, for example, which was subjected to extremely high smoke dose, the uptake of smoke taint phenols by Pinot Noir grapes was 40% lower than either the Chardonnay or the Shiraz grapes (Figure 15).

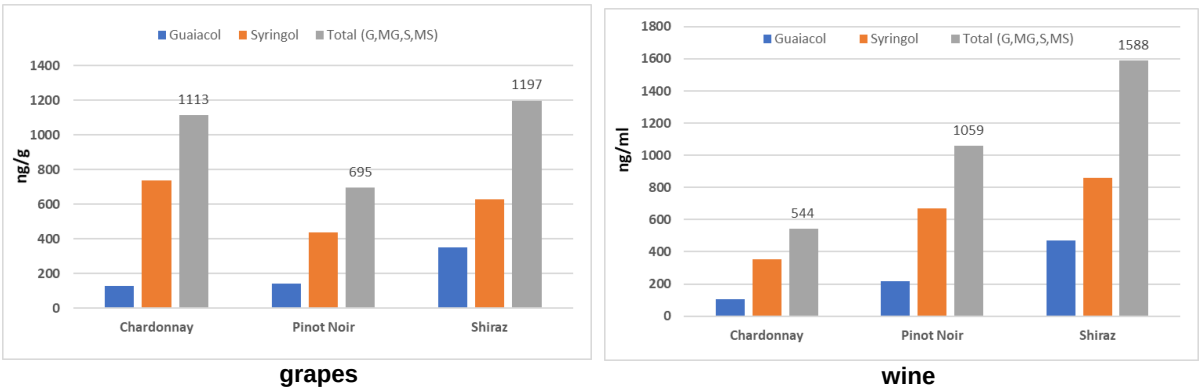


Figure 15: Concentration of phenols in grapes and wine of three different varieties (Chardonnay, Pinot Noir, Shiraz) subjected to the same dose of smoke at one site in NE Victoria during the 2020 bushfires. Numbers above the bar indicate totals for four key smoke taint phenolic compounds. (Note: white varieties were fermented off skins, red varieties on skins)

After fermentation, the concentration of smoke taint phenols in Chardonnay grapes halved, whereas the red wine figures (Pinot Noir and Shiraz) appeared to increase. This is because fermentation was carried out 'on-skins', as discussed above and because of the different units used to present data for grape extraction (ng/g) verses wine extraction (ng/ml). This is a common approach across all laboratories whether research or commercial, but is not clearly understood by the wine industry. If the data for grape and wine extractions are converted to the same unit (ie ng/ml) our study shows that the grape concentrations are almost identical to the wines. This result reinforces why a method which utilises methanol to extract skins (as done in the Macleod method) is a sound extraction technique for correlation studies of grape and wine data.

As mentioned, presently all commercial laboratories express results as ng/g for fruit and ng/ml for wine and this creates an immediate issue for interpretation. It is suggested that in future, laboratories should standardise measurements of both grapes and wine to ng/ml. This would require the grape data to be expressed only on the liquid content of the grapes and discounting the dry weight in grape samples or vice versa. This aspect of smoke taint diagnostics will be addressed in future research.

3.5.3 Effect of fermentation skin contact on smoke taint compounds in wine

This study confirmed previous work to show an extremely high correlation between levels of specific phenols in grapes at harvest and eventual levels of phenols in wines. This is despite the different extraction efficiencies caused by the difference in fermenting on and off skins. Our past studies have shown that the skins contain approximately 60% of the smoke taint compounds, so if skins are not included then the ferments will contain a much lower concentration of phenolic compounds in total, whether smoky phenols or not. As reds are fermented on skins, there will always be higher levels of smoky phenolics in red wines relative to whites.

To illustrate this, two batches of Shiraz grapes subjected to different levels of cumulative smoke dose were each split into three and fermented off skins, fermented for 3 days on skin and 7 days on skin to show the influence of skin contact during winemaking. Resultant wines were analysed for smoke taint compounds. Fermentation without skins (ie a rosé) resulted in wines with significantly less total phenols than the wines fermented on skins (Figure 16). The effect was more pronounced (up to 46% less phenols) for wine made from grapes which had been exposed to a high level of cumulative smoke dose (Shiraz 2; Figure 16). The longer time on skins tended to give a higher total phenol content in the wine than either 0 or 3 days on skins.

This data confirms that reducing time on skins will reduce the smoke taint phenols in wines and is a possible mitigation technique for making wines from smoke-affected fruit in bushfire-affected areas. This will become clearer once sensory analysis of the wines has been conducted.

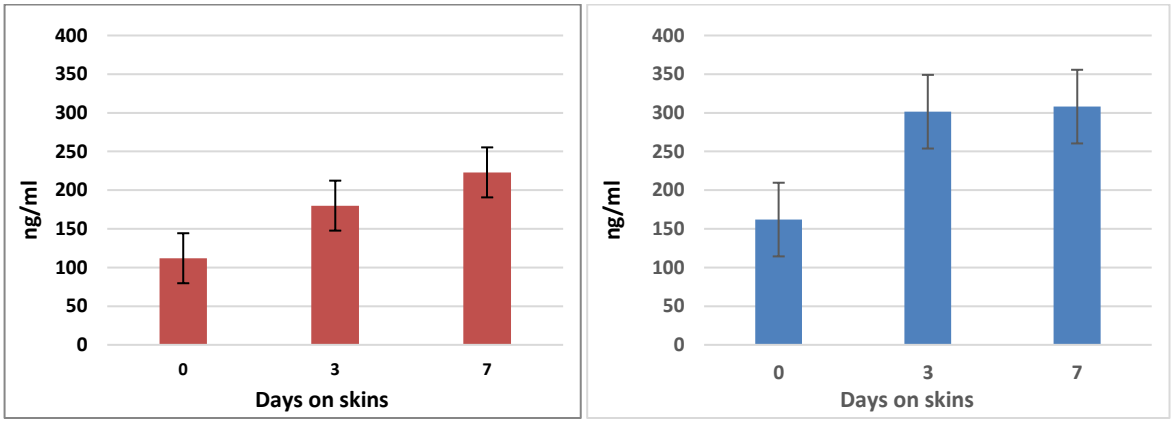


Figure 16. Effect of length of fermentation on skins on the concentration (ng/ml) of smoke tainted phenols (total of guaiacol, methyl-guaiacol, syringol and methyl syringol) in wine from two Shiraz wines made from grapes exposed to different levels of cumulative smoke dose >0.04 obs/m/s: Shiraz 1 on the left (111,000 dose approx) and Shiraz 2 on the right (225,000 dose approx) from bushfires in 2020.

Further analyses will be conducted to determine all relationships of the major smoke taint phenols from smoke dose, smoke composition, grape and wine composition once the full sensory analysis has been conducted.

3.6 Effect of Distance from the 2020 Bushfires

Past studies have shown that all smoke taint phenolic compounds decrease exponentially with distance from fires, as would be expected due to dilution of the smoke with the surrounding clean air. The relative rate of decline in the concentration of the smoke taint compounds also indicated that degradation processes were occurring, with the larger, more heavily substituted compounds such as syringol and 4-methylsyringol reducing in concentration more quickly than the less heavily substituted compounds, such as guaiacol and methyl guaiacol. Data to back up this finding was shown earlier in this report in Figures 7, 8 and 9.

Previous results from prescribed burns and small bushfires has shown that the risk of smoke taint decreases rapidly as the smoke ages (has travelled further from a fire) and that the profile of smoke taint compounds taken up by grapes would be expected to contain less syringyl derivatives at greater distances from fires. In the bushfires of 2020, the effect of distance was more difficult to determine because of the broad area of land being burnt, the mixing of smoke from a number of burns in Victoria and NSW, and the inability to describe exactly where the smoke originated. Also, catastrophic bushfires are generally associated with strong winds which carry the phenolic compounds over large distances quickly. In 2 hours, which is the half-life of some smoke taint phenols and an average wind speed of 40kms, smoke taint phenols can travel over 80kms. This means the heavier phenols, such as syringol, can be carried further distances than during smaller bushfires and controlled burns. However, we still observed a significant decrease in syringyl derivatives (ie syringol and methyl syringol) with distance from the fire (Figs 8 and 9). The fact that all smoke taint phenols were found to correlate well with smoke *dose* but not so well with smoke *concentration* suggests that there may be physiological rebalancing of smoke taint phenolics onto sugars within the grape. This aspect was beyond the scope of the present study and will be analysed further in future studies.

3.7 Effect of Grape Maturity on Smoke Taint Uptake and Final Levels in Grapes and Wine

Somewhat unexpectedly, the levels of phenols in smoke-exposed grapes in the bushfires in Victoria were shown to reduce by around 50% from pre-veraison (EL 3.1-3.4) to harvest (Figure 16, Figure17). Unlike the 2020 bushfires in Victoria, which occurred relatively early in the growing season, past bushfires have generally occurred either later in the season or the smoke has continued from bushfires right throughout the season (ie. as occurred in the Hunter Valley and NSW in 2019-20). The decrease in phenol concentration that was observed in Victoria in 2020 probably occurred as a result of the berries filling with fluid and increasing in size, in the absence of smoke. This result confirms that pre-veraison grapes are susceptible to smoke damage, and in the absence of further smoke, that the concentrations of smoke taint compounds decrease with the growth and ripening of the grapes. Owing to the linear correlation, this is also then reflected in the wine concentrations (Figures 12 and 13). It also showed that, in the event of a smoke event early in the season, grapes can be tested with the Macleod method of extraction to get a reliable result for phenol levels right through till harvest.

These results suggest that it is important to understand how maturity and berry growth stage relate to the final concentration of smoke taint compounds in wine. It is suggested that a test for smoke taint will be most accurate when the berries are fully expanded. If fresh smoke persists, then further testing will always be needed as the phenols continue to be taken up by berries.

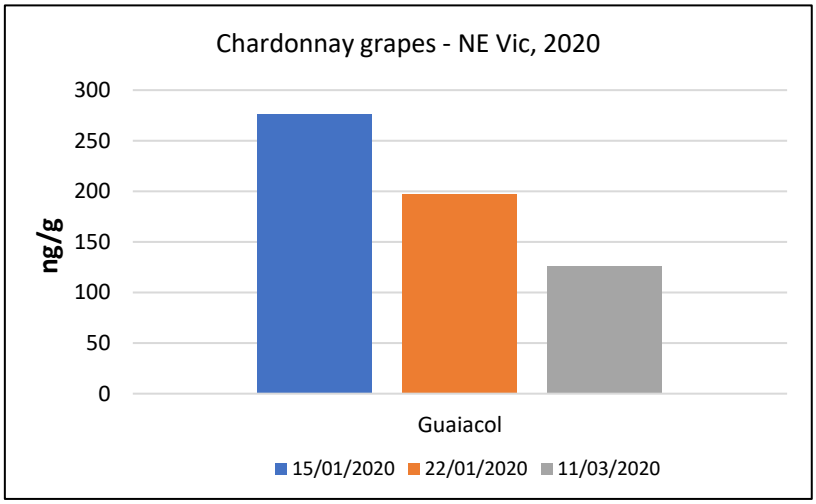


Figure 16: Change in guaiacol concentration in Chardonnay grapes from pre-veraison (EL stage 3.1 -3.4) on15th January to fully mature grapes on 11th March 2020.

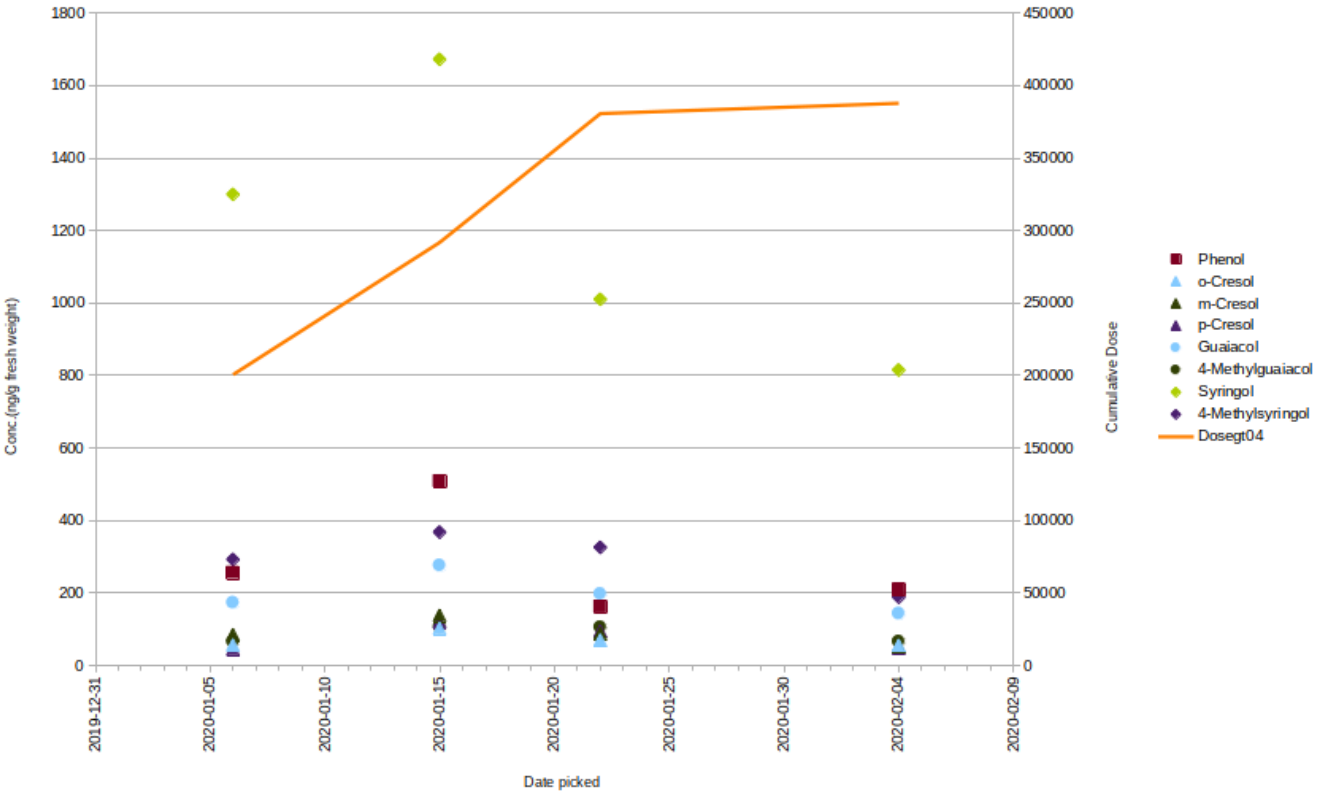


Figure 17: Change in concentration of a range of smoke taint phenols in Chardonnay grapes plotted against time until harvest on 4th February, 2020 and the cumulative smoke dose (% obs/m/s) received. The volume of smoke from the bushfires declined and eventually ceased in mid-January as the fires were extinguished

4 Conclusions

Overall, our in-field measurements of smoke exposure in vineyards during the 2019-20 bushfires have allowed some key relationships to be further developed. Most notable was that smoke dose (time and smoke intensity) can be used as a measure of the concentration of phenolic compounds in smoke. Relationships between smoke dose and the concentrations of key smoke taint phenols in grapes and wine were also confirmed. The project showed how the levels of specific phenolic marker compounds in smoke change with smoke movement and distance from fire.

This project produced an excellent reference set of 91 smoke-tainted wines as a resource for future projects in Australia on smoke taint. The wines:

- Result from a wide range of cumulative smoke dose exposures experienced during the 2020 bushfire events in Australia, and this will help establish accurate risk thresholds which give different sensory levels of smoke taint
- Include data for eight key varieties of wine grapes, thus having high relevance to wine grapes produced in all regions of Australia
- Demonstrated an excellent relationship between smoke dose and grape (and wine) concentrations of phenols, with correlations to sensory outcomes yet to come
- Allowed an observation of the influence on smoke phenol levels of 'no skin' contact fermentation for whites and fermentation on skins for reds. This included the impact of time on skins elevating the levels of smoke taint compounds in wine
- Showed that pre-veraison extraction of some taint compounds can be used as a predictor of taint at harvest provided there is good knowledge on the smoke levels and an allowance is made for berry size (ie moisture levels)
- Provided a large amount of data to support the use of smoke dose and specific marker compounds to set risk thresholds for smoke taint. This is essential for the success of an early warning system for industry based on a network of smoke sensors.

The link with industry on this program has been vital to its success, and collaborative studies of this type are considered essential for solving smoke taint globally. The production of the wines in this project was only possible because of the dedicated cooperation of the wine industry members who harvested and donated smoke-affected grapes in the name of research. We also acknowledge the excellent skill and tireless efforts of the winemakers, Warren Proft and Prasad Patil, and the generosity of Chrismont Wines and Wine Australia for funding this vital project.

5 Recommendations

It is recommended that the data from this project be added to the pool of previous data on smoke, grape and wine chemistry to form the basis of a smoke taint risk assessment tool for the wine industry. Industry interface with the tool would be through the development of a publicly available website and smartphone app which would inform growers of the smoke taint risk associated with smoke events in their area. This would require the commissioning of a much more comprehensive network of smoke detectors in a region, combined with smoke modelling to predict the smoke levels between smoke detectors. Benefits of such an system include quick access to objective data to help growers make informed decisions following smoke events, easier marketing of grapes from areas where low level (insignificant) smoke events have occurred, and informed decisions by winemakers where the smoke taint status of grapes may be delayed pending the results of grape analysis. Land managers such as Forest Fire Management Victoria would also benefit by being able to access real-time data to monitor the spread of smoke from controlled burns.

A comprehensive study of the sensory characteristics of the smoke-affected wines generated in this project is necessary to assess the effect of differing smoke taint compound profiles within smoke, grapes and wine, as would be expected from differing fuel sources and at varying distances from fires. This may enable the development of a standardised, objective assessment method for winemakers, who at present rely on their own ability to assess the suitability of smoke-affected wines for sale.

People vary considerably in their sensorial ability to taste smoke taint, and future projects need to place heavy emphasis on sensory testing to link all data collected from smoke events to smoke taint. This also means being able to interpret how grape and wine levels from the two commercial laboratories relate to smoke taint in wine, as presently the laboratories use different assessment methods, which creates confusion for the grower. Also, owing to the variability in data from commercial laboratories, the difference in winemaking techniques and varieties and the liability for incorrect recommendations, it is at present difficult for commercial laboratories to provide accurate interpretation of test results. Providing a system which standardises results from commercial laboratories and identifies risk on a traffic light system on a public database could improve the prediction of taint throughout the industry and provide more surety for downstream decision-making.

The advances in grape and wine analysis techniques since previous studies, in particular the analysis of bound compounds, allows a much better understanding of the total amount of smoke taint compounds taken up by wine grapes. The Macleod extraction and GCMS analytical method enables the total uptake of smoke taint compounds to be accurately determined at any stage of maturity, which made it extremely suitable for this study. The standardisation of this technique with commercial methods (which measure a select group of compounds) is seen by this author as critically important. Some of the past recommendations for industry may change, once knowledge exists that a greater number of phenols exist in smoke-affected wine, especially at the time of bottling. Our past work has shown that a complete analysis performed at harvest or bottling gives growers greater certainty as to whether smoke taint will occur or develop over time. Our past work has also shown that glycosides are very stable and that their breakdown is unlikely to be the reason for any change in smoke taint as wine ages. Longer term sensory studies on the 91 vintages made in this project will confirm this finding.

6 Media and Communications

- Ian Porter, Presentation to Hunter Valley vignerons, Pokolbin, 19 November 2019
- Ian Porter, Presentation to North East vignerons, 15 January 2020
- Ian Porter, Presentation to the Mornington vignerons, 17 January 2020
- Ian Porter, Presentation to Gippsland vignerons, February 2020
- Ian Porter, Presentation to the North East vignerons, 3 February, 2020
- Ian Porter, Tim Plozza, Pei Zhang, Joanne Bui, David Allen. Smoke Sensing as an Early Warning of Smoke Taint, ASVO Conference, 30th June 2020

7 References

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Lauraguais, A., A. El Zein, C. Coeur, E. Obeid, A. Cassez, M.-T. Rayez and J.-C. Rayez (2016). "Kinetic Study of the Gas-Phase Reactions of Nitrate Radicals with Methoxyphenol Compounds: Experimental and Theoretical Approaches." The Journal of Physical Chemistry A **120**(17): 2691-2699.

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8 Appendices/Attachments

8.1 Details of the site number, harvest date, location, company, variety for grape and wine samples evaluated in the small-scale wine project from the 2020 bushfires in Vic and NSW (withheld from publication until completion of sensory analysis)

8.2 Grape and wine details and final winemaking characteristics (withheld from publication until completion of sensory analysis)

8.3 White wine micro-vinification procedure 2020

The following recipe was followed for white wine (skins off) production in the small scale project.

- 36kg sample of randomly selected bunches collected and delivered to Chrismont.
- Bunches placed into barrel shed for 4 to 6 hours (18 – 20 degrees) to equalise temperature.
- Crush and destem to yellow bin– Add 30mg/kg PMS and 30ppm enzyme (Enartis Arom MP ~1g)
- Transfer to small basket press with scoop and allow to drain with light pressing until 500mL per kg has been collected. ~18L
- Analyse – Be pH TA Temp FSO2
- Add H2T to adjust TA to 7.5 if necessary, pH ideally under 3.40.
- Add PMS is necessary to achieve 10ppm FSO2
- Allow to settle overnight in barrel room (18degs)
- Rack settled juice to another fermenter.
- Rehydrate and add 0.3g/L Yeast Lafort VL1 (5grams)
    - Add yeast to 50mL of 40deg water
    - Wait 10 minutes and introduce to juice
- Seal fermenter store in barrel room
- Monitor ferment and temperature
    - Ferments stored in barrel room set at 18 degrees
    - Add DAP 100ppm half way through ferment
- Once dry, transfer to cool room for settling (5 days)
    - Add 0.1ppm Cu2+
- Analyse: RS, pH, TA, temperature, VA, Alc.
- Rack off gross lees to Cornealius keg.
    - Add 100ppm PMS
    - Add Tartaric Acid again if necessary to achieve 6.2g/L TA
- Seal keg and place in cool room at 5 degs
- Before bottling (June) check SO2, pH TA
- Rack wine to another Cornealius keg
- Analyse and adjust SO2 to 30ppm FSO2
- Final analysis – pH, TA, VA, Alc, RS, SO2
- Bottling
    - Fill bottles from keg
    - Apply screw cap

8.4 Red wine micro-vinification procedure 2020

The following recipe was followed for red wine (skins on) production in the small scale project.

- 26kg sample of randomly selected bunches collected by and delivered to Chrismont.
- Bunches placed into barrel shed for 4 to 6 hours (18 – 20 degrees) to equalise temperature
- Crush and destem to yellow bin– Add 30mg/kg PMS and 40mg/kg enzyme (Enartis Arom MP ~1g)
- Transfer to 30L fermenter with scoop.
- Analyse – Be pH TA Temp.
- Add H2T to adjust TA to 7.5 if necessary, pH ideally under 3.50 – but may not be possible.
- Rehydrate and add 0.3g/L Yeast Lafort XPure (5grams):
    - Add yeast to 50mL of 40deg water.
    - Wait 10 minutes and introduce to must.
- Seal fermenter store in barrel room.
- Monitor ferment and temperature:
    - Ferments stored in cool room set at 18 degrees
    - Ferments mixed once a day (cap submerged once) for the first 5 days
    - Add DAP 200ppm Day 3
    - Day 6 and 7 no plunging.
    - Press on day 7 – skin contact time 7 days
- Drain and press to another 30L fermenter fitted with airlock and bottom valve
    - Scoop out into small basket press, allow to drain, and press gently. Continue pressing until satisfied that full extraction has been achieved.
    - Add 0.1ppm Cu2+
- Analyse: RS, pH, TA, extraction%, VA, Alc.
- Add Tartaric Acid again if necessary to achieve 6.0g/L TA
- Allow to dry out and settle for 5 days.
- Rack off gross lees into 18L Cornealius keg and add PMS 100ppm.
- Seal keg and place in cool room at 5degs
- Before bottling (June) check SO2, pH TA
- Rack wine to another Cornealius keg
- Adjust TA with Tartaric to 6.0g/L if necessary, and SO2 to 80ppm TSO2
- Final analysis – pH, TA, VA, Alc, RS, SO2
- Bottling
    - Fill bottles from keg
    - Apply screw cap

8.5 Locations of grape sampling from wine regions of Victoria and NSW in March 2020

District	Variety										Number
	Chardonnay	Pinot Grigio	Prosecco	Pinot Noir	Sangiovese	Shiraz	Cabernet	Pinot sparkling	Chardonnay sparkling	Extras?	
Beechworth										Nebbiolo	1
Cheshunt (Ch)					(x2) and Rosé					Nebbiolo	7
Cheshunt (DZ)											3
Cheshunt (MM)											4
Cheshunt (Pol)						0, 3 and 7 days					4
Glenrowan										Muscat	3
King Valley (Cav)											4
King Valley (Edi)						(X3)				Nero and Aglianico	5
King Valley (Cor)										Nebbiolo	1
Milawa											2
Mohyu (Cav)											4
Myrrhee (B)											3
Myrrhee (CAVV)											4
Myrrhee (S)											3
Ovens (Dal)											6
Ovens (Fea)											2
Ovens (RR)										Nebbiolo	1
Ovens (Mic)											3
Rutherglen (East)										Durif	4
Rutherglen (West)											3
Whitfield (JD)										Nebbiolo	4
Whitlands (JB)											2
Whoroughly South (MW)											4
Yarra Valley											3
Gippsland											3
NSW (Orange)				(x2)						Sav Blanc	4
NSW (Young)						(x2)				Riesling	4
										Total number	91