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How to make a mineral wine? Relationship between production type in the Chablis vineyard and the search for a mineral wine style

Heber Rodrigues[1*], Dominique Valentin[2], Méven Otheguy[2] and Jordi Ballester[2]

[1] Plumpton College, UK Centre for Excellence on Wine Education, Training and Research. Ditchling Road, Brighton, BN7 3AE, England, UK
[2] Centre des Sciences du Goût et de l'Alimentation, CNRS, INRAE, Institut Agro, Université Bourgogne Franche-Comté, F-21000 Dijon, France

*correspondence:
heber.rodrigues@plumpton.ac.uk

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ABSTRACT

Minerality in wine has consistently gained attention from the wine industry in the last three decades. It has been considered for a long time as an ill-defined and controversial sensory attribute. In the last decade, several academic articles have addressed the conceptual, sensory and chemical delimitation of this fuzzy concept. However, the link to viticulture and winemaking processes has not been studied yet. The goal of this work was twofold: first to produce a typology of practices in Chablis Premier Cru, a PDO (known for its mineral wines) and, second, to explore how Chablis producers conceptualise wine minerality and its link to production practices. We hypothesized that Chablis producers aim to maximise the minerality of their wines and adapt their production strategy accordingly. Two interviews were carried out. Thirty-four wine producers from Chablis participated in the typology interview, of which twenty-seven also participated in the minerality interview. A typology analysis of the producers' viticultural and winemaking practices revealed four types of production strategies (Conventional, Natural, Agroecology and Low Input Winemaking). A short semi-structured interview of the producers' opinions of and attitudes towards minerality and practices leading to wine minerality highlighted the key aspects of the production of mineral wines, namely soil characteristics, harvest date, type of yeasts, fermentation temperature, type of ageing containers and intensity of lees contact, among others. A link between the respondents' production practices and their minerality conceptualisation was found: in some cases, the representation of minerality seemed to be a result of the applied production strategy and not only the other way around; i.e., these winemakers conclude that because their wines are mineral their respective production practice is the best one for making mineral wines, without having deliberately chosen it to make mineral wines.

KEYWORDS: wine minerality, typology, Chablis, wine production, viticulture, wine style

INTRODUCTION

The increasing popularity of the wine descriptor "mineral" (or "minerality"), despite its lack of clear definition, has attracted journalists and wine researchers alike. Contrary to other wine sensory dimensions, such as oakiness or fruitiness, nothing was published on perceived minerality in the scientific literature before 2012. Since then, more than 10 papers have been published on different aspects of wine minerality: conceptual aspects (Ballester *et al.,* 2013; Rodrigues *et al.,* 2015; Deneulin *et al.,* 2016), sensory aspects (Ballester *et al.,* 2013; Parr *et al.,* 2015; Parr *et al.,* 2016; Zaldívar Santamaría *et al.,* 2019) and chemical aspects (Parr *et al.,* 2016; Rodrigues *et al.,* 2017; Starkenmann *et al.,* 2016; Zaldívar Santamaría *et al.,* 2019).

In a study investigating the content and structure of experts' and consumers' social representation of "minerality in wine", Rodrigues *et al.* (2015) showed that wine minerality is conceptualised as being a result of the *terroir* and is widely present in the mind of wine experts and consumers. Wine experts' social representations were also shown to be anchored on shared sensory dimensions, such as shellfish, acidity, and freshness. Other studies, focusing on the sensory aspect of wine minerality have shown that perceived minerality is a multi-faceted descriptor with many sensory sub-dimensions and high inter-individual variability (Ballester *et al.,* 2013; Parr *et al.,* 2015). Recent studies have also tried to combine sensory and chemical approaches. These studies have clearly revealed the involvement of sulfur compounds in perceived minerality (Parr *et al.,* 2016; Starkenmann *et al.,* 2016 and Rodrigues *et al.,* 2017), the low importance of soil minerals (Parr *et al.,* 2016; Rodrigues *et al.,* 2017) and the ambiguous role of organic acids (Parr *et al.,* 2016).

Some of the descriptors or chemical compounds mentioned above are potentially related to winemaking choices (e.g., winemaking reductive conditions, ageing in oak barrels or malolactic fermentation management), while others may result from viticultural choices (e.g., leaf removal, yield *or harvest date). Those choices may be based on winegrowers' beliefs and/or representations*[1].

However, the relationship between the production strategies and the search for a mineral-oriented wine style has not yet been addressed. The goal of the present study was to cast some light on this relationship.

To achieve this goal, we explored the different types of Premier Cru wine production[2] in the Chablis wine region (Burgundy, France), and how these types are related to producers' representation of minerality through the construction of production typologies. Typologies summarise the characteristics of archetypal persons or objects and show the relationships between these characteristics; for example, farmer typologies usually aim to determine the factors influencing farmers' behaviour (Emtage *et al.,* 2007). In social and agricultural sciences, production system typologies have attracted the attention of scientists as a means of, for example, distinguishing patterns in populations of farms (Cortez-Arriola *et al.,* 2015), rural settlements (van Eupen *et al.,* 2012; Daloğlu *et al.,* 2014; Martin-Collado *et al.,* 2014; Cortez-Arriola *et al.,* 2015), food behaviour (Léon *et al.,* 2004; Buyck *et al.,* 2009), business (Gaspar *et al.,* 2008; Montaigne and Coelho, 2012; Bressolles *et al.,* 2014; Dijk *et al.,* 2015) and ill-defined concepts like "agritourism" (Phillip *et al.,* 2010).

In this setting, the typology approach seems to be suitable for understanding the factors determining winemakers' decision making and how they think their practices can influence the minerality in their wines. The choice of the Chablis area for establishing this typology is based on the longstanding reputation of Chablis wines for having mineral character (Ballester *et al.,* 2013; Rodrigues *et al.,* 2017). We hypothesise that, given the importance of the mineral character for the image of Chablis wines, winemakers have adapted their viticultural and winemaking practices to express this mineral character.

To test our hypothesis, we used a three-step approach. The first step aimed to establish a typology of the production systems of Chablis wines. This was achieved through in-depth interviews focusing on viticultural and winemaking practices. The second step aimed to explore the opinions, beliefs and attitudes of the participants regarding wine minerality by carrying out short interviews. The last step aimed to explore the relationship between viticultural and winemaking practices and the producers' representation of minerality.

MATERIALS AND METHODS

1. Case study region

The Chablis winegrowing area (Figure 1) is part of the administrative region of Burgundy, France. This wine area is crossed by a river called Serein, from North-West to South-East. Chablis wines are produced from *Vitis vinifera* Chardonnay. The production is structured in a four-level hierarchy from the most restrictive to the least restrictive quality-oriented specifications (geographical production area, yield and minimal must sugar content, etc). The Chablis area produces high-end wines bearing the "Protected Designation of Origin (PDO) Chablis Grand Cru"; located in a very specific area with optimal agronomical

1 Beliefs and Representation are two distinct but related concepts. Here we consider Representation as networks of object, concepts and relations that reflect a person's comprehension and knowledge of the world. The term belief refers to the attitudes about the world which can be either true or false.

2 The interest of focusing the typology on 1er Cru level is the wider diversity in terms of terroir (soil, climate, slope, plot orientation and so forth) and also de diversity of winemaking approaches of this category of wines.

FIGURE 1. Location of wine producers interviewed in Chablis (green crosses), and the production areas corresponding to PDO Chablis and Petit Chablis (grey area), PDO Chablis Premier Cru (orange areas) and PDO Chablis Grand Crus (red area).

conditions (slope, exposure and soil characteristics) on the right bank of the river (red area in Figure 1). Right below in the hierarchy there are the wines from "Chablis Premier Cru" PDO (orange areas in Figure 1) with 17 main vineyards. A wider area is allowed to produce "Chablis" and "Petit Chablis" wines (grey areas in Figure 1) which have less restrictive production specifications than Premier and Grand Crus.

2. Respondents

To be included in the study, the respondents had to be involved in viticulture and winemaking and to have produced at least one Chablis Premier Cru. Thirty-four wine producers from Chablis participated in the typology interview (28 men and 8 women aged between 23 and 61 years old). Among those 34 participants, 27 participated in the minerality interview (20 men and 8 women). As shown in Figure 1, the respondents' wineries (green crosses) were located in the town of Chablis and neighbouring municipalities.

3. Procedure

The two interviews were conducted in the same order for each respondent. The in-depth interview focusing on the production strategies in viticulture and winemaking was performed first. Then, eight months later, the short interview focusing on the respondents' views of Chablis wine minerality was carried out. The delay between the two steps aimed to limit the respondents' cognitive rationalisation between the two interviews. Respondents were not aware that the project explored the link between production strategies in viticulture and winemaking and their representation of minerality. Before beginning the two interviews, the participants were provided with an information sheet describing what the participation involved and the participants' rights. The researcher responded to any queries prior to the participants completing and signing consent forms, in which they declared themselves as volunteers in the study and engaged not to disclose the subject of the interview in keeping with French ethical requirements at the time of the experiments.

3.1. Typology of production: semi-structured interview

An interview guide was developed based on the structure of the questions in the "wine land register" surveys of the Ministry of Agriculture, Agribusiness and Forestry of the French Republic. The guide was composed of two separate parts. The first part (Table 1) contained questions about viticulture: general information regarding the vineyard, such as soils and plantation characteristics, vineyard structure and vineyard management. The second part (Table 2) contained questions about winemaking practices, as well as the materials and technologies used to produce wines. After completion of a first draft, the interview guide was sent to viticulture and oenology experts for validation and revised according to their comments. Finally, a pre-test with two producers from the Chablis area was carried out and further amendments were made.

The interviews were carried out in the Chablis area between 13 June and 28 August in 2013. They were conducted face-to-face by two interviewers who had been trained to interview the respondents in the same way. The interviews lasted about 50 min on average and were audio-recorded.

3.2. Minerality semi-structured interview

The minerality interview grid included three questions related to both the effect of terroir and the relationship between minerality, viticulture and winemaking practices. The precise questions were the following: *(1) "According to your experience, which plots in the Chablis area yield the most mineral wines?" (2) "Do you think that minerality can be modulated in wines through winemaking practices?" (3) If you were to develop a very mineral wine and you had the choice of raw material and winemaking process, how would you do it?"*

The interviews were conducted in the Chablis area between 23 April and 7 May in 2014. As above, the interviews were conducted face-to-face by the same two interviewers. The interviews lasted 20 min on average and were audio-recorded.

TABLE 1. Viticultural practices interview guide. The stars indicate the questions that were used for the subsequent quantitative analyses.

General vineyard information
1. Area under cultivation *
2. Age of the vines *
3. Massal/clonal selection
4. Rootstocks used
5. Types of soils
6. Orientation of the plots
7. Planting density *
8. Distance between rows
9. Distance between plants within a row
Vineyard management
10. Production system (conventional, reasoned[#], organic…) *
11. Soil work *
12. Cover crops (grassing) *
13. Vine training system *
14. Protection against frost
15. Suckering *
16. Disbudding *
17. Leaf removal *
18. Trimming *
19. Green harvest *
20. Manual or mechanical harvest *
21. Average yield *

[#] A "reasoned approach to viticulture" involves considering all the primary and secondary effects of every process in the management of the vineyard so as to preserve its health, biodiversity and qualitative productivity.

4. Data analysis

4.1. Typology deep interview

The interviews were transcribed and analysed using both a quantitative and a qualitative approach.

4.1.1. Quantitative approach

The interview transcriptions were read by two independent readers to extract a list of activities for each production step, and for each activity a set of modalities; for instance, in the vineyard management section we included the activity "training system" and the three modalities given by the respondents were "Guyot simple", "Guyot double" or "both". The questions that were analysed quantitatively are marked with an asterisk in Table 1 and 2. The choice of the modalities was based on the distribution of the answers; for example, the distribution of AF temperatures showed three clear frequency groups: below 19 °C, between 19 °C and 21 °C and above 21 °C, therefore we used these three intervals to represent applied AF temperature. For numerical questions we used a median split to create two groups; for instance, the median value for free SO_2 added before bottling was 40 mg/L, therefore we used this value as a cut-off point between the two modalities. The frequency of occurrence of the modalities of each activity was then computed. The activities with a modality used by all respondents were considered as non-discriminant and removed from the subsequent analyses. Two activity tables were then created with respondents in rows and activities (nominal variables) in columns.

To establish the viticultural and winemaking typologies we used a multiple correspondence analysis (MCA) of the activity tables. Only the modalities with five or more occurrences were kept in this analysis. MCA codes data by creating several binary columns for each variable with the constraint that only one of the columns will obtain the value 1. This coding schema creates artificial additional dimensions, because one categorical variable is coded with several columns. Consequently, the inertia (i.e., variance) of the solution space is artificially inflated and therefore the percentage of inertia explained by the first dimension is severely underestimated. To correct for this underestimation, we used Benzécri's correction, in which the values below 1/K (with K being the number of initial variables) are dropped and the remaining eigenvalues are scaled by a factor of K/(K-1). See Abdi and Valentin (2007), for a detailed presentation of the correction.

A hierarchical cluster analysis (HCA) with the Ward criterion was then performed on the coordinates of the

TABLE 2. Winemaking practices interview guide. The stars indicate the questions that were used for the subsequent quantitative analyses.

General aspects
1. Winemaking differences between PDO
2. Use of inert gases during winemaking
Pre-fermentative steps
3. Sorting of the grapes *
4. Pressing strategy
5. Use of enzymes *
6. Must fining *
7. Settling technique
8. Aimed turbidity level *
9. SO_2 adjustments
Alcoholic Fermentation (AF)
10. AF yeast *
11. Fermentation activator # *
12. Nitrogen adjustment *
13. Average duration and temperature of AF *
14. Accidental AF stop *
Malolactic Fermentation (MLF)
15. MLF bacteria*
16. Average duration of MFL *
17. Accidental MFL stop?
Ageing conditions
18. Ageing containers *
19. Ageing length *
Pre-bottling and bottling operations
20. Tartaric stabilization*
21. Fining
22. Filtering
23. SO_2 adjustments*
24. Inerting system in bottling line
25. Type of closure? *

Nutrient supplementation for the yeast.

respondents and the first two dimensions of the viticultural and winemaking MCAs. By considering the total number of respondents, we chose to split the viticultural and oenological dendrograms into two clusters. The validation of the clusters identified by splitting the dendrograms was performed using a consolidation approach by aggregation around mobile centres. The modalities defining best the resulting clusters were identified using a hypergeometric law (Lebart *et al*., 2006). All analyses were performed with SPAD software (version 8.2, CISIA-CESRESTA, Montreuil, France).

4.1.2. Qualitative approach

To better understand the typology derived from the quantitative approach, the interview transcriptions were read and analysed separately by three researchers based on content analysis methodology (Berelson, 1952). Content analysis involves drawing inferences and conclusions from the content of the message (Nachmias and Nachmias, 1976), with inferences being made by systematically and objectively identifying specified characteristics of the messages (Holsti, 1968). In this way, each experimenter extracted verbatim (content) from each interview with the purpose of illustrating the explanations provided by the respondents for justifying the ways they choose to manage their vineyard and produce their wines.

4.2. Minerality semi-structured interview

Three independent readers extracted the main themes and items within each theme from the interview transcriptions. To facilitate the interpretation of the data, the number of citations of each item was computed for each typology class.

Items with only one citation (hapax) were either removed or merged with another item with the same meaning; for example, "Valmur Grand Cru" was cited only once and was merged with the more general item "Grand Cru".

RESULTS AND DISCUSSION

1. Typology: deep interview

We extracted the information corresponding to the different questions of our interview guide from the transcriptions of the in-depth interview. Many of the questions referred to very factual aspects of the respondents' viticultural or winemaking choices. To answer these questions, the respondents generally estimated an "average" value across years or plots (for yield or plant density, for instance) or indicated the most frequent practice over the last few years (e.g., no longer using commercial yeast even if they did several years ago). On just a few occasions, the respondents consulted the winery logs to give precise answers.

1.1. Viticultural practices

The modalities extracted from each activity and their frequencies are presented in Table 3. The results are given in two sections following the interview guide: general vineyard information and vineyard management.

First, regarding cultivated area, Table 1 shows that 74 % of the respondents have less than 50 ha under vine. Such small-sized vineyards are quite common in Burgundy.

Of the virtually ubiquitous viticultural practices, we can find soil maintenance, desuckering and trimming. Chablis vineyards were flagged for intense work being carried out in the vineyards. All the respondents carry out soil maintenance to decrease the use of chemical herbicides:

TABLE 3. List of activities and associated modalities extracted from viticultural part of the interviews.

Section	Activity	Modality	Occurrences	%
General vineyard information	Cultivated area	< 50 ha	25	74
		> 50 ha	9	26
	Age of vines	Young < 35 years old	14	41
		Intermediate ⩾ 35 years old	20	59
	Plant density	Low < 6200 /ha	17	50
		Intermediate 6200 to 8000 p/ha	12	35
		High > 8000 p/ha	5	15
Vineyard management	Production system	Some organic	10	29
		No organic	24	71
	Grassing	Yes	12	35
		No	22	65
	Soil work	Yes	34	100
	Training system	Guyot double	16	47
		Guyot simple	8	24
		Both	10	29
	Suckering	Yes	32	94
		No	2	6
	Disbudding	Yes	26	76
		No	8	24
	Trimming	Yes	34	100
	Leaf removal	Yes	16	47
		No	18	53
	Green harvest	Sometimes	1	3
		No	33	97
	Harvest	All or mostly manual	6	18
		All or mostly mechanized	28	82
	Yield	≤ 55 hl/ha	21	62
		> 55 hl/ha	13	38

"*So soil maintenance, as much as possible, we indeed strongly limit the use of herbicides. There is nowadays a general trend of soil working again…»* (R22) and they all also practice trimming. In addition, a large majority (76 %) reported disbudding. All these practices are known to facilitate the passage of machines. In particular, mechanised harvesting is widely used (82 %) in the Chablis area, where it is only forbidden in the PDO Grand Cru plots. The respondents highlight a big improvement in the machines over the last 30 years in terms of damage done to the grapes, as well as obvious economic and logistic advantages: *"The positive points (...) are that we don't have to manage staff. (...) we can go from one plot to another easily. We can better adapt to the ripening of the grapes, I think. Also, from a harvest point of view, the machines have improved. Euh, they are now efficient, depending on the driver and on the setting"* (R12).

Leaf removal was found to be carried out by half of the respondents. The positive comments about this practice are that it helps ripening and improves air circulation, which limits pest development. From a practical point of view, leaf removing facilitates harvesting by hand.

It is interesting to note that green harvest is not a common practice in the Chablis area. The main reason given by the respondents is that it is not necessary if disbudding has been done properly. Some respondents also argued that green harvest results in more vigorous vines the following year: *"I think that it is a heresy. I we come to that, that means that we didn't do a good work before. What I think is that, maybe I am wrong, I think that it has a negative effect. When we remove the lateral shoots and grapes, we give more vigor to the vine the next year"* (R27). Some respondents also added that since they struggle to reach a reasonably high yield, there is no point in doing a green harvest.

Regarding crop yield, 62 % of the vineyards have an average yield of less than 55 hL/ha. The technical specifications of the Chablis appellations set the maximal yield at 60 hL/ha for Petit Chablis and Chablis, 58 hL/ha for Chablis 1er Cru and 54 hL/ha for Chablis Grand Cru. According to several respondents, it is better to obtain a lower viticultural yield, because it is related to higher quality final wines; for example: "*from a quality point of view it is always better to obtain (...) a little less"* (R26). However, some other respondents prefer to maximise the yield: "*we aim at obtaining the authorised yield ... not less*" (R29). Some respondents related low yields to older vines "*… because we actually have lower yields from the oldest vines"* (R24) and report a sensory impact of low yields and old vines on the resulting wine, "*concerning the yield, it is true that older plots tend to have lower yields (...) However, we find that in terms of balance, in particular that of the body and the acidity level, we get more concentrated things. We get less acidic things (...). This means that, in my opinion, with very old vines we can get unbalanced wines and in Chablis we need some acidity. Sometimes we have to harvest some very old sectors quite early, with very low yields when acidities drop and the aromas are untypical"* (R9) or *"From the very old vines (...) we will get less minerality and more richness"* (R2).

About a third of the respondents produce organic grapes. Many of the remaining two thirds said they follow a sustainable production system, as explained by a wine producer: « I think that it's necessary *to act only when needed, but with the appropriate products. That is why for the moment I am not thinking about shifting to organic production. Because I want efficient products, but I want to use them only when it is necessary"* (R12). These respondents did not consider themselves either conventional or organic.

1.2. Winemaking practices

The modalities extracted from each winemaking activity and their frequencies are summarised in Table 4. The results are structured around six sections as in the interview guide: general aspects, pre-fermentative steps, alcoholic fermentation, malolactic fermentation, aging conditions and pre-bottling and bottling operations.

Eighty-one percent of respondents press the grapes using gentle pressure. This practice aims to produce better quality wines with less phenolic compounds, bitterness and herbaceous aromas (Darias-Martín *et al.,* 2004). The respondents also stated that the level of pressure depends on parameters such as ripeness.

Most producers (91 %) said they carry out settling, of whom 53 % aimed at a rather low turbidity (lower than 200 NTU). *"It is an operation that is almost mandatory, who would carry out fermentations without settling first? "*(R23). Must clarification is a pre-fermentative operation that can have a positive impact on wine quality. Limiting must turbidity makes it possible to foster the production of positive fermentative aroma, to the detriment of other volatile compounds, such as higher alcohols, which are generally considered to be responsible for negative odours in wines (Ribéreau-Gayon *et al*., 2006). On the other hand, very low turbidities can negatively affect the AF (Guilloux-Benatier and Feuillat, 1993).

For alcoholic fermentation, 65 % of the producers said they use commercial yeasts and 18 % said they prefer native yeast. The former group explained that they use commercial yeasts, because they are reliable and fast: *"I used a lot of indigenous yeasts before, but I had too many stuck fermentation problems"* (R29).

Seventy-nine per cent reported that the fermentation is completed in less than five weeks. Regarding malolactic fermentation, only 21 % of the producers reported that they add commercial bacteria and 91 % claimed not to have any stuck malolactic fermentations. Those who use commercial bacteria do so for business and logistical reasons: *"The market is in March, in April we are already being asked for wine, so I inoculate right after the alcoholic fermentation"* (R09).

A majority of 97 % of the producers said that they filter their wines. This is a typical practice for obtaining clear wines:

TABLE 4. List of activities and associated modalities extracted from the winemaking part of the interviews.

Table 4 (part 1/2)

Section	Activity	Modality	Occurrences	%
General aspects	Winemaking differences between PDO	Not different	18	53
		Different	16	47
	Use of inert gases during winemaking	Yes	18	53
		No	16	47
Pre-fermentative steps	Grape sorting	Yes	12	35
		No	22	65
	Pressing	≤ 2 bar	26	76
		Between 2 and 4 bar	5	15
		> 4 bar	3	9
	Enzyme addition	Yes	19	56
		No	15	44
	Must fining	Yes	11	32
		No	23	68
	Must settling	Yes	31	91
		No	3	9
	Aimed turbidity level	< 200 NTU	21	62
		≥ 200 NTU	8	24
		Not measured	5	15
	SO_2 adjustments	≤ 40 mg/l	5	15
		> 40 mg/l	29	85
Alcoholic fermentation	AF yeast	Native	6	18
		Commercial	22	65
		Both	6	18
	Fermentation activator	Yes	17	50
		No	17	50
	Nitrogen adjustment	Yes	20	59
		No	14	41
	AF length	< 5 weeks	27	79
		≥ 5 weeks	7	21
	AF temperature	17 ≤ T ≤19	12	35
		19 < T ≤ 21	22	65
	Accidental AF stop	Yes	26	76
		No	8	24
Malolactic fermentation	MLF bacteria	Native	21	62
		Commercial	7	21
		Both	6	18
	MFL length	< 6 weeks	18	53
		≥ 6 weeks	16	47
	Accidental MFL stop	Yes	3	9
		No	31	91
Ageing conditions	Ageing containers	Vats	13	38
		Vats and barrels	21	62
	Ageing time	≤ 12 months	20	59
		> 12 months	14	41

Table 4 (part 2/2)

Section	Activity	Modality	Occurrences	%
Pre-bottling and bottling operations	Tartaric stabilization	Cold	18	53
		CMC	8	24
		Cold and CMC	4	12
		None	4	12
	Wine fining	Yes	27	79
		No	7	21
	Filtration	Yes	33	97
		No	1	3
	Free SO_2 level before bottling	< 40 mg/l	12	35
		≥ 40 mg/l	16	47
		No answer	6	18
	Inert bottling	Yes	29	85
		No	5	15
	Closure	Natural cork	9	26
		Alternatives	6	18
		Natural cork and alternatives	19	56

"*I really like the Kieselguhr filtration, because it straightens the wine, that's it. It makes it clean, straight, bright"* (R8). Eighty-five per cent of the producers have a bottling line equipped with inerting systems. Regarding ageing conditions, 38 % of respondents said they use stainless steel vats and 62 % both stainless steel vats and oak barrels, depending on the type of wine they are aiming for. The respondents are divided in terms of the stoppers they use: 64 % reported using natural cork, while the rest preferred other cork alternatives, such as technical stoppers, screw cap or a combination of closure solutions based on the potential for aging of the wine and marketing strategies.

1.3. Construction of Chablis wine production typology

Figures 2 and 3 show the first two dimensions of the viticulture and winemaking MCA.

After Benzécri's correction, the first two dimensions of the viticulture MCA explain 62.8 % et 29.5 % of the total variance. The first dimension is correlated to vineyard management. It opposes the usage of cover crops, manual harvest, combination of simple Guyot and double Guyot, and organic viticulture on at least part of their vineyards on the one hand (left-hand side of the plot in Figure 2) and a more intensive production approach with higher yields, no cover crops, mechanical harvest, less work on the vines (leaf removal, disbudding) and no organic production on the other (right-hand side of the plot). The second dimension is mostly correlated to the size of the vineyard and the age of the vines. It opposes exploitations of more than 55 ha of vines with an intermediate average vine age (top of the plot) to smaller surfaces with younger vines, planted at a high density and trained using mostly simple Guyot (bottom of the plot).

The HCA carried out on the coordinates of the respondents on the two MCA dimensions resulted in two clusters representing 47 % (Cluster 1) and 53 % (Cluster 2) of the respondents. The modalities best defining the resulting clusters according to a hypergeometric law (α =5 %) are shown in Table 5. The respondents from Cluster 1 were characterised by more frequent practice of grassing between rows, high planting density, a combination of a simple and double Guyot training system, the use of organic viticulture on some of their plots and lower average yields. The respondents from Cluster 2 do not use grassing, have lower planting density, generally use double Guyot, do not have organic viticulture plots and tend to achieve higher yields.

After Benzécri's correction the first two dimensions of the winemaking MCA explain 36.1 % et 24.6 % of the variance. The first dimension is correlated with production time and the use of enological products. It opposes a low usage of enological products during winemaking coupled with a longer production time (left of the plot) to a higher usage of oenological products coupled with more technological interventions and shorter production times (right of the plot). The second dimension is correlated with the type of vinification. It opposes a more natural vinification with natural cork and no tartaric stabilization, nitrogen nutrition, enzymes, or fermentation activators (top of the plot) to a more technological one with closure alternatives, both native and commercial yeasts, nitrogen nutrition and fermentation activators (bottom of the plot).

The HCA carried out on the coordinates of the respondents on the two MCA dimensions resulted in two clusters representing 44 % (cluster 1) and 56 % (cluster 2) of the respondents. The modalities that best defined the resulting clusters according to a hypergeometric law (α = 5 %) are shown in Table 6. Respondents from Cluster 1 were characterised by grape sorting and the use of native microorganisms although they are able to use commercial yeasts as back up in the case of a problem with alcoholic fermentation. Concerning wine ageing, this cluster is characterized by using stainless steel

FIGURE 2. First two dimensions of the multiple correspondence analyses of the wine producers' viticultural practices.

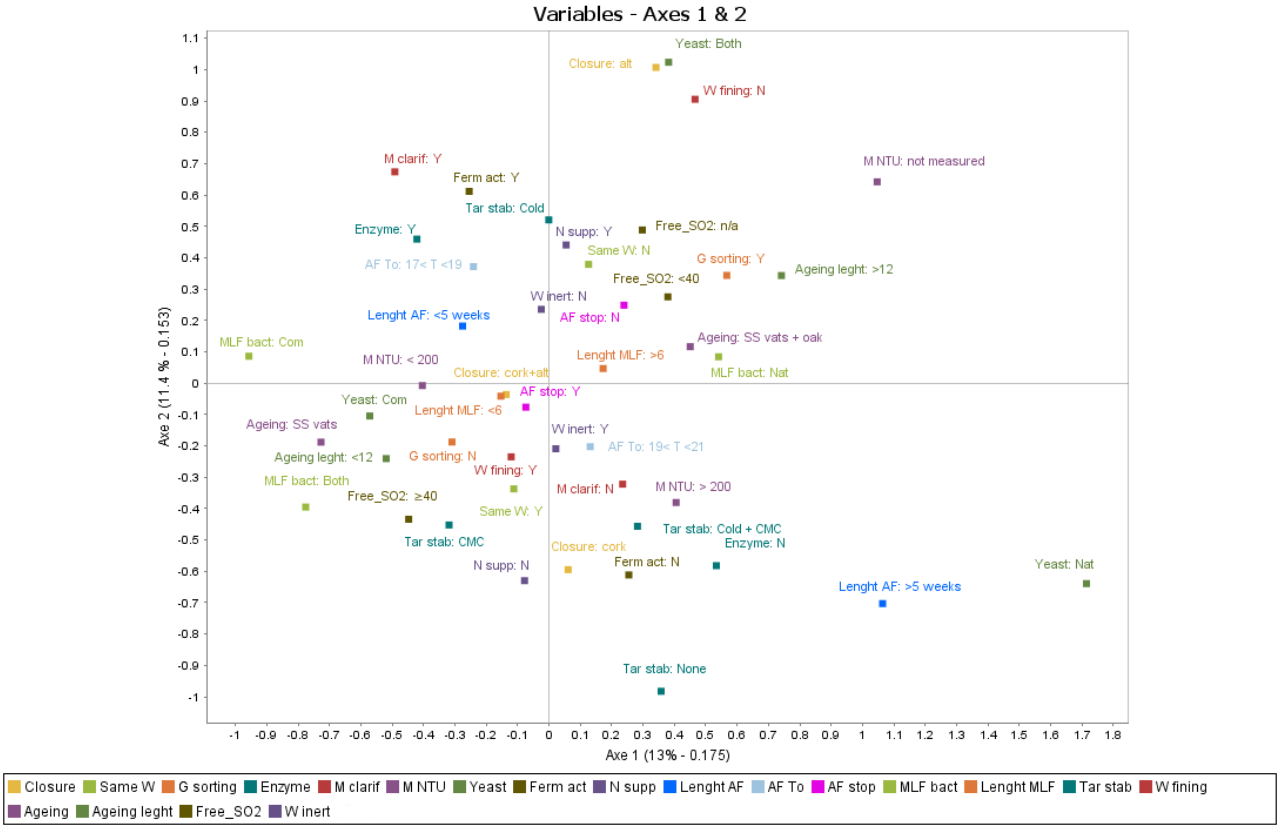

FIGURE 3. First two dimensions of the multiple correspondence analyses of the wine producers' winemaking practices.

TABLE 5. Viticultural modalities discriminating the two clusters obtained from the HCA along with their test-values.

	CLUSTER 1 n = 16		CLUSTER 2 n = 18	
Grassing_YES	4.505	***	-4.505	***
Yield_ < 55	3.102	***	-3.102	***
Density_High	2.152	*	-2.152	*
Pruning_GD + GS	2.128	*	-2.128	*
Grapes production_some ORG	2.128	*	-2.128	*
Grapes production_No ORG	-2.128	*	2.128	*
Density_Low	-2.434	**	2.434	**
Pruning_GD	-2.827	**	2.827	**
Yield_ > 55	-3.102	**	3.102	***
Grassing_NO	-4.505	***	4.505	***

Hypergeometric law, * = p <.05; ** = p <.01; *** = p <.001.

TABLE 6. Winemaking modalities discriminating the two clusters obtained from the HCA along with their test-values.

Variable_ modality	CLUSTER 1 n = 15		CLUSTER 2 n = 19	
MLF bacteria_Native	4.019	***	-4.019	***
Ageing container_SS vats + barrel	3.140	***	-3.140	***
Grapes sorting_YES	3.095	***	-3.095	***
AF yeast_Both	2.676	**	-2.676	**
AF yeast_Native	2.676	**	-2.676	**
Ageing length_> 12	2.351	**	-2.351	**
Turbidity_< 200 NTU	-1.972	*	1.972	*
MLF bacteria_Both	-2.050	*	2.050	*
Free_SO_2 > 40	-2.198	*	2.198	*
Ageing length_< 12	-2.351	**	2.351	**
MLF bacteria_Commerc	-2.351	**	2.351	**
Grapes sorting_NO	-3.095	***	3.095	***
Ageing container_SS vats	-3.140	***	3.140	***
AF yeast_Commercial	-4.791	***	4.791	***

Hypergeometric law, * = p <.05; ** = p <.01; *** = p <.001.

tanks and also oak barrels and ageing the wines longer. It is worth noting that respondents from this cluster are less prone to use high doses of free SO_2. Respondents from Cluster 2 are characterized by not sorting the grapes and having clear juices after settling; they use commercial microorganisms for alcoholic and malolactic fermentations and generally age their wines in stainless steel tanks, and the ageing length is shorter. These respondents aim at having more than 40 mg/L of free SO_2 at bottling.

A four-class typology was obtained by crossing the clusters yielded by the viticulture and the oenology HCA (Figure 4). These four classes reflect different production philosophies that we named: Conventional, Natural, Agroecology and Low Input Winemaking.

Conventional class. This class is composed of twelve respondents and is characterised by an intensive and conventional approach to viticulture. Their priority is to secure a big enough healthy harvest to ensure commercial viability. Therefore, they are not interested in moving towards organic viticulture. The respondents do claim, nonetheless, to use sustainable vine treatments and treat only when necessary: *"some years we manage [the vines] like the organic, then when the pest's pressure is very, very strong, we compensate with chemicals."* (R18). They do not regard organic farming to be a perfect solution from an environmental point of view, in particular because they think that organic farming uses more fuel for treatments and too much copper, which pollutes the soil. For winemaking, they use more inputs and technology. One of the main characteristics of this class is the use of commercial microorganisms to secure clean and fast fermentations because winemakers in this class think that native microorganisms are not reliable: *"I actually used a lot of native yeasts before, but in the end I got too many stuck fermentation problems"* (R29). The respondents use neutral yeast strains to preserve the typicality of their wines

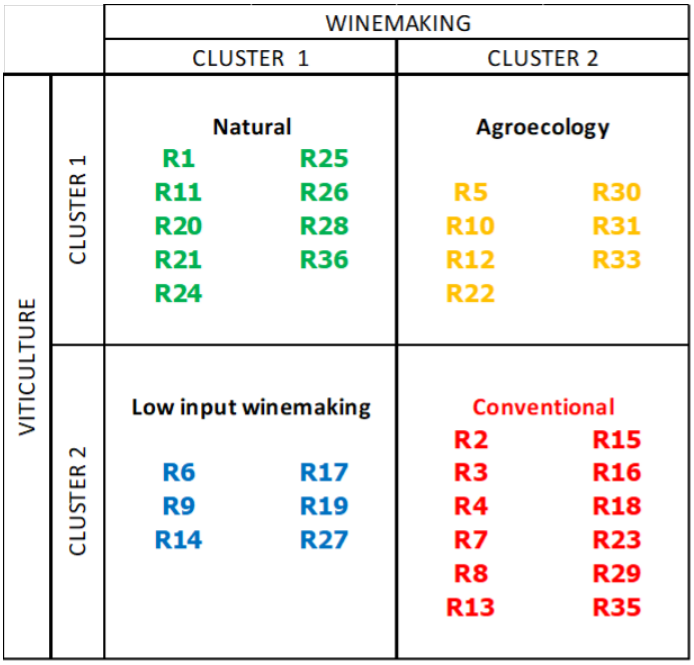

FIGURE 4. Final production typology of the respondents combining viticultural and winemaking aspects of wine production in the Chablis area.

"*They* [*commercial yeasts*] *are efficient and quite neutral; they do not modify the natural aromas and minerality"* (R2). Regarding MLF, the main goal is to reduce its length to optimise winery logistics and enable the early marketing of the wines *"This [inoculating commercial bacteria] allows you to have all the tanks finished by around 15 November to the beginning of December"* (R16). They tend to use more SO_2 to protect the wines from premature oxidation: *"Some trials have been carried out in the Chablis area with lower free SO_2 concentrations at bottling, around 30-35, they obtained wines that don't last long, though. With all the oxidation problems that we see nowadays, I prefer to have a little more sulfites at bottling"* (R13). To sum up, the practices of the respondents from this class suggest that they are quite pragmatic, and that their aim is to reduce production risks, decrease the length of the production process and optimise profitability without compromising quality.

Natural class. This class is composed of nine respondents and is the opposite of the conventional class. The respondents use all or some of the plots for organic viticulture. They care about soil compaction and erosion, which is why they grow cover crops between vine rows: *"Clay rich soils that can, depending on the plot, tend to soil compaction. So we use the root system of cereals to decompact and get some air into the soil"* (R21). They also care about biodiversity: *"Yes, our plots are certified [organic], of course. It is of interest to have living soils ... to find microbial life in the soil again. It is the foundation of organic agriculture"* (R25). By using native microorganisms and using less SO_2, the respondents of this cluster seem ready to take certain risks to make wines as natural as possible. They think that native yeasts give their wines more interesting sensory characteristics: *"wines are more open, fruitier (...). The wines are fleshier and richer! Also, with more personality" (R11)* or *"it brings out the terroir better when they are made using native flora"* (R24). They prefer physical solutions rather than chemical ones; for instance, using technical corks or screw caps in order to protect the wine from oxidation and, as a consequence, limiting added SO_2 at bottling: *"So, it* [SO_2 levels] *depends on the kind of stopper - we use basically DIAM and screw cap, and, from this year on, we don't use cork anymore (...) because it needed a lot of sulfur"* (R1). To sum up, the practices of respondents from this class suggest that they are concerned about consumers' health, biodiversity, and sustainability.

Agroecology class. This class comprises seven respondents which seem to share the principles of viticulture with respondents categorized as "natural class" while their principles of oenology are clearly shared with those of respondents classified as having a conventional approach of winemaking. Even though most of the respondents of this group do not practice proper organic viticulture they declared practicing supervised control of pests and were very interested in decreasing the number of both herbicide and fungicide treatments: *"But I want to add them [pesticides] just when it is necessary. That's it! So, we try to take into the account the weather, the pest pressure, obviously the rainfall and, euh, to intervene only, when necessary, in particular for fungicides. Concerning the weeds, we tend to be more and more light, as I would say. We do not want to tend towards organic production but let's say, we would like to put less and less products, and if possible, plow euh, that's it. So, we do winter plowing systematically, but in the summer, depending on the season and the plot, it is not always easy to get by just by plowing"* (R12). For winemaking, they do not hesitate to use inputs (e.g., commercial yeasts and SO_2) and technology

(e.g., inert gases and technical stoppers) to ensure the quality of their wines: "*Very high! [SO_2 concentration] We are aiming for about a hundred in total and then in free SO_2 we will have forty-five or fifty of free SO_2 euh, knowing that we bottle and the wines stay in our cellar for at least four months before being marketed."* (R10) *"The screw cap does not necessarily add something, something interesting over time if we need the wine to evolve…. I won't use screw cap on Premier Crus, for example. We only use them on Petits Chablis or even on Chablis, because the wines are sufficiently aged and ready to drink. Indeed, the advantage of the screw cap is that it essentially retains a lot of freshness..."* (R22). To sum up, given the practices of the respondents from this class they fall somewhere between the Natural class and the Conventional class: They pay more attention to input reduction in the vineyard while using modern winemaking techniques.

Low Input Winemaking class. This class is composed of only six respondents and is a combination of the viticultural approach of the Conventional class and the oenological approach of the Natural class. Normally, producers who set up low input winemaking processes already have sustainable viticultural practices in place, often with organic or biodynamic certifications. Historically, agroecology was in place well before the emergence of organic or natural wines; for instance, organic wine legislation is quite recent in the EEUU (2012) and the French "natural method" legislation for wines is even more recent (2020). Both organic and "natural method" wines require the use of organic grapes, which is why this cluster is quite unusual. The respondents of this cluster are not ready to make a shift to organic viticulture: *"I find interesting to use as little herbicide as possible, as little product as possible. Then, one has to be aware …, I need to have beautiful harvests, that's why I do not harvest organic (…) I'm too afraid, I have too many bills to pay."* (R14). In winemaking they tend to keep doses of SO_2 low whenever possible and some of them use native yeasts: "*So since we started in 2008, euh we're no longer using active dry yeasts. And I don't think our wines have changed that much, except that they have gained in complexity, yes …*" (R27). To sum up, the practices of the respondents from this class indicate that they are really interested in reducing winemaking inputs, but not to a natural or organic extent, because they are not ready to face the risks of organic viticulture.

2. Minerality interview - Conceptions of wine minerality

The goal of this short interview was to check whether a link exists between different production strategies and the respondents' conceptions of wine minerality. Five main themes emerged from the analysis of the interview: general ideas, origin of the grapes, soil, viticulture and winemaking.

2.1. General ideas

First, most respondents considered minerality to be one of the emblematic sensory characteristics of Chablis wines. The interviews revealed that minerality comes from the terroir, which is consistent with previous findings (Ballester *et al.,* 2013; Rodrigues *et al.,* 2015). The link between minerality and terroir is so strong that sometimes our respondents used terroir as a synonym of minerality; for example, when asked about minerality, respondent 22 answered: *"This is quite a recent phenomenon, but perhaps because there is a generation that seek to know what terroir really is" (*see also R19 verbatim on section 2.5). This association has been suggested recently by Deneulin and Bavaud, 2016. Our respondents think that there is little the winemaker can do to increase minerality; if grapes have the potential for minerality, it will manifest itself at some point, no matter what the winemaker does. This is clearly explained by respondent 22: *"I don't think so, (that minerality can be modulated in the cellar), I think that minerality is like a definition of PDO like Chablis or Grand Cru and it is unchanging. In other words, if you are lucky and you have it in the soil, you will have it in your wine. Whichever type of winemaking you do - vat, traditional in barrels- it doesn't matter…"*. However, some respondents believe that minerality can be masked by certain winemaking practices (see details in Section 2.5).

2.2. Origin of the grapes

The respondents seemed to agree on the minerality potential of Montée de Tonnerre and the Grand crus, in particular Les Clos and Blanchot. Côte de Léchet and Montmains were also reported as having good potential for minerality. There was a lack of consensus regarding Fourchaume: some respondents said it has good minerality, while others said that this is one of the least mineral vineyards. The reasons given are that Fourchaume is well-exposed to sun (hence it has high ripeness) and a significant amount of clay in its soil.

Some respondents stated that the differences in minerality between areas in Chablis are qualitative (different kind of minerality) rather than quantitative (one vineyard can be more mineral than another): "*I think that we can find minerality in all the Chablis areas … we have many different kind of soils here in Chablis … and minerality is expressed in a very different way depending if we are in the north, south, east or west, or produce Premier Crus or Grand Crus*" (R27). Some respondents think that there is a quantitative difference in minerality between vineyards on the right side of the river and those on the left side; however, there is no consensus on this matter. Those who think that the left side is more mineral explain it in terms of lower sun exposure limiting over-ripeness and maintaining acidity levels, which is considered to be an essential component of minerality. Those who claimed that the vineyards on the right side produce wines with higher minerality say that they have stonier soils with more limestone influence.

2.3. Soil

Surprisingly, there were not many references to soil characteristics. Some of the factors that favour mineral wines are deep and limestone soils, as described, for instance, by respondent 22, *"if you have harvested (…) ripe grapes, you are on a limestone terroir with a nice depth, you will get this minerality. And that, nothing can change it"*. On the other hand, high proportions of clay in the soil are regarded by some respondents as a negative factor when it comes

to mineral wines: *"In Séchet, there is basically limestone and you can feel it in the finished wine … we have land in Montmains and it is just clay; there is no minerality there"* (R14) or "*…and I think that this Kimméridgien soil amplifies minerality. While with deeper, less steep soils rich in clay we will get rich powerful wines with less minerality."* (R24).

From a scientific point of view, the link between minerality and terroir is somehow unclear. Indeed, according to Maltman (2013) there is no scientific argument to support the direct relationship between the soil mineral composition and the presence of minerality in the corresponding wines. However, the soil effect described by our respondents may not refer directly to mineral composition, but rather to differences in water availability and temperature induced by different proportions of clay or limestone and their effect on the ripening process.

2.4. Viticulture

It emerges from the interviews that harvest date and therefore grape ripeness are very important factors when it comes to minerality. The harvest date must not be too early, in order to avoid greenness in the wines, or too late, to avoid over-ripeness, which, according to many respondents, has a negative effect on minerality. Some respondents add that a slow ripening of the grapes can have a positive effect as well. The reason given by the respondents is that it is necessary for maintaining acidity and for limiting overripe fruit notes: *"(I would use) grapes from cooler hills, (…) with a slow ripening process, if possible, not grapes which have been very exposed to the sun resulting in very fruity aromas (…) above all, never over-ripeness."* (R9). This agrees with previous studies, which have shown acidity to be an important sub-dimension of minerality, while an excess of fruity notes was negatively correlated with minerality (Ballester *et al.,* 2013; Heymann *et al.,* 2014). Moreover, many respondents seemed to find it important to keep moderate yields and ensure good concentration in the grapes in order to obtain mineral wines.

Removing weeds by ploughing instead of using herbicides is regarded by some respondents as favouring minerality in wines: *"coming back to ploughing gives wines a more intense minerality"* (R19). Likewise, respondent 13, for example, does not think that the use of chemicals in viticulture favours minerality: "*I have the feeling that ploughed vines, where no chemical herbicide is used, will tend to give wines with precisely this expression, of minerality, than vines on soil that is weeded and maybe too compacted … so that the roots are less likely to absorb from the terroir*".

2.5. Winemaking

Most participants think that it is quite difficult to actually increase wine minerality during winemaking; the goal of winemaking would therefore be to preserve the already existing minerality. They thus recommend using a winemaking process that is as neutral as possible. Concerning the yeasts used in AF, the respondents agree on using indigenous yeasts or commercial yeasts providing they are neutral from an aromatic point of view: *"...so I would favor indigenous yeasts, precisely perhaps to maximize also the side, terroir effect, mineral effect, so indigenous yeasts."* (R4) or *"I will use yeasts (...) but yeasts that are neutral and an ageing that tend to, that expresses this minerality"* (R3). The respondents also agree on avoiding cold temperatures during AF in order not to exaggerate the fruitiness of the wines, which can mask wine minerality: *"... warmer alcoholic fermentation, around 23-25 °C in order to make wines that express the terroir more than the fruit"* (R19). Factors involved in the ageing of the wine seem to be critical for obtaining mineral wines, in particular container type, ageing duration and management of the lees. There is a strong consensus that barrel fermentation and ageing can mask wine minerality. Respondents recommend the use of neutral vats (mostly stainless steel) to conduct fermentations and ageing. This is clearly stated by respondent 13: *"in order to have the strongest expression of minerality, you shouldn't mask it with oak, you should rather conduct the ageing in stainless steel tanks"*. Other respondents are less opposed to using oak, providing the barrels have been used for several vintages: *"... I would do 80 % of winemaking in vats and the rest in barrels, (...) we do not use new oak"* (R 24). Long ageing is largely believed to be a positive factor for wine minerality: *"We noticed in our winery that when we conduct longer ageing periods, we succeed in bring out more minerality, in producing wines that have more "tension" than fruit and freshness"* (R 36). Lees contact is a common practice in Chablis white wine production and it has two sensory effects on wine. First, lees keep the wine in a moderate reductive state preventing oxidation and, according to some respondents, sustaining mineral aromas (*e.g.,* oyster shell): *"Chablis wines are characteristic of minerality when they are in a slightly reductive state, not in oxidation (...). By reductive, I don't mean the H_2S kind, I mean a slight reduction, not annoying, but reinforcing the taste of terroir"* (R 19). The role of reduction as an important sub-dimension of minerality has already been pointed out by Ballester *et al.* (2013) and Heymann *et al.* (2014). However, in a study on Sauvignon Blanc, Parr *et al.* (2015) found that reductive aromas were not significant predictors of perceived minerality. It is possible that in the case of Sauvignon Blanc wine, which is often slightly reduced to protect some of the key varietal aromas (*i.e.,* thiols), further reduction is not considered as contributing to minerality as it seems to be the case for Chardonnay wines. Several studies have found significant relationships between sulfur aroma compounds and perceived minerality in Chardonnay (Rodrigues *et al.,* 2017) and in Chasselas (Starkenmann *et al.,* 2016). Parr *et al.* (2016) found that SO_2, which can have a noticeable impact on the redox status of wine, was an important predictor of perceived minerality. In the light of this, it is surprising to note that in our study mentions of SO_2 management were scarce.

Second, lees release some macromolecules (*e.g.,* mannoproteins), which can modify the mouthfeel perception (in particular tactile sensations) by increasing body or "fattiness" (*gras* in French) (Laguna *et al.*, 2019). According to many respondents, this "fattiness" is negatively

correlated with their idea of minerality: *"…the further you push the ripeness, the more your wine will be round and fatty and rich as it will lose the straight, tense and crystalline character that represents better wine minerality in my opinion"* (R13). This result seems to be cultivar dependent, since Parr *et al.* (2015) found that concentration/palate weight were good predictors of Sauvignon Blanc minerality when participants used a nose clip to prevent orthonasal and retronasal information.

3. Link between viticultural and winemaking practices and conceptualisation of minerality

Although many of the ideas mentioned in the previous section are common to most our respondents, others are specific to a class of respondents and usually reveal a link between their conception of minerality and their actual production process.

Concerning the Chablis areas that give the most minerality wines, we observed that the majority of the participants tended to refer to the vineyards in which they grow grapes, possibly because they are not familiar enough with the wines from the other Chablis areas to make confident statements about them. Moreover, the respondents tended to mention their own winemaking practices as the most suitable for obtaining mineral wines; for instance, most of the respondents in the conventional category claimed that using stainless steel vats (to avoid the masking effects of oak) and neutral strains of commercial yeasts were the best ways to make mineral wines, which is consistent with their winemaking approach (see Table 6). Conversely, some of the respondents using native yeasts claimed that they are important for the mineral expression of the wines. The belief that minerality cannot be increased in the winemaking process is best represented by the respondents from the low input winemaking class, and is consistent with their minimalist winemaking approach. They tend, for instance, not to apply low fermentation temperatures to avoid obtaining excessive fruity notes that could mask minerality. However, other respondents admit that what they do is not the best way of emphasising minerality; for example, R6 describes what he would do to make the wine as mineral as possible "*I'd do everything in tanks, that is not what I do in my winery, but in this case, I'd do everything in tanks but … for as long as… 15, 16 months, on lees 15, 16 months like that, … That would be really too mineral"*. Others suggest that they do not try to maximise minerality at all costs, because very mineral wines can be unpalatable for some consumers: *"…at the same time I'd keep some fruitiness all the same. It is still necessary to have fruit in a wine. Because, eventually, it has to be drinkable."* (R19). Furthermore, the respondents from the Conventional and Low impact winemaking classes advocate for a long ageing to increase minerality.

4. Limits of the study

The main limit of this paper is that the field work was carried out in 2013. However, since this date there have not been any major changes in viticultural and winemaking practices in Burgundy, and specifically in Chablis. These practices are quite traditional in this area and are therefore stable over time. As in other parts of Burgundy, organic viticulture has continued to increase in recent years. This trend can be seen in our results. Another topic that could potentially impact viticultural practices is the controversial debate about the re-registration in the EU of the active herbicide ingredient glyphosate. It is likely that some producers will try to anticipate the ban of glyphosate and look for alternatives. Another change (disconnected from the goals of our study) is the series of meteorological events that have seriously affected the Chablis vineyard during recent vintages (2017, 2019 and 2021), in particular frost. As a consequence, producers are now more interested in finding ways of protecting the crops from frost than they were at the time of the study. It is unlikely that these issues had a strong impact on the findings of our study, since the mental representations of minerality and its relationship with production strategies are constructed over a long time. All things considered, we do not think that the small changes in the Chablis vineyard over the last few years compromise the validity of our results.

CONCLUSION

The assumptions of our study were that, in the Chablis area, the producers' conception of wine minerality affect the way they grow vines and make wine, and in turn, that the wines obtained using different production strategies will have differing intensities of mineral character. A typology analysis of the producers' viticultural and winemaking practices showed that different production strategies exist in Chablis. We classified these strategies into four classes and evaluated the link between the producers' strategy in each class and the way they conceptualise minerality was evaluated. The results showed that during the in-depth interview on production strategies only ten respondents (out of 34) spontaneously mentioned minerality in some way. Moreover, of the ten, only four explicitly said that their main goal was to produce mineral wines, implying that their production strategy was oriented to achieve that. Many other factors seem to be more important than producing mineral wines, in particular tradition, logistical or economical issues and, more recently, philosophical attitudes like environmental protection or public health.

Only when minerality was mentioned in the short interview the respondents started to connect production strategies and wine minerality; they mentioned, for example, not using oak and limiting lees contact to avoid oaky notes and fattiness masking minerality, and keeping the wine in a slightly reduced state to preserve shellfish aromas, if they think that they are important for minerality. However, our results generally show that the production strategy is not always tailored to maximise the minerality of wines, since the determinants of minerality described in all four categories are mostly the same. Moreover, these representations are consistent with what was observed in previous literature based on both declarative and behavioural (*i.e.,* based on blind wine tasting) data (Ballester *et al.,* 2013; Heymann *et al.,* 2014).

Finally, in some cases and irrespective of category, it seems that representation of minerality is influenced by the way in which the producers make wine, rather than the opposite. For instance, neutral commercial yeasts are considered to be good for minerality by the producers using neutral commercial yeasts and native yeasts are perceived as favouring minerality by the producers using native yeasts. The producers that systematically inoculate commercial yeasts do not think that the use of indigenous yeasts is a mandatory step for producing mineral wines. Some of the respondents think that the way they make wine, is the "right way" to obtain mineral wines. That suggests that there is maybe an alignment of the minerality representation towards the production strategy as we hypothesised and not only the other way around. This may be because these winemakers think that as their wines are mineral it follows that their production practice is the best one for making mineral wines; i.e., they did not deliberately choose the practice in order to make mineral wines.

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