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# The Impact of Wildfire Smoke on Vineyards and Wines

Chemical Effects, Sensory Damage, and Mitigation Strategies

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Wildfires are becoming more frequent and severe around the world, increasingly threatening vineyards not only through the risk of direct fire damage but also via exposure to smoke. In recent years, wine regions across Australia, California, Oregon, Chile, and Southern Europe have reported significant crop losses due to "smoke taint" — a defect in wine characterized by undesirable smoky or ashy aromas caused by volatile compounds in smoke infiltrating grape skins. The 2020 wildfire season in California, for example, saw over 4 million acres burned. Though few vineyards were destroyed by flames, smoke damage led to losses estimated at more than \$600 million in unharvested grapes and tainted wine. In Australia, the "Black Summer" fires of 2019-

2020 caused an 80–90% harvest loss in regions like Hunter Valley, where wineries chose not to vinify contaminated fruit to avoid damaging their brand reputation.

Smoke taint occurs when smoke from burning vegetation — particularly wood — carries volatile phenols that settle on grape surfaces. These compounds penetrate grape skins and bind with sugars to form odorless glycosides, which later release volatile phenols during fermentation, bottle aging, or even while tasting, as enzymes break the sugar-phenol bond. Key volatile phenols associated with smoke taint include guaiacol, 4-methylguaiacol, and cresols, all of which produce ashy, medicinal, and burnt flavors. These characteristics clash with the expected sensory profile of wine and are generally considered irredeemable flaws.

The phenomenon has become a recurring concern in viticulture due to climate change, which has brought drier, hotter summers that increase wildfire risk. Importantly, vineyards do not need to be close to active fires to be impacted. Smoke can travel for miles and remain suspended over growing areas for days, creating long-term exposure. In Spain, recent fires in Galicia, Castilla y León, and Catalonia have raised awareness about this issue, though consumer understanding remains limited. Growers and winemakers now face the difficult task of assessing and responding to possible smoke contamination before, during, and after harvest.

Chemical analysis shows that once volatile phenols enter the grape skin, they are converted by the plant into glycosidic forms that are not detectable by smell. However, these bound compounds are a sensory "time bomb." During fermentation, wine's natural acidity and yeast activity can break the glycosidic bonds, releasing the aromatic compounds into the wine. Even after bottling, storage time and enzymatic activity in the mouth during tasting can cause a resurgence of smoke-related aromas and flavors. This delayed release explains why some wines appear clean at first but develop smoke taint later.

In recent years, researchers have also identified thiophenols — sulfur-containing compounds — as additional contributors to smoke taint. These were discovered by Oregon State University scientists in 2023. Not previously considered in standard analytical tests, thiophenols add ashy and burnt-rubber notes that correlate with smoke

exposure, especially in cases where guaiacol and related phenols fail to explain the full extent of sensory faults. This discovery has sparked efforts to develop broader diagnostic panels for smoke taint that include new classes of compounds.

Smoke exposure can also disrupt vine physiology. Thick smoke reduces solar radiation, limiting photosynthesis and delaying berry maturation. Ash deposits on leaves may block stomata, further reducing gas exchange. Ozone and other oxidative gases in smoke can trigger stress responses in the vine, lowering fruit quality. While these physiological effects are temporary, they can reduce yield or shift harvest timing. Fortunately, there is no evidence that smoke damage carries over into future vintages. Once the smoke clears and leaves fall, the next season's crop is unaffected.

In terms of sensory impact, smoke taint dramatically reduces wine quality. Common descriptors include ashtray, burnt rubber, medicinal, and tar. In reds, bitterness and an ashy aftertaste are frequent. The result is often a wine that consumers reject, leading to significant commercial losses. Wineries may choose to declassify such wines, sell them for distillation, or in extreme cases, dump them entirely to protect brand equity. Some varietals and wine styles are more vulnerable than others. For example, white wines and light reds made without oak exposure are more prone to show the defect, while full-bodied reds aged in toasted barrels may partially mask smoke notes. Nonetheless, sensory evaluation panels confirm that moderate to high levels of smoke-related compounds are strongly associated with consumer rejection and market devaluation.

Risk factors in the vineyard include the grape's stage of development, proximity to the fire, the density and duration of smoke exposure, and grape variety. The highest risk occurs from veraison to harvest, as mature berries have more permeable skins and higher sugar content to bind volatile phenols into glycosides. Though earlier beliefs held that only late-season exposure was dangerous, newer research from Australia shows that even green fruit can absorb and retain smoke compounds that later impact wine. Table grape stage (E-L 31 onward) is considered the beginning of significant risk. Grape variety also plays a role; some, like Pinot Noir, appear more susceptible than thicker-skinned varieties such as Cabernet Sauvignon, though no variety is fully immune.

Smoke composition also matters. Fresh, dense smoke from nearby fires carries higher levels of reactive phenols than older, dispersed smoke. Weather conditions — especially inversions that trap smoke in valleys — can prolong exposure. Measurements of visibility and airborne particulates (e.g., PM2.5) help estimate exposure levels, but no standard model yet correlates these values precisely with wine impact. Winemakers rely on lab analysis of grapes and test fermentations to guide decisions on whether to harvest, vinify, or abandon a lot.

Economic losses from smoke taint are significant. In California's 2020 fires, insurance claims and contract rejections skyrocketed. Many growers were unable to find labs to analyze their fruit in time due to high demand. Wineries lost not only revenue from the current harvest but also long-term brand equity. In Australia, the 2020 vintage was effectively skipped in parts of Hunter Valley and Adelaide Hills. Similar patterns emerged in Oregon and Chile, where recurring fire seasons have made smoke a seasonal threat. Even in regions without active fires, long-distance smoke can impose indirect damage, as seen when Mediterranean vineyards faced unexpected exposure during the hot summers of 2021 and 2022.

For viticulturists and winemakers, prevention and mitigation are now critical parts of seasonal planning. In the vineyard, key preventive strategies include creating firebreaks by clearing combustible vegetation around vineyard blocks, monitoring smoke levels with satellite and air quality tools, and establishing harvest contingency plans. In some cases, early harvesting may be preferable to risking long exposure, though underripe grapes can compromise wine quality. Spraying water to remove ash or attempting to cover vines with protective barriers have not proven consistently effective. Researchers continue to investigate whether substances like kaolin or biodegradable films can reduce phenol absorption, but field applications remain limited.

In the winery, winemakers can use several mitigation strategies if grapes have been exposed. First, careful hand-harvesting and exclusion of leaves or stems prevent additional phenol extraction. Second, rapid processing at cold temperatures limits the dissolution of smoke compounds. Pressing whole clusters, especially in whites and rosés, minimizes contact between juice and skins. Fractionating the juice to exclude heavy press fractions with higher phenol content is also advised.

Once in fermentation, applying activated carbon can help adsorb volatile phenols, though results vary. Carbon treatments are more effective in whites than in reds and must be tested on small batches to avoid stripping wine of desirable aromas. Chips of toasted oak or added tannins may help mask the defect by enhancing complexity, but they do not remove the compounds. Blending smoke-affected wine with clean wine can dilute the taint, provided the initial impact is moderate. For more severe cases, options like reverse osmosis or nanofiltration have been tested, but they are expensive and may not work reliably. Some winemakers choose to distill the wine for brandy or alcohol, as most smoke-related compounds do not carry over in the distillation process.

Finally, bottling quickly and releasing affected wines early can reduce the risk of late-onset smoke expression. Wines aged too long may release more volatile phenols from glycosides over time. Producers are advised to monitor bottled wines regularly and consider selling smoke-tainted lots under a different label or for non-premium uses to preserve their brand reputation.

As smoke taint becomes a more frequent challenge, research institutions like the Australian Wine Research Institute (AWRI), UC Davis, and Oregon State University are developing new diagnostic tools and mitigation protocols. Some initiatives aim to develop grape varieties with lower phenol uptake or introduce sensor technologies that detect smoke exposure in real time. Governments and industry groups are beginning to offer funding for resilience programs, and new risk insurance models are emerging to cover smoke exposure, not just fire damage.

For now, the wine industry must continue to adapt. Smoke taint has shifted from a rare and anecdotal issue to a consistent seasonal threat in some wine regions. As wildfires continue to rise in frequency and intensity due to climate change, smoke exposure will remain a critical concern for vineyards across the globe. Wineries that invest in monitoring, preventive management, rapid response, and enological mitigation stand the best chance of maintaining product quality and surviving this emerging environmental challenge.