# Monitoring grape ripening by linear sweep voltammetry – Part 2: Obtaining wines of Sauvignon blanc with predefined styles

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Aromatic Sauvignon blanc wines with characteristic profiles are sought after by consumers. Being able to achieve these profiles in a repeatable and predictable way is one of winemakers' objectives. The first winemaking decision, i.e. the choice of harvest date, seems to play an important role in achieving this objective.
The aim of this work was to evaluate the possibility of using voltammetry as describe in part 1 of this article to decide on a harvest date in line with an aromatic profile for Sauvignon blanc.
To achieve this, 17 plots of Sauvignon blanc from the Loire Valley (Vignerons des Côteaux Romanais, Touraine, France) were monitored during ripening using voltammetric measurements on the grapes. 4 plots were vinified in small volumes at 3 harvest dates. Wines were assessed by tasting and varietal thiols (3SH, 3SHA and 4MSP) were measured.
This work highlighted the possibility of choosing a harvest date according to the evolution of the voltammetric signal through a synthetic index (Maturox) to produce wines with different and controlled aromatic profiles. In particular, wines from harvests between 0 and 12 days after the Maturox minimum were described as “fermentative” or “veggie”, those from harvests between 12 and 19 days after the Maturox minimum as “varietal thiol” (boxwood), and those from harvests 19 days after the index minimum as “fermentative thiol” (citrus).

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During its development, the grape berry accumulates and metabolizes various compounds, including organic acids, hexoses, polyphenols and aromas. These compounds have major oenological impacts, and largely determine the profile of the wine produced. The levels of these different compounds change as the grapes mature (Yu Fang *et al*. 2006, Gambuti *et al.* 2007).

Quantifying these compounds of interest can help decide on a harvest date. Some of these compounds are easily quantifiable by professionals, notably sugar and organic acid content. Their measurement, carried out during grape ripening, helps in deciding on harvest dates. It is thus possible to predict the alcohol content or acidity of future wines.

Other compounds, however, are much more difficult to access, either because of their concentration, their form in the grape berry (*i.e.* in precursor form) or the techniques required to analyze them (Arévalo *et* *al.* 2006). Among these compounds, aromas, whether in precursor form or not, are difficult to apprehend and yet play a key role in the organoleptic characteristics of future wine (Jeffery 2013). Harvest date has a major impact on the content of certain aromatic compounds in wines (Nicolini 2020). Work on Shiraz and Cabernet-Sauvignon (Antalick *et al*. 2021 and 2023) has shown the existence of reproducible aromatic profiles using the concept of sugar loading (Deloire 2011) to assess grape maturity.

Sauvignon blanc is a grape variety which aromatic compounds have been extensively studied in recent decades (Swiegers *et al.* 2007, Tominaga *et al*. 1998, 2000a, 2000 b, 2006, Dubourdieu *et al*. 2009, Roland *et al*. 2010). Work on Sauvignon blanc at Adelaide Hills in Australia has shown the possibility of maximizing 3SH precursor content by choosing the harvest date, with precursor levels peaking during grape ripening (Capone *et al*. 2011a, 2012b).

However, thiol precursor conversion rates during alcoholic fermentation are low (<10%) (Subileau 2008). Winemaking processes have a strong impact on the revelation of precursors and on the thiol content of final wines (Leandro 2017). Is it then possible to control the harvest date of Sauvignon blanc plots with the aim of producing wines with reproducible profiles as has been established for Shiraz and Cabernet-Sauvignon?

In previous work, the use of linear sweep voltametry to determine a harvest date on Sauvignon blanc was evaluated by tasting and resulted in different wine profiles (Hastoy *et al*. 2019). It was shown that a voltammetric signal minimum existed on the grape samples during ripening, and that the date of this minimum could be used as a temporal reference during ripening, close to sugar loading stop (Part1 of this article, Pascal *et al.* 2025).

This technology was used to monitor the ripening of various Sauvignon blanc plots in Touraine. Four of them were selected and micro-vinified at different dates in relation to the minimum voltammetric signal. The organoleptic profiles of the wines obtained were characterized by a panel of experts, and their varietal thiol content analyzed. The interest of determining the minimum voltammetric signal to point out different aromatic profile windows was thus confirmed. It was also shown that the concentration of varietal thiols in wines from the 4 plots evolved over time after the voltammetric signal minimum, in a similar way for the 4 plots.

## Materials and methods

### Maturity monitoring

In 2022, 17 plots of Sauvignon blanc from the Vignerons des Côteaux Romanais winery (Loir-et-Cher, France) were monitored during grape ripening. In each plot, representative areas (vigor, yield) of 50 vines were identified, avoiding row heads and border rows. Samples of 200 berries were taken weekly in these zones on both sides of the row, from mid-veraison to harvest. Samples of 200 berries were manually pressed in a plastic bag. The resulting juice was analyzed by linear sweep voltammetry (Polyscan potentiostat, WQS, Vinventions) on a printed electrode (WQS Vinventions, carbon working electrode, Ag/AgCl reference) by applying a potential ramp from 0 to 1200 mV at a sweep speed of 10mV/s. Each Intensity – potential curve was characterized by calculating the Maturox index, a linear combination of areas under curve between 400 and 1000mV. Standard analyses were also carried out on each sample (sugar concentration by refractometry, total acidity by titration with sodium hydroxide in the presence of bromothymol blue and average berry weight)

**Winemaking**

Four plots were micro-vinified three times each. Grapes were picked up with 5 to 6 days between each harvest, making sure that winery harvest date for the whole plot was surrounded by the fractionated harvests. The grapes were harvested by hand from every third vine in the monitoring area, in order to limit the impact of any spatial heterogeneity in the area. The grapes were destemmed, crushed and pressed in an inert 30-liter hydro-press using dry ice. Press juices were sulfited at 5g/hL $SO_2$ by the addition of a solution of sulfites P10 (100g/L pure $SO_2$), enzymed and collected in 12-liter pre-inerted buckets. The musts were settled 12 to 24 h at 3.5°C. After readjusting turbidity to 150-200 NTU, they were inoculated at 20 g/hL with saccharomyces EXCELLENCE® FTH yeasts (Lamothe-Abiet). Modalities with low reducing sugar concentrations were adjusted to 190 g/L during fermentation. Di-ammonium phosphate was added at the start of fermentation to achieve an assimilable nitrogen concentration of at least 0.8 * reducing sugar concentration (mg/L). At the end of alcoholic fermentation, the wines were transferred to bag-in-box bags and kept cold at 4°C.

**Wine evaluation**

A jury of 5 expert members, trained to Sauvignon blanc wines from the Loire Valley tasting, evaluated the wines 2 months after the end of vinification according to a specific tasting grid, including the following descriptors:

- Veggie: herbal and herbaceous notes, with the exception of the boxwood aromas typical of Sauvignon Blanc.
- Fermentative: aromatic amylic notes, strawberry, pear, grenadine, English sweets...
- Varietal thiol: aromatic notes of boxwood, cat's pee, blackcurrant bud.
- Fermentative thiol: aromatic notes of citrus, grapefruit, tomato leaf, sweat
- Ripe thiols: aromatic notes of exotic fruits, mango, papaya, passion fruit, etc.
- Terpenic: aromatic notes of lychee, rose and lime blossom.

For each wine, the tasters defined the "main" aromatic class as well as any "secondary" aromatic class. When the secondary aromatic class was not defined by the taster, it was considered identical to the main class. To make the tasting notes quantitative by assigning an identical weight to each taster for each wine, the value of each descriptor for each wine was calculated using the following formula

Note-Descriptor-a = nb of majority class_descriptor-a *2 + nb of secondary class_descriptor-a

Aroma analyses (3SH, 3SHA, 4MSP) were carried out on wines after alcoholic fermentation by Nyséos in Montpellier.

Mapping was carried out in R-Studio using principal component analysis followed by hierarchical ascending classification (FactoMineR and FactoExtra libraries).

# Results and discussion

**Determination of the minimum of voltammetric signal for the 4 plots and harvest date of the plots in relation to this minimum.**

For each of the 17 plots monitored, the evolution of the Maturox index was tracked (Figure 1) and the date of minimum Maturox index was determined, as explained in part 1 of this article (Pascal *et al.* 2025). As samples are taken weekly, the date of the Maturox minimum is therefore determined plus or minus 3 days.

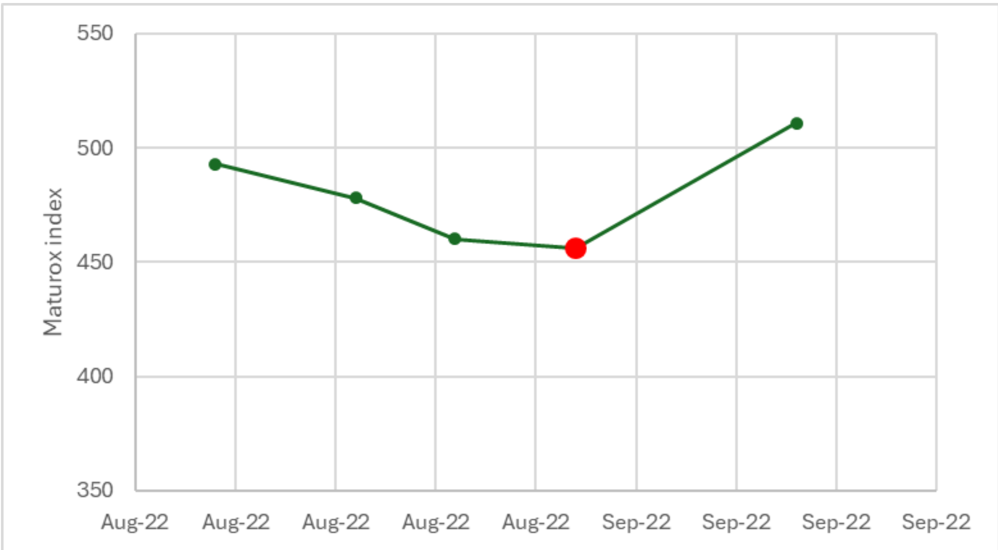



Figure 1: Evolution of the Maturox index (VCR_16). In red, identification of the index minimum (29/08/2022).

The minimum dates are spread over 11 days (Table 1) for the four microvinified plots. Harvest were achieved on 3 different calendar dates, corresponding to different deviations from the minimum index date for the given plot (Table 1), ranging from 2 to 25 days. If we consider the Maturox minimum as an indicator of the progress of sugar loading, as proposed by Hastoy *et al.* (2019) and Pascal *et al.* (2025), the microvinifications were carried out on grapes of different maturity and corresponding to "aromatic windows" (Deloire 2011) potentially leading to different wine profiles.

Table 1: Date of Maturox minimum and deviation from this minimum (in days) for each harvest date

| | Maturox minimum date | Harvest date 1: 08/31 and 09/01. Number of days after minimum Maturox of harvest 1 | Harvest date 1: 07/09. Number of days after minimum Maturox of harvest 2 | Harvest date 1: 12/09. Number of days after minimum harvest Maturox 3 |
|---|---|---|---|---|
| VCR_3 | 19/08 | 13 | 19 | 24 |
| VCR_11 | 24/08 | 7 | 14 | 19 |
| VCR_16 | 29/08 | 2 | 9 | 14 |
| VCR_17 | 18/08 | 13 | 20 | 25 |

The analysis of musts at cellar entry is presented in Table 2. Plot VCR_16 stands out from the other 3 by having much higher levels of assimilable nitrogen and lower reducing sugars. It was also picked earlier than the other 3 plots in relation to the Maturox minimum. The first harvest dates of plots VCR_11 and VCR_17 are the most acidic.

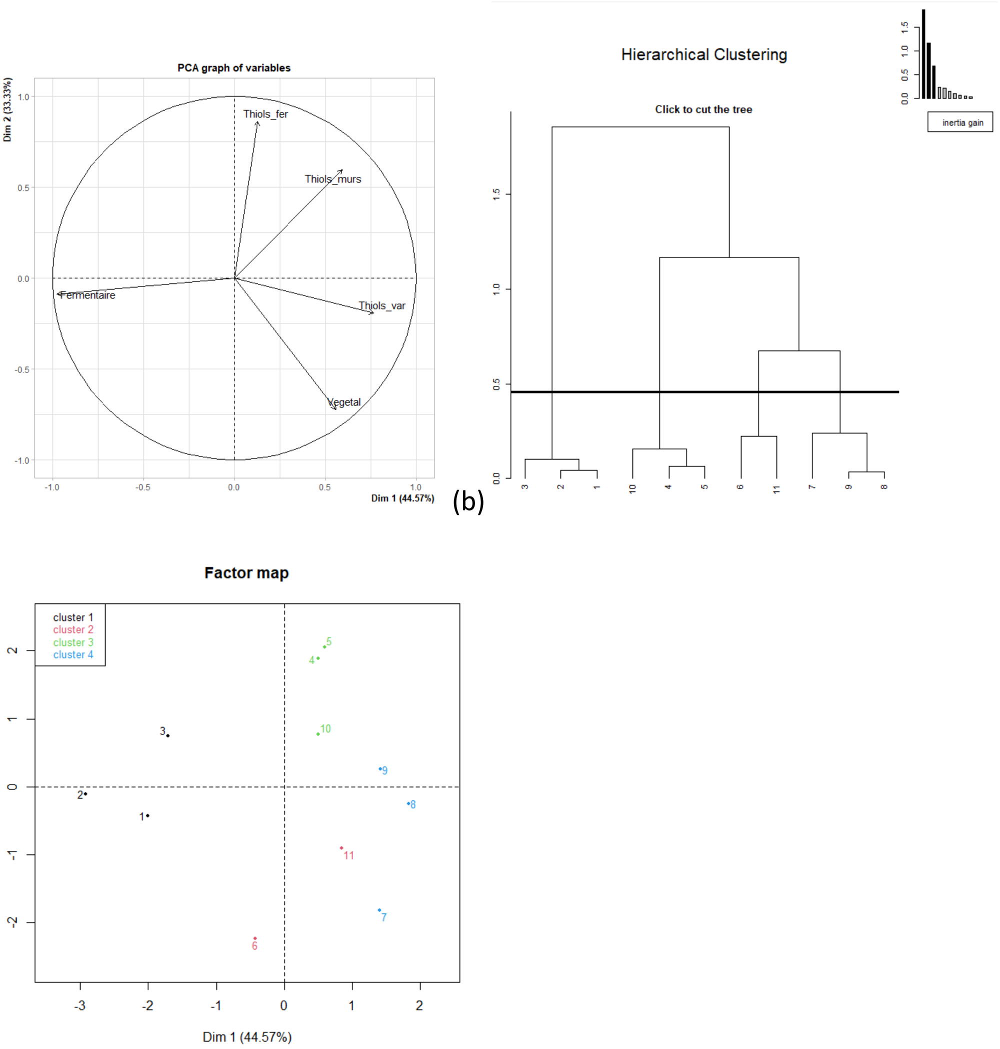
Table 2: Analysis of musts at cellar entry for each harvest date on each plot.

| | Number of days after Maturox minimum | Reducing sugars (g/L) | Total acidity (g/L) | Assimilable nitrogen (mg/L) |
|---|---|---|---|---|
| VCR_3 | 13 | 203 | 4.5 | 69 |
| | 19 | 201 | 4.6 | 125 |
| | 24 | 205 | 3.6 | 86 |
| VCR_11 | 7 | 191 | 5.2 | 95 |
| | 14 | 207 | 4.6 | 53 |
| | 19 | 225 | 4.2 | 64 |
| VCR_16 | 2 | 161 | 4.7 | 206 |
| | 9 | 164 | 4.6 | 222 |
| | 14 | 180 | 4 | 153 |
| VCR_17 | 13 | 223 | 5.1 | 41 |
| | 20 | 220 | 4.6 | 43 |
| | 25 | 229 | 3.4 | 55 |

**<u>Organoleptic description and classification of the wines</u>**

The quantitative variables generated on the tasting results were used to map the wines (Figure 2). The variables “veggie”, “fermentative”, “fermentative thiol”, “varietal thiol” and “ripe thiol” were selected.

Modality VCR_3 date 3 was eliminated from the tasting data processing due to its pronounced iodine notes, the result of *Botrytis cinerea* contamination on the grapes.




(a) (b) (c)

Figure 2: a- PCA performed on tasting variables, b- hierarchical ascending classification, c- graph of individuals with group representation. Black: "fermentative" group, red: "vegetal" group, blue: "varietal thiol" group, green: "fermentative thiol" group.

Principal component analysis and hierarchical cluster analysis revealed 4 groups of wines that can be considered homogeneous on tasting variables. The average sensory profile of each group is shown in Figure 3: each one has a main descriptor to characterize it. The four groups were respectively described as "fermentative", "veggie", "varietal thiol" and "fermentative thiol".

Furthermore, it should be noted that the "fermentative thiol" group (predominantly citrus, grapefruit, tomato leaf, sweat), despite its similar name, has only a very low score on the "fermentative" descriptor (amylic notes, strawberry, pear, grenadine, English sweets). The two descriptors are nearly orthogonal on principal component analysis. The wines of this group have notes of ripe thiol (exotic fruits, mango, papaya, passion fruit).

The "varietal thiol" group (boxwood, cat's pee, blackcurrant bud) seems to present the greatest diversity of aromatic notes, with relatively high average scores also for the "veggie" descriptors (fresh, herbaceous vegetal notes), ripe thiol (exotic fruits, mango, papaya, passion fruit) and fermentative thiol (citrus, grapefruit, tomato leaf, sweat).

The "veggie" and "fermentative" groups seem to present less diversity of aromatic notes, and the other descriptors have low scores for these two groups.

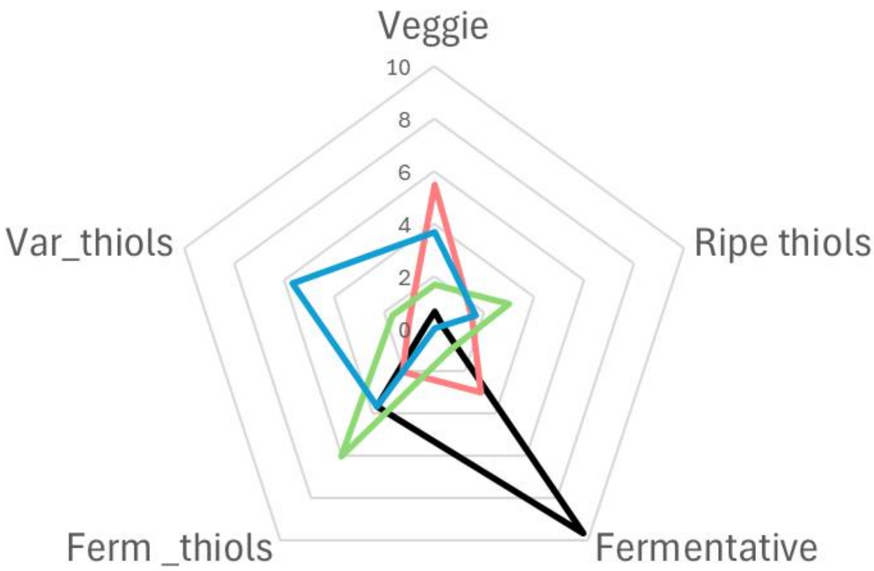



Figure 3: Average tasting scores for wines from different groups determined by PCA and CHA. Black: "fermentative" group, red: "veggie" group, blue: "varietal thiol" group, green: "fermentative thiol" group.

**Analysis of varietal thiols, link with the organoleptic profile of the wines and the harvest date of the plot *vs* Maturox minimum.**

Each group formed on tasting notes include wines from different plots which seems to be distributed according to the number of days after the harvest's minimum Maturox (table 3). The "veggie" and "fermentative" groups are positioned at the shortest times after the minimum Maturox, between 2 and 12 days. The "varietal thiol" group includes wines harvested between 12 and 19 days after the Maturox minimum, while the "fermentative thiol" group includes wines harvested at least 19 days after the Maturox minimum.

In terms of varietal thiol concentration, it appears that in the groups described as "veggie" and "fermentative", the wines present the lowest concentrations analyzed on these samples of 3SH (0-50 ng/L) and 4MSP (0-40 ng/L) and above all, an absence of 3SHA that was not detected in the analysis (Table 3). In average, these wines have a concentration below the perception threshold for 3SH and between 10 and 30 times the perception threshold for 4MSP (Figure 4).

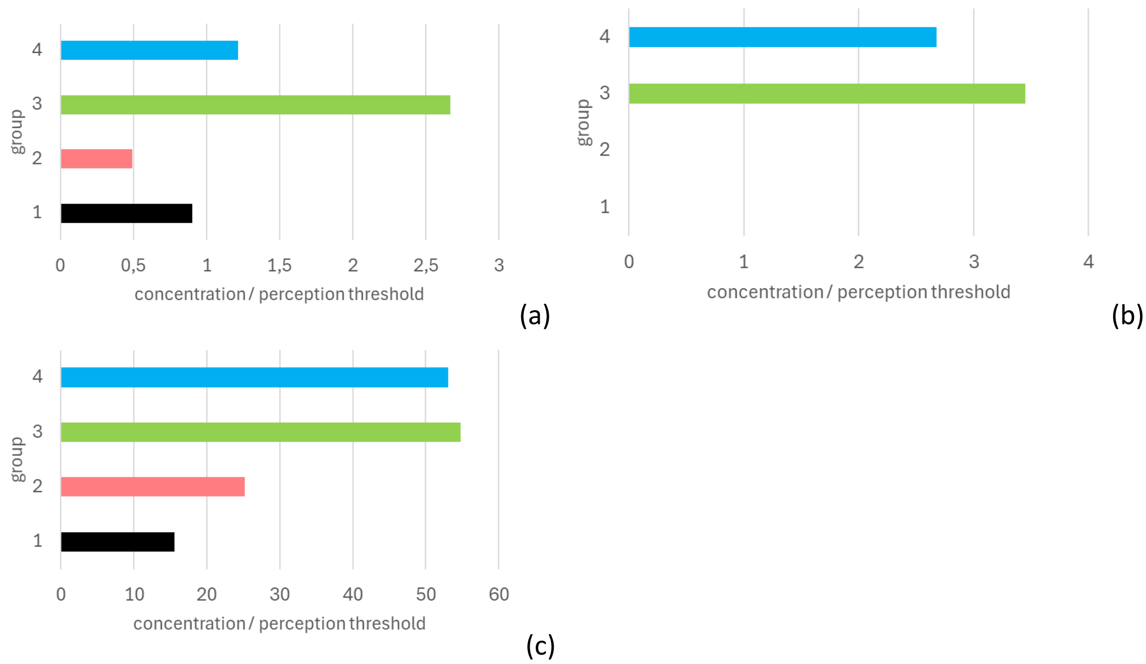



Figure 4: Average olfactory intensity (concentration/perception threshold) for (a) 3SH, (b) 3SHA and (c) 4MSP of the different groups. Black: "fermentative" group, red: "veggie" group, blue: "varietal thiol" group, green: "fermentative thiol" group

Table 3: Harvest date in relation to the plot Maturox minimum, varietal thiol concentration and group for each wine.

| Parcel | Number of days after Maturox minimum | Reducing sugars (g/L) at harvest | Total acidity (g/L) at harvest | Assimilable nitrogen (mg/L) at harvest | Tasting group | 3SH (ng/L) | 3SHA (ng/L) | 4MSP (ng/L) |
|---|---|---|---|---|---|---|---|---|
| VCR_16 | 2 | 161 | 4.7 | 206 | fermentative | 23 | nd | 8 |
| VCR_11 | 7 | 191 | 5.2 | 95 | veggie | 7 | nd | 6 |
| VCR_16 | 9 | 164 | 4.6 | 222 | fermentative | 33 | nd | 12 |
| VCR_3 | 13 | 203 | 4.5 | 69 | veggie | 52 | nd | 34 |
| VCR_11 | 14 | 207 | 4.6 | 53 | fermentative | 106 | nd | 17 |
| VCR_17 | 13 | 223 | 5.1 | 41 | varietal thiol | 77 | 9 | 51 |
| VCR_16 | 14 | 180 | 4 | 153 | varietal thiol | 87 | 15 | 44 |
| VCR_3 | 19 | 201 | 4.6 | 125 | varietal thiol | 56 | 8 | 32 |
| VCR_17 | 20 | 220 | 4.6 | 43 | fermentative thiol | 84 | 14 | 44 |
| VCR_11 | 19 | 225 | 4.2 | 64 | fermentative thiol | 262 | 14 | 34 |
| VCR_17 | 25 | 229 | 3.4 | 55 | fermentative thiol | 135 | 13 | 53 |
| VCR_3 | 24 | 205 | 3.6 | 86 | not evaluated | 269 | 15 | 44 |

The "varietal thiol" group comprises wines with intermediate concentrations (Table 3) of 3SH (50-100 ng/L, on average 1.5 times the perception threshold, Figure 4) and 4MSP (40-50 ng/L, more than 50 times the perception threshold), and around 10-20 ng/L of 3SHA (around 3 times the perception threshold). It differs from the group described as "fermentative thiol" in that the concentration of 3SH is higher in the latter group (over 100 ng/L, between 2 and 2.5 times the perception threshold), while the levels of 3SHA and 4MSP remain in the same order of magnitude.

The "veggie" group shows a higher average concentration of 4MSP than the "fermentative" group: it seems that the aromatic "boxwood" notes typical of 4MSP were not recognized here during tasting but rather assimilated to “veggie” notes. Analyses of other aromatic compounds such as pyrazines or fermentative esters could have been carried out to complete the picture, but they were not achieved in this trial.

In the “fermentative” group, one wine stands out as having a higher 3MH concentration than the other wines in the group (and at the molecule's perception threshold): VCR_11, harvested 14 days after the Maturox minimum. The absence of 3SHA could explain its ranking with wines containing less 3SH. Finally, the wine from plot VCR_3 harvested 19 days after the Maturox minimum was classified in the "fermentative thiol" group, despite having intermediate concentrations of 3SH, 3SHA and 4MSP, quite close to those of wines in the "varietal thiol" group. However, this plot presented *Botrytis cinerea* attacks, which may have contributed to a change in its sensory profile. The next harvest date on this plot (24 days after the Maturox minimum) was eliminated from the tasting for this reason. It did, however, have high varietal thiol concentrations, as did the wines in the "fermentative thiol" group.

On all plots, 4MSP levels exceeded their perception threshold (0.8 ng/L) for all harvest dates, including the earliest, and reached a maximum value between 12 and 20 days after the Maturox minimum (Figure 5). The levels of 3SMH and 3SMHA exceed their perception thresholds from 12 days after the Maturox minimum, and that of 3SH seems to continue rising after 20 days.

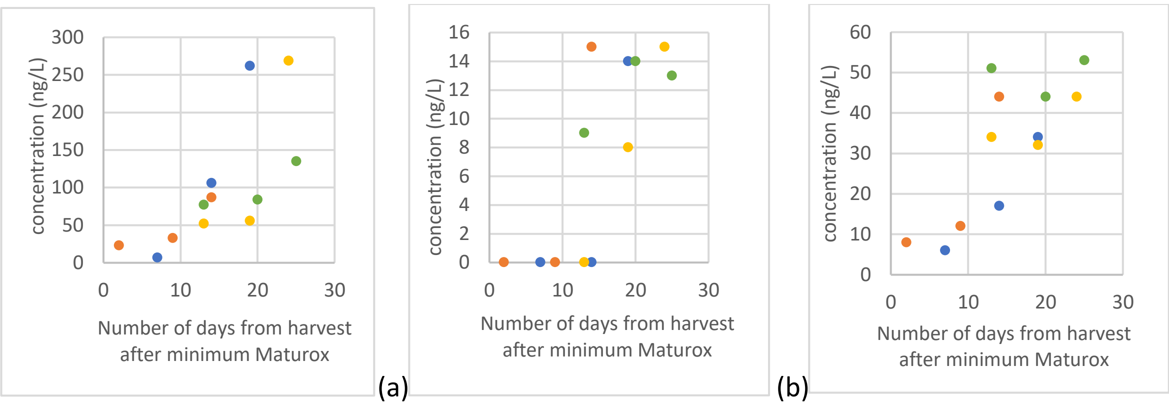



Figure 5: Concentration (ng/L) in (a)3SH, (b) 3SHA and (c) 4MSP as a function of the number of days the plots were harvested after the Maturox minimum. Blue: VCR_11; orange: VCR_16; green: VCR_17; turquoise: VCR_3

In the light of these observations on the 4 plots, it seems that the hypothesis put forward by Hastoy *et al* (2019) is confirmed: linear sweep voltametry, and in particular the use of the Maturox index as proposed in this article, can be used as a time reference during grape ripening to produce given wine profiles. The positioning of harvest dates in relation to the time after the Maturox minimum makes it possible to influence the thiol content of wines and the balance between the different molecules in this aromatic family. On the other hand, conventional analytical parameters (sugar concentration, assimilable nitrogen, total acidity - Table 3) do not give any indication of when a given organoleptic profile should be harvested, in particular to obtain profiles described here as “fermentative”, “veggie” or “varietal thiol”.

## Conclusion

Although thiol precursor revelation rates during winemaking are low (<10%) and strongly impacted by the winemaking process, the work carried out highlights the possibility of producing defined and predictable wine profiles on Sauvignon blanc.

The choice of harvest date has a major impact on the profile obtained. In the present study, grape ripening was monitored by linear sweep voltametry, using the Maturox index, which integrates the intensity of the voltammetric signal over a wide potential zone. Its minimum was chosen as a time reference during the ripening of each plot. The plots were then harvested at 3 different dates, with varying degrees of difference from this minimum for each plot. Wines obtained from harvests at a given distance from this minimum showed similar profiles in tastings, and a link was established with the concentrations of 3 varietal thiols, 3SH, 3SHA and 4MSP, and their relative concentrations.

In concrete terms, when a plot was harvested within 12 days of the Maturox minimum, Sauvignon blanc wines were described as “veggie” or “fermentative”, with 4MSP above its perception threshold, 3SH below its perception threshold and no 3SHA. When harvesting took place more than 12 days after the Maturox minimum, the wines were described as "thiols", with concentrations of all 3 varietal thiols above their perception threshold. The concentration of 4MSP appears to reach its maximum concentration in wines harvested from 12 days after the Maturox minimum. The concentration of 3SH seems to increase beyond these 12 days, which could explain the description of two different aromatic profiles: a dominant veggie thiol (boxwood) when harvested between 12 and 19 days after the Maturox minimum, and a dominant fermentative thiol (citrus) if harvested beyond 19 days due to a higher relative proportion of 3SH.

Monitoring grape ripening by linear sweep voltametry, in particular using the Maturox index and its minimum as a time reference, has enabled us to position harvest dates on the four vinified plots to obtain typical profiles defined by tasting and varietal thiol analysis. Coupled with a suitable winemaking protocol, this method can be used to produce target wine profiles in a winery by optimally selecting harvest dates for each plot.

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