

Effect of juice turbidity on fermentative volatile compounds in white wines

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Summary

'Chardonnay' (n = 4), 'Pinot gris' (n = 3) and 'Müller-Thurgau' juices (n = 3), each at 6 turbidity levels (15, 45, 86, 141, 215 and 350 NTU) obtained by adding increasing amounts of their own fine juice lees, were fermented using 'Montrachet Red Star' yeast. The main volatile compounds in free form which may have a sensory role were measured using GC-FID, with a DB-WAX column, after fixing onto Isolute ENV+ resin. Changes for around 40 volatile compounds and fermentation parameters are shown. Juice turbidity levels just below 100 NTU are the best compromise for obtaining adequate fruity notes and minimising languishing fermentation and off-flavours in white wine, if correct microbiology management at the winery is guaranteed, whereas slightly higher NTU levels could contribute to a slightly more complex aroma. However, variability due to juice turbidity in the range investigated is lower than variability due to yeast strain observed in a previous experiment. Thus the choice of yeast strain to direct white wine aroma must be overriding as compared to NTU levels

Key words: juice, turbidity, wine, aroma compounds, nephelometric units.

Introduction

Since the late Seventies it has been well-known (RIBERAU-GAYON *et al.* 1975, GROAT and OUGH 1978, BERTRAND *et al.* 1978, BERTRAND 1978, HOUTMAN *et al.* 1980 and extensive literature cited) that adequate transparency in white juice - almost independently of the technological approach used to achieve it and variety - is a fundamental prerequisite for obtaining - freely citing HOUTMAN and DU PLESSIS (1986a) - a fine "basic fermentation bouquet, ... being a major wine quality determining factor in the cellar". According to these last authors, juice clarification must be "effective but not too drastic", in order to avoid detrimental effects both on the course of fermentation, largely related to sterols and fatty acids (LAFON-LAFOURCADE *et al.* 1977, COCITO and DELFINI 1997), and on aroma quality, mainly caused by higher production of volatile acidity when clarity is excessive (DELFINI and CERVETTI 1991, DELFINI and COSTA 1993) or volatile sulphur compounds when there is a lack of clarity (KARAGIANNIS and LANARIDIS 2002).

In principle, the effects of juice turbidity on white wine quality are known, but the level of aforementioned severity needs to be better defined, as few papers specify nephelometric turbidity unit (NTU) levels, work within turbidity ranges which are genuinely consistent with proper white wine processing or take into account numerically relevant case studies and varieties (GERBAUX and MEURGUES 1996, KARAGIANNIS and LANARIDIS 2002, BOSSO and GUAITA 2008). Hence this work aims to provide more detail about the effects of juice turbidity on wine composition, focusing on turbidity levels below 400 NTU and volatile compounds potentially affecting specific aroma characteristics. Moreover, variability caused by juice turbidity is compared with variability due to the yeast strain.

Material and Methods

Four different 'Chardonnay', three 'Pinot gris' and three 'Müller-Thurgau' sulphited juices (80 mg·L⁻¹), each at 6 turbidity levels (T0 = 15 NTU, T1 = 45 NTU, T2 = 86, T3 = 141, T4 = 215, T5 = 350) were fermented in 2-L bottles at 19-21 °C using 'Montrachet Red Star' yeast (500 mg·L⁻¹). Turbidity levels were obtained by adding increasing amounts of their own fine juice lees into statically settled brilliant juice (T0). As regards basic analysis of juices, total soluble solids ranged between 18.5 and 21.9 °Brix, pH 3.06-3.29 and assimilable nitrogen 60-224 mg·L⁻¹. After the completion of fermentation, the wines were decanted, sulphited (70 mg·L⁻¹), analysed for basic composition within a week and stored at 4 °C until analysis of volatile compounds, 3 months later.

Assimilable nitrogen was measured according to NICOLINI *et al.* (2004 a, b). Methanol, higher alcohols, acetaldehyde and ethyl acetate were measured using GC-FID with a Carboxen 101 packed column according to the classic method proposed by GABRI and SALVAGIOTTO (1980) and USSEGLIO-TOMASSET and MATTA (1983); vinylphenols were quantified using a HPLC-ECD approach with RP-18e Purospher column (LARCHER *et al.* 2007); higher alcohol acetates, fatty acid ethyl esters, fatty acids, methionol, 2-phenylethanol and other aroma compounds in free form were measured using GC-FID, with a DB-WAX column, after fixing onto Isolute ENV+ resin, expressing data as n-eptanol, R.F. = 1 (BOIDO *et al.* 2003).

ANOVA and Fischer's LSD test (main effects: juice and turbidity level) were applied for data processing, using STATISTICA v. 8.0 (StatSoft Inc., Tusla, OK, USA).

Results and Discussion

The Table shows the mean values and relevant statistical significance (Fischer's LSD test, $p < 0.05$) of basic compositional parameters and volatile compounds of wines given *per* juice turbidity level. Differences between juices are not shown even if statistically significant, being obvious given the experimental design.

Our attention will focus on analytical parameters with a potential role in terms of sensory characteristics and technology. All turbidity levels were statistically well differentiated. Greater turbidity gave shorter fermentations and lower residual sugars, as expected according to the aforementioned literature and HOUTMAN and DU PLESSIS (1986 b), and this cannot be traced back to assimilable nitrogen, since no statistical differences or trends were found for this parameter between turbidity levels (data not shown). As regards the basic analytical parameters, higher turbidity levels also resulted in lower volatile acidity (with a maximum difference of $0.09 \text{ g}\cdot\text{L}^{-1}$ between the extreme means) and acetaldehyde ($15 \text{ mg}\cdot\text{L}^{-1}$), and higher glycerol ($0.9 \text{ g}\cdot\text{L}^{-1}$). The differences observed for ethyl acetate ($3.2 \text{ mg}\cdot\text{L}^{-1}$) are technologically negligible.

As regards C_6 chain length alcohols, typical pre-fermentative compounds, we found a statistically significant increase in hexanol and an increasing trend, though not significant, of *trans* 3-hexen-1-ol and the sum of C_6 alcohols with respect to juice turbidity. This figure agrees with the literature and our previous results, being consistent with the contribution of juice lees to content in linoleic and linolenic acids and related enzymes, and with SO_2 treatments (CORDONNIER and BAYONOVE 1977, DI STEFANO and CIOLFI 1982, BAYONOVE *et al.* 1987, HERRAIZ *et al.* 1990, GOMEZ *et al.* 1993, NICOLINI *et al.* 1996). The statistically significant decrease in *cis* 3-hexen-1-ol could be related to higher isomerases favouring the more stable *trans* form, but this is worth further investigation. Since C_6 aldehydes, characterised by much lower sensory thresholds than the corresponding alcohols (MEILGAARD 1975, HATANAKA 1993), and C-2 unsaturated alcohols were not measured, it is difficult to forecast the effect of turbidity in terms of intensity of perceptible green, vegetal-like notes.

As regards fermentative compounds, 2-methyl-1-propanol and amyl alcohols increased with turbidity, while propanol showed only marginal variations. The maximum difference for the sum of these higher alcohols was about $60 \text{ mg}\cdot\text{L}^{-1}$, with a small direct sensory relevance.

The sum of acetates of higher alcohols (acetates), responsible for fruity notes (ROMANO *et al.* 1987), only differed statistically between the excessively clarified level T0, with the lowest content, and T1, with the highest, whereas a decreasing trend appeared at increasing turbidity levels. This behaviour substantially agrees with that observed by HOUTMANN *et al.* (1980), though here with a less marked decrease. In any case, variations between T1 and T5 were limited, around $250 \text{ }\mu\text{g}\cdot\text{L}^{-1}$. T1, T2 and T0 in decreasing order of content differed significantly from

T3 and T5 for fatty acid ethyl esters (esters). Thus fruity aroma could reach its maximum in correspondence with T1, due to acetates and esters, while the contribution of the former, expressed as the acetates/esters ratio, rises slightly with turbidity from about 1.3 up to 1.5.

Greater turbidity resulted in a clear decrease in hexanoic, octanoic, decanoic and to some extent also butanoic acid, at least from T1 to T5, confirming a previous work of EDWARDS *et al.* (1990) where NTU levels were not specified. The difference in the sum of quoted fatty acids was about $3 \text{ mg}\cdot\text{L}^{-1}$, probably not significant in direct sensory terms. On the other hand, isovaleric acid increased significantly with turbidity, with a difference of about $200 \text{ }\mu\text{g}\cdot\text{L}^{-1}$ in the turbidity range tested, which can probably penalise wine quality by masking more pleasant aromas.

Focusing on other major compounds in terms of sensory relevance, vinylphenols, 2-phenylethanol and methionol increased with turbidity. As regards vinylphenols and 2-phenylethanol, their increase with turbidity - about $90 \text{ }\mu\text{g}\cdot\text{L}^{-1}$ and $9 \text{ mg}\cdot\text{L}^{-1}$, respectively - could contribute to enhancing spicy-floral notes, while a direct methionol-related detrimental effect on wine quality (*e.g.* cabbage notes) seems unlikely given the quantity involved, about $300 \text{ }\mu\text{g}\cdot\text{L}^{-1}$.

Ethyl lactate, as well as γ -butyrolactone, increased significantly with turbidity while ethyl succinate, diethyl succinate and diethyl malate showed the same behaviour with maximum in correspondence with the T3 level, but effects in sensory terms are unimportant.

Spread between turbidity levels (expressed as the maximum average / minimum average ratio) for each analytical parameter was below 1.5, with the exclusion of residual sugars (3.08), methionol (1.85), volatile acidity (1.82) and *cis* 3-hexenol (1.75). The variability of the content of each compound due to juice turbidity is definitely lower than variability due to the yeast strain, as proved by comparing the spread values gathered from a previous experiment (NICOLINI *et al.* 2009) in which 10 yeast strains were used for the fermentation of 6 varietal juices. Thus the choice of yeast strain to direct white wine aroma must be overriding as compared to NTU levels.

In conclusion - in the light of the results of this experiment, which took into account different grape varieties and assimilable nitrogen levels - juice turbidity levels just below 100 NTU are probably the best compromise for obtaining adequate fruity, fermentation notes for white wine, when the risk of languishing fermentation is carefully avoided by correct microbiological management at the winery, but slightly higher NTU levels would not really seem to penalise aroma quality, sometimes contributing to a slightly more complex aroma.

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Table

Volatile compound content in wine with respect to the turbidity of the relevant juice.
 Spread values (maximum average / minimum average) are also given.
 (§ = spread due to yeast strain, re-calculated from NICOLINI *et al.* 2009)

Parameter		Turbidity level						Spread	Yeast spread (§)
		mean value (n=10); Sign. Fisher's LSD test (p<0.05)							
Juice turbidity level	NTU	T0	T1	T2	T3	T4	T5		
		15 a	45 b	86 c	141 d	215 e	350 f		
Fermentation duration	day	T5	T4	T3	T2	T1	T0		
		15.6 a	16.7 ab	17.6 bc	18.0 bcd	19.3 cd	19.6 d	1.26	
Alcohol	% vol	T0	T1	T2	T4	T3	T5		
		11.78 a	11.98 b	12.05 b	12.05 b	12.06 b	12.07 b	1.02	
Total acidity	g l ⁻¹	T0	T1	T2	T3	T4	T5		
		6.34 a	6.36 a	6.45 ab	6.51 b	6.53 b	6.55 b	1.03	
Volatile acidity	g l ⁻¹	T5	T3	T2	T4	T1	T0		
		0.11 a	0.12 ab	0.12 ab	0.13 ab	0.15 b	0.20 c	1.82	
Glycerol	g l ⁻¹	T0	T1	T2	T3	T4	T5		
		5.73 a	6.13 b	6.35 bc	6.55 c	6.60 c	6.64 c	1.16	
Sugar	g l ⁻¹	T5	T3	T4	T2	T1	T0		
		2.4 a	2.7 ab	3.1 ab	3.2 ab	4.7 b	7.4 c	3.08	
Acetaldehyde	mg l ⁻¹	T5	T3	T2	T4	T1	T0		
		49.1 a	51.3 ab	52.1 ab	52.4 ab	56.3 b	64.4 c	1.31	2.38
Ethyl acetate	mg l ⁻¹	T5	T3	T4	T2	T0	T1		
		26.8 a	26.9 a	27.2 a	28.9 ab	29.1 ab	30.0 b	1.12	2.04
Hexanol	µg l ⁻¹	T0	T1	T3	T2	T4	T5		
		846 a	861 ab	889 abc	896 abc	926 bc	936 c	1.11	1.89
<i>trans</i> 3-hexenol	µg l ⁻¹	T0	T3	T1	T2	T4	T5		
		89.7 a	94.4 a	94.7 a	99.4 a	99.9 a	100.5 a	1.12	1.14
<i>cis</i> 3-hexenol	µg l ⁻¹	T5	T4	T3	T2	T1	T0		
		38.1 a	43.4 ab	49.6 bc	58.4 cd	65.3 d	66.8 d	1.75	1.41
Sum of C6 alcohols	µg l ⁻¹	T0	T1	T3	T2	T4	T5		
		1002 a	1021 a	1033 a	1053 a	1069 a	1074 a	1.07	1.78
Propanol	mg l ⁻¹	T3	T1	T4	T5	T2	T0		
		17.9 a	18.1 a	18.1 a	18.1 a	18.2 a	20.3 b	1.13	9.36
2-methyl-1-propanol	mg l ⁻¹	T0	T1	T2	T4	T3	T5		
		28.7 a	30.6 ab	31.2 b	32.4 bc	33.2 c	35.2 d	1.23	2.04
2-methyl-1-butanol	mg l ⁻¹	T0	T1	T2	T3	T4	T5		
		38.1 a	40.5 ab	41.2 bc	43.9 cd	45.8 de	48.4 e	1.27	1.47
3-methyl-1-butanol	mg l ⁻¹	T0	T1	T2	T4	T3	T5		
		154 a	164 b	171 b	181 c	183 c	199 d	1.29	1.32
Sum of higher alcohols	mg l ⁻¹	T0	T1	T2	T4	T3	T5		
		241 a	253 ab	262 b	277 c	278 c	300 d	1.24	1.94
Isobuthyl acetate	µg l ⁻¹	T1	T0	T3	T4	T5	T2		
		14.2 a	15.0 a	15.5 a	15.7 a	15.9 a	16.2 a	1.14	5.82
Isoamyl acetate	µg l ⁻¹	T0	T5	T4	T3	T2	T1		
		2219 a	2570 ab	2614 ab	2638 ab	2651 ab	2724 b	1.23	5.46
Hexyl acetate	µg l ⁻¹	T5	T4	T3	T2	T0	T1		
		147 a	155 ab	178 bc	194 cd	209 d	209 d	1.42	1.75
2-phenylethyl acetate	µg l ⁻¹	T0	T5	T2	T1	T3	T4		
		458 a	518 ab	531 ab	547 b	551 b	555 b	1.21	6.79
Sum of acetates	µg l ⁻¹	T0	T5	T4	T3	T2	T1		
		2900 a	3250 ab	3339 ab	3382 ab	3392 ab	3494 b	1.20	5.04
Ethyl butanoate	µg l ⁻¹	T0	T5	T4	T3	T2	T1		
		123 a	125 ab	129 ab	134 ab	143 b	144 b	1.17	1.62
Ethyl hexanoate	µg l ⁻¹	T3	T0	T4	T5	T2	T1		
		691 a	718 ab	747 ab	751 ab	804 b	826 b	1.20	1.66
Ethyl octanoate	µg l ⁻¹	T5	T4	T3	T2	T0	T1		
		921 a	989 ab	1007 ab	1070 bc	1118 c	1139 c	1.24	1.93
Ethyl decanoate	µg l ⁻¹	T5	T4	T3	T2	T1	T0		
		253 a	263 a	281 ab	318 bc	355 cd	374 d	1.48	1.79
Sum of ethyl esters	µg l ⁻¹	T5	T3	T4	T0	T2	T1		
		2051 a	2113 a	2128 ab	2333 bc	2336 bc	2463 c	1.20	1.80
Isobutanoic acid	µg l ⁻¹	T0	T1	T5	T2	T4	T3		
		815 a	881 ab	903 b	930 b	931 b	931 b	1.14	2.96
Butanoic acid	µg l ⁻¹	T5	T0	T3	T4	T2	T1		
		651 a	676 ab	688 ab	701 ab	722 b	734 b	1.13	1.42

Table, continued

Parameter	Turbidity level						Spread	Yeast spread (§)
	mean value (n=10); Sign. Fisher's LSD test (p<0.05)							
Isovaleric acid	T0	T1	T2	T3	T4	T5	1.23	2.39
$\mu\text{g l}^{-1}$	771 a	832 ab	845 bc	907 cd	933 d	945 d		
Hexanoic acid	T5	T4	T3	T2	T1	T0	1.24	1.61
$\mu\text{g l}^{-1}$	3328 a	3593 ab	3613 ab	3798 bc	4117 c	4125 c		
Octanoic acid	T5	T4	T3	T2	T1	T0	1.28	1.97
$\mu\text{g l}^{-1}$	5306 a	5836 ab	6123 bc	6326 bc	6691 c	6815 c		
Decanoic acid	T5	T4	T3	T2	T1	T0	1.37	1.72
$\mu\text{g l}^{-1}$	1453 a	1524 a	1604 a	1703 ab	1888 bc	1986 c		
4-vinylphenol	T0	T3	T1	T2	T5	T4	1.30	50.8
$\mu\text{g l}^{-1}$	195 a	201 a	221 ab	226 ab	250 b	253 b		
4-vinylguaiacol	T0	T1	T2	T3	T4	T5	1.47	23.1
$\mu\text{g l}^{-1}$	68 a	85 b	88 b	90 b	93 b	100 b		
Sum of vinylphenols	T0	T3	T1	T2	T4	T5	1.33	33.7
$\mu\text{g l}^{-1}$	263 a	291 ab	306 ab	315 ab	347 b	351 b		
Methionol	T0	T1	T2	T3	T4	T5	1.85	9.56
$\mu\text{g l}^{-1}$	349 a	425 b	489 b	576 c	580 cd	647 d		
2-phenylethanol	T0	T1	T2	T5	T4	T3	1.26	2.14
mg l^{-1}	31.89 a	35.37 b	37.12 b	39.80 c	40.03 c	40.32 c		
Ethyl lactate	T0	T1	T2	T3	T4	T5	1.28	1.84
$\mu\text{g l}^{-1}$	489 a	507 a	559 b	592 bc	602 bc	625 c		
Ethyl succinate	T0	T1	T2	T5	T4	T3	1.23	2.81
$\mu\text{g l}^{-1}$	5646 a	6134 ab	6340 bc	6652 cd	6699 cd	6936 d		
Diethyl malate	T0	T2	T1	T5	T4	T3	1.29	1.46
$\mu\text{g l}^{-1}$	38.2 a	46.5 ab	47.4 b	47.7 b	47.7 b	49.1 b		
Diethyl succinate	T0	T1	T2	T5	T4	T3	1.18	2.57
$\mu\text{g l}^{-1}$	84.5 a	95.4 b	95.9 b	96.2 b	97.2 b	99.8 b		
γ -butyrolactone	T0	T1	T2	T3	T4	T5	1.41	4.08
$\mu\text{g l}^{-1}$	204 a	215 ab	245 bc	263 cd	280 d	287 d		

References

- BAYONOVE, C.; ROUFET, M.; CORDONNIER, R.; 1987: Données sur les pré-curseurs d'arôme préfermentaire: cas des acides gras insaturés du raisin. In: A. SCIENZA, G. VERSINI (Eds): The aromatic substances in grapes and wines, 93-112. Proc. Int. Symp., S. Michele a/A, Italy, June 25-27, 1987.
- BERTRAND, A.; 1978: Influence de débouillage et de la température de fermentation sur les teneurs en substances volatiles des vins blancs. Ann. Technol. Agric. **27**, 231-233.
- BERTRAND, A.; MARLY-BRUGEROLLE, C.; SARRE, C.; 1978: Influence du débouillage des moûts et du sulfitage sur les teneurs en substances volatiles des vins et des eaux-de-vie. Conn. Vigne Vin **12**, 35-48.
- BOIDO, E.; LLORET, A.; MEDINA, K.; FARIÑA, L.; CARRAU, F.; VERSINI, G.; DELLACASSA, E.; 2003: Aroma composition of *Vitis vinifera* cv. Tannat: the typical red wine from Uruguay. J. Agric. Food Chem. **51**, 5408-5413.
- BOSSO, A.; GUAITA, M.; 2008: Study of some factors involved in ethanal production during alcoholic fermentation. Eur. Food Res. Technol. **227**, 911-917.
- COCITO, C.; DELFINI, C.; 1997: Experiments for developing selective clarification techniques: sterol and fatty acid loss from grape must related to clarification technique. J. Wine Res. **8**, 187-197.
- CORDONNIER, A.; BAYONOVE, C.; 1977: L'arôme du vin, sa formation enzymatique durant la phase préfermentaire de la vinification. Rivista Italiana E.P.P.O.S. **59**, 158-163.
- DELFINI, C.; CERVETTI, F.; 1991: Metabolic and technological factors causing large amounts of acetic acid productions by yeasts during alcoholic fermentation. Die Weinwissenschaft **46**, 142-150.
- DELFINI, C.; COSTA, A.; 1993: Effects of the grape must lees and insoluble materials on the alcoholic fermentation rate, production of acetic acid, pyruvic acid and acetaldehyde. Am. J. Enol. Vitic. **44**, 86-92.
- DI STEFANO, R.; CIOLFI, G.; 1982: Trasformazione delle aldeidi e degli alcoolici C_6 ad opera dei lieviti nel corso del processo fermentativo. Riv. Vitic. Enol. **35**, 431-435.
- EDWARDS, C. G.; BEELMAN, R. B.; BARTLEY, C. E.; MCCONNELL, A. L.; 1990: Production of decanoic acid and other volatile compounds and the growth of yeast and malolactic bacteria during vinification. Am. J. Enol. Vitic. **41**, 48-56.
- GOMEZ, E.; MARTINEZ, A.; LAECINA, J.; 1993: Influence of SO_2 and yeast development on the evolution of C_6 compounds during the first hours of vinification. Ital. J. Food Sci. **5**, 263-268.
- GABRI, G.; SALVAGIOTTO, R.; 1980: Dosamento gas-cromatografico simultaneo della acetaldedeide, del metanolo, dell'acetato e del lattato d'etile, e degli alcoolici superiori nei distillati alcolici. Vini d'Italia **124**, 37-43.
- GERBAUX, V.; MEURGUES, O.; 1996: Influence du sulfitage et du débouillage des moûts sur l'élaboration et la qualité des vins de Chardonnay. Rev. Oenol. **78**, 15-18.
- GROAT, M.; OUGH, S. C.; 1978: Effects of insoluble solids added to clarified musts on fermentation rate, wine composition, and wine quality. Am. J. Enol. Vitic. **29**, 112-119.
- HATANAKA, A.; 1993: The biogeneration of green odour by green leaves. Phytochemistry **34**, 1201-1218.
- HERRAIZ, T.; HERRAIZ, M.; REGLERO, G.; MARTIN-ALVAREZ, P. J.; CABEZUDO M. D.; 1990: Changes in the composition of alcohols and aldehydes of C_6 chain length during the alcoholic fermentation of grape must. J. Agric. Food Chem. **38**, 969-972.
- HOUTMAN, A. C.; MARAIS, J.; DU PLESSIS, C. S.; (1980): Factors affecting the reproducibility of fermentation of grape juice and of the aroma composition of wines. Vitis **19**, 37-54.
- HOUTMAN, A. C.; DU PLESSIS, C. S.; (1986 a): The effect of grape cultivar and yeast strain on fermentation rate and concentration of volatile components in wine. S. Afr. J. Enol. Vitic. **7**, 14-20.
- HOUTMAN, A. C.; DU PLESSIS, C. S.; (1986b): Nutritional deficiencies of clarified white grape juices and their correction in relation to fermentation. S. Afr. J. Enol. Vitic. **7**, 39-46.
- KARAGIANNIS, S.; LANARIDIS, P.; 2002: Insoluble grape material present in must affects the overall fermentation aroma of dry white wines made from three grape cultivars cultivated in Greece. J. Food Sci. **67**, 369-374.

- LAFON-LAFOURCADE, S.; LARUE, F.; BRECHOT, P.; RIBEREAU-GAYON, P.; 1977: Les stéroïdes «facteurs de survie» des levures au cours de la fermentation alcoolique du moût de raisin. C. R. Hebd. Seances Acad. Sci. Ser. D. **284**, 1939-1942.
- LARCHER, R.; NICOLINI, G.; PUECHER, C.; BERTOLDI D.; MOSER S.; FAVARO G.; 2007: Determination of volatile phenols in wine using high-performance liquid chromatography with a coulometric array detector. Anal. Chim. Acta **582**, 55-60.
- MEILGAARD, M. C.; 1975: Aroma volatiles in beer: purification, flavour, threshold and interaction. In: F. Drawert (Ed.): Geruch- und Geschmacksstoffe, 211-254. H. Carl, Nürnberg.
- NICOLINI, G.; VERSINI, G.; AMADEI, E.; MARCHIO, M.; 1996: 3-Hexen-1-ol isomers in Müller-Thurgau wines: a "varietal" characteristic affected by must sulfiting time. *Vitis* **35**, 147-148.
- NICOLINI, G.; VERSINI, G.; CORRADIN, L.; LARCHER, R.; BERETTA, C.; OLIVARI, A.; ECCLI, E.; (2004 a): Misura dell'azoto prontamente assimilabile dal lievito nei mosti d'uva ed esempi di applicazione. Riv. Vitic. Enol. **57**, 13-27.
- NICOLINI, G.; LARCHER, R.; VERSINI, G.; (2004 b): Status of yeast assimilable nitrogen in Italian grape musts, and effect of variety, ripening and vintage. *Vitis* **43**, 89-96.
- NICOLINI, G.; MOSER, S.; LARCHER, R.; INNOCENTI, M.; ZANON, N.; BARCETTI, P.; 2009: Variabilità indotta da lieviti commerciali nella composizione di vini bianchi sperimentali. *L'Enologo* **45**, 89-96.
- RIBEREAU-GAYON, P.; LAFON-LAFOURCADE, S.; BERTRAND, A.; 1975: Le débouillage de moûts de vendange blanche. *Conn. Vigne Vin* **9**, 117-139.
- ROMANO, F.; VERSINI, G.; BERTAMINI, M.; DALLA SERRA, A.; DELL'EVA, M.; FALCETTI, M.; POLETTI, V.; 1987: Approccio psicofisico all'analisi sensoriale dei vini. Determinazione di una scala psico-fisica intervallare per l'aroma di fruttato tipo mela/caramella/acetone correlato agli acetati e tipo banana/ananas correlato agli esteri. In: A. SCIENZA, G. VERSINI (Eds): The aromatic substances in grapes and wines, 427-439. Proc. Int. Symp. S. Michele a/A Italy, June 25-27, 1987.
- USSEGLIO-TOMASSET, L.; MATTA, M.; 1983: Valutazione dei risultati di un'analisi gascromatografica collaborativa degli alcoli superiori nelle grappe. *Boll. Chim. Lab. Prov.* **34**, 185-207.

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