Evaluation of Energy Saving Using a New Yeast Combined with Temperature Management in Sparkling Base Wine Fermentation

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Abstract: Heat removal accounts for ~90% of the total energy requirements of the winery and is mostly related to the temperature control of the wine tanks used for fermentation and maturation. The aim of this work was to evaluate the effects of a selected wine yeast, chosen to optimize sensory characteristics and minimize SO_2 production at temperatures higher than the standard for winemaking, on energy consumption during the fermentation process of the Franciacorta base wine. Fermentations using the new yeast strain were conducted at 15 and 19°C, and energy consumption was compared. Moreover, the sensory, chemical, and aromatic features of the Franciacorta sparkling base wines were measured. Fermentation required 21.6 $Wh/L_{grape\ must}$ at 15°C and 7.7 $Wh/L_{grape\ must}$ at 19°C, reducing energy use by ~65% at the higher temperature. Use of the tested yeast had positive effects on energy saving during fermentation without compromising sensory, chemical, and aromatic profiles of the resulting wine. This work suggests possible methods for wineries to adopt a more sustainable winemaking process that lowers energy consumption and decreases SO_2 content in wines, which may introduce eco-labeling strategies and price-premium policies.

Key words: energy saving, fermentation, Franciacorta, sparkling base-wine, sustainability, yeast

The increased awareness of, and interest in, environmental sustainability among non-governmental associations, researchers, industries, retailers, and consumers will drive wine suppliers to provide quantitative information about the environmental impact of energy-saving solutions for their processes and products (Flint and Golicic 2009, Szolnoki 2013). The lack of knowledge about ways to improve energy efficiency is a critical barrier, and operators in the wine sector are searching for innovative approaches for energy conservation.

Production of bottle-fermented sparkling wine is increasing globally and reached total sales of $6.2 billion USD in 2014, a 5.5% increase from 2013 (WineByNumbers, yearly report 2015). Many individuals in the industry are interested in variables related to fermentation management of sparkling wine. Moreover, new market trends and concerns from wine consumers have had a significant influence on winemaking and production of sparkling wine. These concerns include health-related topics, such as sulfite reduction in wines (Guerrero and Cantos-Villar 2015), and environmental concerns, such as sustainability of the wine production chain (Pomarici and Vecchio 2014). The traditional method of sparkling wine production consists of two different phases involving yeast fermentation. The first stage involves an alcoholic fermentation of sugars that leads to the transformation of grape must to base wine. In the second stage, sugar is added to the base wine and transformed into sparkling wine by a second fermentation in a closed environment, which is followed by aging inside the bottle (Alexandre and Guilloux-Benatier 2006, Martí-Raga et al. 2015).

Bottle-fermented sparkling wine properties, including flavor, aroma, foaming height and stability, and sulfite content, are affected by every stage of fermentation, as reviewed by Kemp et al. (2015). It is known that different fermentation management during the first fermentation affects the characteristics of the base wines, depending on yeast strain, fermentation temperature, and management of oxygen and nitrogen (Torrens et al. 2008, Martí-Raga et al. 2015). Moreover, the yeast strain can affect the sulfite content during alcoholic fermentation of white wines and of the base wines (Nardi et al. 2012). In this context, base wines containing low sulfite concentrations not only potentially give rise to sparkling wines with lower final sulfite content, which consumers often prefer for health reasons (Pozo-Bayón et al. 2012), but they are also handled more easily by winemakers during malolactic and second alcoholic fermentation (Henick-Kling and Park 1994, Buxaderas and Lopez-Tamames 2012). Extensive literature has described the effect of temperature on yeast metabolism

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(Masneuf-Pomarède et al. 2006, Molina et al. 2007, Deed et al. 2015), but few studies have assessed the influence of temperature on SO_2 production or on aromatic profile specifically related to base wine production.

Previous works have investigated how the use of energy in the different enological processes of the winemaking industry can be managed by the adoption of energy efficiency tools and renewable technologies. Smyth and Russell (2009) analyzed energy use in viticulture and wine production and found that solar renewable technologies could potentially reduce the energy used in the global winemaking industry by 18.3%. Galitsky et al. (2005) gave a detailed account of energy use, from crushing to bottling, in the winery, which also provides a tool for evaluating the impact of implementing efficiency measures and may facilitate strategic planning of efficiency measures based on their estimated impact, costs, and savings.

For quality purposes, the fermentation process takes place at a controlled temperature to which the wine needs to be cooled at the beginning of and throughout fermentation. The fermentation reaction also generates heat that needs to be removed. This heat removal accounts for the majority of the energy requirement in the winery (~90%), and is related to the temperature control of the wine tanks during fermentation and maturation of the wine (Galitsky et al. 2005). The length of the fermentation period is usually controlled by the winemaker to optimize wine quality.

This study aims to evaluate and quantify the potential energy savings from a sustainable management of yeast fermentation by avoiding unnecessary temperature control during winemaking (i.e., cooling during the first fermentation). A new yeast strain was selected for fermentation of Franciacorta base wine due to its low SO_2 production and ability to adapt to a wide range of temperatures. Two fermentation temperatures (15 and 19°C) were tested to quantify the potential energy savings. Moreover, SO_2 production, aromatic profile, and sensory properties of the wines were evaluated at a semi-industrial scale process.

Materials and Methods

Experimental design. Chardonnay grapes from Villa Crespia winery in Adro, Brescia, Italy were harvested at ripening. The new yeast strain was used to perform fermentations at 15 and 19°C. Electric energy consumption was compared between the two temperature conditions, and the amount of energy conserved during fermentation at the higher temperature was estimated. Sensory analysis and alcohol title measurements were performed to verify the quality of the Franciacorta sparkling base wine obtained from the different fermentation conditions. Two vinifications, each performed in duplicate, were prepared by crushing and pressing the grapes and dividing the resulting liquid (juice) into four aliquots after must clarification, which was performed with pectinases at 16°C for 12 hr (as in the usual winery procedure). No SO_2 was added at crushing or at the beginning of fermentation. The composition of the grape must was as follows: pH 3.22, reducing sugars 180.6 g/L, total acidity 8.80 g/L (as tartaric acid), L-malic acid 3.82 g/L, and yeast assimilable nitrogen (YAN) 190 mg/L.

Yeast strain. The *Saccharomyces cerevisiae* yeast strain used in this work was Lalvin ICV Okay (Lallemand) and was chosen for its special ability to produce very low levels of SO_2 and H_2S while completing rapid alcoholic fermentation under a broad range of winemaking conditions, including several fermentation temperatures (Berlese-Noble et al. 2014). The yeast was rehydrated from the active dry form according to manufacturer instructions and added to the must at a final concentration of 0.25 g/L. Yeast was inoculated into the total must mass just before dividing it among the four tanks.

Chemical analyses of musts and wines. Chemical must and wine parameters were analyzed at the set-up of the experiment and at the end of alcoholic fermentation. The analytical methods used were those recommended by the International Organization of Vine and Wine (OIV 2013). Sugars were analyzed by alkylamine resin HPLC (OIV-MA-AS311-03), percent alcohol by volume using densimetry with a hydrostatic balance (OIV-MA-AS312-01A), pH by potentiometry (OIV-MA-AS313-15), and SO_2 (free and total) by titration after distillation (OIV-MA-AS323-04A). Malic acid, total acidity, volatile acidity, and YAN were analyzed by Fourier transform infrared (FTIR) spectroscopy (Cozzolino et al. 2006). Alcohol content, acidity, and sugars were also assessed by FTIR spectroscopy during alcoholic fermentation. Volatiles were analyzed by gas chromatography-mass spectrometry after solid-phase extraction using ENV+ cartridges (IST, Ltd.) according to Boido et al. (2003). In 2012, Azzolini et al. applied the same method to evaluate aroma in the Amarone wine, fermented using two different yeast strains.

Industrial-sized plant. The fermentation plant used in this study was located at the Villa Crespia winery at Adro, Brescia, Italy. All utilities in the winery that required temperature control were served by a centralized refrigeration system (Model 110.E2.G6, RC Group S.p.A.), which supplied a closed-loop cooling circuit that circulated cold water and glycol. Depending on the amount of heat to be subtracted at each fermentation tank (AISI 304 stainless steel equipped with an AISI 316 stainless steel lid, thickness 2.5 mm), a system of valves controlled by thermostats regulated the flow of cooling fluid to maintain a constant temperature inside the tank. Electric energy consumption was quantified for four tanks (two kept at 15°C and two at 19°C). The tanks were placed in the fermentation area of the winery at a depth of 22 m, where the environmental temperature naturally ranged from 16 to 18°C. These conditions are considered normal for wineries producing sparkling base wine and, therefore, accurately represent conditions on an industrial scale.

Table 1 shows the density and heat capacity of the grape must and technical plant parameters. Electrical (η_e) and mechanical (η_m) efficiencies were considered to calculate the effective powers of the compressor and pump, respectively. The glycol-water circuit was assumed to have an efficiency of 85%. The opening times of the valves regulating the input of the liquid refrigerant were recorded, and the temperature differences associated with each opening were measured.

Evaluation of electric energy consumption. The aim was to quantify the energy savings associated with the use of a yeast capable of fermenting at a temperature higher than those standard for fermentation. The compressor for the refrigeration system and the pump for the glycol-water circuit were included in the quantification of electric energy consumption. The calculation methodology was based on the energy balance of a fermentation tank. The equation for the conservation of energy in a tank during fermentation can be generally written as:

$$Q_{acc} = Q_{fermentation} + Q_{wall} + Q_{evaporation} + Q_c \qquad \text{Eq. 1}$$

where Q_{acc} is the heat accumulated by the must and includes $Q_{fermentation}$, the heat generated by the fermentation; Q_{wall}, the heat exchanged by the walls of the tank; $Q_{evaporation}$, the heat lost by evaporation of water and ethanol; and Q_c, the heat required to cool the tank (Colombié et al. 2007). The Q_{acc} must be controlled using a cooling system capable of maintaining the correct fermentation temperature based on the specific yeast requirements.

For each fermentation tank, the mass of the fermenting must was calculated (m, kg), the cycles of glycol-water valve openings were measured (number, n; time, h), and the heat removed from the plant during valve opening was quantified for each cycle ($Q_{acc'}$, kcal). The amount of heat subtracted from each tank during the fermentation process was calculated based on the number of valve-opening cycles (Equation 2).

$$Q_{acc'} = m * C_p * \Delta T \qquad \text{Eq. 2}$$

where $Q_{acc'}$ = heat subtracted from fermentation process for each valve-opening cycle, m = wine mass processed for each tank, C_p = heat capacity, and ΔT = dead-band of 1°C.

The system cycled X times over a temperature dead-band of 1°C for each tank. The sensible heat change during each cycle was calculated and summed to quantify the total refrigeration energy requirements for each tank (Q_{acc}). The effective total cooling load (P_{acc}, kW) was calculated as the ratio between the Q_{acc} and the cumulative duration of valve opening (t, h) for each tank.

The ratio (R) between the $P_{acc,}$ and the effective total cooling load of the refrigerator (P_e, kW), derived from the total cooling load of refrigerator (P_{e_tot}, kW) and the glycol-water circuit efficiency (η_g), was determined for each tank (Equation 3).

$$R = (P_{acc} / P_e) * 100 \qquad \text{Eq. 3}$$

This ratio was used to calculate the electric energy consumption (E_{acc}, kWh) of the refrigerator related to the fermentation process of each tank. Electric energy consumption from pump use (E_{pump}, kWh) and total energy (E_{tot}, kWh) for the fermentation process were also determined. Finally, the energy consumption of fermentation was compared between the two different temperature conditions, and the energy savings were calculated.

Sensory analysis. The test panel that performed the sensory experiments consisted of 32 expert individuals employed in the wine business. A Triangle Test (ISO 4120:2004 – Methodology), a forced-choice procedure, was carried out to determine whether a perceptible sensory difference or similarity existed between the wines fermented at different temperatures. The two wines (blends of the tanks fermented at 15 and 19°C, respectively) were randomly presented within each triad, and judges were asked to assess which wine was different from the others.

Statistical analysis. Student *t*-test (SPSS 19.0 for Windows) was used to analyze differences in wine compounds and sensory scores between the samples.

Results and Discussion

Fermentation kinetics. Monitoring an industrial-sized plant is more complicated than monitoring a laboratory pilot-sized plant. Therefore, a method was developed to measure energy consumption at different fermentation tanks in the plant. The progress of the fermentations at 19 and 15°C is shown in Figure 1. The 19°C tanks fermented in 9 days, whereas the 15°C tanks took 12 days.

Fermentations were run in duplicate, and the kinetics were similar between the two tanks at each temperature. As

Table 1 Input data for analysis of energy consumption.

Parameters	Symbol	Values
Wine processed		2000
Tank 1_19°C (L)		
Tank 2_19°C (L)		2050
Tank 3_15°C (L)		2000
Tank 4_15°C (L)		2050
Grape must density (kg/L)	ρ	1.05
Grape must heat capacity (kcal/kg °C)	Cp	0.855
Refrigerator compressor power (kW)	C	104.7
Refrigerator coefficient of performance	COP	4.12
Pump power (kW)	P	2.2
Electricity efficiency	ηe	0.90
Mechanical efficiency	ηm	0.70
Glycol-water circuit efficiency	ηg	0.85

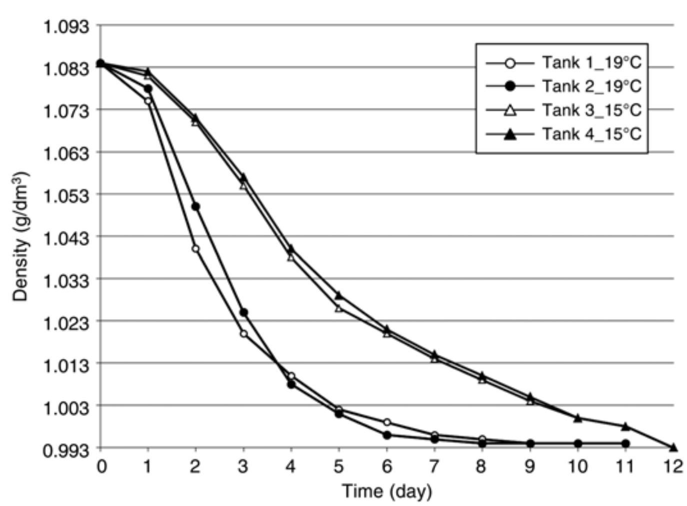

Figure 1 Change in density during the different fermentation conditions.

expected, the 15°C fermentations ended later (3 days) than the 19°C ones. Fermentation was rapid at the beginning in all of the tanks, probably due to good implantation of the yeast and the lack of SO_2 addition (Figure 1). Density reduction started after inoculation with the commercial *S. cerevisiae* strain and was confirmed by data showing no fermentation after 7 days at 19°C in another tank with the same must and non-inoculated yeast (data not shown). Sugar consumption was continuous and reliable throughout the whole process in all of the fermentations, although rate of consumption varied depending on the temperature.

Evaluation of electric energy consumption. Comparing tanks of the same capacity showed that the working time of the refrigerator system during fermentation was 80.2% lower in Tank 1_19°C than in Tank 3_15°C and 73.6% lower in Tank 2_19°C than in Tank 4_15°C (Figure 2).

Table 2 shows the experimental results from the monitoring of each tank. For Tank 1_19°C and Tank 2_19°C, the refrigerator cycled 13 and 18 times, respectively, over a temperature dead-band of 19.0 to 20.0°C and operated for 230 and 300 min, respectively. The system operated for 1160 min in Tank 3_15°C and 1135 min in Tank 4_15°C, corresponding to 28 and 29 cycles, respectively, over a temperature dead-band of 15.0 to 16.0°C (Figure 3). A difference of 1°C in the starting temperature of Tank 1_19°C and Tank 2_19°C musts was observed and likely due to environmental differences in the ambient temperature at the beginning of fermentation. This difference in starting temperature influenced the first transitional period of the fermentation, as shown in Figure 3, but had a negligible effect on the refrigeration requirements, as the effective starting point of the refrigerator system was almost the same for the two tanks at 19°C. Figure 3 shows that the refrigerator switching frequency tended to decrease with time for both of the fermentation temperatures. This may occur because the amount of sugar available for fermentation, and consequently the rate of the exothermic reaction, tends to decrease, which causes the temperature to stabilize. This behavior may have been more noticeable at 19°C after 160 hr

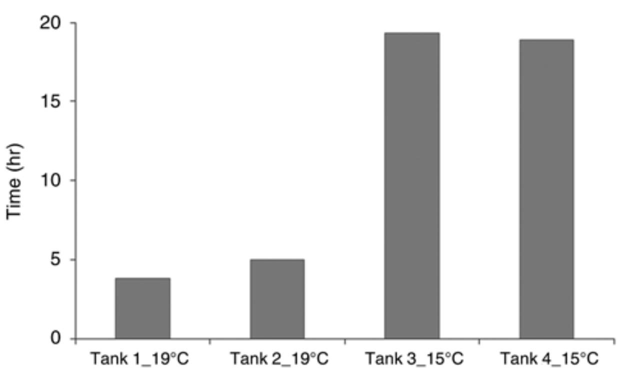

Figure 2 Working time of the refrigerator system during fermentation at 19 and 15°C.

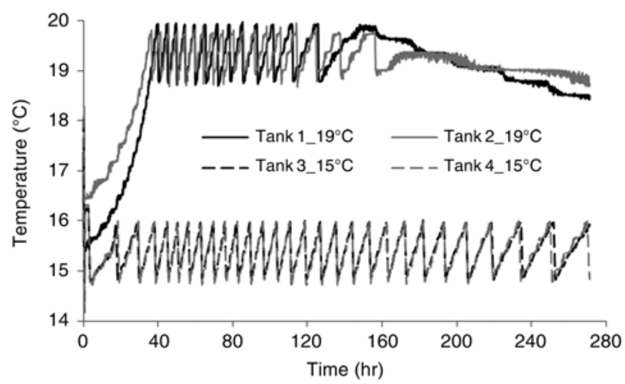

Figure 3 Temperature for each tank monitored, during the fermentation process at 19 and 15°C.

Table 2 Experimental results for each tank monitored at 19 and 15°C.

Parameters	Symbol	Tank 1_19°C	Tank 2_19°C	Tank 3_15°C	Tank 4_15°C
Refrigerator compressor					
Mass of grape must processed (kg)	m	2100	2153	2100	2153
Number of dead-band cycles of ΔT of 1°C	n	13	18	28	29
Heat subtracted during valves opening (kcal)	Q_{acc}	23,342	33,127	50,274	53,371
Effective compressor power (kW)	P_c	65.96	65.96	65.96	65.96
Total cooling load of refrigerator (kW)	P_{e_tot}	271.76	271.76	271.76	271.76
Effective total cooling load of refrigerator (kW)	P_e	231.00	231.00	231.00	231.00
Time of valves opening (hr)	t	3.83	5.00	19.33	18.92
Effective total cooling load (kW)	P_{acc}	7.08	7.70	3.02	3.28
Energy consumption ratio (%)	R	3.07	3.34	1.31	1.42
Energy consumption compressor (kWh)	E_{acc}	7.75	11.00	16.69	17.72
Pump					
Effective pump power (kW)	P_p	1.39	1.39	1.39	1.39
Energy consumption pump (kWh)	E_{pump}	5.31	6.93	26.80	26.22
System					
Total energy consumption (kWh)	E_{tot}	13.06	17.93	43.49	43.94
Energy saving between tanks at the same temperature (%)		27.14	27.14	1.03	1.03
Means (kWh)		15.50	15.50	43.71	43.71
Energy saving between tanks at different temperatures (%)		64.55	64.55	64.55	64.55

of fermentation without the refrigerator running because the environmental temperature in the winery was probably sufficient to maintain the required temperature. However, the heat to be subtracted was mainly due to the exothermic reaction of fermentation, as the load of the refrigerator was higher during the first part of the process. Environmental temperature only plays a role in the final fermentation phase, influencing the valves opening in a limited way. Hence, eventually small variations in environmental temperature in the cellar would be reflected similarly in the energy requirements across all of the tanks. Therefore, the influence of the ambient temperature is negligible when comparing the energy requirements between the two fermentation temperatures (15 and 19°C).

Table 2 shows that Q_{acc} ranged from 23300 to 33100 kcal and 50300 to 53400 for tanks at 19 and 15°C, respectively. As expected, Tank 2_19°C and Tank 4_15°C showed higher values of heat subtracted during valve opening due to a larger mass of fermentation must (2152.5 kg). The effective total cooling load (P_{acc}) for each tank was ~7.4 kW and 3.1 kW for the 19 and 15°C tanks, respectively. Based on these results, the energy consumption ratio (R values in Table 2) was derived for each tank. Using R, P_c, and P_p, the electric energy consumption related to the fermentation process of each tank was calculated for both the compressor of the refrigerator system and the pump. The electric energy consumption of the compressor (E_{acc}) was 7.75 kWh, 11.00 kWh, 16.69 kWh, and 17.72 kWh for Tank 1_19°C, Tank 2_19°C, Tank 3_15°C, and Tank 4_15°C, respectively. For the pump (E_{pump}), electric energy consumption was 5.31, 6.93, 26.80, and 26.22 kWh for Tank 1_19°C, Tank 2_19°C, Tank 3_15°C, and Tank 4_15°C, respectively.

The results showed that maintaining the fermentation tank at 15°C required 43.71 kWh (21.6 $Wh/L_{grape\ must}$), whereas maintaining a temperature of 19°C only required 15.50 kWh (7.7 $Wh/L_{grape\ must}$). Therefore, this difference of 4°C during fermentation yielded a 64.55% decrease in electric energy consumption. Considering an energy cost of 0.10 €/kWh (variable rate), 85% yield from must to sparkling wine, and a 0.75-L bottle, costs were estimated at 0.19 $€_{cent}$/bottle and 0.05 $€_{cent}$/bottle for fermentation at 15 and 19°C, respectively.

Effect of temperature on yeast performance and final properties of the wines. To determine if temperature affected the quality of the wines, the main chemical properties were measured after alcoholic fermentation. Final concentrations of relevant parameters under both conditions are summarized in Table 3. All of the values for wines fermented at 15°C (usual winery procedure) and 19°C (new thermal procedure) were in accordance with quality standards of the winery. Moreover, no measurable SO_2 was produced by the yeast in any of the fermentations, confirming that temperature did not affect sulfite production for this specific strain at the tested conditions. The result is consistent with the characteristics of the yeast strain Lalvin ICV Okay (Noble et al. 2012, Berlese-Noble et al. 2014) and further improves knowledge of the influence of temperature on yeast metabolism by clarifying its lack of SO_2 production at different temperatures. Indeed, previous works have shown that temperature may affect several genes involved in sulfur-related pathways depending on the yeast strain (Deed et al. 2015).

To investigate the possible effect of fermentation temperature on aroma profile, analysis of volatile aromatic compounds was performed at the end of alcoholic fermentation. Indeed, temperature is one of the key parameters that affects aromatic quality of wine (Masneuf-Pomarède et al. 2006, Molina et al. 2007) during alcoholic fermentation. Winemakers traditionally associate cold fermentation with improved aroma production, although experimental data on the key aroma changes that occur with cold-fermented white wines have been equivocal (Torija et al. 2003, Beltran et al. 2006, 2008, Deed et al. 2015). The present study analyzed 93 volatile molecules that belonged to families of fusel alcohols (9), esters (20), fatty acids (5), benzenoids (7), terpenes (18), norisoprenoids (10), carbonyl compounds (8), volatile phenols (9), and lactones (7). Of these, 69 compounds were not significantly different between the two conditions (data not shown) and 24 had significantly different concentrations at the two temperatures (Table 4). Eighteen of these 24 molecules were detected at a higher concentration in wines fermented at 19°C, and 10 of the 24 aromatic molecules were esters (acetates of fusel alcohols and ethyl esters of fatty acids and isoacids). Esters are among the most important groups of aromatic compounds in wine and are produced enzymatically by metabolism of the yeast during fermentation (Swiegers and Pretorius 2005, Styger et al. 2011). Esters make a positive contribution to the general quality of wine and are responsible for the “fruity” and “wine-like” sensory properties (Perestrelo et al. 2006). Of the 10 esters, nine showed a higher concentration at 19°C than at 15°C. In terms of yeast metabolism during fermentation, these results show that aroma production increased at the higher temperature for this strain. Nevertheless, in terms of absolute quantities, concentrations of 13 of the 24 changing-compounds were below sensory thresholds described by Ferreira et al. (2000, 2002), and San Juan et al. (2012) (Table 4). These results may be consistent with previous studies because the previous works studied different strains and sets of temperatures (Masneuf et al. 2006, Molina et al. 2007, Beltran et al. 2008, Deed et al. 2015), and none of these studies investigated Lalvin ICV Okay or fermentation temperatures of 15 and 19°C. As previously shown (Torija et al. 2003), the effect of low temperature on fermentation efficiency and aroma production varies markedly for different *S. cerevisiae*

Table 3 Composition of Chardonnay base wines produced in two vinifications (fermented at 15 and 19°C) in duplicate.

Parameters	Tank 1_ 19°C	Tank 2_ 19°C	Tank 3_ 15°C	Tank 4_ 15°C
Density (g/L)	994.03	993.83	993.19	993.07
Alcohol % (mL/100 mL)	11.6	11.6	11.7	11.8
Residual sugars (g/L)	<2	<2	<2	<2
Total acidity (g/L)	8.9	8.9	8.7	8.6
pH	3.17	3.20	3.17	3.2
Volatile acidity (g/L)	0.34	0.32	0.34	0.23
Malic acid (g/L)	3.21	3.29	3.33	3.17
Total SO_2 (mg/L)	<10	<10	<10	<10

Table 4 Concentration of odor-active compounds at two different fermentation temperatures and *t*-test significance (* $p < 0.1$, ** $p < 0.05$).

Compound	Odor description[a]	15°C Fermentation concn (µg/L)	19°C Fermentation concn (µg/L)	*t*-test	Odor threshold (mg/L)[a]
Isoamyl acetate	banana	3142.2 ± 39.5	3728.6 ± 82.7	**	30
β-phenyl acetate	honey, rose	245.3 ± 5.2	310.2 ± 3.9	**	250
Ethyl hexanoate	white fruits, apple	842.0 ± 16.3	941.8 ± 43.2	*	62
Ethyl octanoate	white fruits	1384.1 ± 32.0	1639.1 ± 56.3	**	580
Ethyl decanoate	white fruits	475.7 ± 4.9	666.3 ± 41.2	**	200
Ethyl 4-hydroxybutanoate	–	756.9 ± 34.8	638.9 ± 2.2	**	20,000
Ethyl 2-hydroxy-4-methylpentanoate	–	3.3 ± 0.0	4.0 ± 0.1	**	10
Diethyl succinate	vinous	27.7 ± 5.6	91.5 ± 8.5	**	200,000
Ethyl lactate	creamy	340.3 ± 22.7	605.8 ± 6.4	**	154,000
Diethyl malate	over-ripe, peach	47.7 ± 5.4	81.2 ± 3.9	**	76,000
Diethyl 2-hydroxyglutarate	–	2.8 ± 0.3	5.9 ± 0.4	**	–
Ethyl cinnamate	fruity, honey, cinnamon	8.9 ± 2.9	2.0 ± 1.1	*	1
2-Hexen-1-ol	herbaceous, cut grass	2.4 ± 0.1	1.4 ± 0.3	**	200
Homovanillic alcohol	–	7.7 ± 0.1	12.5 ± 0.5	**	
Citronellol	floral, citronella	6.0 ± 0.2	4.7 ± 0.3	**	100
Geraniol	floral	1.2 ± 0.3	2.3 ± 0.4	*	20
Vanillin	vanilla	6.8 ± 0.4	10.9 ± 2.0	*	995
Phenyl acetaldehyde	hyacinth	12.0 ± 0.5	17.5 ± 1.1	**	1
γ-butyrolactone	sweet, toast, caramel	177.1 ± 9.2	222.6 ± 11.2	**	35,000
4-Carboethoxy-γ-butyrolactone	coconut	32.8 ± 3.5	60.7 ± 1.3	**	
Isovalerianic acid (3-methylbutyric acid)	sweet, acid, rancid	180.0 ± 3.8	160.1 ± 1.8	**	33
β-damascenone	sweet, apple, tea leaves	4.1 ± 0.1	5.1 ± 0.4	*	0.05
Furfuryl alcohol	wood	2.0 ± 0.2	3.9 ± 0.4	**	2000
Homofuraneol	caramel, roast sweet	4.7 ± 0.0	1.0 ± 0.1	**	125

[a]Odor descriptions and sensory thresholds are reported as described in Ferreira et al. (2000, 2002), Guth (1997), or San Juan et al. (2012).

strains. Therefore, the findings of this study were strongly correlated with the use of this specific yeast, which yielded a slight increase in overall aroma at 19°C relative to 15°C.

Sensory analysis. Finally, a sensory test was performed using a triangular test (a 'forced choice' technique) to guarantee a product with the desired sensory characteristics (as defined by the winery staff in accordance with the quality standards of the company). Only 13 of 32 judges recognized the different sample, whereas 16 correct answers were needed to establish significance at 95% confidence and 18 correct answers at 99% confidence (Roessler et al. 1978). Thus, no significant differences in sensory characteristics were detected between the two temperature conditions. This result was consistent with aroma analyses, as only 25% of the tested aromatic molecules showed a change in concentration with fermentation temperature (most of them were higher at 19°C than at 15°C), and the concentrations of 13 of these 24 molecules were below the sensory threshold. Additionally, the "aroma-buffer effect" (Ferreira 2010), which is exerted by a complex mixture (as wine) and counteracts the sensory effect of changes in a few odorant molecules, may also explain why the panel did not distinguish the wines even though the aromatic profile was slightly different.

Conclusions

In the present study, a new strain of wine yeast was tested in the production of sparkling wine base fermented at a temperature higher than the standard with good sensory results. These features may promote energy conservation and reduce the environmental impact of wine production. Indeed, quantification of electric energy consumption and estimation of energy conservation showed that increasing the temperature from 15°C to 19°C during the fermentation process yielded an energy saving of ~65%. Using this yeast strain promoted energy conservation by enabling fermentation at a higher temperature, thus yielding a direct economic benefit for the producer. Moreover, the use of this yeast strain allows wineries to adopt more sustainable winemaking processes with low SO_2 production and energy consumption, and consequently, propose eco-labeling strategies and price-premium policies that presently have marketing benefits.

This study was the first to quantify energy conservation from sustainable temperature management during base wine fermentation, showing the benefits of such an approach and possibly opening up a new field of investigation. Indeed, more research is needed to investigate energy conservation under other conditions (e.g., white and red vinification, different winery equipment and environmental temperatures, and other yeast strains) to clarify the relevance of these findings in other winemaking contexts.

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