Effect of smoke in grape and wine production

Kristen Brodison
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Sources of further information
Further information on the effects of smoke on grape and wine production and current research can be obtained from the Grape and Wine Research and Development Corporation (GWRDC) at gwrdc.com.au and the Australian Wine Research Institute (AWRI) at awri.com.au

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Introduction

Smoke exposure of grapevines and the development of smoke-related characteristics in the resulting wines is an increasing issue for the wine industry. As Australia faces a warming climate with more bushfires, smoke exposure in vineyards is becoming more regular.

Wines made from grapes exposed to smoke during sensitive growth stages can exhibit aromas and flavours resembling smoked meat, disinfectant, leather, salami and ashtrays. Where unfavourable smoke characteristics are detected by consumers at high concentrations the wine may be unpalatable. Unsalable wines result in financial losses for producers with costs flowing on to wine brands, market presence and future sales.

Few tools and techniques are currently available to remedy the problem of smoke effect in grapes and wine, however a significant advancement has been the development of the Smoke Taint Risk calculator. The risk calculator (known as STAR) was developed by researchers at the Department of Agriculture and Food, Western Australia (DAFWA) and The University of Western Australia (UWA) and predicts the seasonal sensitivity of grapevines to smoke uptake and smoke flavour development in wine.

Use of the STAR calculator, with other postharvest techniques provides opportunity to effectively reduce unwanted smoke effects in grapes and wine. This bulletin details key information on smoke effect, tools and techniques for smoke reduction in vineyards and wineries and the STAR calculator.
Background

The issue of smoke effect in grape and wine production is relatively recent. One of the earliest reports resulted from the Canberra bushfires of 2003. These fires cost the Alpine Valley wine industry an estimated $4 million and caused smoke damage to vineyards in north-east Victoria and south-eastern New South Wales.

The Australian Wine Research Institute (AWRI) began investigations into the nature and amelioration of smoke effect after receiving numerous enquiries from producers noticing smoke-related sensory characters in fruit, juice and wine (Høj et al. 2003).

Since this time, further significant fires have resulted in smoke damage to wine grapes and included:

- 2004, losses to vineyards in the Manjimup and Pemberton regions of south-western Western Australia
- 2007, loss of 15,000 tonnes of fruit in the King and Alpine Valleys, Victoria
- 2009, the Black Saturday fires in Victoria were estimated to cost $299 million in lost revenue.

Consequently, research investigating smoke effects on grape and wine production has increased significantly. This has focused on the effect of smoke exposure on vines and the subsequent smoke-related characteristics in grapes and wine. Further research has investigated the impact of the smoke timing, density, duration and assimilation by grapevines.
Seasonal sensitivity to smoke uptake

To investigate when grapevines are sensitive and susceptible to smoke uptake, apparatus was designed and tested to apply smoke to field-grown vines (Figure 1). This consisted of a steel-framed tent to surround vines to apply smoke from a smoke drum. Work was conducted on both DAFWA and commercial properties.

Research was conducted with Merlot vines over three seasons, during which they were exposed to smoke at key growth stages (10 cm shoots, flowering, pea-size berries, beginning of bunch closure, veraison, grapes with intermediate sugar, berries not quite ripe, and harvest) to understand the level of smoke effect in the final wine (Kennison et al. 2011). Results showed the three key periods of vine sensitivity to smoke were:

- **Shoots 10 cm long to flowering**: low sensitivity
- **Pea-size berries through to three days post-veraison**: variable (low to medium) sensitivity
- **Seven days post-veraison to harvest**: highly sensitive (see Figure 2).

Figure 1 Smoke generation and application apparatus including a tent structure to surround vines.
Smoke exposure can also result in delayed ripening of fruit. On some occasions, studies have shown fruit from smoke-exposed vines to contain lower sugar than fruit from unsmoked vines (Kennison et al. 2009). The delay in ripening is thought to be related to the effect of smoke on the functioning of the grapevine, with further studies investigating the photosynthetic response of grapevines to smoke exposure.

**Effect of smoke on varieties**

The effects of smoke uptake in wine vary depending on the variety. Previous studies focused on Merlot only. These comprehensive studies were conducted over three years. Further studies have investigated the effect of smoke on other varieties including Cabernet Sauvignon, Chardonnay and Sauvignon Blanc. These found the timing of smoke uptake varies with variety. For example, some varieties may be more sensitive to smoke uptake earlier than others.

The difference may be due to a number of factors including seasonal weather conditions and vine health. Wine grape varieties can differ in plant structure and in aspects such as berry skin thickness, which may affect smoke uptake. Winemaking techniques can also influence smoke characteristics in the final wine. Generally, wine from white grape varieties has fewer smoke-related sensory and chemical effects due to the reduced contact time on skins compared with red wine production. All of these factors were considered in developing the smoke risk reduction model (STAR).

**Implications of smoke density and duration**

Extensive field research was conducted by DAFWA to establish the quantity of smoke exposure needed to

<table>
<thead>
<tr>
<th>Grapevine growth stage</th>
<th>Potential for smoke uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoots 10 cm long</td>
<td>Low</td>
</tr>
<tr>
<td>Flowering</td>
<td>Low</td>
</tr>
<tr>
<td>Pea-size berries</td>
<td>Variable (low to medium)</td>
</tr>
<tr>
<td>Beginning of bunch closure</td>
<td>Variable (low to medium)</td>
</tr>
<tr>
<td>Onset of veraison to three days post-veraison</td>
<td>Variable (low to medium)</td>
</tr>
<tr>
<td>From seven days post-veraison to Harvest</td>
<td>High</td>
</tr>
</tbody>
</table>

*Figure 2* Key periods of sensitivity to smoke exposure and development of smoke-related aromas and compounds in wine, derived from three years of research of smoke on field-grown Merlot grapevines.
cause effect. This used field-based smoke detecting equipment (nephelometry) to measure the density and duration of smoke applied to grapevines.

The device measured smoke in units of obscuration per metre (%obs/m). This relates to the impairment of normal vision over a distance of 1 metre. A visual description of smoke obscuration per metre and the associated viewing distance is provided in Figure 3. Smoke was applied to vines at various densities (2.5, 5, 10, 20 and 30%obs/m) and durations (five to 80 minutes) during growth periods defined as sensitive for smoke uptake.

The results showed a single heavy smoke exposure (30%obs/m) for 30 minutes at a sensitive stage of growth (from seven days after veraison to harvest) was sufficient to create smoke-related aromas, flavours and compounds in wine (Kennison et al. 2008). Lower smoke densities for shorter periods also applied at a sensitive vine growth stage can create differences detectable by consumers (Kennison et al. 2012).

Smoke-like aromas and flavours are pronounced in wines produced from high smoke densities (20%obs/m) for short durations, and low smoke densities (2.5%obs/m) for long durations. It is important to note that grape harvesting, handling and winemaking techniques can influence smoke effect. Techniques to reduce the effects are detailed further in this document.

The effect of repeated smoke applications to the same vines was also investigated. Eight applications were made to the same Merlot vines throughout the
growing season. Sensory and chemical analysis showed the smoke to have a cumulative effect on the levels of smoke-related compounds and aromas in resultant wines (Kennison et al. 2008). Therefore, repeated smoke exposure or exposure for a long period results in accumulation of smoke aromas and compounds in the final wine.

**Potential carry-over of smoke**

Grapevines were exposed to eight smoke applications from veraison to harvest (Kennison et al. 2011). Wine from this fruit contained distinct aromas of smoked meat, burnt rubber, leather and disinfectant/hospital. One year later fruit from the same vines was harvested, made into wine and evaluated. Smoke-related aromas and flavours had not carried over to the next season. However, fruit yield was considerably lower (6.4 kilograms) than vines that were not exposed (12.9 kg). Repeated smoke exposure was therefore likely to affect grapevine function and its reproductive capability.

**Effect on wine production**

Wine production with smoke-exposed fruit can require additional tools and techniques to reduce the development of smoke-like characters throughout the winemaking process. Smoke-related volatile phenols have been shown to accumulate in must during fermentation and further accumulate after malolactic fermentation (Kennison et al. 2008).

Generally, the rate of fermentation of grape musts is accelerated with smoke-affected grapes and the smoke-related volatile phenols further accumulate in the bottle over time and during storage (Kennison et al. 2008).

These phenols can be reduced during winemaking, depending on how the fruit is handled and the wine fermentation. Techniques such as hand harvesting, excluding leaf material, whole bunch pressing, separation of press fractions, yeast selection and reverse osmosis have all been found to reduce smoke-related aromas, flavours and compounds in wine. Techniques to reduce smoke characters in wine are detailed in Table 1.
Smoke effect reduction system

Smoke Taint Risk calculator (STAR)

A comprehensive computer-based software tool has been developed by DAFWA and UWA to reduce the incidence and severity of smoke exposure on grapes and wine. The tool can predict the seasonal vine phenological stage and associated susceptibility of the vine to smoke uptake and effect on wine. This tool can also be applied in prescribed burning decisions. The Smoke Taint Risk calculator (STAR) is available on the DAFWA website at agric.wa.gov.au (example shown in Figure 4).

STAR incorporates elements including vineyard location mapping, knowledge of seasonal growth stages, smoke risk factors, in-field smoke detecting equipment and an interactive software interface. It has unrestricted access and the website also contains information on how to use the software.

Figure 4 Example of smoke risk profile produced by STAR for Merlot in the Pemberton region 2011–12.
**Vineyard location mapping**

Vineyards occur over diverse landscapes and large geographical areas. They are predominantly in recognised Geographical Indications (GI) regions that are formally established to encompass regional wine grape production. In general, most production is in recognised GI regions, however some vineyards may be outside them.

Wine production can cover large areas adjacent to other activities such as horticulture, agriculture, forestry and urban development. As part of the smoke risk reduction model, it is imperative to know where vineyards are located and their heaviest concentrations. This is of key importance to manage competing activities and schedule prescribed burns to avoid conflicts with wine grape production.

Knowledge of vineyard locations is essential where owners need to be contacted if smoke or biosecurity issues arise. When fires do occur, the spread of smoke can be tracked by aerial photography to see if it corresponds with wine production areas.

DAFWA has developed a process to capture and map vineyard locations. This has been piloted in WA and can be reproduced elsewhere in Australia. It includes sourcing aerial maps from Landgate that are inspected to identify areas that contain vineyards (Figure 5).

Each vineyard is identified and its owners contacted and provided with a hard copy map of their property to confirm wine grape production. All owners are requested to provide contact details, areas of wine grape production and varieties. This information is entered into a comprehensive and secure database. The locations of vineyards are used for communication on potential smoke events and in planning prescribed burning.

![Figure 5 Example of aerial map showing a wine grape property.](image)
Timing of key growth stages

Research has shown the risk of smoke uptake and development varies depending on the vine growth stage. Therefore knowledge of the true phenological growth stage can determine the potential risks. Timing of growth and development is highly dependent on temperature, with variability of stages due to climate, region, seasonal conditions and variety.

In order to gain a greater understanding of seasonal variability of growth stages, a pilot study was conducted in WA. Researchers obtained historical phenological records from producers and seasonal records from 2011 to 2012. Results showed the timing of key growth stages varied greatly between regions and even within a region. This information is important and needs to be considered at each site to determine the true timing of grapevine sensitivity to smoke uptake.

Calculation of smoke risk factors

Smoke risk factors incorporated into the STAR model have been based on field research and generated from both the chemical and sensory smoke-related properties of wine. It covers key varieties including Merlot, Cabernet Sauvignon, Chardonnay and Sauvignon Blanc. The number of varieties will increase as research progresses in this field.

Smoke detection in the field (nephelometers)

Understanding the timing of smoke exposure and its associated density and duration provides information on the likelihood of taint in the final wine. In order to identify if smoke has been present in the vineyard, smoke detection equipment can be employed.

A number of reliable units are available, including particulate monitors, atmospheric gas detectors, nephelometers and visual monitors (web cameras), all with a variety of functions.

In recent DAFWA research, nephelometer equipment has been used reliably to quantify smoke presence in the vineyard (Figure 6). Nephelometers use a light detector to measure suspended particles in the atmosphere, with the density of these particles related to their light reflectance (Figure 3).

For any smoke detection equipment in the field it is important to consider its function. Cost, portability, weather stability, power source, data download capability and data interpretation also need to be considered.
In case of a smoke event in the vineyard ... 

Smoke events can be frequent and arise from a number of sources. It would be ideal to avoid smoke exposure of grapevines during the growing season, however this is not possible in the Australian landscape. It is therefore imperative that actions and techniques to practically reduce the negative effects of smoke exposure of wine grapes are developed. These actions can be useful if a smoke event is imminent, if a fuel-reduction fire is planned, or an event has occurred.

If a smoke event is imminent

Seasonal prescribed burn information

Fires can be planned or unplanned. Planned fires, or prescribed burns, may be conducted by forest management agencies, local shires, local and volunteer bushfire brigades and landholders. Lighting fires is restricted during summer when smoke is most damaging to wine grape production. However, fires can still conflict with grape production, especially during later seasons when fruit production coincides with autumn fires.

State forest management departments may conduct management activities that produce smoke, including prescribed burning. In WA, the Department of Environment and Conservation (DEC) conducts yearly prescribed burns in spring and autumn. These are undertaken for a variety of purposes that include:

- reduction of forest fuel loads to minimise wildfires
- protection of life, property and the community
- enhancement of biodiversity values
- to rehabilitate vegetation after timber or mining activities
- to research fire effects and fire interaction with the environment.
DEC uses a Master Burn Plan in order to identify the areas requiring prescribed burning for the coming year and to indicate the burning schedule for three years ahead. Information on the timing of prescribed burns is communicated widely to industry and the community. This information is readily available from the DEC website at dec.wa.gov.au or by phoning +61 (0)8 6467 5000. In other states, contact your relevant forest management department.

**Registration of sensitive sites**

‘Sensitive Sites WA’ is a DAFWA service designed to help locate sensitive agricultural production systems within the agricultural regions. A sensitive site is defined as a property whose owner and DAFWA believe may be sensitive to impact from activities on nearby land. This service aims to assist with risk assessment and risk mitigation plans for ongoing production and to help protect sensitive agricultural production systems.

Examples of a sensitive site may include production certified as organic and/or biodynamic and viticulture. Specific examples of activities on neighbouring lands that are known to impact on wine grape production include:

- Smoke effect in grapes and wine from planned and unplanned fires
- Off-target spray drift damage
- Eucalyptus characteristics in wine from adjoining blue gum plantations
- Pest and disease risks from neglected vineyards.

Properties identified as sensitive sites are defined on a map that is accessible at agric.wa.gov.au/PC_94554.html?s=1295170843.

If you wish to register interest to include your property email sensitivesites@agric.wa.gov.au or phone +61 (0)8 9368 3333.

**Formalising end of harvest dates**

In order to reduce potential conflicts between smoke events and wine grape production, many strategies can be employed. Producers can communicate key vine growth stages regularly to forest management agencies and local shires, particularly ripening timing, to reduce potential conflicts.

Ideally, central communication points could be established in each region to disseminate information, where both formal and informal communication can be employed. These strategies would be individual to each region and could include:

- Regional wine producing groups to register their interest in communicating end of harvest dates with local shires and forest management agencies
- Organisation of a central communication point within each agency involved
- Wine producers to provide regular (weekly) feedback on the progress and timing of harvest dates to their regional association
- Central communication points to collect end of harvest timing from grape producers and communicate these to forest management agencies and local shires
- Central communication point to provide regular feedback and communication between forest management agencies, local shires and wine grape producers.
If a smoke event has occurred

Sampling, sending and testing of grapes

Following a smoke event, one option is to have samples tested for the presence of the smoke-related marker compounds such as guaiacol, 4-methylguaiacol, cresols and syringols.

Samples can include grape berries, grape juice, leaves and wine. Testing of grapes and juice can indicate whether the fruit has been exposed to smoke. Low levels of these compounds can be naturally present in fruit, with these levels elevated in smoke-exposed fruit.

Guaiacol and 4-methylguaiacol detection in fruit cannot be used as a determinant of the smoke-effect intensity in the final wine as this is influenced by fruit handling and processing. If you are concerned that grapes may have been affected by smoke, sampling is best done as close to harvest as possible. Testing may be ineffective on grapes sampled earlier.

Testing laboratories may interpret test results however a ‘bench-top’ or ‘small-lot’ fermentation of grapes prior to harvest is suggested to indicate smoke-effect intensity in the final wines. Research is ongoing to determine more effective analysis of grapes for the presence of smoke-related characters.

When taking samples, collection of fruit and vine material should be done early in the day prior to high temperatures and vine stress. Samples should be taken across the entire vineyard area and be collected randomly. Samples should be kept cool, and frozen if to be posted interstate.

Plant Health Certificates to facilitate quarantine requirements for movement of grapevine material interstate are often required and can be obtained from the relevant State Departments of Agriculture/Primary Industry. For instance, a Plant Health Certificate is required for movement of plant material from WA to eastern Australia and can be obtained from Quarantine WA by phoning +61 (0)8 9334 1800.

A number of laboratories offer testing for the presence of smoke-related compounds in grapevine samples. Many are in eastern Australia and include The Australian Wine Research Institute, +61 (0)8 8303 6600 and Vintessential Laboratories, 1300 652 342.

Additional laboratories may analyse smoke-related compounds and these services vary in location, cost and type. In cases of extreme smoke exposure of an entire region, a central collection point is often organised by state governments to move material for testing interstate.

Techniques to reduce smoke effect

After smoke exposure of field-grown grapevines, a number of techniques can be employed in both the vineyard and winery to reduce the concentration of smoke-related aromas, flavours and compounds in the final wine. Many are detailed in Table 1 and are more effective when used in combination rather than alone.
Table 1 Techniques to reduce smoke-related aromas, flavours and compounds during handling and processing grapes and wine.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand harvest fruit</td>
<td>Minimise breaking or rupturing of skins as long as possible(^1,2)</td>
</tr>
<tr>
<td>Exclude leaf material</td>
<td>Leaf material can contribute smoke-related characteristics when in contact with fruit and juice(^1,2)</td>
</tr>
<tr>
<td>Wash grapevines</td>
<td>Canopy leaf plucking followed by high-pressure cold water wash in the vineyard can remove ash(^7), however washing the entire canopy (including leaves) can accentuate smoke compounds in fruit(^8)</td>
</tr>
<tr>
<td>Maintain structure of harvested fruit</td>
<td>Fruit maceration and skin contact with juice can lead to higher concentrations of smoke-related compounds(^2)</td>
</tr>
<tr>
<td>Keep fruit cool</td>
<td>Fruit processed at 10°C had less extraction of smoke-related compounds than fruit processed at 25°C(^1,2)</td>
</tr>
<tr>
<td>Whole bunch press</td>
<td>This has been shown to reduce extraction of smoke-derived compounds particularly in whites(^1,3)</td>
</tr>
<tr>
<td>Separate press fractions</td>
<td>Smoke characters could be minimised in the first 400 L/t when combined with fruit cooling. Free-run juice can contain fewer smoke characters(^1,2,3)</td>
</tr>
<tr>
<td>Conduct fining trials before fermentation</td>
<td>Carbon, PVPP and isinglass have shown variable effectiveness in reducing smoke characteristics but are not selective. Fermentation management requires further consideration after fining(^1,2,3)</td>
</tr>
<tr>
<td>Consider yeast selection</td>
<td>Some yeast strains can alter smoke-related aromas, flavours and chemical composition of wine(^4)</td>
</tr>
<tr>
<td>Minimise fermentation time on skins</td>
<td>Fermentation that reduces skin contact time can reduce smoke aromas and flavours(^1,4,5)</td>
</tr>
<tr>
<td>Consider addition of oak chips and tannin</td>
<td>Oak chips can reduce intensity of smoke characteristics through increased wine complexity(^4)</td>
</tr>
<tr>
<td>Reverse osmosis of wine</td>
<td>Reverse osmosis can be effective in smoke reduction, however taint was found to return in the wine over time(^6)</td>
</tr>
<tr>
<td>Market wine for quick sale</td>
<td>Smoke-related characteristics can evolve in bottle as wine ages(^1,3,6)</td>
</tr>
</tbody>
</table>

Management of fire-damaged grapevines

During a fire, grapevines may be physically damaged by flames and/or by radiant heat from the fire. Often both the physical damage (Figure 7) and radiant heat damage (Figure 8) may appear similar and range from slight scorching of leaves to complete destruction of the vine.

Fire may damage all grapevine structures and result in injury or death of leaves, leaf petioles, buds on canes and shoots (including latent buds), flowering and fruit production organelles and the vascular system. Depending on the degree of damage, vines may recover to full fruit production or be irrevocably damaged and die.

At any given vineyard site, fire damage is often inconsistent and highly variable. Weather conditions, fire ferocity and the growth stage can all contribute to the degree of vine damage. A limited number of investigations of grapevines following fire have focused on assessing the immediate damage and applying pruning treatments. Useful techniques for assessment of grapevines after fire damage include:

- **Visual vine assessment**: To be conducted immediately after the fire and include assessing damage that may be ‘nil’ (no visible damage), ‘low’ (such as minor leaf scorch), ‘medium’ (damage to leaves, inflorescence/fruit) or ‘high’ (severe scorching and damage to all plant parts from contact with flames). Visual assessment should

Figure 7 Physical fire damage to Chardonnay vines.

Figure 8 Radiant heat damage to grapevines.
be based on individual varieties and record the location of vine damage within a block.

- **Cambium assessment**: A small knife incision in the trunk can be made to investigate the colour of the cambium tissue. Healthy tissue is moist and green, damaged tissue is dry and pale, while dead tissue is dry and brown (Whiting 2011).

- **Trunk staining**: This was investigated by Scarlett et al. (2011) where transect sections of trunk are cut and stained with methylene blue. If the segment is bright blue then the tissue is ‘viable’, if the trunk segment is a dirty blue or brown then the tissue is ‘unviable’. This method is destructive to the vines, however provides an immediate indication of the fire’s effect.

- **Bud dissection**: Can provide indication of viability and potential fruitfulness of buds within cane material. With a microscope, dissection of buds indicates whether they are alive (green) or dead (brown/black). Dissection is best conducted prior to winter pruning in order to provide information on the optimal number of buds to retain on the vine and their position within the canopy.

After comprehensive assessment of grapevines after fire damage, a number of management techniques can be employed to aid recovery. Techniques depend on the severity of damage that includes:

- **No damage**: Continue vine management as usual, paying attention to grapevine health, and apply additional irrigation to vines that show heat stress symptoms from the fire.

- **Low damage**: Continue vine management as usual, applying additional irrigation after the fire, and consider a pruning strategy to investigate (bud dissection) and retain viable buds during vine dormancy.

- **Medium damage**: Apply irrigation as soon as possible after fire. Monitor vines for stress and further signs of decline, and investigate health status of cambium material in trunks. Investigate bud fruitfulness prior to dormant pruning as additional buds may need to be retained to encourage growth and fruitfulness. Vine fruitfulness may be impacted in the following season and additional training of replacement vine shoots, arising from the crown and cordon, may be required.

- **High damage**: Likelihood of survival is low. Vines should be irrigated to encourage recovery, however destructive methods of survival assessment (trunk staining) would provide an immediate indication of viability. Grapevines may be minimally pruned to encourage shoot growth in viable buds and further assessed for survival in the following season. Replanting or grafting of unproductive vines may be required.

Applying irrigation is a common treatment, however may be difficult if irrigation lines have been damaged from the fire.
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