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Exploring the impact of yeast derivatives on aromatic and sensory profiles of white and red wines: a multifactorial study

Laurie Favieres[*1,2], Marion Bastien[2], Céline Poncet-Legrand[1], Thierry Doco[1], Aude Vernhet[1], Teddy Godet[1], Valérie Nolleau[1], Stéphanie Roi[1], Stéphanie Carrillo[1], Nathalie Sieczkowski[2], Julie Mekoue[2], Peggy Rigou[1]

[1] SPO, Univ Montpellier, INRAE, Institut Agro, Montpellier, France

[2] Lallemand SAS, 19 rue des briquetiers, 31702 Blagnac Cedex, France

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**correspondence:*
laurie.favieres@supagro.fr

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ABSTRACT

Specific inactivated Yeast Derivatives (SYDs) are obtained from *S. cerevisiae* yeasts by various processes (thermal, mechanical, and enzymatic) and have diverse oenological applications to improve wine quality. However, different impacts on wine sensory characteristics and aromas were reported depending on SYD types and fractions, wine matrices, and experimental settings. Few works have examined the impact of SYDs on aromas while also considering their effects on wine macromolecules influencing organoleptic properties. This work aimed to implement a multifactorial approach to study the impact of different SYDs on the aromatic composition and the sensory profile of one white and one red wine at a pilot scale. Concomitant analyses of wine characteristics, including oenological properties, polyphenolic and polysaccharidic compositions, were performed. Wines were treated with various *S. cerevisiae* SYDs provided by Lallemand at oenological dosages. The impacts on olfactory and gustatory properties were studied with a sensory panel of trained judges using monadic profiling. The volatile profile of wines was determined by HS-SPME-GC-MS, polysaccharide content by GC-MS following hydrolysis and derivatisation, and polyphenol content and profiles by UV-visible spectrophotometry and size-exclusion chromatography.

Yeast derivative and wine matrix effects were observed in the variation of volatile compounds in treated wines compared to the control wine for all chemical classes. Results from the chemical analysis showed that the release of aroma compounds in the headspace varied according to the SYDs used. This effect was accentuated in the white wine, thus highlighting the matrix effect. Correlations between significant aroma variations in the headspace and their hydrophobicity were found. The wines resulting from the different treatments could be separated by sensory and principal component analysis (PCA), and according to the modulated sensory attributes, such as red and black fruit, citrus. In addition to improving the understanding of the interaction phenomena between SYDs and aroma compounds in wine, these results may also help anticipate the sensory and aromatic impacts of their use in oenological applications.

KEYWORDS: yeast derivatives, volatile compounds, interactions, wine matrix

INTRODUCTION

Ageing on lees has long been used to enhance wine quality through the release of polysaccharides, peptides, lipids and amino acids from yeast during autolysis. These components interact with volatile and phenolic compounds, improve mouthfeel, reduce astringency and contribute to wine tartaric, colloidal colour and aroma stability (Andújar-Ortiz, 2011; Andújar-Ortiz *et al*., 2014; Bautista *et al*., 2007; Feuillat *et al*., 2001). However, this process is slow and may introduce risks of microbiological instability or undesirable sensory changes over extended periods.

To overcome these limitations, specific yeast derivatives (SYDs) have been introduced as efficient alternatives to traditional ageing on lees. SYDs are mainly produced from *Saccharomyces cerevisiae* through physical or enzymatic processes. Inactivated yeasts are derived from biomasses inactivated by heat and/or a change in pH and used without dose limitations (OIV, 2013b), while yeast cell walls must not exceed 40 g/hL (OIV, 2013a). Protein extracts from yeast derivatives are also obtained through physical processes followed by liquid extraction and can be applied at a maximum recommended dose of 60 g/hL in red wines and 30 g/hL for white and rosé wines (OIV, 2024). Mannoproteins, extracted from yeast cell walls through physico-chemical or enzymatic processes, must not exceed 40 g/hL in wines (OIV, 2004). Depending on their composition, SYDs can serve various oenological purposes such as enhancing colloidal stability, preventing oxidation, and improving aroma, taste, and mouthfeel of the resulting wines (Andújar-Ortiz *et al*., 2014; Comuzzo *et al*., 2006; González-Royo *et al*., 2017; Pozo-Bayón *et al*., 2009; Ruipérez *et al*., 2022; Stamenković Stojanović *et al*., 2023).

Moreover, SYDs have been shown to influence wine sensory profiles by binding or releasing volatile compounds (Ames & Elmore, 1992; Ames & Leod, 1985; Comuzzo *et al*., 2006; Del Barrio-Galán *et al*., 2012; Lafon-Lafoucarde *et al*., 1984; Lubbers, Charpentier, *et al*., 1994; Lubbers *et al*., 1994; Pozo-Bayón *et al*., 2009). Variability in commercial SYDs composition and solubility resulting from the use of different yeast strains, manufacturing processes, and source materials challenges the comparison of their effects across scientific studies; such variability leads to inconsistent impacts on wine aroma and sensory properties (Rigou *et al*., 2021).

Most of the research has focused on the effects of one specific type of SYDs used to produce a particular wine style, but few have led a comparative study of their short-duration applications on different wine types. Therefore, this study aimed to evaluate the effects of a diverse range of specific yeast derivatives—inactivated dry yeast, yeast cell walls, protein extracts, and mannoproteins—on the quality of red and white wines after fermentation. Treatments were carried out for a short-term period and in accordance with the recommendations for use. Combining chemical analysis of neutral polysaccharides, polyphenols, and volatile compounds with sensory analysis, we evaluated the impact of these preparations through a multifactorial approach.

MATERIALS AND METHODS

1. Wine's preparation and treatments

The study was performed with wines produced by the experimental research unit of Pech Rouge (INRAe, Narbonne, France). The red wine (RW) G14 was obtained by inoculation of the must with 20 g/hL of NT 202 *S. cerevisiae* yeast (Oenobrands, Montferriez-sur-lez, France) and 20 g/hL of Go FermProtect™ (Lallemand Inc., Montreal QC, Canada) for the alcoholic fermentation and 10 g/hL of ML PRIME™ *Lactiplantibacillus plantarum* (Lallemand Montreal QC Canada) for the malolactic fermentation. For the white wine (WW), G5 must was inoculated with 20 g/hL of Lalvin R2™ (Lallemand Montreal QC, Canada) *S. cerevisiae* yeast and 30 g/hL of Go FermProtect.

Specific *S. cerevisiae* inactivated yeast derivatives (SYDs) were provided by Lallemand Inc. (Montreal, QC, Canada): inactivated yeasts (IY), selected cell walls (CW), a yeast protein extract (YPE), and mannoproteins (MP).

Post-fermentation treatments of both wines with 0.6 g/L of SYDs lasted 15 days and were performed in triplicate. Stock solutions at 100 g/L of IY, CW and YPE were prepared by rehydrating and solubilising the dry powder in osmose water, while a stock solution of MP at 100 g/L was prepared in osmosis water and homogenization at room temperature. 20 L beer kegs were inerted with nitrogen, topped up with wine added with 120 mL of stock SYDs solution. The oxygen level was measured just after the barrels were filled. Barrels were stored at a controlled temperature (15 °C) and stirred by rolling once a week. After 15 days of treatment, wines were filtered, bottled and stored at 15 °C.

As a control, a model wine (ethanol 12 % v/v, tartaric acid 3.5 g/L, NaCl 2.175 g/L, glycerol 6 g/L, pH 3.5) was subjected to identical treatment.

2. Analytical methods

2.1. Oenological properties determination

Oenological parameters such as pH, alcohol volume (%), volatile acidity (VA), total acidity (TA) (g/L H_2SO_4) and Total polyphenols index (TPI) were determined according to the method developed by Glories *et al.* (Glories, 1984). Colour parameters (L*, a* and b*, respectively, corresponding to lightness, red-green balance and blue-yellow balance, colour difference $\Delta E\text{^}* = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2}$), free and total SO2 content (mg/L), were determined using the International Organisation of Vine and Wine (OIV) official methods (OIV, 2009b, 2009a, 2009b, 2011, 2011, 2015, 2015). Anthocyanins content (mg/L) was measured by the method of Puissant-Léon *et al.* (Puissant & Léon, 1967). The absorbance measurements were performed with an Evolution 300 Spectrophotometer (Thermo Fisher Scientific, France).

2.2. Neutral polysaccharides analysis

Polysaccharides in wines were analysed by high-performance size exclusion chromatography (HSPEC) as described by

Ducasse *et al.* (Ducasse *et al*., 2010). Briefly, wines (5 mL) were depigmented in polyamide CC6 columns previously equilibrated with NaCl 1 M. Wine polysaccharides and oligosaccharides not retained in the polyamide column were eluted by two bed volumes of 1 M NaCl. High-performance size-exclusion chromatography (HPSEC) was performed by loading 2 mL of the concentrated total wine carbohydrate on a Superdex-30 HR column (60 × 1.6 cm, Pharmacia, Sweden) with a precolumn (0.6 × 4 cm) equilibrated at 1 mL/min with 30 mM ammonium formiate, pH 5.6. The elution of polysaccharides and oligosaccharides was monitored using an Erma-ERC 7512 (Erma, Tokyo, Japan) refractive index. The isolated fractions of polysaccharides and oligosaccharides were freeze-dried, redissolved in water and freeze-dried again four times to remove the ammonium salt. Identification and quantification of neutral glycosyl-residue composition of wine polysaccharides was done as described by Ducasse *et al.* (Ducasse *et al*., 2010). Inositol and allose were used as internal standards. Chromatographic analysis was performed by a SHIMADZU GC-2010-Plus gas chromatography system using a fused silica capillary column DB-225 (30m × 0.25 µm × 0.25 mm ID) (Agilent J&W, Santa Clara, USA) with H_2 as the carrier gas. The wine polysaccharide composition was estimated from the concentration of individual glycosyl residues determined by GC–MS after hydrolysis, reduction and acetylation as previously described by Ducasse *et al.* (Ducasse *et al*., 2010).

2.3. Polyphenols determination

Molecular size distribution of polyphenols was analysed by High Performance Size-Exclusion Chromatography (HPSEC-DAD) according to the method developed by Vernhet *et al.* (Vernhet *et al*., 2020) with slight modifications described by Assunçao *et al.* (Assunçao, 2022). 1 mL of sample was dried under vacuum with Genevac, then dissolved in 500 µL of distilled water and frozen for lyophilisation. The freeze-dried residue was dissolved in 500 µL of eluent (94 % v/v dimethylmethanamide, 1 % v/v acetic acid, 5 % water and 0.15 M of LiCl) for white and model wines and 1 mL of the same eluent for red wines. An ultrasonic bath was used to solubilise the samples at room temperature. Samples were then centrifuged at 20,000 g for 10 min, and supernatants were collected for analysis. A total of 200 µL of supernatant was used for white and model wines analysis, and 50 µL was used for red wine samples. Samples were injected into a 1260 Infinity II HPLC system (Agilent Technologies, Santa Clara, USA). Chromatographic analysis was performed with OpenLab and ChemFlow software.

2.4. Volatile analysis of wines (HS-SPME-GC-MS)

2.4.1. SPME sampling conditions

SPME analysis was performed using the CTC CombiPal autosampler and according to the method reported by Yang *et al*. (Yang *et al*., 2019) with some modifications. 1 mL of wine sample was poured into a 20 mL headspace vial (BGB Analytic) and 9 mL of water, 1 g NaCl and 10 µL of internal standard 1-Octanol at 0.04 g/L were added. Wine dilution in water aimed at reducing the ethanol effect on volatility and adsorption of aroma compounds on the fibre, thus improving the method's sensitivity (Davis & Qian, 2019). A 2 cm 50/30 µm divinylbenzene/carboxen/polydimethylsiloxane fibre (Supelco) was used for headspace extraction. SPME of the sample was run at 40 °C for 30 min, and after 15 min of sample equilibration at the same temperature and under agitation at 250 rpm. Between each sample, the fibre was conditioned in a second injector at 270 °C for 30 min. Sample injection was performed by direct introduction of the SPME fibre into the GC injector and under the conditions described in the next section.

2.4.2. GC-MS analysis

GC-MS analysis was performed using a TRACE 1300 (Thermo Scientific) gas chromatograph coupled to an ISQ 7000 (Thermo Scientific) single quadrupole mass spectrometer. The analytical column used was a FFAP capillary column with dimensions 30 m × 0.25 mm × 0.25 µm (Agilent Technologies, USA). The method of Yang *et al.* (2019) was used with some modifications. Fibre was desorbed in splitless mode in the GC injector for 3 min at 250 °C (Yang *et al*., 2019). The carrier gas used was ultra-pure helium at a flow rate of 1 mL/min. The oven was heated at 40 °C for 3 min, then heated up to 210 °C at 3 °C/min, then at 245 °C at 5 °C/min, and this temperature was held for 5 min. The temperature of the transfer line was 240 °C, and the ion source was set at 230 °C. Mass detector conditions were as follows: voltage of electron impact was 70 eV, mass scanned started at 0.50 min and ranged from m/z 47 to 250 at a frequency of 0.2 s per scan.

Compound identification was performed using NIST, Wiley and other internal libraries. Kovats indices were calculated from the retention times of n-alkanes (C10-C20) and compared with Kovats indices found in the literature. Semi-quantification was performed by calculating the area ratio of compounds against the area ratio of the internal standard in the sample. The mean variation of the concentration of the compounds in the wines' headspace was determined by dividing the difference between the mean concentration of the compound in the treated wines and the control wine by the mean concentration of the compound in the control wine.

2.5. Sensory analysis of wines

2.5.1. Panel selection and training

Sensory analyses were carried out in an open room by judges from Lallemand's internal panel, that is regularly trained on wine descriptors with the "Make Scents of Wine" kit. The olfactory properties of the white wines were analysed by 16 judges (10 women and 6 men), and gustatory properties by 14 judges (3 men and 11 women). The olfactory and gustatory properties of the red wines were analysed by 14 judges (11 women and 3 men). Sensory descriptors were selected for the panel with validation from the judges using a pivot wine containing all the samples in equivalent proportion (Thuillier *et al*., 2015).

2.5.2. Quantitative descriptive analyses

Validated white wine aroma attributes were citrus fruit (lemon, grapefruit), amylic (banana, candy), exotic fruit (mango, passion fruit), fleshy fruit (peach, pear), floral and vegetal. Red wine aroma attributes were red fruit (strawberry, raspberry, redcurrant), black fruit (blackberry, blueberry, blackcurrant), spicy (pepper, liquorice, cinnamon, tobacco), vegetal (bell pepper, mint). The following gustatory properties were evaluated for both wines: warmth, acidity, volume, sweetness, balance, astringency, bitterness and persistence. White wines were served at 16 °C and red wines at 18 °C, in INAO crystallin wine glasses. For all tests, wines were given in randomised order following William's Latin square design (Williams, 1949). Wine sensory properties were evaluated on a scale of 0 to 10 by monadic profiling using the TastelWeb software (ABT Informatique, France).

2.6. Statistical analysis

A one-way Analysis of Variance (ANOVA) was carried out for all the data obtained, and means and standard deviations were calculated. Significant differences were evaluated by the Tukey Honest Significant Difference (HSD) Test with Bonferroni adjustment. Results were considered significant at $p < 0.05$. For sensory analysis, significant differences were considered for $p < 0.05$, while a trend was considered for $0.05 < p < 0.10$. PCA analysis was carried out on mean values after standardisation.

All the statistical evaluations were performed using R software (version 4.3.2) and RStudio (2023.09.1+494) for Windows.

RESULTS AND DISCUSSION

1. Interactions between aroma compounds and yeast derivatives in red and white wines

1.1. Influence of SYD's solubility on wine volatile composition

The relative concentrations of volatile compounds in the wines' headspace after 15 days of treatment with SYDs are shown in Tables 1 and 2, and the variation of the concentration of the compounds in the wines' headspace compared to the control wine is shown in Figure 1. Volatile compounds either increased or decreased in red and white wine headspaces, but different trends depend on the solubility of the SYDs. The most insoluble fractions (IY and CW) mostly led to a stronger increase in the concentration of volatile compounds, whereas the most soluble fraction (YPE and MP) led to a stronger decrease in the concentration of volatile compounds. This trend was mainly observed with the white wines. In addition, insoluble SYDs affect the variation of a greater number of aroma compounds than soluble PDLs. More precisely, for white wines, IY and CW (that are mostly insoluble) led to a significant increase of the concentrations of 35 % and 47 % of the total volatile compounds and a decrease of concentration for 7 % and 5 % of compounds, respectively. Whereas, YPE and MP, which are mostly soluble, led to a low increase of only 9 % and 5 % of compounds and a decrease of 7 % and 16 % of compounds, respectively. For red wine, insoluble IY and CW also led to significant increases in the concentration of 18 % and 51 % of the compounds, respectively and decreases in the concentration of 15 % of the total compounds for both fractions. However, soluble YPE and MP led to an increase in concentration for a greater number of compounds (20 % and 25 % respectively) when compared to white wine. At last, red wine treatment with IY and CW resulted in a reduced concentration of 15 % of the total compounds, 7 % by YPE treatment and 18 % for MP, similar to the results observed in the white wine results.

All chemical families of volatile compounds were impacted by the SYDs, with pronounced effects on esters, acids, alcohols and terpenoids. However, some specific aroma compounds do not vary according to the general trends observed.

Indeed, regarding ester compounds, there is a tendency to increase in most white wines, whatever the solubility of the product (18 % for IY, 18 % for CW, 26 % for YPE, and a non-significant –13 % for MP) whereas in red wines, it decreased for the most insoluble fractions (–29 % for IY, –25 % for CW) and increased for the most soluble ones (non-significant +12 % for YPE and 23 % for MP). Ethyl octanoate has been shown in other studies to fluctuate in wines' headspace and wines over a period of several days of treatments with yeast derivatives (Del Barrio-Galán *et al*., 2012; Juega *et al*., 2015). Del-Barrio *et al.* (2012) have observed that ethyl octanoate decreased and then increased in model wine solutions between 15 and 30 days with several commercial yeast derivatives, and Juega *et al.* (2012) also observed the same variation between 10 and 20 days with lees (Juega *et al*., 2012). These results show that, in addition to the solubility of the products, the contact time is an important parameter which will have an impact on the final aromatic quality of the wine. Isoamyl acetate rose with mostly insoluble SYDs (35 % for IY and 18 % for CW) and decreased with soluble SYDs (–9 % for YPE and –17 % for MP). However, some authors have shown that the concentration of isoamyl acetate in the wine's headspace was not significantly impacted by whole mannoproteins or mannoprotein fractions after 24 h of treatment at 0.150 g/L (Chalier *et al*., 2007). The differences observed may be due to the shorter treatment time or the lower concentration used. Indeed, Del Barrio-Galan *et al.* (2012) observed that the concentration of isoamyl acetate in model wine solution increased after 60 days of treatment with parietal extracts, yeast cell walls and mannoproteins at 0.4 g/L. (Del Barrio-Galán *et al*., 2012). On the contrary, they observed its decrease in white wines after 2 months of treatments with increasing concentration (0.1–0.4 g/L) of an inactive dry yeast (Del Barrio Galán *et al*., 2018). Once again, these results highlight the possible reversibility of interaction phenomena between PDLs and aroma compounds and the importance of carefully controlling contact time, concentration and manufacturing of SYDs.

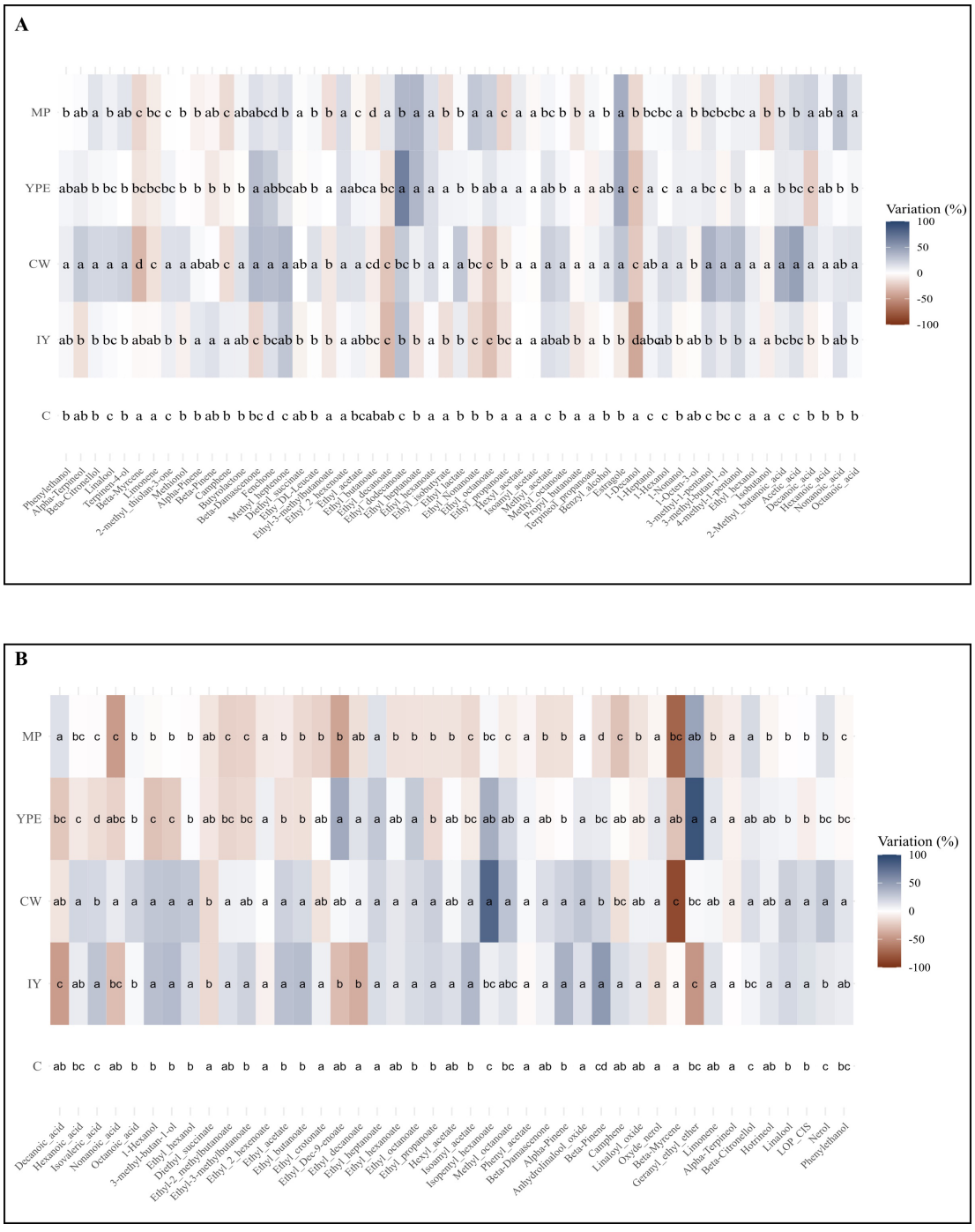

FIGURE 1. Heat maps of the variation of volatile compounds' concentration found in the red wines (A) and white wine headspace (B). C = control wine, IY = inactivated yeast, CW = cell walls, YPE = yeast protein extracts, MP = mannoproteins. Different letters indicate significant differences for $p < 0.05$.

Regarding acids, the concentration decreased as IY decreased its concentration while it increased with CW increased in both wines. For example, IY decreased the concentration of decanoic acid in the WW's headspace by 46 %. Other soluble fractions also had the opposite effects on decanoic acid concentration in the RW (–22 % for YPE and +22 % for MP). Lafon-Lafoucarde *et al.* (2004) found that yeast cell walls reduce octanoic acid (–54 %) and decanoic acid (–80 %) in white wines at 0.5 g/L after 24 h of treatment, whereas Comuzzo *et al.* (2006) report an increase of decanoic acid in the headspace of white wine treated with a yeast autolysate at 1 g/L after 15 days of treatment (Comuzzo *et al.*, 2006; Lafon-Lafoucarde *et al.*, 1984). However, Comuzzo *et al.* (2006) also detected the presence of acids in the raw yeast products and concluded that the increase of decanoic acid was due to the release of the compound from the raw products. Indeed, most insoluble yeast derivatives, such as yeast lees, cell walls have been reported to release exogenous volatile

TABLE 1. Volatile composition of the red wines' headspace after 15 days of contact determined by HS-SPME-GC-MS. Concentrations are expressed as equivalent of octan-1-ol in µg/L. (Part 1/2).

Compounds	RI	RI Ref	C	IY	CW	YPE	MP
Acids			49.1 ± 6.7	52.8 ± 7.5	63.7 ± 9.5	52.5 ± 7.4	56.5 ± 7.9
2-Methyl butanoic acid	1,666	1,666	8.1 ± 0.4 c	8.9 ± 0.7 bc	11.4 ± 0.9 a	9.0 ± 0.6 b	9.1 ± 0.4 b
Acetic acid	1,453	1,453	17.5 ± 1.7 c	19.9 ± 2.1 bc	25.9 ± 2.8 a	19.3 ± 1.5 bc	20.8 ± 0.9 b
Decanoic acid	2,270	2,270	1.7 ± 0.2 b	1.6 ± 0.2 b	2.0 ± 0.1 a	1.3 ± 0.2 c	2.1 ± 0.09 a
Hexanoic acid	1,842	1,842	5.8 ± 0.3 b	5.8 ± 0.4 b	6.3 ± 0.3 a	6.1 ± 0.2 ab	6.1 ± 0.1 ab
Nonanoic acid	2,164	2,164	1.2 ± 0.1 b	1.4 ± 0.2 ab	1.4 ± 0.2 ab	1.2 ± 0.2 b	1.6 ± 0.3 a
Octanoic acid	2,057	2,057	14.8 ± 0.9 b	15.2 ± 0.7 b	16.83 ± 0.26 a	15.46 ± 0.52 b	16.9 ± 1.1 a
Alcohols			2,697.8 ± 649.8	2946.0 ± 715.7	3401.3 ± 839.7	2624.5 ± 624.2	2774.8 ± 671.9
1-Decanol	1,758	1,758	0.4 ± 0.0 a	0.3 ± 0.0 d	0.3 ± 0.0 c	0.3 ± 0.0 c	0.4 ± 0.0 b
1-Heptanol	1,449	1,449	2.6 ± 0.2 c	2.7 ± 0.1 abc	2.77 ± 0.1 ab	2.9 ± 0.1 a	2.7± 0.1 bc
1-Hexanol	1,346	1,346	47.3 ± 1.8 c	53.0 ± 5.0 ab	55.23 ± 2.8 a	47.8 ± 4.0 c	48.5 ± 3.4 bc
1-Nonanol	1,655	1,655	2.8 ± 0.1 b	2.7 ± 0.1 b	3.2 ± 0.0 a	3.0 ± 0.1 a	3.1 ± 0.1 a
1-Octen-3-ol	1,445	1,445	1.5 ± 0.1 ab	1.5 ± 0.1 ab	1.4 ± 0.1 b	1.6 ± 0.1 a	1.4 ± 0.1 b
3-methyl-1-pentanol	1,319	1,320	3.6 ± 0.2 c	4.2 ± 0.4 b	5.0 ± 0.5 a	3.9 ± 0.4 bc	4.0 ± 0.4 bc
3-methyl-butan-1-ol	1,204	1,212	2,265.2 ± 105.6 bc	2,495.7 ± 279.9 b	2,928.9 ± 327.4 a	2,174.6 ± 167.1 c	2,342.4 ± 124.1 bc
4-methyl-1-pentanol	1,307	1,308	2.4 ± 0.2 c	2.8 ± 0.3 b	3.2 ± 0.2 a	2.8 ± 0.1 b	2.6 ± 0.1 bc
Ethyl hexanol	1,484	1,484	5.2 ± 0.3 a	5.5 ± 0.2 a	5.7 ± 0.4 a	5.2 ± 0.6 a	5.6 ± 0.6 a
Isobutanol	1,067	1,067	23.3 ± 1.7 a	21.5 ± 1.5 a	22.0 ± 1.5 a	22.9 ± 0.1 a	19.0 ± 0.6 b
Benzyl alcohol	1,867	1,867	2.3 ± 0.1 b	2.3 ± 0.1 b	2.56 ± 0.2 a	2.4 ± 0.0 ab	2.3 ± 0.1 b
Phenylethanol	1,899	1,899	341.2 ± 13.3 b	353.9 ± 15.7 ab	371.1 ± 22.0 a	357.3 ± 4.0 ab	343.0 ± 4.9 b
Estragole	1,656	1,656	1.9 ± 0.3 b	1.7 ± 0.3 b	2.5 ± 0.2 a	2.8 ± 0.2 a	2.7 ± 0.3 a
Esters			1,449.2 ± 123.6	1,372.3 ± 121.8	1,438.1 ± 125.7	1,529.2 ± 129.4	1,491.8 ± 126.6
Diethyl succinate	1,673	1,673	15.1 ± 0.6 ab	14.2 ± 1 b	15.1 ± 0.6 ab	14.9 ± 0.9 ab	15.4 ± 0.5 a
Ethy DL-Leucate	1,537	1,538	2.3 ± 0.2 b	2.3 ± 0.1 b	2.6 ± 0.1 a	2.4 ± 0.1 b	2.4 ± 0.2 b
Ethyl-3-methylbutanoate	1,010	1,041	28.1 ± 1.1 a	25.2 ± 2.6 b	25.2 ± 0.7 b	28.1 ± 0.7 a	24.0 ± 0.7 b
Ethyl 2 hexenoate	1,329	1,328	1.2 ± 0.2 a	1.2 ± 0.2 a	1.3 ± 0.1 a	1.3 ± 0.1 a	1.4 ± 0.1 a
Ethyl acetate	-	-	310.7 ± 16.5 bc	329.8 ± 18.9 ab	353.1 ± 34.1 a	325.9 ± 7.5 abc	299.3 ± 4.4 c
Ethyl butanoate	-	-	93.5 ± 5.3 ab	88.5 ± 6.0 bc	86.0 ± 3.4 cd	97.0 ± 2.8 a	82.2 ± 2.9 d
Ethyl decanoate	1,630	1,631	39.4 ± 6.0 ab	26.6 ± 1.4 c	29.0 ± 4.7 c	33.8 ± 8.0 bc	43.8 ± 6.7 a
Ethyl dodecanoate	1,836	1,836	0.3 ± 0.0 c	0.4 ± 0.0 b	0.4 ± 0.0 bc	0.5 ± 0.1 a	0.4 ± 0.1 b
Ethyl heptanoate	1,317	1,317	1.32 ± 0.1 b	1.2 ± 0.1 b	1.4 ± 0.1 b	1.8 ± 0.3 a	1.8 ± 0.2 a
Ethyl hexanoate	1,210	1,254	191.5 ± 53.2 a	195.8 ± 33.3 a	222.7 ± 12.4 a	222.5 ± 36.5 a	220.7 ± 24.7 a
Ethyl isobutyrate	-	-	16.5 ± 0.8 a	14.2 ± 1.4 b	16.9 ± 1.1 a	17.6 ± 0.3 a	14.2 ± 0.5 b
Ethyl lactate	1,336	1,337	8.5 ± 0.4 b	9.4 ± 0.9 b	10.9 ± 0.9 a	9.0 ± 0.3 b	8.7 ± 0.3 b
Ethyl Nonanoate	1,527	1,527	1.0 ± 0.1 b	0.8 ± 0.2 c	0.9 ± 0.1 bc	1.0 ± 0.1 b	1.3 ± 0.1 a
Ethyl octanoate	1,423	1,426	242.1 ± 17.4 b	172.3 ± 36.7 c	180.8 ± 5.9 c	272.9 ± 33.4 ab	297.5 ± 27.4 a
Ethyl propanoate	-	-	13.6 ± 0.7 a	11.7 ± 0.9 bc	12.5 ± 0.7 b	14.4 ± 0.3 a	11.1 ± 0.4 c
Hexyl acetate	1,257	1,257	2.0 ± 0.5 a	2.0 ± 0.1 a	2.0 ± 0.2 a	2.1 ± 0.2 a	2.2 ± 0.0 a
Isoamyl acetate	1,097	1,096	448.5 ± 32.4 a	446.4 ± 40.4 a	443.7 ± 12.8 a	450.5 ± 30.5 a	435.0 ± 9.9 a
Methyl acetate	-	-	1.5 ± 0.1 c	1.7 ± 0.1 ab	1.8 ± 0.2 a	1.7 ± 0.1 ab	1.6 ± 0.0 bc
Methyl octanoate	1,376	1,374	1.4 ± 0.2 b	1.6 ± 0.1 ab	1.7 ± 0.1 a	1.5 ± 0.2 b	1.4 ± 0.1 b
Propyl butanoate	-	-	29.0 ± 1.7 a	25.9 ± 2.3 b	28.3 ± 2.2 a	28.8 ± 1.0 a	25.8 ± 0.5 b
Terpineol propanoate	1,487	1,747	1.7 ± 0.1 a	1.6 ± 0.1 a	1.7 ± 0.1 a	1.6 ± 0.2 a	1.7 ± 0.2 a

TABLE 1. Volatile composition of the red wines' headspace after 15 days of contact determined by HS-SPME-GC-MS. Concentrations are expressed as equivalent of octan-1-ol in µg/L. (Part 2/2).

Compounds	RI	RI Ref	C	IY	CW	YPE	MP
Ketones			2.7 ± 0.3	3.5 ± 0.1	3.7 ± 0.4	3.1 ± 0.4	3.2 ± 0.2
Methyl heptenone	1,319	1,319	2.7 ± 0.31 c	3.5 ± 0.1 ab	3.7 ± 0.4 a	3.1 ± 0.4 bc	3.2 ± 0.2 b
Lactones			1.1 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	1.1 ± 0.1	1.2 ± 0.1
Butyrolactone	1,612	1,611	1.1 ± 0.1 b	1.2 ± 0.1 ab	1.3 ± 0.1 a	1.1 ± 0.1 b	1.2 ± 0.1 ab
Norisoprenoids			7.0 ± 4.0	7.8 ± 4.8	9.3 ± 5.0	8.9 ± 5.0	7.8 ± 4.4
Beta-Damascenone	1,800	1,800	0.7 ± 0.2 bc	0.56 ± 0.1 c	0.9 ± 0.1 a	0.9 ± 0.1 a	0.8 ± 0.2 ab
Fenchone	1,368	1,383	6.3 ± 0.5 d	7.3 ± 0.7 bc	8.3 ± 0.8 a	7.9 ± 0.3 ab	7 ± 0.2 cd
Sulfur compounds			9.8 ± 0.2	9.9 ± 0.3	11.3 ± 0.2	10.1 ± 0.0	9.8 ± 0.2
2-methyl thiolan-3-one	1,510	1,510	4.8 ± 0.2 c	5.2 ± 0.3 b	5.5 ± 0.3 a	5.1 ± 0.1 bc	4.8 ± 0.1 c
Methionol	1,707	1,707	5.0 ± 0.4 b	4.7 ± 0.5 b	5.8 ± 0.5 a	5.0 ± 0.3 b	5.0 ± 0.1 b
Terpenes			1,382.9 ± 470.5	1,538.1 ± 524.9	1,416.2 ± 487.8	1,345.5 ± 463.7	1,297.5 ± 441.2
Alpha-Pinene	-	-	1,185.6 ± 56.7 b	1,321.4 ± 131.7 a	1,226.4 ± 8.6 ab	1,166.4 ± 52.2 b	1,111.6 ± 53.6 b
Beta-Pinene	1,043	1,065	133.6 ± 18.1 ab	153.4 ± 31.6 a	1,34.7 ± 11.7 ab	119.7 ± 15.0 b	128.5 ± 17.5 ab
Camphene	-	-	15.1 ± 0.8 b	16.3 ± 1.3 a	12.8 ± 0.1 c	14.3 ± 0.7 b	12.6 ± 0.3 c
Beta-Myrcene	1,123	1,124	1.9 ± 0.2 a	1.8 ± 0.2 ab	1.3 ± 0.1 d	1.6 ± 0.2 bc	1.5 ± 0.1 c
Limonene	1,149	1,152	44.8 ± 2.7 a	43.5 ± 2.2 ab	38.7 ± 1.6 c	40.7 ± 2.0 bc	40.7 ± 1.5 bc
Estragole	1,656	1,656	1.9 ± 0.3 b	1.7 ± 0.3 b	2.5 ± 0.2 a	2.7 ± 0.2 a	2.7 ± 0.3 a
Terpenols			15.7 ± 3.7	15.7 ± 3.8	18.9 ± 4.4	16.3 ± 3.8	16.9 ± 4.0
Alpha-Terpineol	1,684	1,685	2.5 ± 0.5 ab	2.2 ± 0.5 b	3.2 ± 0.6 a	2.7 ± 0.6 ab	2.6 ± 0.5 ab
Beta-Citronellol	1,762	1,762	3.7 ± 0.2 b	3.9 ± 0.2 b	4.5 ± 0.2 a	3.9 ± 0.3 b	4.2 ± 0.3 a
Linalool	1,544	1,545	9.0 ± 0.3 c	9.2 ± 0.6 bc	10.8 ± 0.6 a	9.3 ± 0.3 bc	9.6 ± 0.5 b
Terpinen-4-ol	1,586	1,586	0.4 ± 0.0 b	0.4 ± 0.1 b	0.5 ± 0.0 a	0.4 ± 0.0 b	0.5 ± 0.1 ab
Total			5,615.2 ± 347.2	5,947.2 ± 381.8	6,363.7 ± 428.7	5,591.1 ± 336.5	5,659.4 ± 352.4

*Different letters in a row indicate statistically significant differences ($p < 0.05$). RI Ref = kovats retention index reference value, RI = calculated retention index.

compounds—mainly pyrazines, acids and esters—in model conditions and wines (Comuzzo *et al*., 2006; Del Barrio-Galán *et al*., 2012; Pozo-Bayón *et al*., 2009). However, in our study, no release of exogenous compounds was observed in the model wine after 15 days of applying SYD products. It suggests that a release of acids from the SYDs, if it occurs, is too low to be detected with the analytical method used. As a result, the increase of compounds in the headspace of the white and red wines is more likely to be a salting out effect from the soluble fractions of the yeast derivatives as reported by other authors (Dufour & Bayonove, 1999; Lubbers, Voilley, *et al*., 1994).

Regarding the terpenols, β-citronellol significantly increased in both wines HS in the presence of CW (WW: 16 %; RW: 20 %), YPE (WW: 10 %) and MP (WW: 18 %; RW: 13 %) while IY showed non-significant variations. Linalool mainly increased with CW (WW: 23 %; RW: 20 %) and IY (WW: 19 %). A slight increase with MP (RW: 7 %) was observed. Those results are consistent with those obtained by Rodríguez-Bencomo *et al.* (2014), who observed a reduction of the loss of terpenols in model wine with inactive dry yeast attributed to the presence of small peptides with antioxidant activities (Rodríguez-Bencomo *et al*., 2014).

Regarding the norisoprenoids, such as β-damascenone, the contact of CW, YPE and MP with red wine had a strong impact on the increase of its concentration in the wine HS (34 %, 32 % and 15 %, respectively). This increase was lower in white wine and only in the presence of CW (16 %) and IY (7 %). However, MP had an opposite effect in WW and led to a decrease of its concentration of 14 %. The lower increase in white wines could suggest that wine components limit the interaction of SYDs with volatile compounds. In the literature, other authors showed that SYDs can decrease norisoprenoids concentrations in wines' headspace (Chalier *et al*., 2007; Lubbers, Charpentier *et al*., 1994; Lubbers, Voilley *et al*., 1994). β-ionone, a compound exhibiting structural similarity to β-damascenone, has been shown by Del Barrio-Galán *et al.* (2012) to increase after 15 days of treatment in white wine with yeast lees, autolysates and yeast wall extracts, even though no significant release of these compounds was noted in model wine. Furthermore, a decrease in this compound's concentration was observed in the wine after 30 and 60 days of treatment, suggesting that specific yeast derivatives could

TABLE 2. Volatile composition of white wines headspace after 15 days of contact determined by HS-SPME-GC-MS. Concentrations are expressed as equivalent of octan-1-ol in µg/L.*Values with different letters in the same row indicate statistically significant differences ($p < 0.05$). RI Ref = Kovats retention index reference value, RI = calculated retention index (Part 1/2).

Compounds	RI	RI Ref	C	IY	CW	YPE	MP
Acids			329.1 ± 83.5	318.3 ± 88.4	378.9 ± 101.9	312.6 ± 86.9	340.5 ± 86.8
Decanoic acid	2,270	2,270	51.9 ± 14.2 ab	28.0 ± 6.6 c	45.5 ± 12.7 ab	38.6 ± 4.7 bc	59.8 ± 13.8 a
Hexanoic acid	1,833	1,833	55.9 ± 4.8 bc	61.3 ± 3.3 ab	67.3 ± 5.4 a	50.1 ± 4.6 c	55.2 ± 5.7 bc
Isovaleric acid	1,666	1,666	6.5 ± 0.3 c	8.3 ± 0.4 a	7.7 ± 0.3 b	5.5 ± 0.5 d	6.4 ± 0.3 c
Nonanoic acid	2,164	2,164	5.9 ± 2.1 ab	4.1 ± 1.0 bc	6.4 ± 1.2 a	4.7 ± 0.9 abc	3.1 ± 0.7 c
Octanoic acid	2,056	2,056	209.0 ± 16.7 b	216.6 ± 14.6 b	252.0 ± 19.8 a	213.8 ± 34.3 b	216.0 ± 25.4 b
Alcohols			2,376.6 ± 884.1	3,095.5 ± 1195.1	3,019.3 ± 1151.3	1,887.4 ± 670.2	2,373.5 ± 890.8
1-Hexanol	1,346	1,346	111.6 ± 10.2 b	147.1 ± 14.6 a	143.2 ± 23.3 a	80.6 ± 5.4 c	109.7 ± 11.1 b
3-methyl-butan-1-ol	1,203	1,203	1,901.9 ± 183.3 b	2,550.7 ± 269.2 a	2,464.1 ± 333.2 a	1,452.9 ± 142.8 c	1,912.5 ± 216.8 b
Ethyl hexanol	1,484	1,484	6.4 ± 0.5 b	7.4 ± 0.26 a	8.1 ± 0.6 a	6.5 ± 0.3 b	6.3 ± 0.8 b
Phenylethanol	1,894	1,894	356.7 ± 21.8 bc	390.4± 13.3 ab	404.0 ± 38.7 a	347.4 ± 12.1 bc	345.0 ± 38.3 c
Esters			9,593.5 ± 1,189.4	11,285.0 ± 1,415.6	11,099.5 ± 1,396.7	10712.1 ± 1,443.9	8,264.8 ± 1031.1
Diethyl succinate	1,673	1,673	96.9 ± 14.2 a	80.3 ± 7.0 b	80.3 ± 5.3 b	86.2 ± 5.3 ab	85.3 ± 12.8 ab
Ethyl-2-methylbutanoate	-	-	9.2 ± 1.9 ab	10.7 ± 1.3 a	9.9 ± 1.3 a	7.5 ± 1.0 bc	7.2 ± 1.6 c
Ethyl-3-methylbutanoate	1,010	1,041	17.3 ± 3.5 b	21.2 ± 2.7 a	18.5 ± 2.4 ab	14.3 ± 2.0 bc	13.8 ± 3.1 c
Ethyl 2 hexenoate	1,328	1,328	10.3 ± 1.7 a	9.6 ± 1.2 a	10.4 ± 0.8 a	11.1 ± 1.4 a	9.3 ± 2.5 a
Ethyl acetate	1,253	1,254	238.5 ± 24.4 b	313.2 ± 26.1 a	292.5 ± 47.8 a	205.2 ± 25.8 b	216.4 ± 25.9 b
Ethyl butanoate	-	-	191.3 ± 28.1 b	254.3 ± 32.2 a	226.3 ± 33.6 a	164.1 ± 22.2 b	158.3 ± 24.5 b
Ethyl crotonate	1,137	1,146	2.4 ± 0.5 a	2.6 ± 0.4 a	2.1 ± 0.1 ab	2.4 ± 0.5 ab	1.88 ± 0.3 b
Ethyl Dec-9-enoate	1,683	1,682	15.0 ± 5.2 ab	10.4 ± 1.94 b	15.5 ± 5.8 ab	21.4 ± 12.1 a	8.7 ± 3.4 b
Ethyl decanoate	1,631	1,631	367.5 ± 56.2 a	229.5 ± 64.9 b	390.7 ± 202.5 a	419.1 ± 166.7 a	313.6 ± 66.5 ab
Ethyl heptanoate	1,317	1,317	1.6 ± 0.3 a	1.9 ± 0.6 a	1.9 ± 0.3 a	2.0 ± 0.2 a	1.8 ± 0.6 a
Ethyl hexanoate	1,212	1,212	2,046.7 ± 175.8 ab	2,289.0± 267.6 a	2,285.0 ± 115.7 a	2,106.7 ± 247.5 ab	1,772.8 ± 392.0 b
Ethyl octanoate	1,426	1,426	4,669.5 ± 644.3 b	5,509.4 ± 209.7 a	5,516.5 ± 429.7 a	5,890.2 ± 639.9 a	4,066.8 ± 965.8 b
Ethyl propanoate	-	-	6.3 ± 0.9 b	7.6 ± 0.9 a	7.9 ± 1.9 a	5.3 ± 0.7 b	5.5 ± 0.7 b
Hexyl acetate	1,253	1,254	172.3 ± 35.5 ab	200.4 ± 11.8 a	180.2 ± 30.8 ab	175.6 ± 4.2 ab	149.7 ± 44.3 b
Isoamyl acetate	1,096	1,096	1,702.6 ± 135.6 b	2,298.4 ± 273.0 a	2,005.4 ± 294.0 a	1,548.6 ± 201.8 bc	1,408.9 ± 202.7 c
Isopentyl hexanoate	1,448	1,447	9.9 ± 3.8 c	10.8 ± 2.5 bc	17.9 ± 5.5 a	13.9 ± 2.0 ab	10.3 ± 1.3 bc
Methyl octanoate	1,375	1,374	3.1 ± 0.5 bc	3.5 ± 0.7 abc	4.1 ± 0.4 a	3.7 ± 0.4 ab	2.9 ± 0.9 c
Phenyl acetate	1,789	1,788	33.2 ± 2.8 a	32.3 ± 2.9 a	34.4 ± 2.8 a	34.9 ± 0.5 a	31.8 ± 3.6 a
Norisoprenoids			2.5	2.7	2.9	2.4	2.1
Beta-Damascenone	1,800	1,800	2.5 ± 0.4 ab	2.6 ± 0.1 a	2.9 ± 0.4 a	2.4 ± 0.1 ab	2.1 ± 0.3 b
Terpenes			909.3 ± 279.6	1,254.0 ± 390.4	1,082.4 ± 343.5	917.2 ± 275.0	159.9 ± 39.3
Alpha-Pinene	-	-	716.4 ± 47.1 b	996.3 ± 130.8 a	874.3 ± 118.5 a	706.9 ± 68.5 b	619.1 ± 72.7 b
Beta-Pinene	1,043	1,065	107.2 ± 12.9 cd	162.5 ± 15.8 a	129.8 ± 13.0 b	117.5 ± 9.4 bc	91.8 ± 10.3 d
Camphene	-	-	13.2 ± 2.6 ab	15.5 ± 2.2 a	11.4 ± 1.1 bc	13.0 ± 2.0 ab	9.5 ± 1.5 c
Beta-Myrcene	1,123	1,124	9.6 ± 5.0 a	9.4 ± 2.7 a	1.3 ± 0.8 c	6.9 ± 1.4 ab	2.6 ± 1.8 bc
Geranyl ethyl ether	1,501	1,506	2.4 ± 1.1 bc	1.2 ± 0.1 c	2.5 ± 0.8 bc	4.6 ± 1.0 a	3.5 ± 1.9 ab
Limonene	1,149	1,152	60.5 ± 4.6 ab	69.1 ± 8.1 a	63.3 ± 0.9 ab	68.3 ± 11.1 a	52.5 ± 6.1 b

TABLE 2. Volatile composition of white wines headspace after 15 days of contact determined by HS-SPME-GC-MS. Concentrations are expressed as equivalent of octan-1-ol in µg/L.*Values with different letters in the same row indicate statistically significant differences ($p < 0.05$). RI Ref = Kovats retention index reference value, RI = calculated retention index (Part 2/2).

Compounds	RI	RI Ref	C	IY	CW	YPE	MP
Terpenols			824.5 ± 217.9	964.0 ± 260.9	989.8 ± 269.8	865.2 ± 229.7	1,432.8 ± 264.3
Compounds	RI	RI Ref	C	IY	CW	YPE	MP
Alpha-Terpineol	1,685	1,685	37.7 ± 8.0 a	37.5 ± 5.8 a	34.7 ± 3.6 a	35.2 ± 8.2 a	34.6 ± 7.5 a
Anhydrolinalool oxide	1,177	1,199	7.4 ± 1.5 a	8.6 ± 1.2 a	9.5 ± 1.6 a	8.3 ± 2.8 a	7.5 ± 1.9 a
Beta-Citronellol	1,762	1,762	3.6 ± 0.2 c	3.8 ± 0.1 bc	4.2 ± 0.3 a	4.0 ± 0.4 ab	4.3 ± 0.0 a
Hotrineol	1,606	1,607	71.7 ± 7.8 ab	81.0 ± 2.2 a	77.1 ± 12.6 ab	76.7 ± 3.9 ab	68.2 ± 7.5 b
Linalool	1,545	1,545	669.6 ± 58.1 b	799.5 ± 39.2 a	826.7 ± 20.9 a	705.2 ± 23.1 b	666.6 ± 74.7 b
Linaloyl oxide	1,058	1,096	8.7 ± 1.0 ab	9.8 ± 0.5 a	9.36 ± 0.4 ab	8.2 ± 0.9 ab	7.6 ± 2.2 b
LOP CIS	1,727	1,732	4.28 ± 0.3 b	4.9 ± 0.2 a	5.0 ± 0.1 a	4.0 ± 0.3 b	4.3 ± 0.2 b
Oxyde nerol	1,454	1,450	19.9 ± 4.6 a	17.0 ± 0.5 a	21.2 ± 3.2 a	22.1 ± 2.2 a	18.9 ± 5.1 a
Nerol	1,793	1,793	1.6 ± 0.2 c	1.8 ± 0.1 b	2.1 ± 0.1 a	1.7 ± 0.1 bc	1.9 ± 0.1 b
Total			1,4035.3	16,919.4	16,572.8	14,696.9	12,573.6

*Values with different letters in the same row indicate statistically significant differences ($p < 0.05$). RI Ref = kovats retention index reference value, RI = calculated retention index.

modulate the concentration of this compound over time (Del Barrio-Galán *et al*., 2012). β-ionone interaction with SYDs was mainly linked to its hydrophobicity, which could also be the case for β-damascenone.

1.2. Influence of the volatile compounds' physico-chemical properties on the interactions

Yeast derivatives have been shown to sorb volatile compounds, and their sorption capacity depends on surface hydrophobicity and electron acceptor-donor properties. For example, Pradelles *et al.* (2008) observed that the sorption of 4-ethylphenol was greater in yeast cell walls with higher hydrophobicity and lower electron donor capacity (Pradelles *et al*., 2008). Based on these observations, it can be inferred that the most insoluble yeast derivatives (IY and CW) possess stronger hydrophobic surfaces than YPE and MP, potentially explaining the modulation of certain compounds over time. Similarly, just as the hydrophobicity of yeast derivatives influences their interaction with volatile compounds, the physicochemical properties of aroma compounds themselves should be considered to elucidate their interactions with yeast derivative products. Several authors have reported that the physico-chemical properties of volatile compounds have great importance in their interactions with yeast derivatives (Chalier *et al*., 2007; Dufour & Bayonove, 1999; Lubbers, Charpentier *et al*., 1994; Lubbers *et al*., 1994). In this study, we have investigated the correlations between significantly positive or negative variation of the volatile compounds in the wines' headspace and their physicochemical properties, according to the type of wines and yeast derivative product. Results are shown in Table 5. This analysis demonstrated that aroma compound variation is negatively correlated with their hydrophobicity and boiling point, indicating that the most hydrophobic and least soluble compounds are more likely to be retained in wine after treatment with SYDs. For example, in red wine, the concentration of certain esters is significantly reduced in the headspace (e.g., ethyl decanoate (LogP = 4.86), ethyl octanoate (LogP = 3.84)), whereas others remain unaffected by the treatment (e.g., ethyl hexanoate (LogP = 2.82)) (Figure 1). This observation aligns with findings from other studies, such as those reported by Lubbers *et al.* (1995), who observed that ethyl octanoate was more strongly retained in model wine added with yeast cell walls at 1 g/L than ethyl hexanoate or isoamyl alcohol (Lubbers, Charpentier, *et al*., 1994). Similarly, Chalier *et al.* (2007) observed that hexanol (LogP = 2.03) was less retained by mannoproteins than ethyl hexanoate (LogP = 2.82) or β-ionone (LogP = 3.71) under model conditions (Chalier *et al*., 2007). However, Chalier *et al.* (2007) also reported inconsistencies in this relationship, noting that isoamyl acetate, despite being more hydrophobic than 1-hexanol, was not retained by mannoproteins. This observation was attributed to the potential selectivity of SYD binding sites for volatile compounds, a phenomenon that was also observed by Chassagne *et al*. (2005) in their study on volatile phenols sorption by dried yeast biomass (Chassagne *et al*., 2005). Although correlations could be established when considering compounds that decreased in the wine headspace, few significant correlations could be established for compounds that increased in the wines' headspace, likely due to the wide diversity of compounds involved across both matrices.

1.3. Influence of wine matrix on interactions

1.3.1. Oenological properties

Oenological parameters of the studied red and white wines are shown respectively in Table 3. Significant increases in free and total SO_2 content were observed in the wines treated with mannoproteins. This increase was due to the production process of mannoproteins in which SO_2 is used for better conservation. No significant differences were observed for the alcohol volume (%), volatile acidity and tartaric acid. The significant increase in pH for white wines treated with CW and YPE is negligible. Total Polyphenol Index (TPI) analysis did not show any significant differences between the wines.

1.3.2. Polysaccharides content

Polysaccharide content was quantified in all wine modalities (Table 4) to evaluate the potential of SYDs to modify wine polysaccharide composition and their effect on aroma compounds retention or release. (Del Barrio Galán *et al*., 2018; Ruipérez *et al*., 2022). No significant differences were found between the control wine and the wines treated with IY, CW and YPE for both red and white wines. As expected, wines treated with MP had a significantly higher concentration of mannoproteins due to their residual presence after filtration.

TABLE 3. Oenological parameters of red and white wines after 15 days of treatment.

Parameters	C	IY	CW	YPE	MP
			Red wines		
pH	3.7 ± 0.0 ab	3.7 ± 0 b	3.7 ± 0.0 b	3.7 ± 0.0 a	3.7 ± 0.01 b
Alcohol Vol (%)	11.6 ± 0.0 ab	11.7 ± 0.0 a	11.7 ± 0.0 ab	11.7 ± 0.0 a	11.6 ± 0.0 b
VA (g/L H2SO4)	0.3 ± 0.0 a	0.3 ± 0 a	0.3 ± 0.0 a	0.3 ± 0.0 a	0.3 ± 0.0 a
TA (g/L H2SO4)	3.4 ± 0.0 a	3.1 ± 0.0 a	3.1 ± 0.0 a	3.1 ± 0.1 a	3.1 ± 0.0 a
Free SO2 (mg/L)	26.7 ± 0.6 b	27.3 ± 0.6 b	26.7 ± 2.3 b	27.3 ± 0.6 b	36.0 ± 1.0 a
Total SO2 (mg/L)	67.0 ± 1.0 b	69.7 ± 0.6 b	67.0 ± 3.6 b	71.0 ± 0.0 b	83.3 ± 0.6 a
TPI	85.2 ± 0.8 a	84.1 ± 0.6 a	84.8 ± 0.3 a	85.4 ± 1.5 a	86.7 ± 1.6 a
Anthocyanins (mg/L)	922.3 ± 14.8 a	927.2 ± 16.5 a	931.6 ± 7.5 a	930.8 ± 14.5 a	958.9 ± 17.1 a
DO420	6.21 ± 0.1 a	6.0 ± 0.1 bc	6.09 ± 0.1 ab	5.9 ± 0.0 c	5.9 ± 0.0 bc
DO520	11.3 ± 0.2 a	10.8 ± 0.2 bc	11.1 ± 0.2 ab	10.6 ± 0.0 c	10.5 ± 0.0 c
DO620	2.4 ± 0.0 a	2.3 ± 0.0 bc	2.4 ± 0.1 ab	2.3 ± 0.01 bc	2.3 ± 0.0 c
L	5.7 ± 0.2 c	6.2 ± 0.2 abc	5.9 ± 0.3 bc	6.3 ± 0.1 ab	6.5 ± 0.1 a
a	31.9 ± 0.5 c	33.0 ± 0.5 abc	32.4 ± 0.8 bc	33.2 ± 0.2 ab	33.8 ± 0.1 a
b	9.9 ± 0.3 c	10.6 ± 0.3 abc	10.2 ± 0.5 bc	10.8 ± 0.1 ab	11.2 ± 0.1 a
ΔE calculated with Control		1.4	0.6	1.7	2.4
			White wines		
pH	3.8 ± 0 b	3.81 ± 0 b	3.83 ± 0 a	3.83 ± 0.01 a	3.81 ± 0 b
Alcohol Vol (%)	12.09 ± 0.01 a	12.1 ± 0.02 a	12.11 ± 0.02 a	12.11 ± 0.02 a	12.11 ± 0.02 a
VA (g/L H2SO4)	0.32 ± 0.01 a	0.33 ± 0.01 a	0.34 ± 0.02 a	0.33 ± 0.01 a	0.32 ± 0 a
TA (g/L H2SO4)	2.33 ± 0.01 a	2.3 ± 0.04 a	2.34 ± 0.02 a	2.34 ± 0.03 a	2.36 ± 0.01 a
Free SO2 (mg/L)	29.33 ± 0.58 b	30 ± 1 b	31 ± 1 b	31.33 ± 0.58 b	39.67 ± 0.58 a
Total SO2 (mg/L)	137.33 ± 0.58 c	136.67 ± 2.31 c	141 ± 0 b	138 ± 1 bc	153 ± 0 a
DO420	0.08 ± 0 ab	0.07 ± 0 c	0.08 ± 0 b	0.07 ± 0 c	0.09 ± 0 a
L	99.2 ± 0 ab	99.37 ± 0.06 a	99.27 ± 0.06 a	99.3 ± 0.1 a	99.07 ± 0.06 b
a	-1.05 ± 0.05 ab	-1.02 ± 0.01 ab	-1.08 ± 0.02 b	-1 ± 0.06 ab	-0.97 ± 0.05 a
b	6.44 ± 0.07 ab	5.71 ± 0.17 c	6.37 ± 0.01 b	5.79 ± 0.21 c	6.72 ± 0.04 a
ΔE calculated with Control		0.75	0.10	0.66	0.32

*Different letters in a row indicate statistically significant differences ($p < 0.05$).

Mannoproteins increased by 218 mg/L in the white wines and by 414 mg/L in the red wines. Previous studies have reported a salting out effect of mannoproteins on aroma compounds such as 3-methylbutanol, 1-hexanol and ethyl octanoate but a retention of other compounds such as isoamyl acetate and ethyl hexanoate in model wines (Dufour & Bayonove, 1999; Lubbers, Voilley, *et al*., 1994). This aligns with the results of this study concerning the ethyl octanoate in the red wine treated with MP, however no significant increase of 1-hexanol or 3-methylbutan-1-ol were found in the headspace of either red or white wines treated with MP.

1.3.3. Polyphenols composition

Polyphenols have been reported to reduce volatile compound solubility in wines (Dufour & Bayonove, 1999; Dufour & Sauvaitre, 2000; Jung *et al*., 2000; King & Solms, 1982; Voilley *et al*., 1990). It has been shown that SYDs can sorb phenolic compounds such as tannins and anthocyanins but also hydroxycinnamic acids such as coumaric acid, caffeic acid and trans-caftaric acid (Del Barrio-Galán *et al*., 2012; Mekoue *et al*., 2015; Mekoue Nguela *et al*., 2016; Razmkhab *et al*., 2002). Therefore, the impact of SYDs on wine polyphenol profiles was determined as the interaction between SYDs and polyphenols may contribute to the retention or release of volatile compounds. Significant decreases in Abs 420 (yellow, oxidation products), Abs 520 (red, anthocyanins) and Abs 620 (blue, specific polymeric pigments) were observed for red wines treated with IY, EP and MP. The SEC-DAD profile (Figure 2) at 280 nm shows a peak between 22 and 25.55 minutes, potentially corresponding to tannins with degrees of polymerization ranging from 7 to 78; a peak between 25.55 and 26.65 minutes, corresponding

TABLE 4. Neutral polysaccharide content of red and white wines after 15 days of treatment. Concentrations are expressed in mg/L.

PS	C	IY	CW	YPE	MP
Red wines					
RGII	273.1 ± 27.8 a	262.8 ± 11.5 a	262.8 ± 11.7 a	264.9 ± 7.6 a	301.2 ± 48.0 a
PRAGs	492.9 ± 62.1 ab	454.5 ± 25.2 ab	505.2 ± 37.8 ab	397.3 ± 4.5 b	548.9 ± 78.8 a
MPs	182.6 ± 19.6 b	186.4 ± 10.1 b	210.7 ± 11.2 b	160.3 ± 2.0 b	597.4 ± 96.3 a
PSTot	948.6 ± 102.1 b	903.8 ± 44.8 b	978.7 ± 59.5 b	822.4 ± 8.9 b	1447.5 ± 222.4 a
White wines					
RGII	24.6 ± 0.9 a	22.9 ± 1.9 a	26.7 ± 4.5 a	25.7 ± 9.2 a	29.9 ± 6.4 a
PRAGs	46.6 ± 2.8 a	42.2 ± 0.9 a	49.8 ± 0.7 a	48.2 ± 0.1 a	53.7 ± 2.0 a
MPs	82.2 ± 5.7 b	89.3 ± 7.9 b	91.8 ± 6.9 b	91.5 ± 8.3 b	300.2 ± 15.5 a
PSTot	153.3 ± 9.3 b	156.9 ± 10.9 b	169.8 ± 8.1 b	169.9 ± 5.1 b	377.5 ± 27.6 a

*Different letters in a row indicate statistically significant differences ($p < 0.05$).

TABLE 5. Correlations of volatile compound properties with their variations in the wines' headspace. R and R2 correspond respectively to the Pearson correlation coefficient and coefficient of determination. ns indicates that correlation was not significant ($p < 0.05$), and nd indicates that no correlation was determined.

SYD	Wine	Number of values	LogP	Boiling Point (°C) at 760 mmHg
IY	Red wine	8	(R = -0.86) ; (R2 = 0.74)	(R = -0.80) ; (R2 = 0.63)
CW		9	(R = -0.73) ; (R2 = 0.54)	(R = -0.76) ; (R2 = 0.57)
YPE		4	(R = -0.77) ; (R2 = 0.59)	(R = -0.81) ; (R2 = 0.66)
MP		10	(R = -0.13) ; (R^2 = 0.02) ns	(R = 0.01) ; (R^2 = 0) ns
IY	White wine	3	(R = -0.91) ; (R^2 = 0.83) ns	(R = -0.96) ; (R^2 = 0.93) ns
CW		1	nd	nd
YPE		3	(R = -0.76) ; (R^2 = 0.57) ns	(R = 0.59) ; (R^2 =0.35) ns
MP		7	(R =-0.88) ; (R2 = 0.78)	(R = -0.81) ; (R2 = 0.66)

R and R2 correspond respectively to Pearson correlation coefficient and coefficient of determination. ns indicate that correlation was not significant ($p < 0.05$) and nd indicates that no correlation was determined.

to tannin oligomers with degrees of polymerization up to 5, as well as anthocyanins; and finally a shouldering between 26.65 and 28 minutes, likely corresponding to smaller phenolic compounds such as procyanidins B1 and B2, catechin, and epicatechin. No significant differences were observed in these grouped polyphenol fractions between the wines, which is consistent with the TPI results. Regarding anthocyanins, no significant differences were observed between the fractions in the SEC-DAD profile at 520 nm, contrary to the oenological analysis of anthocyanins, which showed a decrease of absorbance for YPE and MP. Differences between the measurement of absorbance at 520 nm and SEC-DAD profiles at 520 nm could be attributed to slight differences in pH conditions during measurements. The pH has a strong influence on the percentage of anthocyanins in flavylium form that absorb at 520 nm (Brouillard & Dubois, 1977): absorbances are measured at 280 and 520 nm after dilution in HCl 1M, whereas the SEC eluent is composed of DMF with 1 % acetic acid.

However, for the red wines, the SEC-DAD profile at 420 nm shows a significant decrease in the polyphenol fraction between 22 and 25.55 minutes, as well as between 28 and 29 minutes (likely corresponding to caffeic acid) for the wine treated with IY. In addition, wines treated with protein extracts and mannoproteins showed significantly higher colorimetric parameters than the control wine. Treated wines were significantly brighter (higher L), redder (increase in a) and more yellow-hued (increase in b), especially with YPE. However, the colour difference can be considered not perceptible to the eye as it's inferior to 2.3 for all the wines except the MP treated (Ayala *et al*., 1997; Mokrzycki & Tatol, 2011; Sharma & Bala, 2003). However, an increase in L could also be attributed to the clarification and stabilisation capacities of SYDS treatments (Fernandes *et al*., 2015).

For the white wines, a decrease of ABS420 and the b colour parameter was observed for both IY and CW modalities (Table 3), but the colour difference of the wines was not perceptible (). SEC-DAD profiles of white wines showed slight differences between control and treated wines. A significant decrease of the SEC profile peak area between 24.4 and 27.4 min was observed for IY, while a non-significant decrease was observed for CW. An increase of absorbance at 280 nm at 30 min for YPE-treated wine was observed and is related to the SYD treatment since it was also observed in the model wine. The decreases in the presence of IY and CW, along with the reduction of ABS420 and b parameter, align and indicate either a reduction of yellow to brown pigments due to their sorption on SYD or a protective effect of IY and CW against oxidation reactions in the wine. Indeed, other studies have reported similar observations with yeasts and cell walls reducing oxidation in white wines either by sorbing pigments or by reducing compounds whose oxidation produces these pigments. Razmkhab *et al.* (2002) demonstrated that dehydrated yeasts and yeast cell walls could reduce flavonoids such as catechin and epicatechin in white wines after 24 hours at a concentration of 2.8 g/L (Razmkhab *et al*., 2002). Del Barrio-Galán *et al.* showed that yeast lees could reduce hydroxycinnamic acids after 15 days of contact in a model solution (Del Barrio-Galán *et al*., 2012). A reduction of acids such as coumaric acid or caffeic acid could also contribute to the reduction of ABS420; however, no significant difference was observed at the retention times corresponding to these compounds (28 and 31 min). The impact of SYD treatments on polyphenol composition highlights an antioxidant activity of the SYDs and may also explain the higher concentrations of some volatile compounds. Indeed, yeast derivatives have been shown to have antioxidant properties that limit aroma loss. For example, Rodríguez-Bencomo *et al.* (2014) reported that yeast derivatives with or without glutathione in model wine significantly reduced the loss of alpha-terpineol, linalool (Rodríguez-Bencomo *et al*., 2014). This conservation of terpenol compounds was attributed to the antioxidant properties of small peptides from soluble yeast fractions with sulfur compounds (Rodríguez-Bencomo *et al*., 2014). The presence of yellow/brown pigments was less noticeable in the white wines than the red wines, suggesting fewer oxidation reactions in the white wine and therefore explaining the stronger trend to higher release of some volatile compounds in the white wines' headspace than in the red wines.

2. Impact of yeast derivatives on wine sensory profiles

The results of the sensory analysis of the red wines are presented in Figure 4. No significant decrease was observed for the olfaction analysis. However, for the retro nasal analysis, a significant reduction ($p = 0.043$) in the intensity of the vegetal note was detected with IY and CW treatments. Additionally, a downward trend ($p = 0.063$) in the reduction of the spice note was observed with CW treatment.

A principal component analysis (PCA) was conducted on the standardised mean scores of the sensory descriptors, using the type of derivative as a categorical variable (Figure 5). The first two dimensions explained 93.29 % of the total variance, indicating that most of the variance is captured by these axes. The wines were well represented in this space, with cos^2 values of 0.69 for IY-treated wines, 0.95 for the CW-treated wines and 0.78 for the YPE-treated wines on dimension 1, and 0.71 for MP-treated wines on dimension 2. The control wine was represented on both dimensions with a cos^2 of 0.45 on dimension 1 and 0.48 on dimension 2. The descriptors were also well represented on these axes, with cos^2 sums greater than 0.90.

Dimension 1, which explains 68.28 % of the total variance, is positively correlated with the vegetal ($r = 0.91$), spice ($r = 0.95$) descriptors. It is also negatively correlated with the red fruit descriptor ($r = –0.95$). This dimension indicates that the wine treated with YPE was mostly not distinguished from the control wine and was primarily characterised by vegetal and spice notes. Additionally, these wines were characterised by a less intense red fruit note, in contrast to the wine treated with CW, which presented stronger red fruit notes. Dimension 2, representing 29.01 % of the total variance, is negatively correlated with the black fruit descriptor ($r = –0.95$). This dimension primarily explains the variance of the wine treated

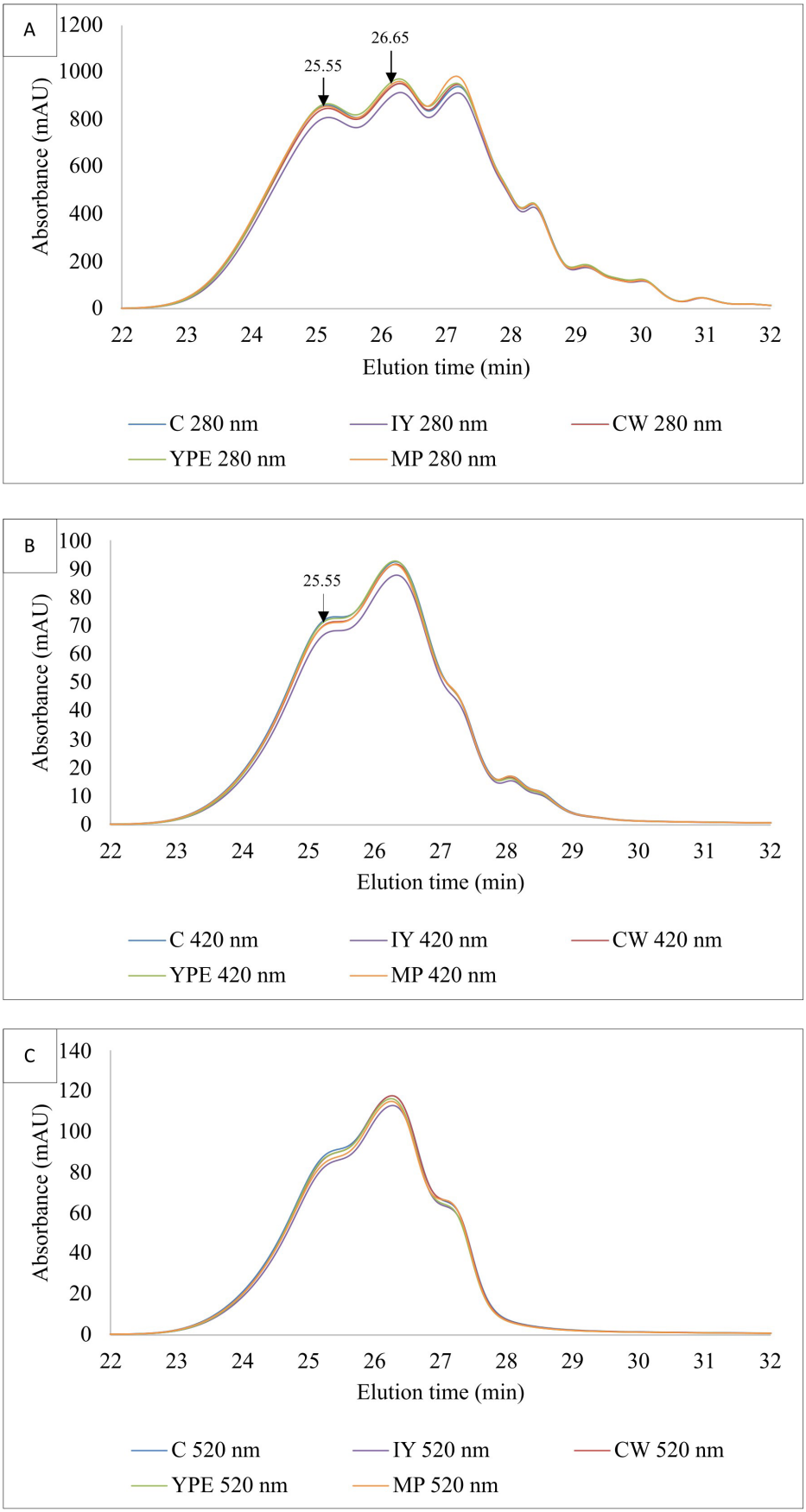

FIGURE 2. SEC-DAD profiles of red wine polyphenols at 280 nm (A), 420 nm (B) and 520 nm (C): C = control wine, IY = inactivated yeast, CW = cell walls, YPE = yeast protein extracts, MP = mannoproteins.

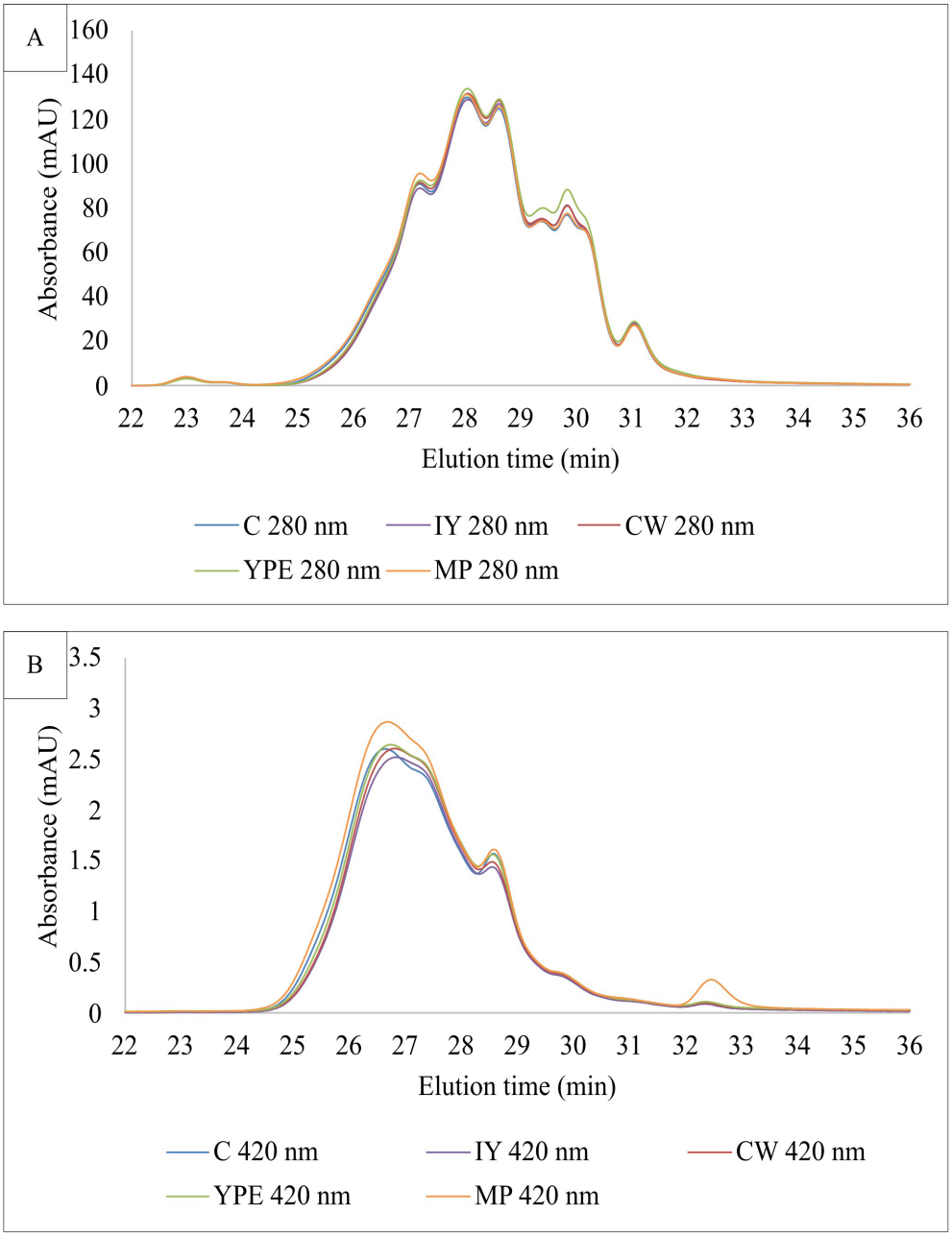

FIGURE 3. SEC-DAD profiles of white wine polyphenols at 280 nm (A), 420 nm (B) and 520 nm (C): C = control wine, IY = inactivated yeast, CW = cell walls, YPE = yeast protein extracts, MP = mannoproteins.

with MP, indicating that MP strongly modulated the black fruit note of the wine. It also suggests that the control wine was also characterised by a low black fruit note, meaning that MP might have enhanced this descriptor in the red wine. The two dimensions suggest that IY modulated the wine's sensory profile, perceived with lower vegetal and spicy notes. MP-treated wines resulted in higher black fruit notes, while CW-treated wines resulted in higher red fruit notes. Finally, YPE treatment conserved the sensory profile of the treated red wine like the control red wine. To our knowledge, there are no other studies that report the sensorial effect of yeast derivative products at low dosage over a similar period of time. However, on a relatively short-term treatment of 2 months, two SYD (parietal extracts rich in mannoproteins at 0.4 g/L and polysaccharides extracted from cell walls) have been shown to reduce the fruity note of red wines. However, this impact was reversed after 6 months of storage with an increase of fruity notes (Del Barrio-Galán *et al.*, 2011).

The results of the sensory analysis of the white wines by olfaction are presented in Figure 4. No significant differences were observed between the treated wines and the control white wine. Regarding the retro nasal analysis, a decrease in the sensory descriptors' intensity was observed, although not significant. More specifically, a downward trend ($p < 0.068$)

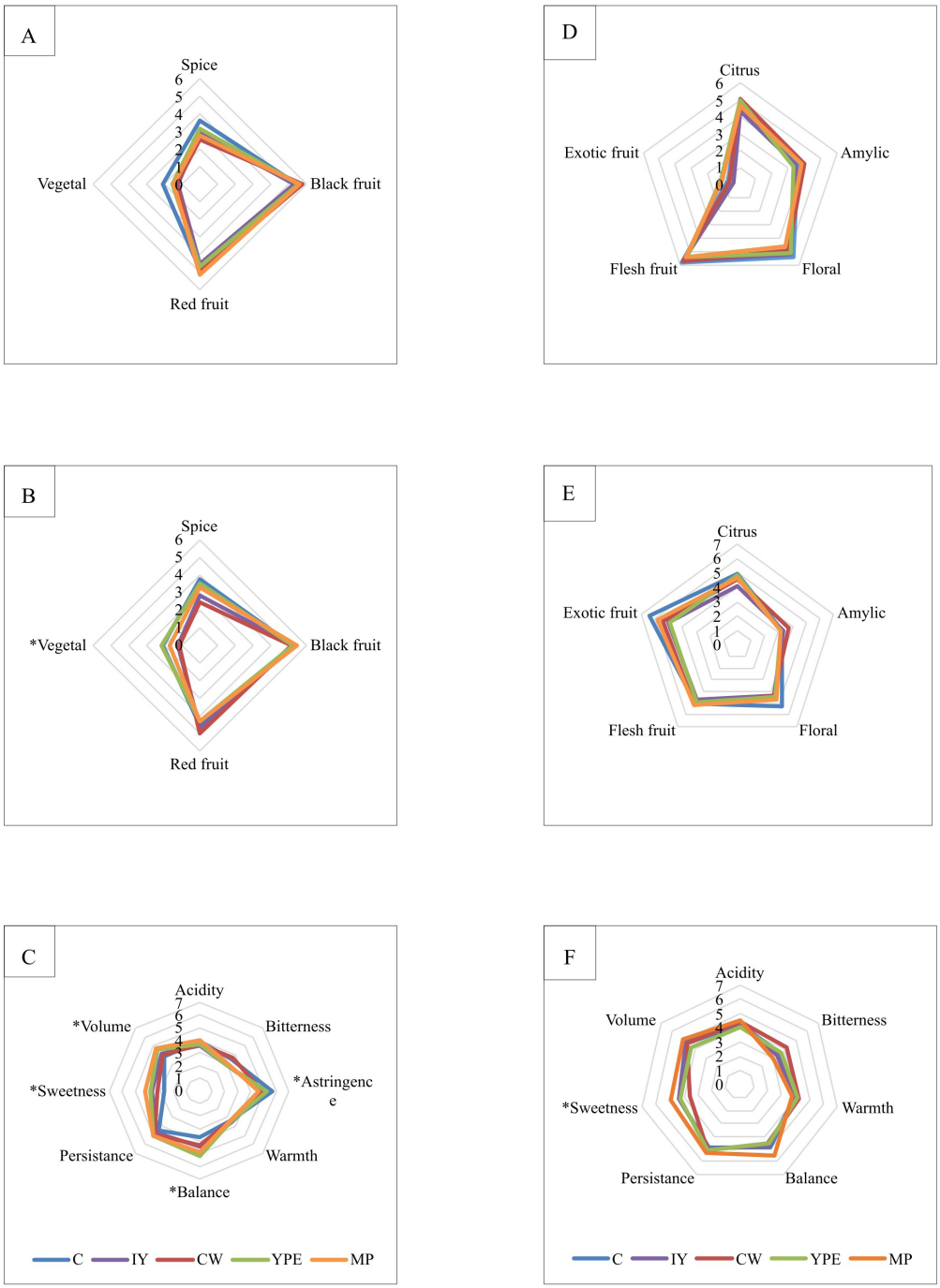

FIGURE 4. Diagrams of the olfactive (A, D), retro-nasal (B, E), and gustatory (C, F) descriptors of red wines (A–C) and white wines (D–F) after 15 days of treatment. The asterisk indicates statistically significant differences for $p < 0.05$.

was observed for the fleshy fruit note intensity in wines treated with IY and CW. A principal component analysis (PCA) was conducted on the retro nasal sensory descriptor scores, using the type of yeast derivative as a categorical variable Figure 5. The first two principal dimensions explained 83.82 % of the total variance. The first dimension, which explained 52.63 % of the variance, was positively correlated with fleshy fruit ($r = 0.83$), citrus fruit ($r = 0.72$) and vegetal ($r = 0.95$) notes, and negatively correlated with the floral note ($r = –0.73$). This dimension mainly explained the variance of the control wine and the wine treated with IY. These correlations indicate that the IY treatment of wine could modulate the perception of most sensorial descriptors but amylic, leading to a reduction of fleshy fruit, exotic fruit and vegetal notes and an increase of the floral note.

The second dimension, explaining 24 % of the variance, was negatively correlated with the amyllic note ($r = –0.96$) and positively correlated with the floral ($r = 0.67$) and citrus ($r = 0.78$) notes, primarily explaining the variance of the

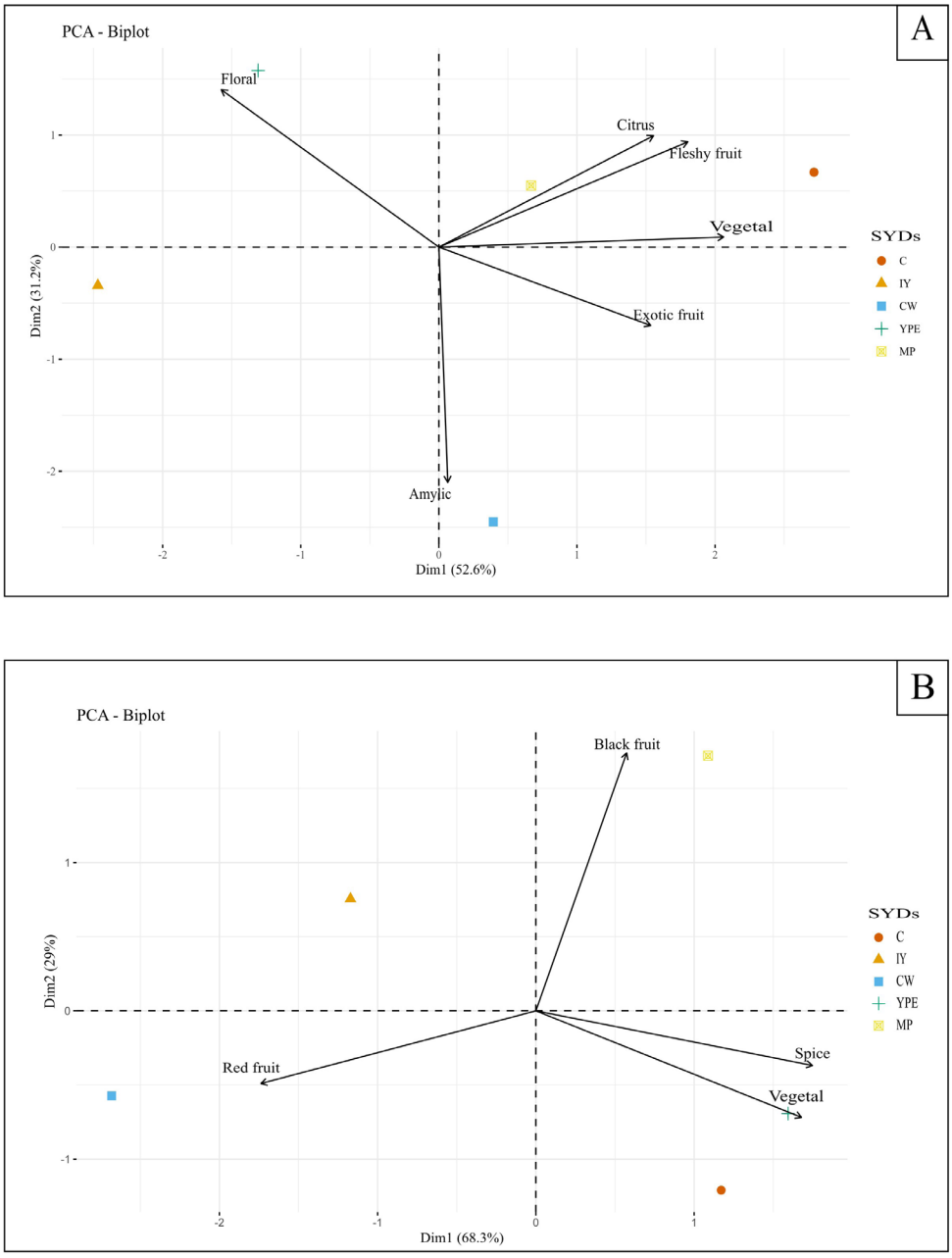

FIGURE 5. PCA biplot of the sensory descriptors of the red wines (A) and white wines (B) evaluated by retro nasal analysis after 15 days of treatments by specific yeast derivatives: Control wine (C), inactivated yeast (IY), yeast cell walls (CW), yeast protein extract (YPE), mannoproteins (MP).

wines treated with CW and YPE. This dimension indicated a differentiation between the CW-treated wines, which had a more intense amylic note and lower floral intensity, and YPE-treated wines, which exhibited the opposite trend. The variance of the MP-treated wine was better represented on the fourth dimension, which explained only 7 % of the variance of the whole results.

PCA results of the IY-treated white wines were concordant with the ANOVA analysis. IY-treated wines seemed to be characterised by less fleshy fruit notes but also less vegetal, exotic fruit notes. The downward trend for fleshy fruit notes was not observed in the PCA analysis for CW-treated wines, as they are not correlated to the first dimension. However, those CW-treated wines were more correlated to a stronger amylic note and lower floral notes.

Even though the volatile profiles were determined by semi-quantification, IY and CW-treated wines had globally a higher amount of volatile compounds in the headspace with a notable increase of highly odorant compounds (3-methyl-butan-1-ol) (Figure 1). The increase of these highly odorant compounds in those wines could explain the reduction of the floral note for CW-treated wines. Indeed, Ferreira *et al.*

(2016) observed that some higher alcohols (3-methyl-butan-1-ol) could suppress some fruity notes (Ferreira *et al*., 2016). Inversely, the reduction of 3-methyl-butan-1-ol in YPE-treated white wines could be linked to the greater perception of the floral note. As said in section 1.2, the modification of the volatility of the aroma compounds could be the cause of the sensory modification observed in the retro-nasal analysis. Comuzzo *et al.* (2006), also observed a modification of the sensory profile of white wines treated with yeast derivatives (yeast extracts and autolysates) at 0.2 g/L with the apparition of fruity and floral notes after 15 days although the compounds suspected to be responsible for such notes were not detected in the treated model wine (Comuzzo *et al*., 2006).

CONCLUSION

This study provides evidence that the short-term application of SYDs at oenological doses under pilot conditions results in significant changes in the volatile compound profiles of both white and red wines. These modulations are attributed to the retention or release of compounds in the wine's headspace, independently of their chemical families. However, the correlations established between volatile compound properties (mainly hydrophobicity and boiling point) and SYD surface properties suggest that the most hydrophobic compounds are more susceptible to interact and be modulated by SYDs. The release of volatile compounds in the wine headspace may be due to salting out effects of SYDs and/or an antioxidant effect that reduces the loss of aroma compounds during storage.

Furthermore, more insoluble SYDs significantly influenced the variation of aromas in the headspace depending on their solubility. This effect was particularly evident in white wines and may be linked to differences in the surface properties of SYDs in relation to their diverse structural and compositional characteristics.

Moreover, the SYDs impact was more pronounced in the white wine matrix compared to the red wine matrix, suggesting that interactions or competitions between SYDs and the phenolic compounds of red wines may alter the volatility of aroma compounds. Additionally, the reduction in certain phenolic compounds associated with oxidation phenomena may contribute to a better preservation of volatile compounds. The addition of SYDs did not alter the neutral polysaccharide composition of the wines, except for an increase in mannoproteins in the case of MP treatment.

At last, SYD treatment induced changes in the organoleptic properties of the wines, as a consequence of the chemical interactions described. Once again, those results emphasise the fact that a better understanding of the interaction mechanisms occurring between aroma compounds of the wine and SYDs is a key to better control the wine aroma modulation and, therefore, of its sensory properties through short-term applications of SYD in wines.

ETHICAL STATEMENT

The sensory study did not require formal ethical approval from the French National Committee on Health Research Ethics. Panellists from Lallemand participated in this study as part of their work assignments, with respect for their rights and privacy. All participants gave their consent to participate in the research project.

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