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What is the expected impact of climate change on wine aroma compounds and their precursors in grape?

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Abstract

The intrinsic quality of a wine is strongly linked with its volatile compound composition involved in the complexity of wine's subtle flavor nuances. Those reminiscent of green pepper, herbaceous, blackcurrant, blackberry, figs or prunes are strongly linked with the maturity of the grapes. Nowadays it is well accepted that macroscopic effects of climate change modify the environmental conditions of grape growing at local scale in all the vineyards across the world. The expected effects on grape and wine production can be positive when they increase the maturity of the grapes, but when the conditions are too warm and too dry they induce opposite effects producing grapes and wines with a lower intrinsic quality. These effects were perceived in young wines but also in older wines kept several years in bottle.

In this article, we provide some examples of effects of climate change and growing conditions on grapevine and wine quality expressed as flavors and antioxidant composition. We also report some results associated with the incidence of grape growing conditions on white and red wine aging potential and on the composition of old wines.

Finally, we discuss the opportunities for vine growers and winemakers to manage the quality of their grapes and wines in this climate change context.

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Introduction

The aromatic component of wine is a decisive criterion of its sensory quality. This quality is based on the perception of aromatic nuances of varying intensity and complexity, often associated with the expression of a single grape variety or a mixture of grape varieties that is modulated by the soil and can thus contribute to the recognition of a typical or sensory identity (another word for typicality). The aromatic component is due to the presence in wine of many volatile compounds from families that contribute to the perception of aroma thanks to their vegetal, floral or fruity notes, or through complex sensory phenomena involving a mixture of the volatile compounds. Moreover, the preservation of this typical aromatic component during wine aging, possibly enriched by a «reducing» aging bouquet over time, is the signature and specificity of wines made from grapes that have ripened in temperate climates.

The prospects of climate change over the next century raise questions about the potential impact of a global rise in average temperature on the aromatic potential of grapes and wine quality. This paper presents current knowledge about the impact of various eco-physiological parameters of the vine on the aromatic compounds of wines; the consequences likely to be observed for wines in the context of climate change are also discussed.

1. The aromatic component of wines

The aromatic nuances perceived when wines are tasted result from a combination of volatile compounds, at least fifty, in the headspace above a glass of wine. These compounds act as stimuli at the olfactory epithelium level before being converted into nerve impulses and becoming sensations in the mind (Shepherd, 2006). In the last forty years, almost 1,000 volatile compounds have been identified in wine; their contents range from several hundred milligrams per liter to levels likely below ten picograms per liter. The odor thresholds of these compounds are also highly variable and are mostly found in the picogram range and up to a dozen milligrams per liter for less odorous compounds. Thus, certain trace compounds can play an important role in wine aroma, while other much more abundant compounds yet play a minor role.

A distinction has to be made between the groups of volatile compounds contributing to wine aroma. First, there are the strictly fermentative compounds produced by wine microorganisms (S. cerevisiae yeast, lactic acid bacteria) involved in the floral, fruity and milky notes of young wines, especially the major ethyl esters of fatty acids and higher alcohol acetates. Next, there are the compounds produced by the secondary metabolism of grapes present in wines such as derivatives of carotenoids [ß-damascenone (apple sauce, floral), ß-ionone (floral, violet), TDN (1,1,6-trimethyl-1,2-dihydronaphtalene; notes of kerosene), vitispirane (woody nuances, camphor)], lactones (fruity, coconut, peach and apricot) and furanones (caramel, cooked sugar). This group also includes those specifically associated with the aroma of certain varieties: for example, monoterpenes, which contribute to floral characteristics of Muscat varieties, or sesquiterpenes such as (-) rotundone, which contribute to notes of black pepper. Volatile thiols (sulfur-containing compounds with grapefruit boxwood notes or passion fruit) are involved in the typical aroma of Sauvignon blanc wine and many white and red varieties like Colombard, Chenin, Gewürztraminer, Semillon, Petit Manseng, Arvine, Merlot, and Cabernet-Sauvignon. Certain compounds of this family can contribute to the toasted notes associated with wine aging bouquet. A member of the methoxypyrazine family, 2-methoxy-3-isobutylpyrazine (IBMP), reminiscent of green pepper and pea pod, contributes also to the flavor of grapes and wines. Most of the compounds exist as precursors in fruits: volatile hydroxylated forms (e.g. polyols with little odor) or glycosides for monoterpenes and norisoprenoid C13 derivatives, S-conjugated forms for thiol precursors, Maillard reaction products (furanones) and lipid derivatives (lactones). Except for methoxypyrazines, their concentrations increase in grapes during ripening depending on the prevalent climatic conditions (temperature, light), the availability of water and organic/inorganic compounds, and the physiological characteristics of the vines. The formation of these compounds is associated with chemical and enzymatic reactions which depend on the physiological state of the berry and the eco-physiological conditions of the vine. Knowledge of these reactions is still fragmentary (Schwab and Wüst, 2015).

2. **Temperature/light relationship and the aromatic component of wines**

The primary consequence of an increase in average temperature during grape ripening is that the herbaceous vegetal notes of wines are limited. These notes are linked in part to the methoxypyrazines, especially IBMP. Like other pyrazines of the same family, IBMP evokes hints of unripe green bell pepper and pea pod, and it is a varietal trait of wines vinified from unripe grapes from the Carmenet family, in particular Cabernet franc, Fer Servadou, Cabernet-Sauvignon, Carmenère, Merlot and Sauvignon blanc. The work of Allen and Lacey (1993) and Falcao *et al.* (2007) showed that IBMP levels in wines are lower when the temperature is higher during the growing season. This phenomenon is amplified by exposure of the grapes to light and the removal of the basal leaves that contain IBMP during the nouaison-grape closure stages of the vine (Ryona *et al.,* 2008; Gregan *et al.,* 2012.). Conversely, the IBMP content is higher in grapes from vigorous vines with a high vegetation density (Allen and Lacey, 1993). However, as is sometimes observed, water stress, which can contribute to stuck ripening, may lead to grapes with IBMP concentrations that negatively impact the aromatic component of wines.

On the other hand, the concentrations of carotenoid derivatives, especially C13-norisoprenoid derivatives, are higher whenever grapes are more exposed to light and high temperature. This leads to a greater breakdown of grape carotenoids between veraison and maturity. In particular, TDN, a compound involved in the kerosene notes of Riesling wines and synthesized during bottle aging from non-volatile precursors, is more abundant in wines elaborated from grapes ripened in warmer climates (Marais *et al.,* 1992b). Nevertheless, this is not always the case for other C13-norisoprenoid derivatives such as ß-damascenone, contributing to fruity notes in wines, given the complexity of the reaction mechanisms in the berries leading to the formation of this compound from precursor forms. In fact, two authors reported lower concentrations of ß-damascenone in white varieties in conditions of exposure to light and higher temperature (Marais *et al.,* 1992a; Kwasniewski *et al.,* 2010). In general, most studies on the aromas and aroma precursors of fruity and floral nuances (monoterpenes) underline the benefit of higher temperatures during ripening but also their negative effect on fruit metabolism whenever they are excessively high.

Recently, a study was carried out in Bordeaux on the aromatic component of red wine from overripe black grapes (notes of jammy fruit, prune, dried fig). It was demonstrated that these wines have a greater abundance of chemical compounds belonging to the furanones (candy, caramel flavors) and lactones and showed the contribution of these compounds to these aromatic notes (Allamy *et al.,* 2015; Allamy *et al.,* 2016). Moreover, the analysis of different vintages from a Pomerol estate containing a high percentage of Merlot showed higher concentrations of massoia lactone (dried figs and coconut flavors) and γ-nonalactone (coco, cooked peaches) during years with higher average temperatures, such as 2003 vintage (Figure 1). For this vintage, concentrations reached the detection threshold of these compounds, with 10 µg/L and 27 µg/L for massoia lactone and γ-nonalactone, respectively. Presumably, increased perception of overripe fruity notes, as occurs in very hot vintages, is one of the consequences to be expected from global warming.

It is interesting to compare these values to those found in “traditional” warm climate, where vines were irrigated, such as in Napa Valley (California). As depicted in Figure 2, average values of the last eight vintages were close to the γ-nonalactone concentration of 2003 vintage in Bordeaux. In these red wines, lowest concentrations were found in 2011 vintage; a cool and wet vintage in Napa.

3. Vine water status: an additional parameter influencing the aromatic potential of grapes

One of the indirect consequences of global warming is a change in the water status of the vine, which will obviously impact the physiology of the plant (van Leeuwen and Darriet, 2016) and the biosynthesis of aromatic compounds and their precursors. Regarding the volatile thiol precursors, a link has been established between the presence of moderate vine water deficit and the accumulation of S-conjugate precursors, water deficit leading to shoot growth cessation and the accumulation of secondary metabolites in the berry. Conversely, severe water deficit affects the ripening of the grapes and leads to a lowering of volatile thiol precursor levels in grapes (Peyrot des Gachons *et al.,* 2005).

The work of Armin Schüttler (2012), conducted at the Geisenheim Institute on the Riesling variety for several years and at the same site, investigated the impact of vine water status and various thinning practices on several chemical families (monoterpenes, volatile thiols, norisoprenoid C13 derivatives). The main finding was that the effects of water deficit on the aromas and flavor precursors in grape vary according to the family of aromatic compounds considered

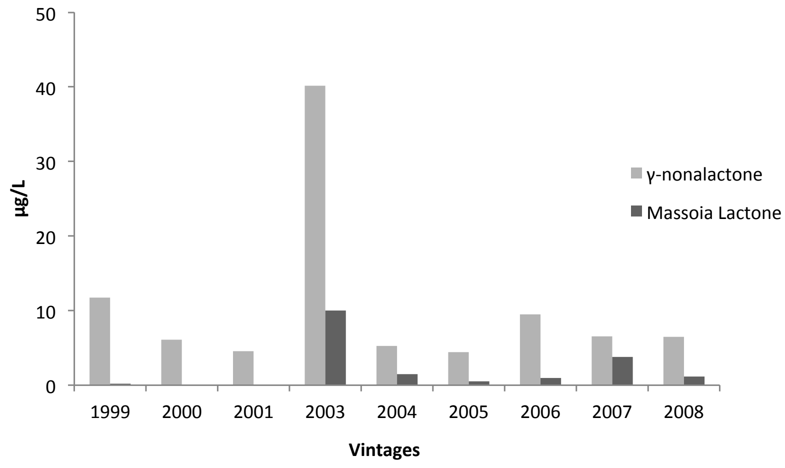

Figure 1 - Content of massoia lactone and γ-nonalactone in Pomerol red wines from the same estate (Bordeaux) between 1999 and 2008 (Pons *et al.,* 2011, and Personal results).

Analyses were performed in 2011.

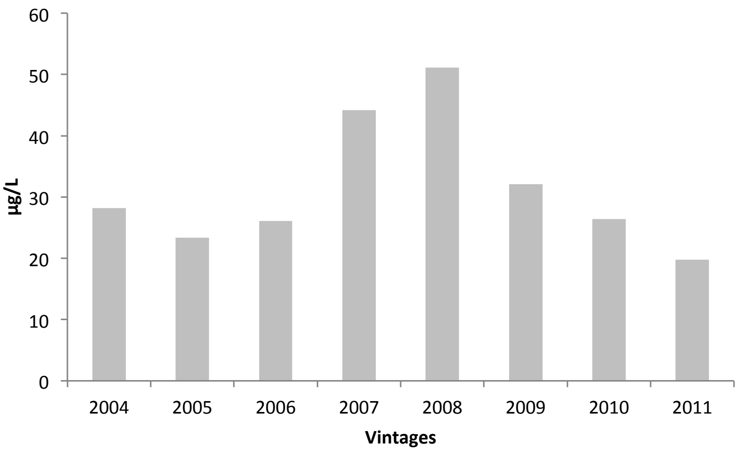

Figure 2 - Content of γ-nonalactone in red wines from the same estate (Napa Valley) between 2004 and 2011.
Analyses were performed in 2013.

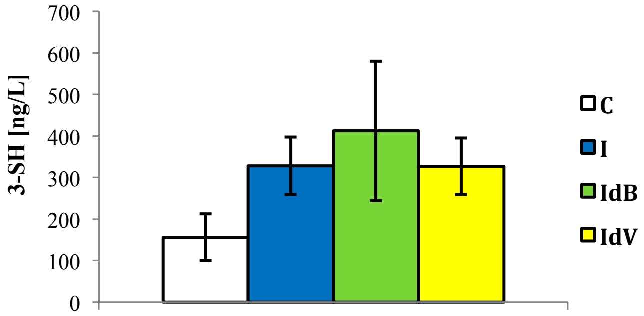

Figure 3 - 3-sulfanylhexan-1-ol (varietal thiol) content in wine in 2009 vintage as a function of water deficit and cluster exposure. (C) non-irrigated modality with water deficit that was strong in 2009; (I) irrigated modality with water deficit that was moderate in 2009; (IdB) modality with irrigation and early thinning; and (IdV) modality with irrigation and thinning at veraison.
The water deficit modalities are identical to modalities (I), (IdB) (IdV) (according to Schüttler *et al.,* 2011, 2013).

(Schüttler *et al.,* 2011, 2013). For example, as depicted in Figure 3, 3-sulfanylhexanol (3SH) levels in wines analyzed in 2009 were not significantly changed by thinning and improved cluster exposure, whether early or late, while the volatile thiol content was much lower when water deficit was high, as Peyrot des Gachons *et al.* (2005) had previously observed. For this reason, a water regime that is too restrictive requires adaptation of the plant material.

Regarding (-) rotundone, a compound associated with notes of black pepper in Syrah wines and playing a role in the aroma of the Duras variety, the work of Scarlett *et al.* (2014) also showed a lower content of this compound in wines from vines having faced greater water deficit.

Thus, the cumulative effects of temperature and more restrictive water status cause a change in the metabolism of fruit that can sometimes lead to stuck ripening. For this reason, the effects of water deficit on the biosynthesis of the aromatic potential of grapes could be more pronounced in conditions where nighttime temperatures remain high. It is therefore important to investigate more precisely in the years to come the direct consequences and the extent of these expected changes, not only on the aromatic potential of grapes but also on the quality and sensory perception of wines.

4. Wine aging potential

The modification of the aromatic potential of grapes during ripening is also likely to influence the biosynthesis of other berry metabolites such as phenolic compounds and glutathione, which impact the aromatic component by their reactions. Thus, during dry years, Sauvignon blanc grapes are richer in flavan-3-ols (tannins) and less rich in glutathione, an important antioxidant for reducing the risk of premature aromatic aging of grapes and wines. Analysis of Sauvignon musts from the same winery showed significant differences in glutathione levels in grapes, with lower levels in hot (2003) and dry (2005) years (Pons *et al.,* 2015; Figure 4).

5. Adaptive strategies

Over the past 20 years, vine physiology has been advanced in temperate-climate vineyards because of higher

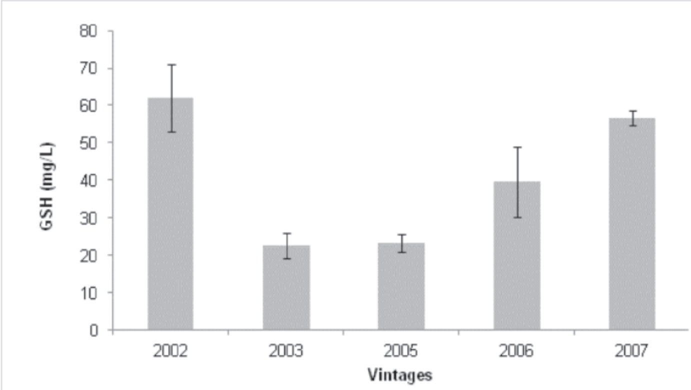

Figure 4 - Average glutathione content in must of Sauvignon blanc grapes harvested at maturity in two vineyards in the Graves region (Bordeaux) for the years 2002 to 2007 (Pons *et al.,* 2015).

temperatures and at the same time growers have increased the delay between veraison and harvest (so-called "hang-time"; van Leeuwen and Darriet, 2016). Hence, the vegetal traits related to a lack of grape maturity are now less perceived and winemakers can craft wines that express their full potential of floral and fruity notes, combined with freshness and sometimes cooked fruit. Climate change is likely to impact significantly both the organoleptic characteristics of wines and their aging potential, in particular by reducing the level of acidity in grapes and wines.

Care in choosing harvest dates and adapting trellising modes (limiting thinning, managing mineral and nitrogen nutrition, making sure that the plant's vigor is sufficient and that water deficit is not excessive) is the primary adaptive means for preserving the aromatic potential of grapes. Furthermore, promoting clonal diversity within varieties can be a starting point for adaptation. If climate change were to become very extreme, non-local later-ripening varieties could offer alternatives once their potential to reveal the diversity of terroirs in their aromatic and flavor components has been assessed. A major issue concerns changes in rainfall patterns and their potential impact on the development of pathogens. Thus, in a context of limited or significant change in climatic conditions, researchers and experimenters should now analyze the specific consequences of these multifactorial phenomena on the aromatic and flavor components of wines and their aging potential. Work in this direction is now underway at ISVV (Drappier *et al.,* 2016; Wu *et al.,* 2016).

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