



UNIVERSITÀ  
DEGLI STUDI  
DI UDINE

## Università degli studi di Udine

Application of multi-pass high pressure homogenization under variable temperature regimes to induce autolysis of wine yeasts

*Original*

*Availability:*

This version is available <http://hdl.handle.net/11390/1098512> since 2020-03-26T16:59:55Z

*Publisher:*

*Published*

DOI:10.1016/j.foodchem.2016.12.038

*Terms of use:*

The institutional repository of the University of Udine (<http://air.uniud.it>) is provided by ARIC services. The aim is to enable open access to all the world.

*Publisher copyright*

(Article begins on next page)

Manuscript Number:

Title: Application of multi-pass high pressure homogenization under variable temperature regimes to induce autolysis of wine yeasts

Article Type: Research Article (max 7,500 words)

Keywords: high pressure homogenization; Saccharomyces; autolysis; wine; inactive dry yeasts

Corresponding Author: Dr. Piergiorgio Comuzzo, Ph.D.

Corresponding Author's Institution: Università degli Studi di Udine

First Author: Piergiorgio Comuzzo, Ph.D.

Order of Authors: Piergiorgio Comuzzo, Ph.D.; Sonia Calligaris; Lucilla Iacumin; Federica Ginaldi; Sabrina Voce; Roberto Zironi

Abstract: The effects of the number of passes and processing temperature management (controlled vs uncontrolled) were investigated during high pressure homogenization-induced autolysis of *Saccharomyces bayanus* wine yeasts, treated at 150 MPa. Both variables were able to affect cell viability, and the release of soluble molecules (free amino acids, proteins and glucidic colloids), but the effect of temperature was averagely more evident. *S. bayanus* cells were completely inactivated in 10 passes without temperature control (corresponding to a processing temperature of 75 °C). The two processing variables also affected the volatile composition of the autolysates produced: in particular, higher temperatures led to a lower concentration of volatile compounds. The management of the operating conditions, may allow to modulate the compositional characteristics of the products obtained, making them suitable for different winemaking applications.

## Cover Letter

Yeast derivatives (YDs) are perhaps the most used enological products in the wineries, after active dry yeasts. They are basically inactive dry yeasts or yeast autolysates, promoted by the suppliers for a wide series of applications: fermentation enhancers, flavor and aroma modulators, mouthfeel enhancers, scavengers against undesired compounds and antioxidant preparations.

Despite their wide utilization, very few commercial YDs are specifically tailored for winemaking use and winemakers are often forced to use formulations developed for other food products. One of the most critical points is that, in food industry, these additives are generally used as flavoring and aromatizing agents, so that they may release off-flavors when they are added into the wine. These off-flavors are mostly connected with the thermal treatments that occur during manufacturing (e.g. compounds from Maillard reaction or oxidative breakdown of lipids). For this reason, the development of non-thermal alternative processes for the obtainment of such products may open new opportunities for the production of commercial preparations suitable for winemaking use.

In a previous paper, we have demonstrated the potential of high pressure homogenization (HPH) for inducing autolysis of wine yeasts. This manuscript aims to investigate the effects of the number of passes and processing temperature management (controlled vs not controlled) on yeast autolysis induction, as well as on the characteristics of the yeast autolysates produced (e.g. release of free amino acids, colloids, and volatile compounds).

HPH demonstrated to be an interesting technique from this point of view, because it may allow different winemaking applications, such as the production of specific preparations of yeast derivatives, to be used either as yeast nutrient supplement, or for wine storage and ageing, depending on the processing conditions. Moreover, HPH appeared also a promising tool, for the direct application in the wineries, with the purpose of shortening the time needed for *sur lie* maturation. As far as we know, this is currently one of the few papers dealing with these aspects.

### Highlights

Number of passes and process temperature affect HPH-induced autolysis of wine yeasts

*S. bayanus* cells were inactivated in 10 passes without temperature control at 75 °C

Temperature control more effective than multi-pass for release of soluble molecules

Lower temperatures led to higher concentration of ethyl esters and aroma compounds

Different operating conditions allow to modulate the composition of the autolysates

**Application of multi-pass high pressure homogenization  
under variable temperature regimes to induce autolysis of  
wine yeasts**

**Piergiorgio Comuzzo\*, Sonia Calligaris, Lucilla Iacumin, Federica Ginaldi, Sabrina  
Voce, Roberto Zironi**

Università degli Studi di Udine, Dipartimento di Scienze Agroalimentari, Ambientali ed  
Animali, via Sondrio 2/A, 33100 Udine – Italy

\* Corresponding Author

Piergiorgio Comuzzo

Tel: + 39 0432 55 8166

Fax: + 39 0432 55 8130

e-mail: [piergiorgio.comuzzo@uniud.it](mailto:piergiorgio.comuzzo@uniud.it)

**Abbreviated running title**

Yeast autolysis by different high pressure homogenization conditions

## **Abstract**

The effects of the number of passes and processing temperature management (controlled vs uncontrolled) were investigated during high pressure homogenization-induced autolysis of *Saccharomyces bayanus* wine yeasts, treated at 150 MPa. Both variables were able to affect cell viability, and the release of soluble molecules (free amino acids, proteins and glucidic colloids), but the effect of temperature was averagely more evident. *S. bayanus* cells were completely inactivated in 10 passes without temperature control (corresponding to a processing temperature of 75 °C). The two processing variables also affected the volatile composition of the autolysates produced: in particular, higher temperatures led to a lower concentration of volatile compounds. The management of the operating conditions, may allow to modulate the compositional characteristics of the products obtained, making them suitable for different winemaking applications.

**KEYWORDS:** high pressure homogenization; *Saccharomyces*; autolysis; wine; inactive dry yeasts

## 1 Introduction

Inactive dry yeasts (IDY) and yeast autolysates (also known as yeast derivatives) are a group of important winemaking additives, used for different purposes, including their ability to provide substances which are naturally released into the wine, during the traditional practice of *sur-lie* maturation (Pozo-Bayón, Andújar-Ortiz, & Moreno-Arribas, 2009). As well known, during ageing on the lees, natural yeast autolysis occurs and wine progressively enriches in important compounds, such as peptides, sterols, amino acids and mannoproteins (Pérez-Serradilla & Luque de Castro, 2008). Despite these interesting modifications, *sur-lie* maturation is a slow process and during the several months required for wine evolution, wine itself may be subjected to non-negligible risks of microbiological spoilage and sensory modifications (Pozo-Bayón et al., 2009).

The ability of yeast derivatives to increase wine colloidal content (Pozo-Bayón et al., 2009), their capacity to interact with aroma compounds modulating their volatility (Comuzzo, Tat, Fenzi, Brotto, Battistutta, & Zironi, 2011) and their claimed antioxidant capacity (Rodríguez-Bencomo et al., 2014; Comuzzo, Battistutta, Vendrame, Páez, Luisi, & Zironi, 2015b) suggest the use of these products as potential alternatives of *sur-lies* ageing. Unfortunately, commercial IDYs may often negatively affect wine sensory characters, by releasing off-flavors (Comuzzo, Tat, Tonizzo, & Battistutta, 2006), formed because of the high temperatures to which they are subjected during manufacturing (Münch, Hofmann, & Schieberle, 1997). For this reason, a process allowing to speed up yeast autolysis, reducing the heating during manufacturing, may be helpful for the production of yeast derivatives specifically tailored for winemaking use and to limit the release of such off-flavors into the wine.

High pressure homogenization (HPH) is a mechanical processing method, used since different decades to extract intracellular components (i.e. proteins and enzymes) from

microorganisms, including *Saccharomyces* cells (Follows, Hetherington, Dunnill, & Lilly, 1971; Hetherington, Follows, Dunnill, & Lilly, 1971). It is known that HPH may induce cell disruption, through cavitation, shear and turbulence phenomena that occur when yeast suspension is forced through the narrow gap of the homogenizer valve (Popper & Knorr, 1990). Despite the ability of HPH in promoting *Saccharomyces* cell breakdown is well documented, very few publications deal with the effects of such technology in inducing the autolysis of wine yeasts (Patrignani et al., 2013), or with its use for the production of yeast derivatives (Comuzzo, Calligaris, Iacumin, Ginaldi, Palacios Paz, & Zironi, 2015a).

In a recent paper (Comuzzo et al., 2015a), the potential of HPH for the production of autolysates for winemaking use, was examined. In particular, the study focused on the effects of pressure level (from 0 to 150 MPa) on the viability of yeast cells, the release of soluble molecules and colloids in wine-like solution (indices of autolysis occurrence), and the volatile composition of the autolysates produced. Results showed the good potentialities of this technique to obtain yeast derivatives with interesting volatile composition. At the same time, the tested conditions did not allow the complete inactivation of yeast cells leading to the need of a processing optimization.

In the present research, the effects of the number of HPH passes at 150 MPa and processing temperature (controlled vs not controlled) on the characteristics of a yeast autolysate were investigated. In particular, cell viability, the content of glucidic colloids (e.g. mannoproteins), free amino acids and soluble proteins as well as the volatile composition of the autolysates obtained were determined, with the purpose of finding evidences on how HPH processing variables may potentially affect the composition and the performances in wine of the products obtained.

## **2 Materials and Methods**



## 2.1 Reagents and materials

Bacteriological peptone and Malt Extract Agar were purchased from Oxoid (Basingstoke, UK). Sodium hydroxide, boric acid, sodium chloride, copper sulfate pentahydrate, sodium tartrate, sodium carbonate, tartaric acid and ethanol (96 % v/v) were from Carlo Erba Reagents (Milan, Italy). Bovine serum albumin (BSA) fraction V, *o*-phthaldialdehyde, *N*-acetyl-L-cysteine, Folin-Ciocalteu's phenol reagent and HPLC grade isoleucine (Ile) were obtained from Sigma-Aldrich (St. Louis, MO, USA). Milli Q grade water was produced by a Milli-Q Advantage A10 apparatus (Merck Millipore, Billerica, MA, USA) and microfiltered at 0.2  $\mu\text{m}$  before use. Commercial *Saccharomyces bayanus* (Mycoferm Cru-05 active dry yeast preparation) was from EverIntec (Pramaggiore, VE, Italy).

## 2.2 High pressure homogenization treatments

Aliquots of 40 g of active dry yeast preparation (ADY) were suspended in 400 ml of Milli Q grade water, in sterile Erlenmeyer flasks. After 10 min, to allow the yeast rehydration, the samples were processed by using a two stage high pressure homogenizer (Panda PLUS 2000, Gea Niro Soavi, Parma, Italy) provided with two cylindrical tungsten carbide homogenizing valves. The first one, was set at 150 MPa, whereas the second was fixed at 5 MPa. Samples (400 ml) were homogenized at 150 MPa and a flow rate of  $10.0 \text{ l h}^{-1}$ , via 1, 4, 6 and 10 passes. Two different sets of experiments were carried out: the first one was without any temperature control, whereas in the second, the homogenizer inlet and outlet were connected to a heat exchanger (Julabo F70, Julabo GmbH, Seelbach, Germany) set at 4 °C, to avoid the heating of the suspensions during processing. Sample temperature was measured before and after homogenization, by a copper-constantan thermocouple (Ellab, Hillerød, Denmark) connected to a portable data logger (mod. 502A1, Tersid, Milan, Italy). All the experiments were carried out in three repetitions.

Before each homogenization treatment, the equipment was subjected to three different washing steps in order to avoid the presence of residual (viable) yeast cells and reduce the risk of cross contamination between the different samples. The first washing cycle was a rinsing with microfiltered Milli Q grade water (1 l), then a mixture of water: ethanol 1:1 v/v (1 l) was circulated, and subsequently, a final rinsing with microfiltered Milli Q water (1 l) was carried out. The operating conditions used for such three washing steps have been determined to not have any viable cell detectable in the water collected after the final rinse.

After homogenization, 10 ml of each treated suspension were collected in sterile Falcon tubes and subjected to microbiological analysis as reported below. The remaining part of the suspension was collected in food-grade aluminum trays (approx. in a 1 cm layer), frozen at -20 °C, and freeze-dried by using a pilot plant model Mini Fast 1700 (Edwards Alto Vuoto, Milan, Italy). At the end of the process, the samples were finally ground in a ceramic mortar and stored in 50 ml sterile Falcon tubes (0/+4 °C), until chemical and GC-MS analyses. As a reference sample, the active dry yeast preparation used for the trials, was subjected to the same analytical determinations reported below.

### *2.3 Microbiological analyses*

One (1) ml of each sample was mixed with 9 ml of saline-peptone water (8 g l<sup>-1</sup> sodium chloride, 1 g l<sup>-1</sup> bacteriological peptone) in a sterile Falcon tube and vortexed for 1.5 min using a VWR vortex mixer (International PBI, Milan, Italy). Additional decimal dilutions were made in the same solution, and yeast cells were plated in three repetitions on Malt Extract Agar. Plates were then incubated at 25°C for 48-72 h under aerobic conditions and colonies were counted.

#### 2.4 Glucidic colloids

The glucidic colloids soluble in wine-like medium were assessed by ethanol precipitation, by a modified version of the method published by Usseglio-Tomasset & Castino (1975); 1.00 g of freeze-dried powder was suspended in 10 ml of hydroalcoholic-tartaric buffer (12.00 % v/v ethanol in 33 mM tartaric acid, pH 3.20). After 10 min, the suspension was centrifuged (5000 rpm for 10 min) and 5 ml of the supernatant was mixed with 25 ml of ethanol 96 % v/v and kept for 24 h at 0/+4 °C. The precipitate of glucidic colloids was separated by vacuum filtration on a 0.45 µm nylon membrane (Albet-Hahnemühle, Barcelona, Spain) and then determined by weighing, after complete evaporation of ethanol (carried out at 50 °C, until constant weight). Results were expressed in mg of total colloids per g of freeze-dried powder.

#### 2.5 Soluble proteins

Soluble proteins were analyzed according to the Lowry assay as reported by Regenstein & Regenstein (1984). One (1.00) g of freeze-dried powder was suspended in 100 ml of hydroalcoholic-tartaric buffer (12.00 % v/v ethanol in 33 mM tartaric acid, pH 3.20). After 10 min, the suspension was centrifuged (5000 rpm for 10 min) and 400 µl of the limpid supernatant was transferred in a 10 mm optical path length glass cuvette. A mixture of 2 % w/v sodium carbonate in 0.1 M sodium hydroxide solution (1.96 ml), 1 % w/v copper sulfate pentahydrate (20 µl) and 2 % w/v sodium tartrate (20 µl) was added, and the sample was carefully homogenized. After 10 min at ambient temperature, 200 µl of Folin-Ciocalteu's reagent was introduced and the content of the cuvette was further mixed. After additional 30 min, the absorbance of the sample was measured at 750 nm, reading against a blank obtained by replacing the supernatant with 400 µl of Milli Q grade water. Results were given in mg g<sup>-1</sup> of freeze-dried powder, according to a calibration line prepared with increasing amounts of bovine serum albumin.

## 2.6 Free amino acids

Free amino acids were determined by OPA derivatization, according to the method published by Dukes & Butzke (1998). Two aliquots (50  $\mu$ l each) of the same supernatant used for the analysis of soluble proteins (see Section 2.5) was subdivided in two 10 mm optical path length quartz cuvettes. The first one (cuvette A) was diluted in 3 ml of a solvent mix containing ethanol (100 ml l<sup>-1</sup>), sodium hydroxide (3.837 g l<sup>-1</sup>), boric acid (8.468 g l<sup>-1</sup>) and *N*-acetyl-L-cysteine (0.816 g l<sup>-1</sup>). The second (cuvette B) was mixed with the same solvent buffer, additionally containing 0.671 g l<sup>-1</sup> of *o*-phthaldialdehyde. After 10 min, the absorbance of both cuvettes was measured at 335 nm, reading against Milli Q grade water. The net absorbance of the sample was calculated by subtracting the absorbance of cuvette A, (reference) from that of cuvette B (derivatized sample); the results were expressed in mg g<sup>-1</sup> of freeze-dried powder, on the basis of a calibration line obtained with isoleucine (Ile).

## 2.7 SPME-GC-MS analyses

The characterization of the volatile composition of the headspace of the freeze-dried powders was carried out by solid-phase microextraction and gas chromatography. The equipment used was a GC-17A gas chromatograph, coupled with a QP-5000 mass spectrometer (both from Shimadzu, Kyoto, Japan). Two (2.00) g of each freeze-dried sample were introduced in 50 ml amber glass vials and sealed with PTFE/silicone septa. SPME was carried out by a 2 cm length 50/30  $\mu$ m DVB/Carboxen/PDMS fiber (from Supelco, Bellefonte, PA, USA), at 40 °C for 15 min. To allow the thermal equilibration of the sample, the vials were pre-conditioned for 15 min before microextraction.

GC separation was carried out on a J&W DB-Wax capillary column, 30 m x 0.25 mm i.d., 0.25  $\mu$ m film thickness (Agilent Technologies Inc., Santa Clara, CA, USA), according to the conditions reported by Comuzzo et al. (2015a). Electron impact mass spectra were recorded at 70 eV and the identification of volatile compounds was carried out by comparison of their

mass spectra and retention times with those of standard compounds, or by comparison of mass spectrum, with those reported in the mass spectrum libraries Wiley 6 and NIST 107. Linear retention indices were also calculated on the basis of the retention times of *n*-alkanes, and compared with those reported in literature.

## 2.8 Statistical analyses

Statistical elaborations were carried out by using the specific software Statistica for Windows, Version 8.0 (StatSoft, Tulsa, OK, USA). The values collected for the different parameters analyzed and the absolute areas of the volatile compounds detected in the headspace of the freeze-dried powders were processed by One-way ANOVA and Tukey HSD Test. Significant differences between the samples were assessed at  $p < 0.05$ . Additionally, concerning SPME-GC-MS analyses, aroma compounds were grouped, sample by sample, according to their chemical class and total absolute areas obtained for each chemical group were analyzed by Principal Component Analysis (PCA).

## 3 Results and Discussion

### 3.1 Effect of HPH treatment on yeast viability

The effects of the different operating conditions on yeast viability are reported in Fig. 1. The number of passes affected the microbial population in both controlled and uncontrolled temperature conditions. However, when the temperature remained below 32°C, the number of viable microorganisms was slightly reduced, and more than 6.0 Log CFU g<sup>-1</sup> of viable cells was detected after 10 passages of the yeast suspension into the homogenizer (Fig. 1a). In such conditions, the reduction of yeast population may be attributed mainly to the mechanical stress suffered during the passage of the suspensions through the homogenization valves. The resistance of *Saccharomyces* cells towards high pressure treatments is in agreement with the data reported by Patrignani et al. (2013) and Comuzzo et al. (2015a).

Contrary, an intense and progressive reduction of viable yeasts was evident when the temperature was not controlled during processing and increased up to 75 °C (Fig. 1b). It is well known that HPH treatments may provoke an increase of the temperature, in the products subjected to homogenization (Popper & Knorr, 1990). The temperature raise was able to promote an intense cell death, and as it reached values close to 70 °C (6 and 10 passes), the number of viable cells became lower than 2 Log CFU g<sup>-1</sup>. This correspond to the maximum value recommended by the World Organization of Vine and Wine (O.I.V.), for what concerns the presence of viable cells in the yeast autolysate preparations for winemaking use (Resolution Oeno 496/2013, 2013).

Considering the flow rate of the process (10 l h<sup>-1</sup>), the volumes treated (200 ml) and the number of passes (up to 10), the extent of the heating carried out in the present experiment (75 °C as maximum value for the processing with 10 passes) was, anyway, less intense and prolonged than those normally applied in other thermolytic processes, during which temperatures higher than 75-80 °C were held for some hours (Peat, 1961; Halasz & Lasztity, 1991; de la Torre, Flores, & Chong, 1994). The reduction of processing temperature is expected to improve the quality characteristics of the autolysates, which might be less subjected to thermal degradation and production of off-odors deriving from Maillard reaction and lipid oxidation (Ames & McLeod, 1985; Nagodawithana, 1992).

Due to the negligible impact of the management conditions (controlled vs uncontrolled) on product temperature, after processing the suspensions via single pass (Fig. 1), the analytical determinations described below were carried out, for samples 1P, only on the three repetitions obtained without temperature conditioning.

### *3.2 Release of proteins and free amino acids in wine-like solution*

To study the performances of HPH-yeast autolysates after processing, they were freeze-dried

and suspended in wine-like solution (ethanol 12.00 % v/v, pH 3.20), to assess the release of soluble compounds.

Figure 2 reports the average values of soluble proteins and free amino acids, released by the freeze-dried autolysates; as control, data regarding ADY were also reported. In comparison with the levels detected in the ADY preparation, the amount of proteins released in the medium (Fig. 2a) increased significantly, just after the first HPH pass. A further increase of the number of passes, did not determined any statistical difference on protein solubilization, independently on the type of applied temperature regime. Anyway, the samples derived from no temperature controlled process showed a content in soluble proteins, slightly lower than the corresponding samples obtained with temperature control. This can be attributed to the higher extent of heating (Fig. 1), which might have determined a more intense protein denaturation. In terms of concentration, however, the values reported in Fig 2a are quite low, and this might be positive for what concerns the potential use of these autolysates in winemaking, because proteins are reported to bind wine aroma compounds, reducing their volatility and perception (Voilley, Beghin, Charpentier, & Peyron, 1991).

The behavior of free amino acids (FAA) reflects that of proteins (Fig. 2b), with some minor differences. The amount of FAA released in model wine increased from a value close to 2 mg g<sup>-1</sup> in the ADY preparation, to about 4-6 mg g<sup>-1</sup> in the samples processed without temperature control, with no significant effects given by the number of passes. Contrary, in the products obtained with thermal conditioning, the number of passes caused a significant increase of FAA release above the fourth passage through the homogenizer valve. This approximately double concentration of soluble amino acids detected in the autolysates produced in controlled temperature conditions, might be linked with their minor involvement in Maillard reaction, as a consequence of the lower extent of heating registered for this set of samples (Ashoor & Zent, 1984). This observation is interesting, because it seems clear that the opportunity to control or not the processing temperature may affect the composition of the yeast

autolysates obtained by HPH: for instance, when the IDY preparation is requested as nutrient supplement to be used during alcoholic fermentation, the processing with temperature control might be advisable for increasing FAA content. Contrary, a high level of free amino acids might be negative in the attempt of using IDYs during wine ageing, because such molecules might become substrate for the growth of unwanted microorganisms, such as wild lactic acid bacteria strains or *Brettanomyces* spp.

### 3.3 Release of glucidic colloids in wine-like solution

The release of soluble glucidic colloids (SGC) reflects the same general behavior found for free amino acids and proteins (Fig. 3). As previously reported, this group of macromolecules represents basically yeast glycoproteins (Comuzzo, Tat, Liessi, Brotto, Battistutta, & Zironi, 2012), and they are considered to positively contribute to wine structure and composition. SGC increased from less than 50 mg g<sup>-1</sup> in the ADY preparation, to values higher than 150 mg g<sup>-1</sup> after one homogenization passage, confirming the capacity of HPH processing to promote cell autolysis (Comuzzo et al. 2015a). The increase of the number of passes determined a progressive increment of the SGC solubilized, particularly in conditions of controlled temperature. Anyway, differently respect to what observed for amino acids and soluble proteins (where the effects of heating seemed more efficient than the number of passes in promoting solubilization), the role of temperature conditioning, on the release of glucidic colloids, appeared less important, and the increase of the number of passages showed a non-negligible effect in promoting the solubilization of these macromolecules. As shown in Fig. 3, the highest concentration detected was higher than 200 mg g<sup>-1</sup>; this means that, considering the amounts normally used for inactive dry yeast supplementation in winemaking (200-400 mg l<sup>-1</sup>), the yeast derived product manufactured by HPH in the present conditions, might be able to increase wine colloidal content of 40-80 mg l<sup>-1</sup>.



### 277      3.4 Volatile composition of the freeze-dried powders

278      Fifty volatile compounds were tentatively identified in the headspace of the autolysates  
279      obtained by multi-pass HPH, under different temperature regimes (Table 1).

280      Concerning their origin, some of them are well known yeast metabolites (e.g. alcohols, short-  
281      chain fatty acids and ethyl esters); others may arise from the thermal and oxidative  
282      degradation of the lipid fraction ( $\gamma$ - and  $\delta$ -lactones, hexanal, nonanal and certain carboxylic  
283      acids) (Nawar, 1969; Grosch, 1987). However, it should be pointed out that the development  
284      of Maillard reaction between sugar and proteins is expected to be the main critical factor able  
285      to affect the formation of odor compounds in yeast derivatives (Ames & McLeod, 1985;  
286      Münch et al., 1997). In effects, some of the compounds reported in Table 1 (furaldehyde,  
287      pyrazines and 2-methyl-thiazolidine) may derive exactly from Maillard reaction  
288      (Nagodawithana, 1992). Aldehydes, such as 2- and 3-methylbutanal, may be produced from  
289      the Strecker degradation of isoleucine and leucine, respectively. Such aldehydes may be  
290      oxidized to 3-methylbutanoic and 2-methylpropanoic acid (Ames & McLeod, 1985), which  
291      have been detected as some of the most abundant compounds in the volatile composition of  
292      yeast derivatives, and may be responsible of off-flavors perceivable in wine (Comuzzo et al.,  
293      2006).

294      The results of Principal Components Analysis (PCA), carried out after grouping all the aroma  
295      compounds on the basis of their chemical class, are reported in Fig. 4. The projections of  
296      variables and cases highlight that ADY preparation was different respect to the yeast  
297      autolysates obtained after HPH. Moreover, among high pressure treated samples, it was  
298      possible to distinguish two different groups, depending on the mode of temperature  
299      management. In particular, the powders obtained under controlled temperature conditions  
300      (4P\_TC, 6P\_TC, 10P\_TC) and the sample 1P, appeared richer in alkyl-pyrazines, alcohols  
301      and esters. Contrary, samples processed without thermal control (4P, 6P, 10P) had a less  
302      intense volatile profile, closer to that shown by the original ADY preparation, and this<sub>13</sub>

might be due to a more intense volatilization connected to the higher extent of heating registered for these samples.

ANOVA results confirm these considerations (Table 2); the main differences among the treatments were related for the most, to alcohols, ethyl esters, alkyl-pyrazines, fatty acids and carbonyl compounds. Higher Alcohols were not present in significant concentrations in the active dry yeast, whereas their content increased even after a single-pass treatment. This is likely connected with the ability of HPH to induce autolysis (Comuzzo et al., 2015a), promoting in such a way the release of these compounds. ANOVA and Tukey HSD Test well highlighted the differences among the samples. In particular, the content of alcohols showed a tendential decrease, as the temperature and the number of passes increased, and the powders obtained without thermal conditioning had a lower concentration of such molecules in their headspace. This might be due to volatilization phenomena, or to their thermal degradation, both induced by heating. Exceptions to this trend were represented by 1-hexanol and 2-ethyl-1-hexanol, whose concentration appeared to be greater in ADY and in some of the samples processed without thermal control.

Ethyl esters were tentatively identified in the products obtained by single-pass treatment, confirming that these compounds may be released during the autolytic process (Alexandre and Guilloux-Benatier, 2006). The samples obtained with temperature control did not show any significant difference from the sample 1P, while the powders produced without thermal conditioning were characterized by a statistically lower content of esters. According to this trend, the esters concentration appeared to be more affected by heating, rather than by the number of homogenization passes, even if a certain reduction of the average values was observed, as the number of cycles increased (Table 2).

The concentrations found for alkyl-pyrazines also highlighted some minor differences among the samples. Pyrazines were not detected in ADY preparation, while they were found in HPH treated samples, for most of them, even after one single pass. The increase of the number of

passes did not significantly modify their amount, while the effect of processing temperature on such heterocyclic compounds was more evident, and it was similar to that observed for alcohols and esters. In fact, even if without broad statistical confirmations, pyrazines were averagely present in greater extent in the samples produced with thermal conditioning, and in lower amounts in those obtained without temperature control. This behavior, became statistically significant in the case of 2,3,5-trimethylpyrazine (the most abundant, tentatively identified in the former group of samples but not in the latter), while it was not found for 3-ethyl-2,5-dimethylpyrazine, the sole among such compounds which did not follow this trend. The lower presence of pyrazines in the samples not thermally controlled might be connected with the fact that they might be further involved in subsequent steps of Maillard reaction itself during processing. The same phenomena did not occur in the samples produced by controlling temperature.

Few differences were found concerning fatty acids composition. From the statistical point of view, no significant differences were marked among the samples, for the most of the compounds detected, neither as a function of the number of passes, nor depending on the way of temperature management during the process. Unlike, significant differences among the autolysates produced with and without temperature conditioning, were found in the case of 2-ethylhexanoic and octanoic acid. These two compounds were both present in high concentration in the samples obtained with thermal control probably due to the effect of heating on the degradation of lipid components. This trend was found also for hexanoic acid, even if without any statistical confirmation.

The carbonyl compounds detected in the powders can be divided in two subgroups: the first one is represented by acetoin, a well known yeast metabolite, while the second includes compounds that are reported as oxidation products of lipids (e.g. hexanal, heptanal or nonanal) (Grosh, 1982) or breakdown derivatives of carotenoids (e.g. 6-methyl-5-heptene-2-one) (Schreier, Drawert, & Junker, 1977). Acetoin level did not show any significant

modification induced by varying the processing variables, and the compound was found to be present in higher amounts in the ADY preparation. Contrary, significant differences were found for all the compounds included in the second group of volatiles, highlighting, for all of them, a greater concentration in the powders obtained without temperature conditioning. The number of passes, instead, did not modify substantially the content of such molecules.

#### **4 Conclusions**

In conclusion, high pressure homogenization confirmed its ability to induce autolysis of wine yeasts and its potential to be applied in the production of inactive dry yeasts for winemaking. Both the number of passes and processing temperature were able to affect yeast viability and the release of soluble molecules (glucidic colloids, proteins and free amino acids), but the latter appeared more powerful for tailoring the compositional characteristics of the IDYs produced.

In the conditions of the present experiment, suitable levels of viable cell inactivation (in compliance with the limits recommended by the O.I.V. in inactive dry yeasts and yeast autolysates for winemaking – Resolution Oeno 496/2013, 2013), were achieved with 6-10 homogenization passes, under uncontrolled temperature regime, with a temperature of the yeast suspension after processing, which raised up to 70-75 °C. Such conditions are quite difficult to be scaled-up at industrial level, due to the high number of homogenization steps required, but these results suggest that HPH may anyhow be used in the manufacturing of inactive dry yeasts (e.g. in combination with natural or added enzymes), for making the natural autolytic process faster and more rational.

The management of processing temperature could also be a suitable tool for tailoring the composition of the yeast derivatives produced by HPH. An interesting observation, connected to the opportunity to control or not the processing temperature, is related to the release of soluble macromolecules (glucidic colloids in particular) and free amino acids. Being equal

the number of passes, higher temperatures only slightly affected the levels of soluble colloids, but the heating led to reduced concentrations of soluble amino acids in the autolysates. This information may be important for the production of IDYs to be used as fermentation enhancers, for which a higher content of soluble amino acids is required: for such application, a suitable temperature control might be recommended.

Finally, temperature and number of passes also affected the volatile composition of the yeast derivatives produced; even in this case, the former variable gave effects that were averagely more evident. The autolysates obtained without cooling were less characterized from the point of view of their volatile composition; such minor concentration in aroma molecules could be interesting when IDY supplementation is required for increasing wine colloidal content (e.g. during ageing), without affecting wine sensory profile with the release of exogenous aromas. Contrary, the higher concentration in ethyl esters, detected in the samples obtained with temperature control, may represent an interesting opportunity to simulate the natural enrichment of wine itself in these molecules, during ageing on the lees.

Further investigations will be required to assess the potential effects of such yeast autolysates produced by HPH on the colloidal and volatile composition of the wines, in comparison with traditionally produced IDY preparations as well as with commercial IDY products.

## References

Acree, T., & Arn, H. (2016). Flavornet and human odor space. Gas chromatography - olfactometry (GCO) of natural products. URL <http://www.flavornet.org/flavornet.html>, Accessed 19.04.2016.

Alexandre, A., & Guilloux-Benatier, M. (2006). Yeast autolysis in sparkling wine. A review. *Australian Journal of Grape and Wine Research*, 12, 119-127.

Ames, J.M., & McLeod, G.M. (1985). Volatile components of a yeast extract composition. *Journal of Food Science*, 50, 125-135.

405 Ashoor, S.H., & Zent, J.B. (1984). Maillard reaction of common amino acids and sugars.  
 406 *Journal of Food Science*, 49, 1206-1207.

407 Baek, H.H., & Cadwallader, K.R. (1999). Contribution of free and glycosidically bound  
 408 volatile compounds to the aroma of muscadine grape juice. *Journal of Food Science*, 64, 441-  
 409 444.

410 Comuzzo, P., Tat, L., Tonizzo, A., & Battistutta, F. (2006). Yeast derivatives (extracts and  
 411 autolysates) in winemaking: Release of volatile compounds and effects on wine aroma  
 412 volatility. *Food Chemistry*, 99, 217-230.

413 Comuzzo, P., Tat, L., Fenzi, D., Brotto, L., Battistutta, F., & Zironi, R. (2011). Interactions  
 414 between yeast autolysates and volatile compounds in wine and model solution. *Food*  
 415 *Chemistry*, 127, 473-480.

416 Comuzzo, P., Tat, L., Liessi, A., Brotto, L., Battistutta, F., & Zironi, R. (2012). Effect of  
 417 different lysis treatments on the characteristics of yeast derivatives for winemaking. *Journal*  
 418 *of Agricultural and Food Chemistry*, 60, 3211-3222.

419 Comuzzo, P., Calligaris, S., Iacumin, L., Ginaldi, F., Palacios Paz, A.E., & Zironi, R. (2015a).  
 420 Potential of high pressure homogenization to induce autolysis of wine yeasts. *Food*  
 421 *Chemistry*, 185, 340-348.

422 Comuzzo, P., Battistutta, F., Vendrame, M., Páez, M.S., Luisi, G., & Zironi, R. (2015b).  
 423 Antioxidant properties of different products and additives in white wine. *Food Chemistry*,  
 424 168, 107–114.

425 Culleré, L., Escudero, A., Cacho, J., & Ferreira, V. (2004). Gas chromatography-olfactometry  
 426 and chemical quantitative study of aroma of six premium quality spanish aged red wines.  
 427 *Journal of Agricultural and Food Chemistry*, 52, 1653-1660.

428 Davies, N.W. (1990). Gas chromatographic retention indices of monoterpenes and  
 429 sesquiterpenes on methyl silicone and Carbowax 20M phases. *Journal of Chromatography*,  
 430 503, 1-24.

431 de la Torre, M., Flores, L.B., & Chong, E. (1994). High cell density yeast production: process  
 432 synthesis and scale-up. In E. Galindo, & O.T. Ramirez (Eds.), *Advances in Bioprocess*  
 433 *Engineering* (pp. 67-74). Dordrecht, The Netherlands: Springer Science + Business Media.

434 Dukes, B.C., & Butzke, C.E. (1998). Rapid determination of primary amino acids in grape  
 435 juice using an o-phthalaldehyde / N-acetyl-L-cysteine spectrophotometric assay. *American*  
 436 *Journal of Enology and Viticulture*, 49, 125-134.

437 Follows, M., Hetherington, P.J., Dunnill, P., & Lilly, M.D. (1971). Release of enzymes from  
 438 bakers' yeast by disruption in an industrial homogenizer. *Biotechnology and Bioengineering*,  
 439 13, 549-560.

440 Gonzalez-Rios, O., Suarez-Quiroz, M.L., Boulanger, R., Barel, M., Guyot, B., Guiraud, J.P.,  
 441 & Schorr-Galindo, S. (2007). Impact of "ecological" post-harvest processing on coffee aroma:  
 442 II. Roasted coffee. *Journal of Food Composition and Analysis*, 20, 297-307.

443 Goodner, K.L. (2008). Practical retention index models of OV-101, DB-1, DB-5, and DB-  
 444 Wax for flavor and fragrance compounds. *LWT - Food Science and Technology*, 41, 951-958.

445 Grosch, W. (1987). Reactions of hydroperoxides-products of low molecular weight. In H.W.-  
 446 S. Chan, *Autoxidation of unsaturated lipids* (pp. 95-140). London: Academic Press.

447 Halasz, A., & Lasztity, R. (1991). *Use of yeast biomass in food production*. Boca Raton,  
 448 USA: CRC Press, (Chapter 9).

449 Hetherington, P.J., Follows, M., Dunnill, P., & Lilly, M.D. (1971). Release of protein from  
 450 baker's yeast (*Saccharomyces cerevisiae*) by disruption in an industrial homogeniser.  
 451 *Transactions of the Institution of Chemical Engineers*, 49, 142-148.

452 Jennings, W., & Shibamoto, T. (1980). *Qualitative analysis of flavor and fragrance volatiles*  
 453 *by glass capillary gas chromatography*. New York, USA: Academic Press.

454 Lopez, R., Ferreira, V., Hernandez, P., & Cacho, J. (1999). Identification of impact odorants  
 455 of young red wines made with Merlot, Cabernet Sauvignon and Grenache grape varieties: a  
 456 comparative study. *Journal of the Science of Food and Agriculture*, 79, 1461-1467.

457 Madruga, M.S., & Mottram, D.S. (1998). The effect of pH on the formation of volatile  
 458 compounds by heating a model system containing 5'-IMP and cysteine. *Journal of Brazilian*  
 459 *Chemical Society*, 9, 261-271.

460 Münch, P., Hofmann, T., & Schieberle, P. (1997). Comparison of key odorants generated by  
 461 thermal treatment of commercial and self-prepared yeast extracts: influence of the amino acid  
 462 composition on odorant formation. *Journal of Agricultural and Food Chemistry*, 45, 1338-  
 463 1344.

464 Nagodawithana, T. (1992). Yeast-derived flavors and flavor enhancers and their probable  
 465 mode of action. *Food Technology*, 46, 138-144.

466 Nawar, W.W. (1969). Thermal degradation of lipids: a review. *Journal of Agricultural and*  
 467 *Food Chemistry*, 17, 18-21.

468 Organisation Internationale de la Vigne et du Vin, O.I.V. (2013). *Monograph on yeast*  
 469 *autolysates*. Resolution Oeno, 496/2013.

470 Patrignani, F., Ndagijimana, M., Vernocchi, P., Gianotti, A., Riponi, C., Gardini, F., &  
 471 Lanciotti, R. (2013). High-pressure homogenization to modify yeast performance for  
 472 sparkling wine production according to traditional methods. *American Journal of Enology*  
 473 *and Viticulture*, 64, 258-267.

474 Peat, S., Whelan, W.J., & Edwards, T.E. (1961). Polysaccharide of baker's yeast. Part 4.  
 475 Mannan. *Journal of the Chemical Society (London)*, 1, 28-35.

476 Pérez-Serradilla, J.A., & Luque de Castro, M.D. (2008). Role of lees in wine production: A  
 477 review. *Food Chemistry*, 111, 447-456.

478 Popper, L., & Knorr, D. (1990). Application of high pressure homogenization for food  
 479 preservation. *Food Technology*, 44, 84-89.

480 Pozo-Bayón, M.Á., Andújar-Ortiz, I., & Moreno-Arribas, M.V. (2009). Scientific evidences  
 481 beyond the application of inactive dry yeast preparations in winemaking. *Food Research*  
 482 *International*, 42, 754-761.



483 Regenstein, J.M., & Regenstein, C.E. (1984). *Food protein chemistry*. New York, USA:  
 484 Academic Press.

485 Rodríguez-Bencomo, J.J., Andujar-Ortiz, I., Moreno-Arribas, M.V., Simò, C., Gonzales, J.,  
 486 Chana, A., Davalos, J., & Pozo-Bayon, M.A. (2014). Impact of glutathione-enriched inactive  
 487 dry yeast preparations on the stability of terpenes during model wine aging. *Journal of*  
 488 *Agricultural and Food Chemistry*, 62, 1373-1383.

489 Schreier, P., Drawert, F., & Junker, A. (1977). The quantitative composition of natural and  
 490 technologically changed aromas of plants. IV. Enzymic and thermal reaction products formed  
 491 during the processing of tomatoes. *Zeitschrift fuer Lebensmittel-Untersuchung und-*  
 492 *Forschung*, 165, 23-27.

493 Usseglio-Tomasset, L., & Castino, M. (1975). I colloidi solubili di natura glucidica dei mosti  
 494 e dei vini. Parte I. *Rivista di Viticoltura ed Enologia*, 28, 374-391.

495 Voilley, A., Beghin, V., Charpentier, C., & Peyron, D. (1991). Interaction between aroma  
 496 substances and macromolecules in a model wine. *Lebensmittel-Wissenschaft und -*  
 497 *Technologie*, 24, 469-472.

498 Welke, J.E., Manfroi, V., Zanus, M., Lazarotto, M., & Alcaraz Zini, C. (2012).  
 499 Characterization of the volatile profile of Brazilian Merlot wines through comprehensive two  
 500 dimensional gas chromatography time-of-flight mass spectrometric detection. *Journal of*  
 501 *Chromatography A*, 1226 (124-139).

502 Wong, J.M., & Bernhard, R.A. (1988). Effect of nitrogen source on pyrazine formation.  
 503 *Journal of Agricultural and Food Chemistry*, 36, 123-129.

504 Yeo, H.C.H., & Shibamoto, T. (1991). Microwave-induced volatiles of the Maillard model  
 505 system under different pH conditions. *Journal of Agricultural and Food Chemistry*, 39, 370-  
 506 373.

## 508 **Figure Captions**

509 **Fig. 1.** Viable yeasts in the active dry yeast preparation (ADY) and in the samples obtained by HPH  
 510 treatment (150 MPa), as a function of the number of passes (1P, 4P, 6P, 10P), in controlled (a) and  
 511 not controlled temperature conditions (b). Different letters mark significant differences among yeast  
 512 counts, according to ANOVA and Tukey HSD test ( $p < 0.05$ ). Vertical bars represent standard  
 513 deviation. For the sample 10P, data are reported in CFU g<sup>-1</sup> (<10 CFU g<sup>-1</sup>).

514  
 515 **Fig. 2.** Soluble proteins (a) and free amino acids (b) in the active dry yeast preparation (ADY) and  
 516 in the freeze-dried powders obtained by HPH treatment (150 MPa), as a function of the number of  
 517 passes (1P, 4P, 6P, 10P), in controlled and not controlled temperature conditions. Different letters  
 518 mark significant differences according to ANOVA and Tukey HSD test, at  $p < 0.05$ . Vertical bars  
 519 represent standard deviations.

520  
 521 **Fig. 3.** Soluble glucidic colloids in the active dry yeast preparation (ADY) and in the freeze-dried  
 522 powders obtained by HPH treatment (150 MPa), as a function of the number of passes (1P, 4P, 6P,  
 523 10P), in controlled and not controlled temperature conditions. Different letters mark significant  
 524 differences according to ANOVA and Tukey HSD test, at  $p < 0.05$ . Vertical bars represent standard  
 525 deviations.

526  
 527 **Fig. 4.** Results of PCA carried out on the absolute areas of the volatile compounds detected by  
 528 SPME-GC-MS, and grouped basing on their chemical class. The projection of both cases (samples)  
 529 (a) and variables (chemical groups) (b) on the factor plane is reported. ADY: active dry yeast; 1P,  
 530 4P, 6P, 10P: HPH treatments (1, 4, 6 and 10 passes at 150 MPa) without temperature control;  
 531 4P\_Tc, 6P\_Tc, 10P\_Tc: HPH treatments (4, 6 and 10 passes at 150 MPa) with temperature control.

532

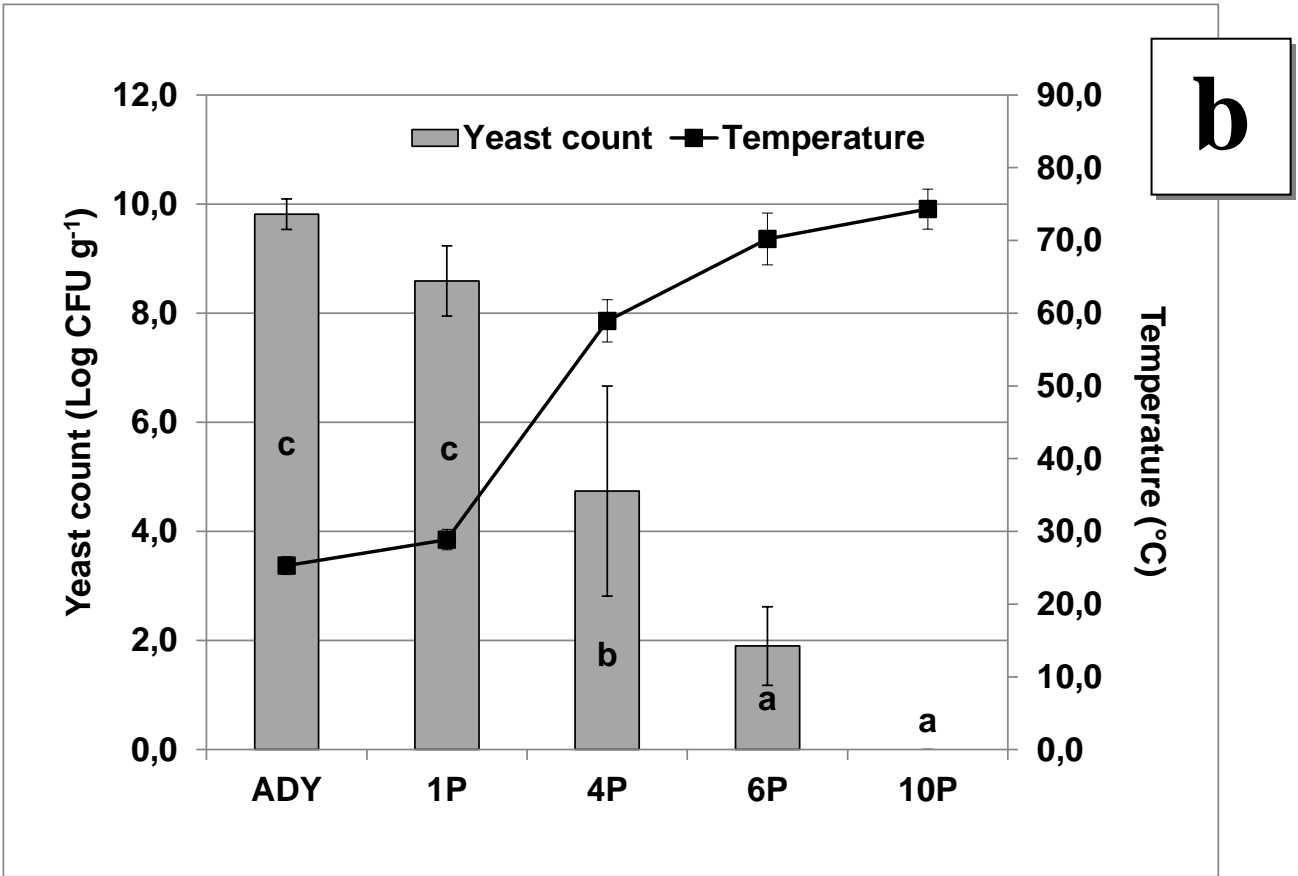
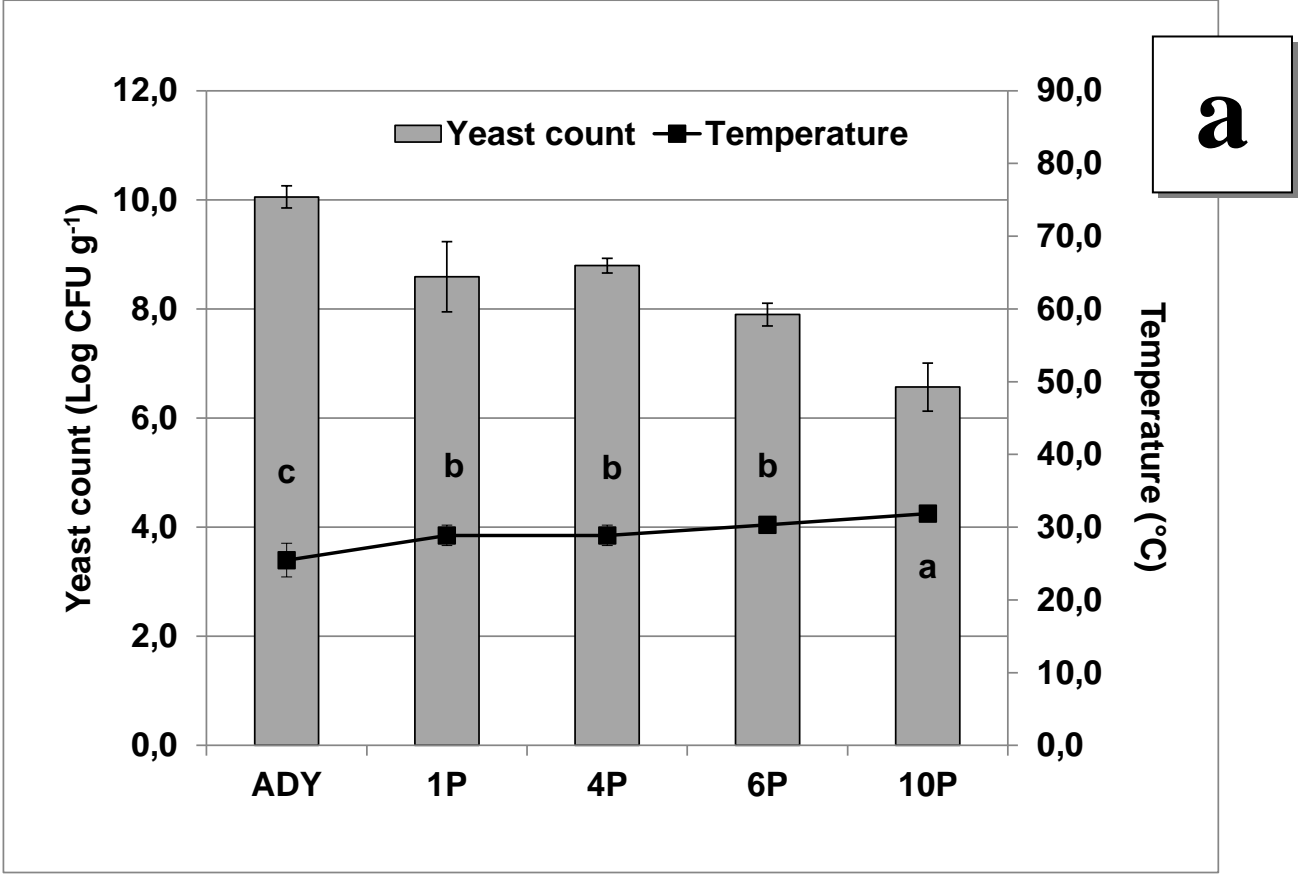
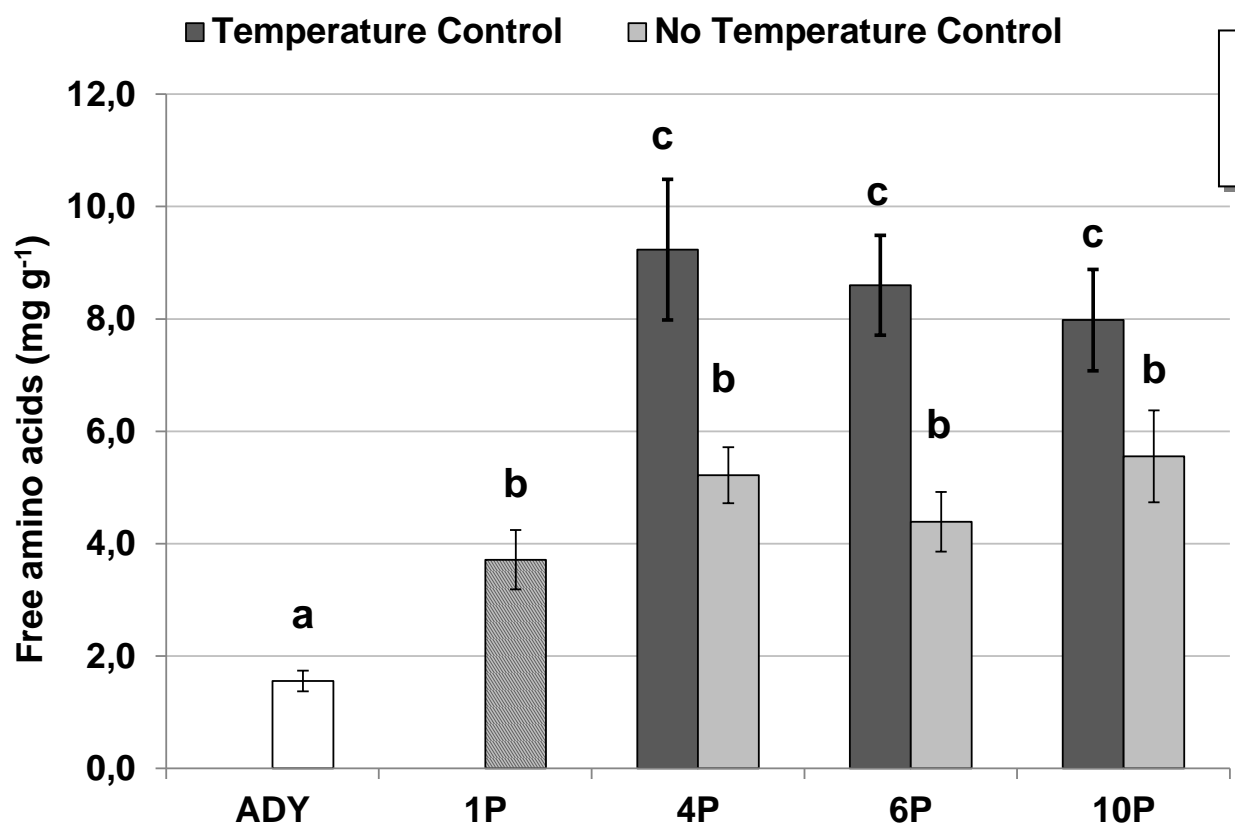
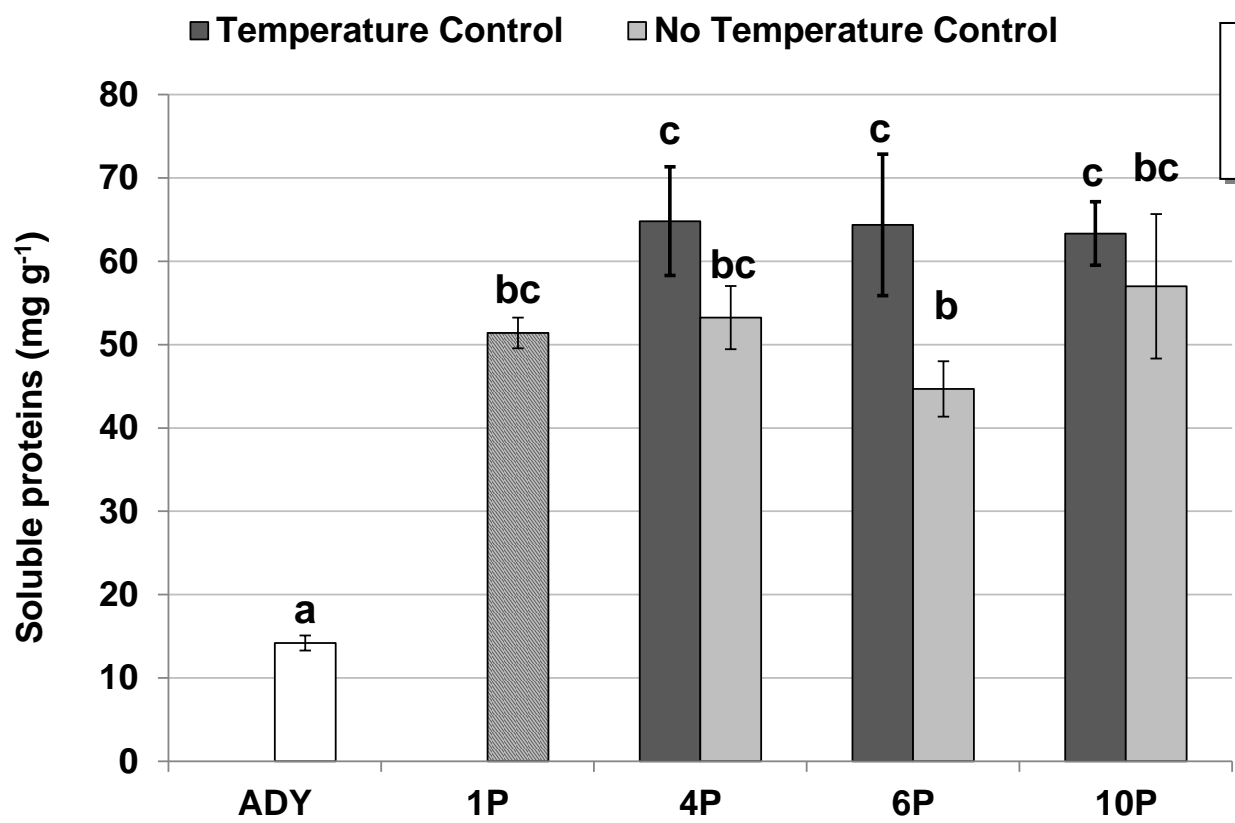
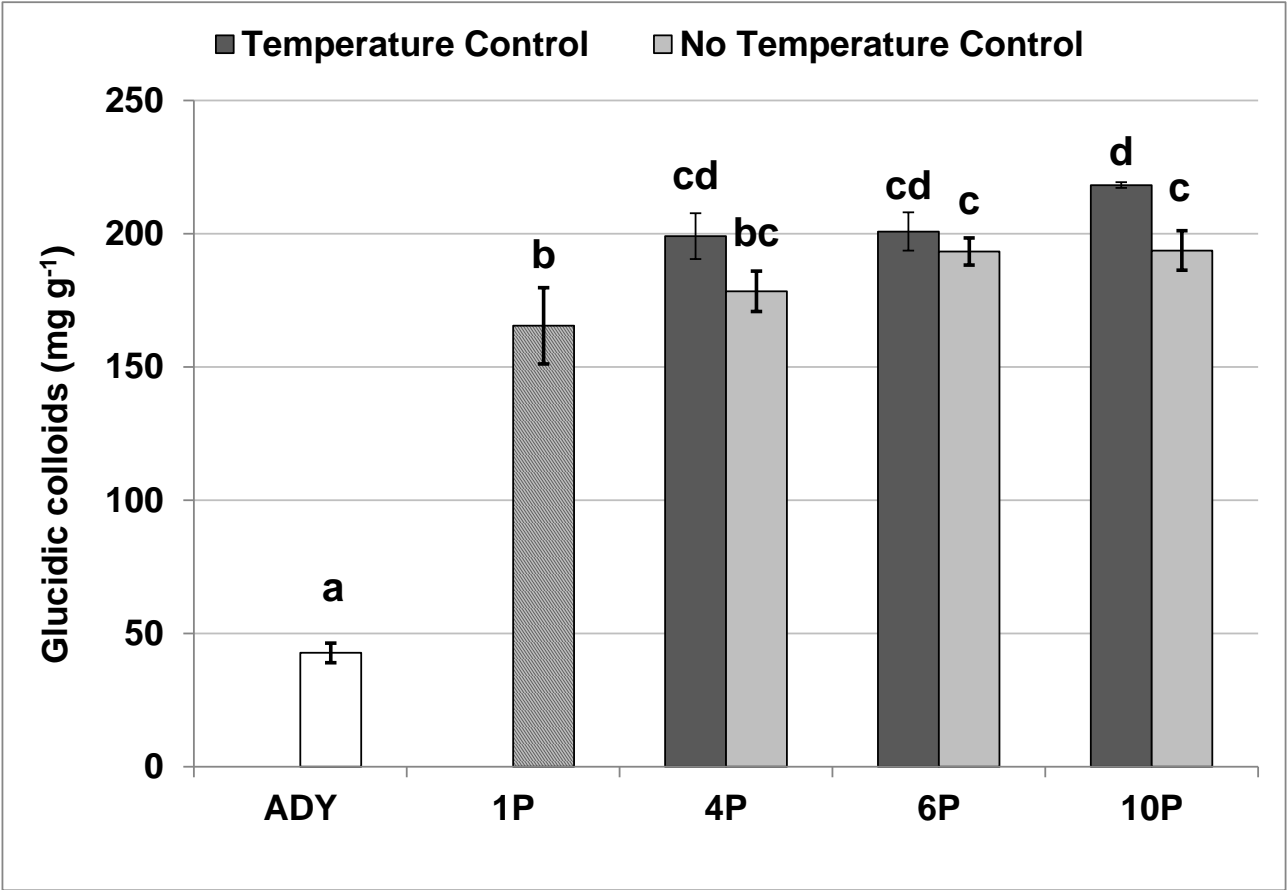


Fig. 1



**Fig. 2**

587  
588  
589  
590  
591



592  
593  
594

Fig. 3

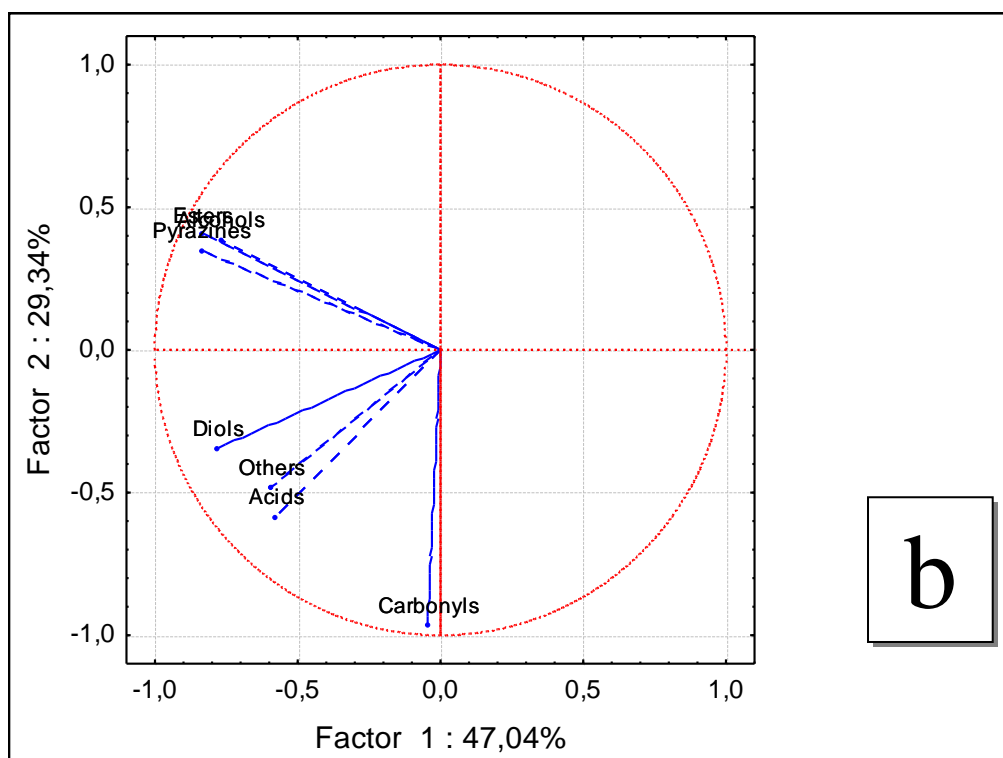
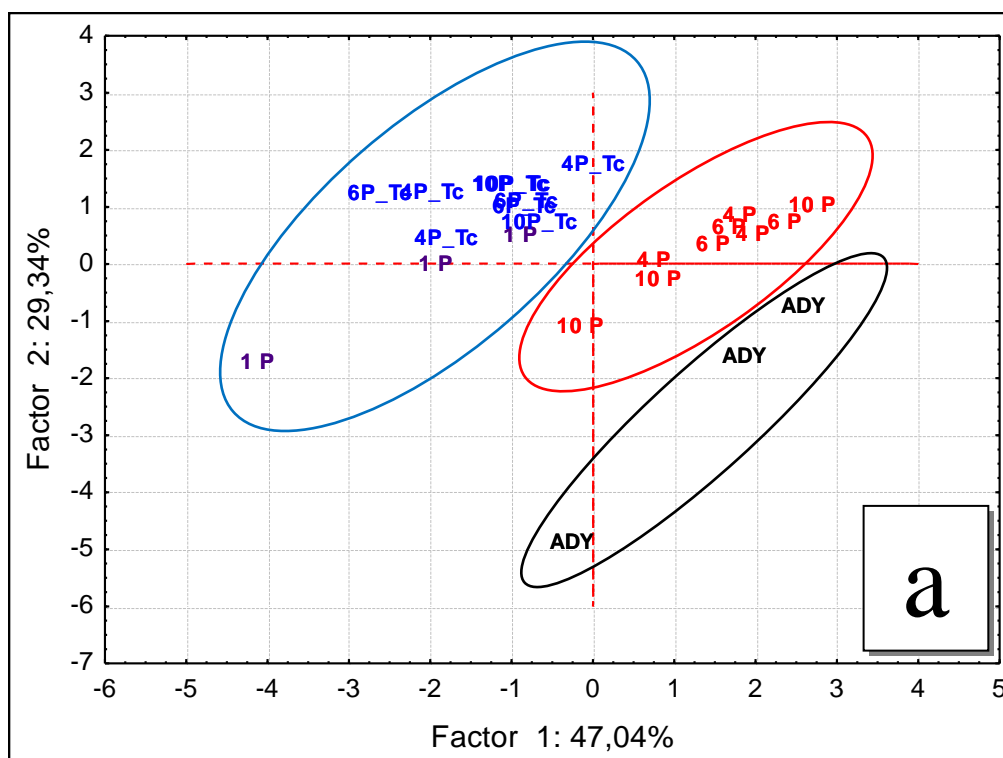


Fig. 4

621

622

623

624

Table 1

Volatile compounds tentatively identified by SPME-GC-MS, in the headspace of the samples analyzed.

Compound	Ir <sup>a</sup>	Ir <sub>(lit)</sub> <sup>b</sup>	Ref. <sup>c</sup>	IM <sup>d</sup>
1 ethyl acetate				MS
2 ethanol	936	929	Acree & Arn, 2016	MS, RI
3 ethyl butanoate	1.038	1.034	Baek & Cadwallader, 1999	MS, RI
4 ethyl 2-methylbutanoate	1.053	1.051	Baek & Cadwallader, 1999	MS, RI
5 ethyl 3-methylbutanoate	1.069	1.082	Cullere et al., 2004	MS, RI
6 hexanal	1.080	1.084	Jennings & Shibamoto, 1980	MS, RI, S
7 2-methyl-1-propanol	1.093	1.096	Lopez et al., 1999	MS, RI
8 1-butanol	1.149	1.145	Baek & Cadwallader, 1999	MS, RI, S
9 β-myrcene	1.162	1.166	Davies, 1990	MS, RI
10 heptanal	1.182	1.184	Goodner, 2008	MS, RI
11 2- and 3-methyl-1-butanol	1.212	1.210	Baek & Cadwallader, 1999	MS, RI, S
12 ethyl hexanoate	1.237	1.234	Baek & Cadwallader, 1999	MS, RI, S
13 unknown	1.252			
14 3-hydroxy-2-butanone (acetoin)	1.281	1.290	Baek & Cadwallader, 1999	MS, RI, S
15 2,6-dimethyl-pyrazine	1.326	1.325	Jennings & Shibamoto, 1980	MS, RI
16 6-methyl-5-hepten-2-one	1.333	1.336	Comuzzo et al., 2015	MS, RI
17 ethyl heptanoate	1.333	1.325		MS, S
18 ethyl lactate	1.341	1.358	Acree & Arn, 2016	MS, RI
19 1-hexanol	1.359	1.359	Lopez et al., 1999	MS, RI, S
20 2-ethyl-6-methylpyrazine	1.382	1.384	Comuzzo et al., 2006	MS, RI
21 nonanal	1.388	1.382	Jennings & Shibamoto, 1981	MS, RI
22 2-butoxyethanol	1.400			MS
23 2,3,5-trimethylpyrazine	1.401	1.408	Comuzzo et al., 2006	MS, RI
24 2-methyl-thiazolidine	1.420	1.415	Yeo & Shibamoto, 1991	MS, RI
25 ethyl octanoate	1.432	1.435	Baek & Cadwallader, 1999	MS, RI, S
26 3-ethyl-2,5-dimethylpyrazine	1.445	1.464	Comuzzo et al., 2006	MS, RI
27 acetic acid	1.448	1.451	Baek & Cadwallader, 1999	MS, RI, S
28 2-furaldehyde (furfural)	1.452	1.475	Lopez et al., 1999	MS, RI, S
29 2,3,5,6-tetramethylpyrazine	1.474	1.458	Ames & McLeod, 1985	MS, RI
30 2-ethyl-1-hexanol	1.493	1.490	Madrugá & Mottram, 1998	MS, RI, S
31 benzaldehyde	1.542	1.528	Baek & Cadwallader, 1999	MS, RI, S
32 ethyl 3-hydroxybutanoate	1.514			MS
33 propanoic acid	1.530	1.528	Münch et al., 1997	MS, RI, S
34 2,3-butandiol	1.545	1.545	Baek & Cadwallader, 1999	MS, RI
35 2-methylpropanoic acid	1.567	1.548	Münch et al., 1997	MS, RI, S
36 1,2-propandiol	1.582	1594	Wong & Bernhard, 1988	MS, RI
37 dihydro-5-methyl-2(3H)-furanone (γ-valerolactone)	1.595	1617	Jennings & Shibamoto, 1981	MS
38 dihydro-2(3H)-furanone (γ -butyrolactone)	1.618	1.632	Jennings & Shibamoto, 1981	MS, RI, S
39 butanoic acid	1.627	1.612	Münch et al., 1997	MS, RI, S
40 ethyl decanoate	1.635	1.634	Lopez et al., 1999	MS, RI, S
41 2-furanmethanol	1.655	1.673	Comuzzo et al., 2006	MS, RI
42 3-methylbutanoic acid	1.669	1.672	Baek & Cadwallader, 1999	MS, RI, S
43 diethyl succinate	1.676	1.642	Jennings & Shibamoto, 1980	MS

	<b>Compound</b>	<b>Ir<sup>a</sup></b>	<b>Ir<sub>(lit)</sub><sup>b</sup></b>	<b>Ref.<sup>c</sup></b>	<b>IM<sup>d</sup></b>
44	5,6-dihydro-2 <i>H</i> -pyran-2-one	1.688			<i>MS</i>
45	3-(methylthio)-1-propanol (methionol)	1.711	1714	Lopez et al., 1999	<i>MS, RI</i>
46	hexanoic acid	1.848	1854	Lopez et al., 1999	<i>MS, RI, S</i>
47	2-phenylethanol	1.902	1.922	Baek & Cadwallader, 1999	<i>MS, RI, S</i>
48	1,4-butandiol	1.924	1861	Jennings & Shibamoto, 1980	<i>MS</i>
49	2-ethylhexanoic acid	1.947	1974	Welke et al., 2012	<i>MS, RI</i>
50	octanoic acid	2.059	2060	Lopez et al., 1999	<i>MS, RI, S</i>

- a     Ir: Retention index
- b     Ir<sub>(lit)</sub>: Retention index from literature
- c     Ref.: bibliografic reference
- d     IM: *S* comparison of mass spectra and retention time with those of standard compounds; *RI* comparison of order of elution with those reported in literature; *MS* comparison of mass spectra with those reported in Wiley 6 and NIST 107 mass spectrum libraries

626

627



629 Effect of HPH treatments (150 MPa) on the volatile composition of the freeze-dried powders. ADY: active dry yeast; 1P, 4P, 6P, 10P: HPH treatments (1, 4, 6  
630 and 10 passes) without temperature control; 4P\_Tc, 6P\_Tc, 10P\_Tc: HPH treatments (4, 6 and 10 passes) with temperature control. Different letters mark  
631 significant differences according to ANOVA and Tukey HSD test, at  $p < 0.05$ . SD: standard deviation.

Compound	Rt <sup>a</sup>	Absolute area / 1000																															
		ADY			1P			4P_Tc			6P_Tc			10P_Tc			4P			6P			10P										
		Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD								
<i>Acids</i>																																	
acetic acid	16,8	181798	±	7266	b	58372	±	29767	a	98544	±	53522	ab	83105	±	30705	a	58724	±	21995	a	56272	±	10607	a	41548	±	9280	a	73617	±	49072	a
2-methylpropanoic acid	20,5	118098	±	113510	a	177846	±	76090	a	130535	±	38677	a	136560	±	30376	a	128831	±	26163	a	144347	±	52402	a	129336	±	38840	a	182951	±	116161	a
butanoic acid	22,2	27063	±	26176	a	16997	±	11016	a	9653	±	5902	a	12725	±	4531	a	11645	±	3266	a	9970	±	4509	a	8803	±	3585	a	16040	±	12987	a
3-methylbutanoic acid	23,5	66043	±	77127	a	149490	±	87686	a	109432	±	60460	a	131037	±	41831	a	111916	±	35724	a	88601	±	44662	a	75083	±	35185	a	146391	±	115190	a
hexanoic acid	28,4	3235	±	3239	a	3405	±	2122	a	1976	±	259	a	1393	±	1224	a	2433	±	786	a	0	±	0	a	0	±	0	a	606	±	688	a
2-ethylhexanoic acid	31,0	0	±	0	a	0	±	0	a	711	±	631	ab	1554	±	283	b	1085	±	969	ab	0	±	0	a	0	±	0	a	0	±	0	a
octanoic acid	33,8	0	±	0	a	14960	±	11716	b	0	±	0	a	1680	±	2910	a	787	±	1363	a	0	±	0	a	0	±	0	a	132	±	229	a
<i>Alcohols</i>																																	
ethanol	3,3	122445	±	28115	a	1217247	±	96244	e	970939	±	39987	cd	946836	±	8793	cd	932973	±	14120	bcd	811894	±	25910	b	837218	±	39074	bc	845959	±	59638	bc
2-methyl-1-propanol	6,2	31173	±	53992	a	361173	±	122000	c	299241	±	33400	bc	174116	±	28157	ab	127623	±	20666	a	112491	±	43891	a	101455	±	26006	a	106295	±	50009	a
2- and 3-methyl-1-butanol	9,5	208380	±	360925	a	1620151	±	244887	c	1633470	±	75973	c	1330683	±	83097	bc	1179959	±	109112	bc	1029730	±	211711	bc	983472	±	181846	b	934591	±	302713	b
1-hexanol	14,0	5402	±	2924	bc	8489	±	702	c	1048	±	393	a	1037	±	899	a	2177	±	749	ab	2078	±	330	ab	1820	±	256	ab	2390	±	2176	ab
2-ethyl-1-hexanol	18,3	8058	±	902	b	3272	±	1402	a	1566	±	586	a	1919	±	557	a	3036	±	1416	a	2437	±	919	a	3134	±	283	a	3935	±	2796	a
2-phenylethanol	29,9	5070	±	2563	a	53863	±	32661	bc	58792	±	20303	c	32896	±	12835	abc	24147	±	9953	abc	8905	±	4417	a	7595	±	3892	a	13933	±	8554	ab
<i>Carbonyls</i>																																	
hexanal	5,9	0	±	0	a	5596	±	1503	b	129	±	223	a	0	±	0	a	0	±	0	a	4197	±	1105	b	4370	±	1456	b	4055	±	2451	b
heptanal	8,6	0	±	0	a	14272	±	2434	c	0	±	0	a	0	±	0	a	0	±	0	a	6494	±	2398	b	6929	±	2819	b	8230	±	2124	b
3-hydroxy-2-butanone (acetoin)	11,6	95462	±	62134	b	30859	±	24727	ab	20374	±	6536	a	9843	±	3682	a	4894	±	1933	a	7837	±	3816	a	7383	±	1663	a	8816	±	6410	a
6-methyl-5-hepten-2-one	13,2	0	±	0	a	0	±	0	a	0	±	0	a	0	±	0	a	1717	±	2973	ab	6239	±	1015	c	5151	±	902	bc	3618	±	2105	abc
nonanal	15,0	0	±	0	a	6211	±	1133	bcd	3650	±	631	b	4372	±	1114	bc	3729	±	596	b	6816	±	1161	cde	7364	±	1405	de	9390	±	1506	e
<i>Heterocyclic compounds</i>																																	
2-methyl-thiazolidine	16,0	0	±	0	a	0	±	0	a	6222	±	9679	a	3363	±	3355	a	0	±	0	a	0	±	0	a	0	±	0	a	0	±	0	a
dihydro-5-methyl-2(3H)-furanone (γ-valerolactone)	21,4	0	±	0	a	7722	±	4214	a	3322	±	4557	a	7069	±	1234	a	6038	±	1314	a	3438	±	5954	a	1349	±	2336	a	6424	±	5589	a
dihydro-2(3H)-furanone (γ-butyrolactone)	22,0	30431	±	10759	b	10780	±	5016	a	8349	±	2512	a	8443	±	1482	a	7959	±	1074	a	8551	±	3344	a	7957	±	1498	a	9990	±	4655	a
5,6-dihydro-2H-pyran-2-one	24,1	2390	±	2073	ab	4053	±	1194	b	0	±	0	a	0	±	0	a	659	±	1142	a	994	±	239	a	867	±	266	a	541	±	503	a

632  
635  
636

Table 2. Continued

Compound	Rt <sup>a</sup>	Absolute area / 1000																															
		ADY			1P			4P_Tc			6P_Tc			10P_Tc			4P			6P			10P										
		Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD								
<i>Diols</i>																																	
2,3-butandiol	19,8	22793	±	14276	a	22037	±	11445	a	21827	±	2950	a	16581	±	3363	a	10856	±	1600	a	8403	±	1818	a	7418	±	2850	a	13595	±	5020	a
1,2-propandiol	20,9	9553	±	6907	ab	12755	±	5017	abc	13930	±	4052	abc	22285	±	2986	c	18070	±	4449	bc	7892	±	2741	ab	1692	±	586	a	6394	±	5526	ab
1,4-butandiol	30,4	0	±	0	a	0	±	0	a	1211	±	168	b	1212	±	280	b	894	±	452	ab	1103	±	110	b	1534	±	284	b	686	±	795	ab
<i>Esters</i>																																	
ethyl acetate	2,8	0	±	0	a	0	±	0	a	169376	±	60706	d	111520	±	17077	cd	72708	±	26615	bc	26011	±	7142	ab	30946	±	5759	ab	15428	±	4701	ab
ethyl butanoate	4,9	0	±	0	a	76065	±	4671	b	66828	±	28331	b	69142	±	21649	b	51437	±	15886	bc	0	±	0	a	0	±	0	a	0	±	0	a
ethyl 2-methylbutanoate	5,3	0	±	0	a	17092	±	202	b	16281	±	8888	b	14378	±	13225	b	2808	±	4864	b	0	±	0	a	0	±	0	a	0	±	0	a
ethyl 3-methylbutanoate	5,6	0	±	0	a	12311	±	6100	b	7955	±	4209	b	8515	±	4657	b	6295	±	3190	b	0	±	0	a	0	±	0	a	0	±	0	a
ethyl hexanoate	10,2	0	±	0	a	55528	±	10108	b	98161	±	29681	b	72522	±	14668	b	73791	±	29887	b	1245	±	1467	a	0	±	0	a	570	±	987	a
ethyl heptanoate	13,2	0	±	0	a	16211	±	1618	b	12898	±	3690	b	12141	±	1792	b	8624	±	7847	ab	0	±	0	a	0	±	0	a	0	±	0	a
ethyl lactate	13,5	0	±	0	a	16623	±	6946	b	5560	±	2847	a	5357	±	3939	a	4830	±	3792	ab	0	±	0	a	0	±	0	a	0	±	0	a
ethyl octanoate	16,3	13870	±	5378	a	1042294	±	83438	b	1038839	±	237474	b	931907	±	301368	b	935959	±	359645	b	43077	±	17782	a	15083	±	5607	a	23177	±	26642	a
ethyl 3-hydroxybutanoate	18,9	0	±	0	a	2375	±	1077	a	606	±	1050	a	1204	±	1383	a	747	±	772	a	0	±	0	a	219	±	379	a	2565	±	3806	a
ethyl decanoate	22,5	8902	±	2604	a	93992	±	12175	b	102659	±	30056	b	92958	±	26716	b	96502	±	41188	b	2388	±	784	a	985	±	516	a	2249	±	2262	a
diethyl succinate	23,7	0	±	0	a	75487	±	40743	b	14778	±	2450	b	6749	±	569	b	8755	±	7963	b	0	±	0	b	0	±	0	b	0	±	0	b
<i>Pyrazines</i>																																	
2,6-dimethyl-pyrazine	13,0	0	±	0	a	2987	±	2024	a	1773	±	263	a	6452	±	6440	a	7572	±	5665	a	983	±	992	a	1118	±	564	a	1093	±	1893	a
2-ethyl-6-methylpyrazine	14,8	0	±	0	a	3376	±	1987	a	1505	±	1501	a	2880	±	1587	a	2099	±	1116	a	742	±	516	a	656	±	568	a	1188	±	1280	a
2,3,5-trimethylpyrazine	15,4	0	±	0	a	10609	±	5485	b	10949	±	2852	b	10941	±	4430	b	7929	±	3456	ab	0	±	0	a	0	±	0	a	0	±	0	a
3-ethyl-2,5-dimethylpyrazine	16,7	0	±	0	a	0	±	0	a	1071	±	1855	ab	1873	±	1683	ab	3165	±	223	b	2732	±	848	ab	1939	±	630	ab	2394	±	1113	ab
2,3,5,6-tetramethylpyrazine	17,7	0	±	0	a	0	±	0	a	268	±	465	a	523	±	688	a	1221	±	1058	a	979	±	1288	a	0	±	0	a	250	±	432	a
<i>Others</i>																																	
β-myrcene	8,0	0	±	0	a	177243	±	28048	b	4112	±	1998	a	10701	±	765	a	6701	±	2535	a	9834	±	8019	a	9918	±	6492	a	4550	±	1737	a
unknown	10,6	102094	±	19610	a	40652	±	3264	a	36154	±	62620	a	46507	±	18478	a	75214	±	39600	a	10617	±	2328	a	35146	±	42167	a	34396	±	40136	a
benzaldehyde	18,7	0	±	0	a	13408	±	12939	a	1892	±	1903	a	2971	±	1531	a	2576	±	957	a	2046	±	580	a	2031	±	540	a	4019	±	2892	a
3-(methylthio)-1-propanol (methionol)	24,7	0	±	0	a	3459	±	2405	bc	5828	±	1014	c	3661	±	1371	bc	2324	±	1012	ab	711	±	423	ab	579	±	198	ab	1016	±	1002	ab

<sup>a</sup> Rt: retention time

637  
638  
639