Impacts of Winemaking Methods on Wastewaters and their Treatment

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The volume, composition and organic load of wastewaters from five wineries producing white, rosé and red wines by thermovinification, as well as traditionally vinified red wines (75 000 hL to 240 000 hL wine), were studied in terms of the vinification methods used. Liquid-phase vinifications (white, rosé, thermovinification) produce wastewaters rich in sugars: 70% of the chemical oxygen demand (COD) when the must is treated, and flows depend on the daily supply of grapes, representing 40 to 46% of the annual volume of wastewaters during the first month of activity (September). In contrast, solid-phase vinifications do not produce large quantities of waste at harvest, and wastewaters produced mainly during devatting are characterised by a predominance of ethanol (≤ 75% COD) and by staggered flows towards the second month (October), which are less intense (26.7 to 33.6%) and more spread out. The specific pollution coefficients of liquid-phase vinifications (5.18 to 6.04 kg COD/t grapes) are greater than those of solid-phase vinifications (3.82 kg COD/t grapes). The higher the winery's liquid-phase vinification rate, the more the maximal monthly volume of waste will be intense and early. These results should contribute to the improved design and management of winery wastewater treatments.

The highly pronounced seasonal variations in winemaking processes, and their wide diversity (depending on winery size, types of wines produced, etc.), result in sudden discharges of wastewaters, making it difficult to assess the flows to be treated and how the treatment should be managed. A number of studies have been carried out to assess water consumption, water volume and the pollution load in order to determine the environmental impacts of these processes and to effectively design and manage treatments (Mourgues & Maugenet, 1972; Maugenet, 1978; Picot, 1992; Duarte *et al*., 1998; Lemiere *et al*., 1998; Picot & Cabanis, 1998; Rossi *et al*., 1998; Viaud *et al*., 1998; Sheridan *et al*., 2004; Bories *et al*., 2005; Rochard, 2005; Vogdt & Schleenstein, 2006). In these studies, the harvest was considered to be the period with the greatest output (Grenier *et al*., 1998; Duarte *et al*., 2004). However, the impacts of the different vinification methods were rarely taken into consideration. The production of white, rosé and red wines is subject to different technological processes, particularly liquid- or solid-phase vinification. Moreover, winemaking techniques evolve in relation to innovation in vinification processes. An example of this is thermovinification or flash-release, where the grapes are heated to make must and red wine by off-skin vinification (Escudier *et al*., 2008).

Assessment of the organic pollution load from wineries by extrapolation based on data from a limited number of sites is sensitive and can have adverse consequences on treatment design and performance. Each winery is a particular case, depending on its winemaking capacity, the types of wines it produces, its equipment and its available resources and water management. In order to satisfy the aims of sustainable development, we must improve our knowledge of the organic pollution load output from wineries and consider the impact of oenological management sequences involving wastewaters and treatments.

This study deals with the characterisation of effluents from various types of off-skin and on-skin winemaking processes, in white wines, rosé wines and thermovinification of red wines, and traditionally vinified red wines, at the level of their composition as well as at the level of matter flow and their impact on the treatment.

MATERIALS AND METHODS

Wineries and wastewaters

Vinification conditions at and wastewaters produced by five wineries located in France (Languedoc-Roussillon and Aquitaine regions) were studied in 2006, 2007 and 2008. Table 1 presents the general characteristics of these wineries. Wineries A and B produce mainly white wines, whereas wineries C, D and E primarily produce traditional red wines, as well as some red wines produced by thermovinification.

Wastewaters were sampled at the level of the collection tank, upstream of the treatment facilities, and were maintained at -18°C.

Methods used to analyse winery wastewaters

Glucose, fructose and ethanol were analysed by HPLC: mobile phase water/H_2SO_4 0.004M (0.5 mLmin^{-1}) with on-line degassing, Waters 717 autosampler, Aminex HPX-87H column (Bio-Rad, Hercules, CA, USA), Waters RI 2410 refractive index detector and EMPOWER software (Waters, Milford, MA, USA). COD was measured with an MN029 COD-1500 test kit (Macherey-Nägel, Düren, Germany).

RESULTS AND DISCUSSION

Winemaking processes and the origin of wastewaters

Winemaking can be broken down into two major categories: liquid-phase vinification for white and rosé wines and thermovinification

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for red wines, and solid-phase vinification for traditional red wines (Fig. 1).

The vinification of white, rosé and sparkling wines, as well as thermovinification (heating, flash-release), use similar technological processes based on the treatment of the must, followed by alcoholic fermentation. Treating the must involves clarification of the must by racking, the filtration of must deposits and pressing. These operations are carried out as the grapes arrive at the winery and generate wastewaters rich in sugar. Therefore, the earlier the ripening date of the grape varieties used to make the wine, the earlier the wastewaters from the vinification of white and rosé wines will be produced. Alcoholic fermentation of the clarified musts only produces waste during wine racking, which is spread out over the months following the harvest.

Solid-phase vinification is based on a very different technological process. As the grapes arrive at the winery they are placed directly in vats for alcoholic fermentation, with no waste emission. After alcoholic fermentation, which can last from one to several weeks, devatting is accompanied by washing of the vats and pressing of the fermented pomaces, steps that produce wastewaters rich in alcohol whose flows are staggered in relation to the harvest and to the quantities of grapes used. The type of vinification used determines wastewater composition and flow.

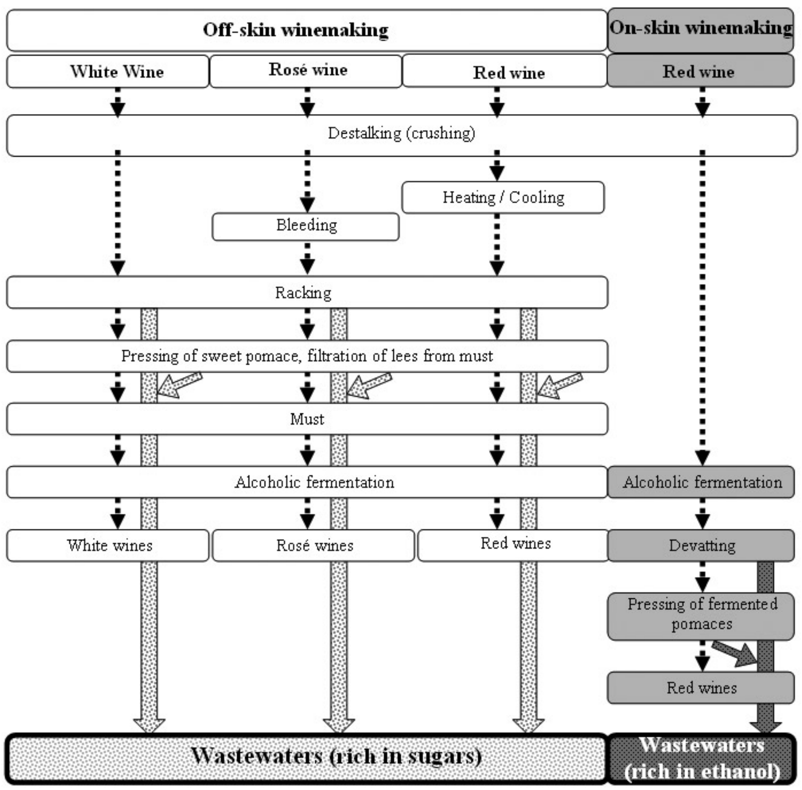

FIGURE 1

Winemaking processes and the origin of wastewaters.

TABLE 1

Characteristics of wine production and wastewaters from the wineries studied

Winery	A	B	C	D	E
Total wine production (hL)	75 000	117 000	140 000	140 000	240 000
White wine (%)	50	50	18	12	10
Rosé wine (%)	25	18	14	13	10
Red wine thermovinification (%)	14	15	8	15	25
Total off-skin vinification (%)	89	83	40	40	45
On-skin vinification (red wine) (%)	11	17	60	60	55
Wastewaters (m^3/year)	4 802	8 238	4 395	10 000	13 787
L wastewaters/L wine	0.64	0.704	0.314	0.71	0.574

Wastewater production from various winemaking methods

Monthly volumes of wastewater are indicative of the pronounced differences between wineries at harvest time and during winemaking (Fig. 2).

For wineries A and B, which use mainly liquid-phase vinifications (89 and 83% of the wine produced respectively), the maximal volume of wastewaters is produced at a very high intensity during the first month of activity (September), representing 40 and 46% of the annual volume respectively. The volume of wastewater decreases sharply during the following month (October), at 19.2 and 24%, respectively, and is very low in November (3.7 and 4.4% of the total respectively).

In wineries C, D and E, where solid-phase vinification is predominant (55 to 60%), the maximal monthly volume of wastewater tends to be staggered towards the second month of activity (October), particularly for wineries D and E (Fig. 1). The intensity of the maximal monthly volume of wineries using solid-phase vinification (26.7, 28.8 and 33.6% for wineries C, D and E respectively) is lower than that of wineries that use mainly liquid-phase vinification. The wastewater volume is spread out over four months, from September to December.

The proportion of the volume of wastewaters corresponding to the period extending from the harvest to the end of winemaking, from September to December, does not vary considerably between

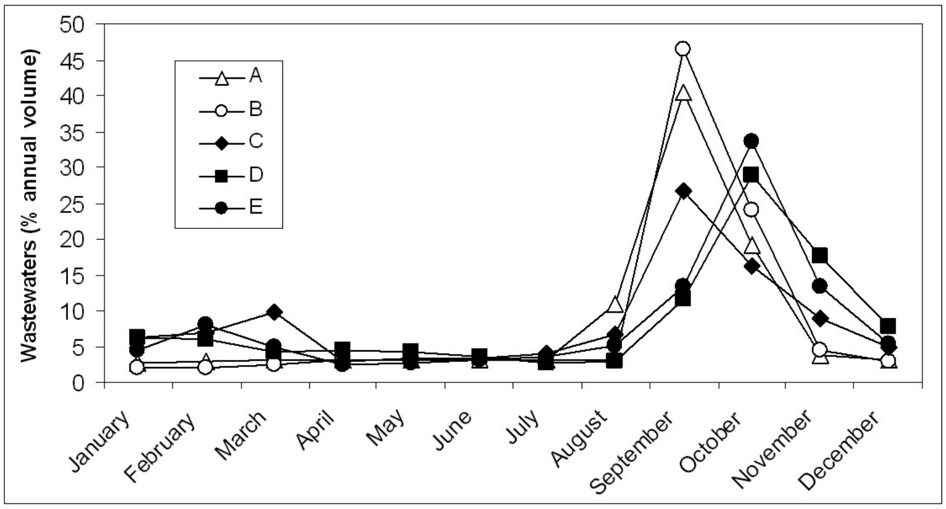

FIGURE 2

Monthly breakdown of wastewater volumes produced by the five wineries studied.

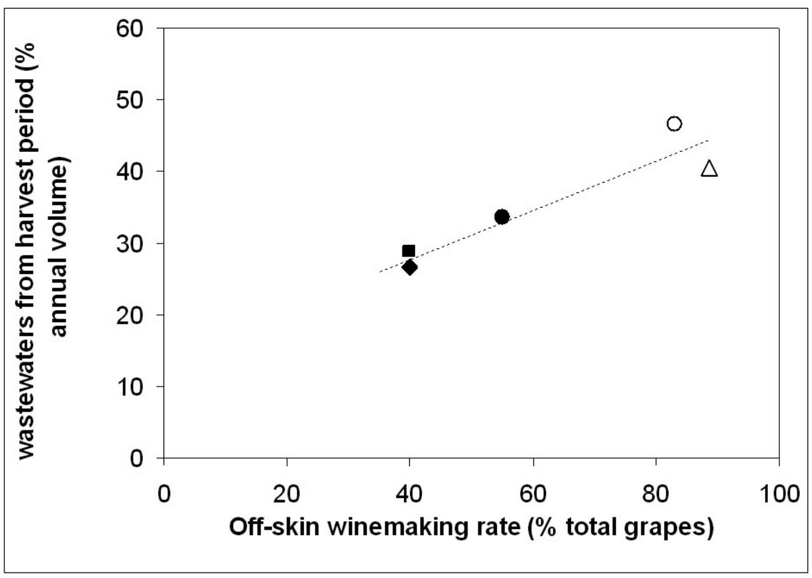

FIGURE 3

Relationship between the off-skin winemaking rate and the volume of wastewaters produced during liquid-phase vinification for wineries A, B, C, D and E (the same symbols as in Fig. 2).

the five wineries and represents 65.6 to 74.9% of the annual volume (Table 2). These values are in agreement with general data. For this period, which includes the harvest and liquid- and solid-phase vinifications, the differences between the wineries can be attributed to water consumption methods, the type of equipment used and the scale effects characteristic of each winery.

Figure 3 illustrates the relationship between the volume of wastewaters produced during the liquid-phase vinification (harvest) and the liquid-phase vinification rate in the five wineries. The higher the liquid-phase vinification rate, the greater the proportion of the volume of wastewaters produced during the harvest period.

Organic load versus winemaking processes

Table 3 indicates the flow in volume and in COD discharged during the vinification of white and rosé wines and in thermovinification, and during the vinification of traditional red wines (winery C). This winery has the advantage of carrying out vinifications according to a time frame that makes it possible to break down the flows according to the type of vinification (white, rosé, thermovinification and vatting).

The specific pollution coefficients of off-skin vinification (6.04 and 5.18 kg COD/tonne of grapes) are 57 to 36% higher than those of on-skin vinification (3.82 kg COD/tonne of grapes). Similarly, the specific volume coefficients of off-skin vinification (359 and

TABLE 2

Proportion of the volume of wastewaters produced from September to December in the five wineries studied (% annual volume)

Winery	A	B	C	D	E
Volume of wastewater produced from September to December (% annual volume)	65.6	74.9	68.5	74.3	74.9

TABLE 3

Organic load and volume of wastewaters from vinification processes (winery C)

	Off-skin winemaking		On-skin
	White wine	Rosé and thermovinification of red wines	Solid-phase vinification of red wines
Grapes (t)	3 054	2 602	10 428
Wastewaters (m^3)	1 096	511	2 733
COD discharged (kg COD)	18 462	7 411	39 884
Wastewater volume/grapes (L/t)	359	357	262
Organic load/grapes (kg COD/t)	6.04	5.18	3.82

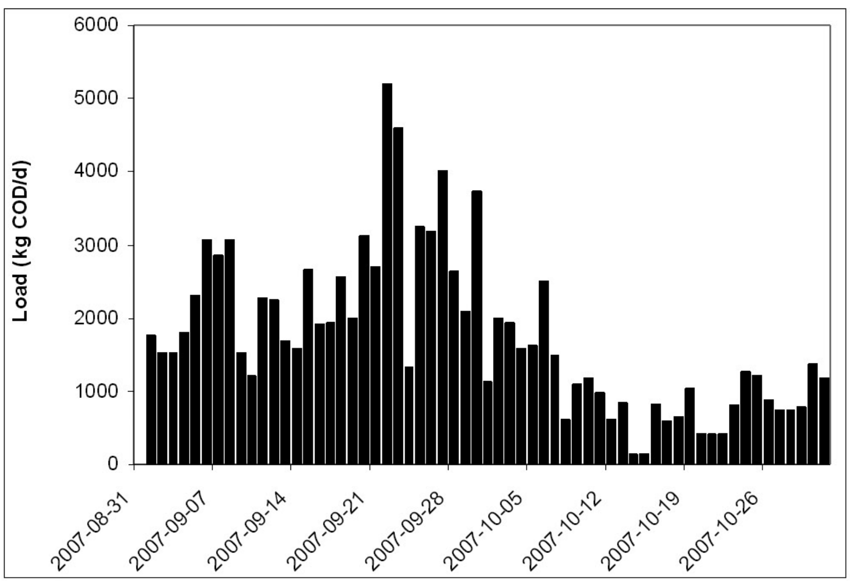

FIGURE 4

Organic load discharged by winery C during harvest and vinifications.

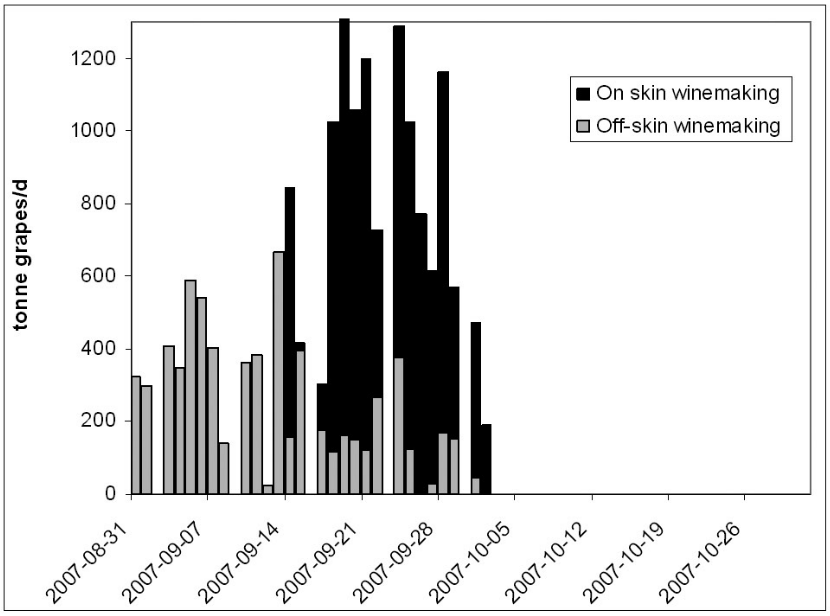

FIGURE 5

Quantities of grapes used for off-skin and on-skin vinifications (winery C).

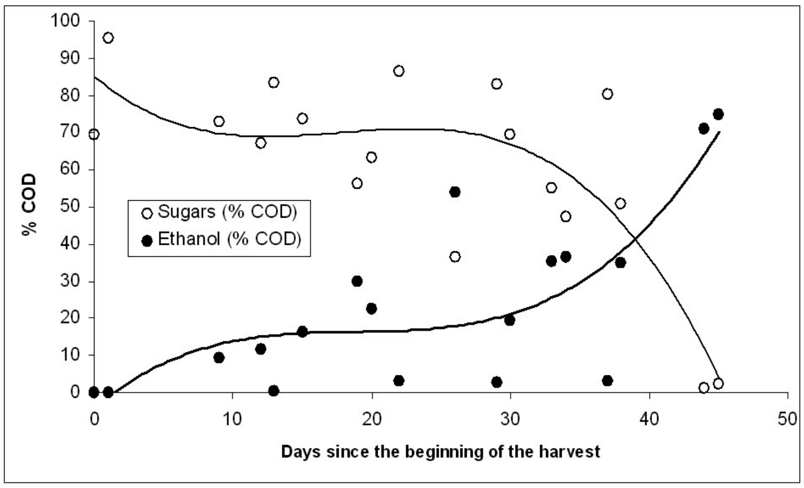

FIGURE 6

Proportion of sugars and of ethanol in the COD (%) of wastewaters from a winery that uses mainly liquid-phase vinification (winery A).

357 l of wastewater/tonne of grapes) are 37% higher than those of on-skin vinification (262 l of wastewater/tonne of grapes).

As a result, the organic loads discharged are high from the beginning of white wine vinification (1 500 to 3 000 kg COD/d), whereas the quantities of grapes used at that time (350 to 600 t/d) are much smaller that those used for on-skin vinification (800 to 1 250 t/d) (Figs 4 and 5). The organic loads arriving at the winery treatment station therefore reach the station's nominal capacity during the first days of harvest, which could possibly have a negative impact on the effectiveness of the treatment for the entire period, due to the sudden rate increase, the absence of acclimation of the microbial flora, organic overload, etc.

Wastewater composition versus winemaking processes

Figure 6 illustrates the evolution of the sugar content (glucose + fructose) and the ethanol content (% COD) in the organic load (COD) during the harvest in wastewaters from a winery using primarily liquid-phase vinification (winery A). For 37 days of the harvest, corresponding to liquid-phase vinifications, the majority of the COD is due to sugars (55 to 80% of the COD), whereas ethanol accounts for less than 30% of the COD. At the end of the harvest, the sugar content is negligible and ethanol then becomes the major constituent of the COD.

In contrast, in the case of a winery that uses mainly solid-phase vinification (winery E), ethanol is the main compound in

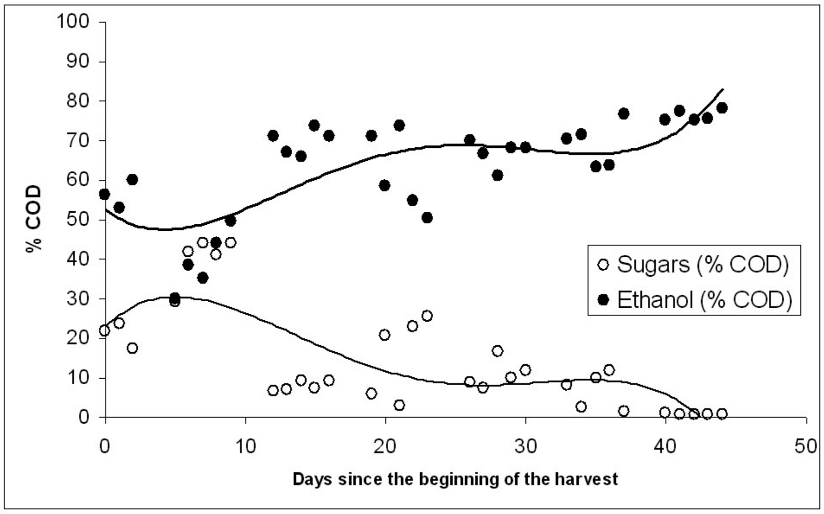

FIGURE 7

Proportion of sugars and of ethanol in the COD (%) of wastewaters from a winery that uses mainly solid-phase vinification (winery E).

the organic load from the beginning and its proportion increases throughout the harvest, from 40 to 75% of the COD (Fig. 7). Sugars, present during the first ten days of the harvest (20 to 45% of the COD) while the winery is producing white and rosé wines, then decrease sharply after this period (0 to 20%).

The massive presence of sugars for one month per year in the wastewaters of wineries using mainly liquid-phase vinification may lead to problems with organic treatment, especially since wastewaters with high sugar loads are present in the first month after treatment has begun again. Another environmental impact of liquid-phase vinifications concerns foul-smelling compounds that are easily produced by the anaerobic fermentation of sugars during the storage of wastewaters (ponds, spreading) and that may cause odour nuisances from the beginning of wastewater emission (Bories *et al*., 2007).

CONCLUSION

The disparity between liquid- and solid-phase winemaking is revealed by waste dynamics and flows. In off-skin winemaking (white, rosé and thermovinification), effluents result mainly from the cleaning of the equipment used to treat the must (racking, pressing, filtering), operations that take place consecutively as the grapes arrive at the winery. Waste flow is linked to the quantity of grapes used. Effluents from liquid-phase vinification are highly reduced at the end of the grape harvest.

In contrast, because of the varying lengths of time that the grapes remain in the vat (from several days to several weeks), solid-phase vinification (classical red wines) only generates wastewaters at the time of devatting and pressing of the fermented pomace, meaning that waste flows are staggered in relation to the harvest and spread out over time.

Specific pollution coefficients (kg COD/kg grape) show that off-skin winemaking generates more organic load than solid-phase vinification.

The composition of winery wastewaters also reveals the impact of the winemaking method used. The pollution load of effluents from off-skin winemaking, in the case of white wines as well as rosés, is mainly due to sugars (glucose and fructose). In the same way, the thermovinification of red wines generates effluents in which sugars are the main components of the organic load. All liquid-phase winemaking techniques have similar management sequences: crushing, clarification of the must by racking, filtration of the must deposits and alcoholic fermentation of the clarified musts. Classical winemaking of red wines, which includes fermentation on the skins, followed by devatting with pressing of the pomace, generates effluents in which ethanol takes the place of sugars.

The impact of winemaking methods on wastewater treatment design is considerable. For wineries whose main activity is off-skin winemaking, the flow of waste to be treated is high during the first days of harvest, and the treatment plant must be designed appropriately and be able to operate at full load very rapidly. In the case of wineries where different types of winemaking take place, waste flows may be quite large at the beginning of the harvest as a result of their pollution ratio and the simultaneity of vinifications (white, rosé, thermovinification), even if the off-skin winemaking volumes are relatively limited, and will continue after the harvest with solid-phase winemaking. The environmental impacts of liquid-phase vinification in relation to wastewater treatment may include organic overload and disruptions to biological systems due to massive occasional discharges of wastewaters with a heavy sugar load at the beginning of winery activity, as well as in relation to odour nuisances in the case of wastewater storage (lagooning, natural evaporation, spreading).

Taking the impact of winemaking methods on wastewaters into consideration should contribute to the improved operation and design of treatment plants, and also to the development of new, sustainable winemaking processes.

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