Impact of Smoke Exposure on Wine

Photo: Alexander Levin, © Oregon State University

Smoke from a local wildfire rises over a vineyard. Compounds in smoke can be transferred to grapes.

James Osborne and Elizabeth Tomasino

An increase in the frequency of wildfires in California, Oregon and Washington in recent years has exposed wine grapes in some areas to high levels of smoke. Smoke from wildfires contains a number of different volatile phenol compounds that can be transferred to grapes and potentially released during wine making. When present at certain concentrations, these volatile phenol compounds can impart a "smoky," "ashtray" or "campfire" flavor that consumers may find objectionable.

Unfortunately, our understanding of the effect of smoke exposure on wine is limited, making it challenging to develop strategies to prevent exposure or mitigate its effects. Here is a summary of what we know now, and a list of current best practices that can help preserve wine quality.

Volatile compounds and wine quality

Wildfire smoke contains hundreds of different volatile compounds. When grapevines are exposed to smoke, many of these compounds can accumulate

James Osborne, enology Extension specialist and associate professor, and Elizabeth Tomasino, associate professor, both of the Department of Food Science and Technology, Oregon State University.

Oregon State University

EM 9253
September 2019

in the grape berries. The volatile compounds are transported into the grapevine primarily through the waxy cuticle of the grape berry and through the leaves.

Of all of the compounds present in smoke, the volatile phenols guaiacol, 4-methylguaiacol, 4-ethylguaiacol, 4-ethylphenol, eugeneol, o-cresol, p-cresol, furfural and syringol are thought to have the largest impact on wine sensory qualities.

Once absorbed into plant tissues, these compounds typically bind to sugars, forming nonvolatile glycosides. During fermentation and aging, these glycosides may break down, releasing the free volatile compounds. The glycosides can also be broken down in the mouth by enzymes in saliva, resulting in a wine that might not have a perceivable smoky smell but will have an effect in the mouth.

So, what impact do these compounds have on the sensory qualities of a wine?

Most commonly, smoke-affected wines are described with words such as "smoky," "ashtray," "tarry," "ash," "toasted," "spicy," "burnt rubber," "leather" and "phenolic." Changes in mouthfeel can also occur with an increased drying sensation in the mouth. It has also been noted that other wine-like characteristics may decrease, suggesting that smoke compounds can mask other wine characteristics.

To date, the key compound or compounds responsible for the sensory effect of smoke on wine have not been agreed upon, although much work has focused on 4-methyl guaiacol and guaiacol. These compounds are products of lignin degradation and are widely used as indicator compounds to assess the degree to which grapes and wine have been affected by smoke exposure.

Service labs test for these two compounds, but currently it is challenging to predict wine sensory impacts based on the concentration of 4-methyl guaiacol and guaiacol in grapes unless concentrations are relatively high or relatively low.

It is also unclear if 4-methyl guaiacol and guaiacol are directly responsible for the sensory changes caused by smoke exposure. A number of studies report that wines described as having high smoke impacts had nondetectable levels of these compounds or concentrations below their sensory thresholds.

A wide range of sensory thresholds for smoke volatile compounds in wine have also been reported (Table 1), making it difficult to predict at what concentration these compounds impact wine sensory qualities.

More research is needed to clarify what specific compound or compounds are directly responsible for smoke-related changes in wine sensory qualities.

Table 1. Published threshold levels for smoke compounds in wine

Compound	Detection threshold (µg/L)	
	WHITE WINE	RED WINE
Guaiacol	95[a]	75[a] 23[c]
4-Methyl guaiacol	65[a]	65[a]
4-Ethylguaiacol	70[a]	150[a] 110[b]
4-Ethyl phenol	1100a[a]	1200[a] 605[b]
m-Cresol		20[c]
p-Cresol		64[c]
o-Cresol		62[c]

a. Boidron, J.N., P. Chatonnet and M. Pons. 1988. Influence du bois sur certaines substances odorantes des vins. *Connaissance de la Vigne et du Vin*

b. Chatonnet, P., D. Dubourdieu, J. Boidron, and M. Pons. 1992. The origin of ethylphenols in wine. *Journal of the Science of Food and Agriculture*

c. Parker, M., P. Osidacz, G.A. Baldock, Y. Hayasaka, C.A. Black, K.H. Pardon and I.L. Francis. 2012. Contribution of several volatile phenols and their glycoconjugates to smoke-related sensory properties of red wine. *Journal of Agricultural and Food Chemistry*

Human perception

An additional challenge is the effect the chemical properties of a particular wine have on how volatile compounds are perceived. This is known as the matrix effect, and it can result in compounds present at the same concentration being perceived very differently in two different wines.

An example of the matrix effect would be the perception of the citrus-smelling compound limonene in water versus orange juice. In a simple matrix such as water, only 200 micrograms per liter of the compound limonene is needed for a person to smell orange or lemon. However, in a more complex matrix such as orange juice, more than 13,000 micrograms per liter would be necessary to produce the characteristic smell of oranges. This matrix effect is particularly important in wine, which is a complex mixture of volatile and nonvolatile compounds.

Many other compounds in wine can affect the perception of smoke aroma. You might be able to detect a smoke aroma in one wine but not another — even when that compound is present at the same concentration in both. This makes it challenging to provide sensory thresholds for smoke compounds, because the threshold will depend on other factors in the wine.

Photo: Denise Dewey, © Oregon State University

Smoke from a wildfire blankets a vineyard. The timing of smoke exposure during grapevine growth can affect the concentration of smoke aroma compounds.

Further complicating the issue is the natural variability between humans in their ability to perceive certain aromas and tastes. A good example of this is people's sensitivity to the cork-taint compound trichloroanisole, or TCA. The published threshold is 1 nanogram per liter of TCA, but the sensitivity range for this varies widely. Some people can perceive TCA at levels as low as 0.01 nanogram per liter, and others won't begin to detect it until levels reach 1,000 nanograms per liter.

The same perception sensitivities may exist for compounds associated with smoke impacts. Overall, these factors explain why it's too early to provide a single threshold value for smoke aroma compounds in wine. Researchers need to conduct robust and thorough sensory studies that factor in both the matrix effect and individual sensitivities before making predictions.

Timing

While we don't know what exact compound or combination of compounds causes smoke characteristics in wine, reducing the overall concentration of these compounds should be the primary goal. The concentration of smoke aroma compounds in grapes is affected by a number of factors:

- The length of time the grapes were exposed to smoke.
- The concentration and composition of the smoke.
- The fuel source.
- The timing of smoke exposure during grapevine growth.

Grapes are particularly sensitive to the uptake of smoke compounds between veraison and harvest. An Australian study found the most sensitive time was seven days post-veraison, with decreasing accumulation of smoke compounds closer to harvest. However, smoke exposure anytime post-veraison can result in elevated concentrations of smoke compounds in grapes.

Grapes that have not been exposed to smoke can naturally contain low levels of compounds associated with smoke exposure. Syrah, in particular, can have low levels of glycosylated guaiacol. During the fermentation process, the free volatile forms of smoke compounds increase due to the hydrolysis of glycosidically bound forms. A recent study reported that the first half of fermentation was the most hydrolytic time period in the wine-making process, likely due to yeast enzymatic activity. However, glycosidically bound smoke compounds remain in the wine post-fermentation. These compounds could affect the wine as it ages due to acid hydrolysis.

Red wines are at higher risk of exhibiting smoke-like aromas because they are fermented in contact with the grape skins. Grape skins contain a higher proportion of the glycosidically bound smoke compounds than pulp. The longer the skins remain in contact with the pulp, the higher the concentration of these compounds in wine.

Limiting skin contact — such as in the production of rosé or white wines — can lower the concentration of smoke aroma compounds. White and rosé wines can exhibit smoke-like aromas due to the presence of the smoke compounds in the pulp of the berry, but the risk is much lower than in red wines.

The smoke volatile compounds 4-methyl guaiacol and guaiacol can also be present in wines that have been barrel aged, because these compounds are formed in the barrel during toasting. In wines matured in oak, the concentration of 4- methylguaiacol can range from 1 micrograms per liter to 20 micrograms per liter, while guaiacol can range between 10 micrograms per liter and 100 micrograms per liter. This complicates interpretation of results from analysis of wines aged in barrels; 4-methyl guaiacol and guaiacol will be present even in wines made from grapes that were not exposed to smoke.

Reducing the effect

At the winery, a number of techniques can be used to reduce the extraction and expression of smoke compounds in wine. Many of these techniques are more effective in combination. While they may reduce the impact of grape smoke exposure on wines, these strategies are unlikely to eliminate the issue.

Firstly, grape lots suspected of having been exposed to smoke should be separated before being processed and fermented. Testing grape lots for 4-methyl guaiacol and guaiacol prior to harvest will help identify lots that are at greatest risk of developing smoky characteristics during wine production.

Keep material other than grapes, known as MOG, from getting processed. Leaf material can contain smoke compounds that may be extracted into the wine. Washing berries is not an effective strategy; the compounds are present in the skins and pulp, rather than on the surface of the berry.

Produce a rosé wine from smoke-exposed red grapes rather than a red wine. This process minimizes the amount of skin contact.

Other actions that can reduce the concentration of smoke compounds in white and rosé wines include:

- Minimizing berry breakage during harvest.
- Keeping fruit cool from picking to pressing.
- Whole cluster pressing.
- Separating free run juice from press fractions.

Pressing red wines early is not an effective way to reduce the concentration of smoke compounds; these compounds are extracted into the wine early to mid-fermentation.

There is a report of yeast strain impacting the perception of smoky wine characteristics, but more work needs to be done in this area to determine the role that yeast play. Consider trialing yeast strains, focusing on those that enhance fruity characteristics. These traits may help reduce the perception of smokiness. In a similar way, one study found oak chip additions enhanced the complexity of wines and reduced the perception of smoky characteristics.

Fining juice or wine with activated carbon can reduce the concentration of some smoke compounds, but this fining agent is unselective and can also remove desirable compounds. If you are considering the use of activated carbon on juice or wine, conduct fining trials to determine whether it is effective, what rate to use, and the impact on other juice or wine components.

Finally, reverse osmosis, or RO, and spinning cone treatment of wines can reduce the concentration of the free forms of smoke compounds in wine. This may only be a temporary solution, however, as RO does not remove the bound forms of these compounds. Over time, hydrolysis of bound forms can result in a reappearance of the smoky characteristics.

Development of these technologies is ongoing, with the goal of removing bound as well as free smoke compounds.

Key points

- Exposure of wine grapes to smoke can result in a number of volatile phenol compounds accumulating in the grape berry.
- In grapes, most smoke volatile phenol compounds are glycosidically bound and can be released during fermentation and aging of the wine.
- Guaiacol and 4-methylguaiacol can be used to determine whether grapes have been exposed to smoke. But these compounds are not well correlated with the sensory perception of smoky characteristics in wine. Low levels of guaiacol and 4-methylguaiacol can also be present naturally in some grapes such as Syrah and in barrel-aged wines.
- We don't yet know what exact compound or combination of compounds causes wine smoky sensory characteristics, but guaiacol, 4-methylguaiacol, 4-ethylguaiacol, 4-ethylphenol, eugeneol, o-cresol, p-cresol, furfural and syringol are suspected to contribute.
- Determining sensory thresholds for individual smoke aroma compounds in wine is difficult due to the influence of the wine matrix in which the compound is present.
- Concentration of smoke aroma compounds in grapes is affected by length of smoke exposure, proximity to fire, concentration and composition of the smoke, fuel source, and timing of exposure.
- Concentration of smoke aroma compounds in wine is affected primarily by their concentrations in the grape, and skin contact during fermentation.
- Current best practices to reduce risk of smoke characteristics in wine include identifying and separating grape lots that are at risk of developing smoky wine characteristics, preventing material other than grapes from getting into the fermenter, minimizing skin contact early in the process, whole cluster pressing whites, using oak or oak chips to reduce the perception of smoky wine characteristics, and using yeast strains that may enhance fruity characteristics.
- Reverse osmosis and spinning cone treatment of wine can reduce the concentration of the free forms of the smoke aroma compounds, but smoky characteristics may reappear over time.

References

Boidron, J.N., P. Chatonnet and M. Pons. 1988. Influence du bois sur certaines substances odorantes des vins. *Connaissance de la Vigne et du Vin* 22:275–294.

Caffrey, A., L. Lerno, A. Rumbaugh, R. Girardello, J. Zweigenbaum, A. Oberholster and S.E. Ebler. 2019. Changes in smoke-taint volatile-phenol glycosides in wildfire smoke-exposed Cabernet sauvignon grapes throughout winemaking. *American Journal of Enology and Viticulture*, in press.

Chatonnet, P., D. Dubourdieu, J. Boidron and M. Pons. 1992. The origin of ethylphenols in wine. *Journal of the Science of Food and Agriculture* 60:165-178.

De Vries, C.J., A. Buica and J.B.M. McKay. 2016. The impact of smoke from vegetation fires on sensory characteristics of Cabernet sauvignon wines made from affected grapes. *South African Journal of Enology and Viticulture* 37:22-30.

Fudge, A.L., M. Schiettecatte, R. Ristic, Y. Hayasaka and K.L. Wilkinson. 2012. Amelioration of smoke taint in wine by treatment with commercial fining agents. *Australian Journal of Grape and Wine Research* 18:303-307.

Hayasaka, Y., K.A. Dungey, G.A. Baldock, K.R. Kennison and K.L. Wilkinson. 2010. Identification of a ß-D-glucopyranoside precursor to guaiacol in grape juice following grapevine exposure to smoke. *Analytica Chimica Acta* 660:143-148.

Kennison, K.R., K.L. Wilkinson, A.P. Pollnitz, H.G Williams and M.R. Gibberd. 2009. Effect of timing and duration of grapevine exposure to smoke on the composition and sensory properties of wine. *Australian Journal of Grape and Wine Research* 15:228-237.

Kennison, K.R., K.L. Wilkinson, H.G. Williams, J.H. Smith and M.R. Gibberd, M.R. 2007. Smoke-derived taint in wine: Effect of postharvest smoke exposure of grapes on the chemical composition and sensory characteristics of wine. *Journal of Agricultural and Food Chemistry* 55:10897-10901.

Krstic, M.P. D.L. Johnson and M.J. Herderich. 2015. Review of smoke taint in wine: smoke-derived volatile phenols and their glycosidic metabolites in grapes and vines as biomarkers for smoke exposure and their role in the sensory perception of smoke taint. *Australian Journal of Grape and Wine Research* 21:537-533.

Parker, M., P. Osidacz, G.A. Baldock, Y. Hayasaka, C.A. Black, K.H. Pardon and I.L. Francis. 2012. Contribution of several volatile phenols and their glycoconjugates to smoke-related sensory properties of red wine. *Journal of Agricultural and Food Chemistry* 60:2629-2637.

Pollnitz, A.P., K.H. Pardon, M. Sykes and M. Sefton. 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 isotopes dilution analyses. *Journal of Agricultural and Food Chemistry* 52:3244-3252.

Ristic, R., P. Osidacz, K.A. Pinchbeck, Y. Hayasaka, A.L. Fudge and K.N. Wilkinson. 2011. The effect of winemaking techniques on the intensity of smoke taint in wine. *Australian Journal of Grape and Wine Research* 17:S29-S40.

Singh, D.P., H.H. Chong, K.M. Pitt, M. Cleary, N.K. Dokoozlian and M.O. Downey. 2011. Guaiacol and 4-methylguaiacol accumulate in wines made from smoke-affected fruit because of hydrolysis of their conjugates. *Australian Journal of Grape and Wine Research* 17:S13-21.

Wirth, J., W.F. Guo, R. Baumes and Z. Gunata. 2001. Volatile compounds released by enzymatic hydrolysis of glyconjugates of leaves and grape berries from *Vitis vinifera* Muscat of Alexandria and Shiraz cultivars. *Journal of Agricultural and Food Chemistry* 49:2917-2923.

Revised September 2019