OENO One
VINE AND WINE OPEN ACCESS JOURNAL
By IVES International Viticulture & Enology Society

DOI: https://doi.org/10.20870/oeno-one.2023.57.1.7313

OPEN ACCESS

ORIGINAL RESEARCH ARTICLE

Are the characteristics of sparkling wines obtained by the Traditional or Charmat methods quite different from each other?

Bruno Cisilotto*[1,2], Fernando Joel Scariot[1], Luisa Vivian Schwarz[1], Ronaldo Kauê Mattos Rocha[1], Ana Paula Longaray Delamare[1] and Sergio Echeverrigaray[1]

[1] Laboratory of Enology and Applied Microbiology, Institute of Biotechnology, University of Caxias do Sul, Brazil
[2] Federal Institute of Education, Science and Technology of Rio Grande do Sul (IFRS), Campus Bento Gonçalves, Brazil

*correspondence:
bruno.cisilotto@bento.ifrs.edu.br

Associate editor:
Fernando Zamora

Received:
26 December 2022

Accepted:
27 February 2022

Published:
17 March 2023

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ABSTRACT

In this study, we performed an analytical and sensorial comparison between sparkling wines produced by the Traditional and Charmat methods using the same base wine, yeast strain, inoculum, and aged on the lees during the same periods. The absence of evident differences in the results of the analyses of physicochemical and volatile compounds was confirmed by the sensory analysis. In general, during the tests, more evaluators could identify differences in the first stages in which sensory analyses were performed. As the ageing time on the lees increase, fewer evaluators could differentiate between the sparkling wines. It was observed that more than half of the evaluators could not differentiate the samples in all stages. Based on our data, we conclude that the method used for the second fermentation is not the determinant of the eventual differences currently associated with sparkling wine produced by the Traditional and Charmat methods.

KEYWORDS: volatile compounds; sensory analysis; triangle test; qualitative similarities

INTRODUCTION

Sparkling wines are produced in different regions around the world, and their production involves different grape varieties, which are associated with edaphoclimatic characteristics, and different winemaking methods, which determine their specificities and, eventually, geographic names (appellation of origin). Sparkling wines can have different concentrations of residual sugar, acidity, ethanol, and diluted carbon dioxide (Di Gianvito *et al*., 2019). Sparkling wine with two fermentations is the result of the refermentation of the base wine, and there are two main methods to conduct it: the Champenoise, Traditional, or Classic method, or the Granvas, Bulk, or Charmat–Martinotti method (commonly called only Charmat). In the Traditional method, the second fermentation of the base wine takes place in sealed bottles (Butnariu, 2020; Buxaderas *et al*., 2022), while in the Charmat method, the second refermentation takes place in an isobaric tank (Butnariu, 2020). The term Champenoise should only be used officially for sparkling wines produced within the Champagne denomination of origin in France (Council regulation (EEC) N° 3309/85 of 18 November 1985 and EEC N° 2333/92 of 13 July 1992).

Each method has its technological peculiarities. In the Traditional method, the second fermentation is conducted in small-volume glass bottles (normally 750 ml), and the bottles remain static in a horizontal position, with the lees decanted at the bottom of the bottle. Usually, a fining agent (clarifier) is added to facilitate the removal of the lees during the "*remuage* and *dégorgement*" (Di Gianvito *et al*., 2019; Togores, 2018). Conversely, in the Charmat method, the second fermentation takes place in large-volume pressure tanks, usually made of stainless steel. The tanks have an internal shaker that keeps the liquid homogeneous. Moreover, these wines are filtered before bottling and do not need the addition of clarifiers (Jackson, 2020; Togores, 2018). Regarding ageing on lees (yeast cells and other precipitates), normally, the sparkling wines made by the Traditional method age for longer periods (more than one year) compared with those produced by the Charmat method (less than six months). However, there is possible to extend the time of contact with the lees in the Charmat method, currently named "long Charmat" (Jackson, 2020).

It seems that, technically, the differences attributed to the method used during the second fermentation (prise de mousse or foaming) of sparkling wines are overestimated, as during this fermentation: (1) just 20 to 25 g/L of sugar is consumed, giving 1 to 1.5 % (v/v) ethanol; (2) aromatic precursors present in the grape juice were metabolised during the first fermentation, and are less available for further biotransformation; (3) yeast population is relatively low ($\leq 10^8$ cells/mL), and yeast aromatic contribution during ageing is controversial (Sawyer *et al*., 2021). Therefore, there are other factors before the second fermentation, which are much more significant in the overall "difference" currently attributed to the "sparkling wine method" used.

Over time, wine communication and marketing have emphasised "the better quality of Traditional sparkling wines" to the point that consumers disregard wines produced by other methods, even without trying them (Vecchio *et al*., 2018; Verdonk *et al*., 2021). Moreover, as happen in different wine categories, some wines are more prone than others to ageing and benefit more or less from this process (Ribéreau-Gayon *et al*., 2021). For this reason, and the commercial appeal, normally the best base wines, more suitable for ageing, are currently destinated to the Traditional method, leaving the younger and lighter wines to be used in the Charmat method. Given this fact, quantitative and qualitative comparisons between sparkling wine-making methods using commercial sparkling wines should be avoided (Culbert *et al*., 2017). In this case, the variable "winemaking method" cannot be considered an independent variable as it is not directly associated with the quality of the final product. However, what would happen if we used the same base wine and inoculum in both methods and aged them for the same period? Taking this question in mind, we evaluate sparkling wines produced on an industrial scale using the same base wine, yeast strain, and inoculum and fermented by Traditional and Charmat methods. To compare these wines, we evaluate their physicochemical parameters, volatile composition, and sensorial attributes.

MATERIALS AND METHODS

1. Yeast Inoculation

The yeast *Saccharomyces cerevisiae* strain LALVIN® EC1118 (Lallemand, Canada) in active dry form was used in all the experiments. After hydration (manufacturer's protocol), the adaptation to the alcoholic medium by a gradual increment of ethanol- base wine (1st day 25 % wine/water; 2nd day 50 % wine/water; 3rd day 75 % wine/water, and from 4th day just wine), during yeast multiplication. Sugar concentration was kept near 15 g/L, and readily yeast assimilable nitrogen (YAN) was maintained near 0.75 g/L (35 % yeast extract and 65 % ammonium phosphate dibasic). This process was conducted in a specific tank with a temperature control system (12 °C), homogenisation (20 min of homogenisation followed by 80 min without homogenisation), and aeration (3 min compressed air injection followed by 180 min without injection). The percentage of ethanol at the time of inoculation was 13.3 % v/v, and the total yeast population was 3.5×10^7 cells/mL with a viability of 70 %. The base wine was inoculated with 1.4×10^6 viable cells/mL, representing 4 % (v/v) of the final fermentation volume.

2. Base wine and tirage

The second fermentation in both Charmat and Traditional methods was conducted at the Chandon of Brazil winery (Garibaldi, RS, Brazil) on an industrial scale. The base wine of sparkling wine used was a blend (*assemblage*) of Chardonnay (36 %), Riesling Italic (30 %), and Pinot noir (34 %) vinified in white. The base wine had: 1 g/L of reducing sugars; 11.2 % alcohol (v/v); 6 g/L of total acidity (expressed in tartaric acid); a pH of 3.27; 0.28 g/L of volatile acidity;

14 mg/L of free sulfur dioxide (SO_2), and 80 mg/L of total SO_2. Before the second fermentation, the base wine was submitted to a tartaric stabilisation for 20 days at –2 ± 1 °C and then filtered (tangential filter Bucher Vaslin—Flavy FX 06, France).

The base wine, 22 g/L sucrose, and yeast inoculum (4 % v/v) were transferred to a vertical pressure tank (50,000 L) equipped with a rotating stirrer. Part of the wine was bottled for the Traditional method in specific sparkling wine bottles with a volume of 750 ml and was added 3 g/hL of clarifiers (bentonite + alginate; CLEANSPARK—Laffort, France) to help remove the yeasts after fermentation. The closure of the bottles was made with a plastic *bidule* and a metal crown (stainless steel) TOP+ (PE.DI, Italy). The rest of the wine remained in the pressure tank (Charmat method) without the addition of clarifiers.

3. Second fermentation, ageing of sparkling wines and sample collections

The second fermentation, in both methods, was conducted at a temperature of 12 ± 1 °C. It was considered the end of fermentation when the amount of reducing sugars was below 3 g/L, finished after 11 weeks (77 days). During the maturation period on the lees, the temperature of the tank (Charmat method) was reduced to 6 °C (a temperature used by the winery), and the bottles (Traditional method) were kept at 10 °C, a temperature commonly used in the Traditional method (simulating an ageing cellar). In the Charmat method, the wine was continuously homogenised by an internal propeller at 60 rpm throughout the fermentation period and subsequent ageing. Conversely, in the Traditional method, the bottles remained immobile during the whole period.

During the second fermentation, samples were collected weekly (three bottles and approximately 1.5 L from the pressure tank). During this period, physical and chemical analyses for fermentation monitoring were performed. After the end of fermentation at the times of 4, 9, 12, 16, and 22 months of ageing, the sparkling wines were prepared for sensorial and chemical analyses. In the Traditional method, *remuage* and subsequent *dégorgement* were performed. In the Charmat method, an isobaric filtration (0.45 µm membrane filter) was performed, followed by the bottling. At each time, approximately 20 bottles of each method were prepared. In both methods, 50 mg/L of SO_2 was added at the time of corking. Sugar (expedition liqueur) 10 g/L (Brut) was added only at 22 months in a portion of the bottles in both methods. In this case, in the Charmat method, the sparkling wine was filtered with a tangential filter (Bucher Vaslin—Flavy FX 06), after which the expedition liqueur was added to the pressure tank, and then the sparkling wine was filtered again with a plate filter (cellulose plates) and then with a membrane filter (0.45 µm) before bottling. In the Traditional method, post *dégorgement*, the process of adding the expedition liqueur was conducted manually. After corking, the sparkling wines remained in an upright position in an ageing room at a temperature between 16–20 ºC. In all stages, the sensory analyses were conducted between 3 and 4 months after corking.

4. Oenological analysis

The wine density was performed by direct reading with a specific gravity hydrometer (0.900/1.000 scale) and was expressed in g/L. Reducing sugars (hydrolysed) were quantified by the modified Lane–Eynon procedure (Zoecklein *et al*., 1990), which is based on the property of sugars to reduce alkaline copper sulfate under specified heating conditions. The values found were expressed in g/L of reducing sugars. The pressure level inside the bottles was measured using an aphrometer and in the tank using a manometer and was expressed in atmospheric pressure (atm) at 20 ºC.

Ethanol was determined by distillation (Super Dee Digital Distilling Unit - Gibertini, Italy) and measurement of the distillate density at 20 °C using an alcoholmeter. The alcohol was expressed by volume-volume percentage (% v/v). The determination of pH was performed with a Thermo Electron Orion Model 310 pH meter (MA, EUA), and total acidity (TA) was measured by titration with 0.1 N sodium hydroxide solution using bromothymol blue as an indicator (OIV, 2015). The results were expressed in g/L of sulphuric acid.

Volatile acids evaluation was done by steam distillation in Super DEE (Gibertini, Italy) and quantified by titration (OIV, 2009). Volatile acidity was expressed as g/L of acetic acid. The concentration of free and total SO_2 was measured using colorimetric titration by the Ripper method (Adams, 1988). The result was expressed in mg/L.

The yellow colour (Abs 420 nm), tint (Abs 420 nm/ Abs 520 nm), and colour intensity (Abs 420 nm + Abs 520 nm + Abs 620 nm) of wines were determined by absorbance using a spectrophotometer (Pró-tools UV–1600—Shanghai Mapada Instruments, China) and expressed as optical density units (Ribéreau-Gayon *et al*., 2021). Turbidity was evaluated by a turbidimeter (2100P—Hach, USA) and expressed in NTU (Nephelometric Turbidity Units).

5. Analysis of volatile compounds

Volatile compounds were analysed at 0 (base wine), 4, 12, and 22 months. Extraction of volatile compounds was performed in triplicate (three bottles of each method) using solid phase microextraction (SPME) with polyacrylate fibre Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS—50/30 µm) (Supelco, Sigma-Aldrich, USA), according to the adapted methodology (Xiao *et al*., 2015). Where in 20 ml headspace vial with silicone septum was added, 8 ml of foaming sample, 2 g of sodium chloride, and 80 µL of 3-octanol (10 mg/L) as standard compound. In a thermostatic bath, the fibre was exposed to the space above the liquid (headspace), and the sample was magnetically stirred at 50 ºC for 50 minutes.

After extraction, the fibre was applied to the injector of the GC/MS apparatus. A gas chromatograph (GC) 6890 coupled to a mass selective detector (MS) 5973 (Agilent Technologies, USA) was used, with an HP-INNOWAX column (30 m × 0.25 mm × 0.25 µm). Oven conditions were 40 °C for 2 min, increasing at a rate of 3 °C/min to 230 °C for 2 min.

The injector temperature was set to 230 °C, and the fibre was injected in desorption permanence for 5 min in split-less mode with helium at a constant flow rate of 1.2 mL/min. MS parameters included electron impact ionisation with electron energy of 70 eV and mass range of m/z 30-550, using ion-selective monitoring (SIM) mode. The area of each peak was determined by ChemStation software (Agilent Technologies). Identification of the compounds was obtained by comparing the retention index (RI) with those reported in the literature and the fragment mass patterns with those in the Wiley (Hewlett-Packard, Palo Alto, CA) and NIST Database. Quantification of the compounds was performed by comparing the area of the compounds with the area of the internal standard (3-octanol).

6. Sensory analysis

During the sensory analyses and after the end of the research, all ethical-legal precepts were maintained, according to Resolution 466/2012 of the National Health Council (Brazil). The project was submitted and approved by a research ethics committee of the Federal Institute of Education, Science and Technology of Rio Grande do Sul (reference number: 3.622.321).

6.1. Triangle test

The forced-choice discriminatory method, the ISO 4120 triangle test, was used to compare the differences between the two sparkling winemaking methods (ISO, 2004). In all stages of sensory analysis, each evaluator performed the test only once. The evaluators had sufficient knowledge and sensory acuity to discriminate the samples at the desired level (oenologists, oenology teachers, viticulture and oenology students, sommeliers, and other professionals in the beverage and food sector). Among the judges, 58 % were men and 42 % women, with an average age of 30 years (youngest 18 years and oldest 70 years). The tests were conducted in 5 stages, with a total of 369 tests applied. The sensory analyses took place in specific rooms following ISO 8589 (ISO, 2007). The sparkling wines were served in ISO glasses (40 ml in each glass) with three samples simultaneously at a temperature of 8 °C. Each participant received full instructions on the operation of the test before the start of the evaluation as described in ISO 4120. At all stages, the samples were served in presentation order, followed by a sorting protocol with a balanced, randomised design.

The results of the triangle test assume a binomial distribution (0, the taster did not correctly identify the different sample; 1, the taster correctly identified the different sample). The results of each stage were obtained based on the number of right and wrong answers to the total number of evaluators and are presented in Figure 3 with relevant information for each stage in which the tests were performed. In all stages, a level of statistical rigour was defined with a low risk of concluding that there are differences when there is not (type I or α error), being $\alpha = 0.05$ with a 95 % probability of detecting differences between the samples. To verify whether the number of hits for each stage obtained significant differences, the tables and formulas described in the ISO 4120 method were used. Furthermore, the confidence intervals were calculated (bilateral with a critical value of 95 %) for the proportion of the population that can discriminate the samples in each evaluation step.

6.2. Quantitative descriptive analysis (QDA)

A quantitative descriptive analysis adapted from the standards described in ISO 8586 was performed (ISO, 2012) to quantify the typical characteristics of sparkling wines at the last collection point (22 months) with samples without expedition liqueur (Nature) and with expedition liqueur (Brut—10 g/L of sugar) in both methods. For this analysis, an expert panel (oenologists working in sparkling wine production) of 12 judges (7 men and 5 women) was assembled. The intensity of each attribute was assessed

TABLE 1. Order of the samples evaluated in the Quantitative Descriptive Analysis (QDA).

Types (Sweetness)	Order	Method	Ageing temperature
*Reference sample	1	Charmat	-
Nature	2	Traditional	ageing at 10 °C
	3	Traditional	ageing at 6 °C
	4	Charmat	ageing at 6 °C
	5	Traditional	ageing at 6 °C
	6	Charmat	ageing at 6 °C
	7	Traditional	ageing at 10 °C
Brut	8	Charmat	ageing at 6 °C
	9	Traditional	ageing at 10 °C
	10	Traditional	ageing at 10 °C
	11	Charmat	ageing at 6 °C

*Reference sample = commercial sparkling wine, long Charmat Extra Brut; Nature = without added expedition liqueur; Brut = addition of 10 g/L sugar.

using a 12 cm unstructured line scale labelled as "low" at the left end and "high" at the far right of the line. The global descriptors defined were visual, colour intensity, in the aromas, genuineness, positive intensity, tropical fruits, citrus fruits, dry fruits, flowers, spice, bread dough, herbaceous/vegetable, defects, and the taste sensations, Genuineness, positive intensity, body, sweetness, acidity, persistence, harmonious, bitterness, defects, and Quality (general). Among these attributes, those related to aromas of spice, herbaceous/vegetable, aromas defects, and taste defects were not presented in the results because they were not detected by the participants (values lower than 0.5 on a scale up to 10).

To evaluate the sparkling wines, ISO glasses were used (40 ml per glass). The samples were tasted "blind" at individual tables under artificial lighting with white LED lamps. The wines were served individually and randomly (defined by lottery), separated into Nature and Brut with one repetition. Before starting the analysis, a joint evaluation was made with the participants, where a commercial sparkling wine (reference sample, commercial sparkling wine, long Charmat Extra Brut) was analysed, and the characteristics of the product were discussed among the judges to present the evaluation form, answer questions and balance opinions. The service temperature of the sparkling wines was controlled at 8 °C. In total, 11 samples were analysed in the order described in Table 1.

The results obtained were submitted to a parametric statistical analysis as described below (item 3.7). The results of the sample with the Traditional method aged at 6 °C (the same ageing temperature as the Charmat method) were not presented as they did not differ from the other sparkling wines.

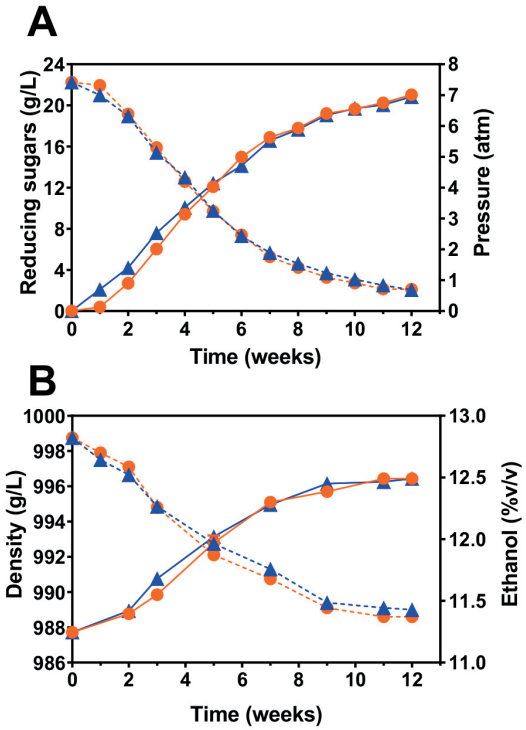
7. Statistical analysis

Statistical analyses comparing treatments at each time point during fermentation and ageing were performed with two-tailed unpaired t-tests with a P value of less than 0.05 was considered significant. In the results referring to the triangular test, the statistical analyses were performed following the models and tables available in the ISO 4120 standard (ISO, 2004). In the quantitative descriptive analysis and analysis of volatile compounds, the one-way ANOVA statistical test was performed, followed by the Tukey test, with a p-value less than 0.05 considered significant.

RESULTS

1. Second fermentation of sparkling wine

The kinetics of the second fermentation of the sparkling wines using the Charmat or Traditional method were similar (Figure 1). This shows that the control and homogeneity of the processes were efficient, which helps to make our sensory and analytical comparison valid. Moreover, the



C

End of fermentation

Analysis	Traditional	Charmat
pH	3.3±0	3.3±0
Total acidity (g/L)	3.9±0	3.9±0
Volatile acidity (g/L)	0.3±0	0.3±0
SO_2 free (mg/L)	5.3±0.2	5.3±0.2
SO_2 total (mg/L)	70±1	74±1
Abs 420 nm	0.102±0.001	0.100± 0.001
Abs 520 nm	0.026±0.001	0.025±0.001
Abs 620 nm	0.007±0,001	0.006±0.001
CI*	0.134±0.003	0.131±0.003
Tint**	3.9±0.02	4.08±0.08

FIGURE 1. Monitoring of fermentations in the two methods conducted at 12 °C.

A = Reducing sugars (dotted line) x increasing pressure - atmospheric pressure (atm) measured at 20 °C; B = Decrease in density measured at 20 °C (dotted line) x increased ethanol concentration; C = table with analyses at the end of fermentation. * CI = Colour intensity (Abs 420+520+620); Tint** = (Abs 420/520); Error bars in line graphics represent standard deviation (SD). Table values are presented as mean ± SD. Both SD were obtained from triplicate samples (3 bottles and 3 tank samples) within the same experiment. Single comparisons were performed between the methods with unpaired two-tailed t-tests between treatments at each stage at which sensory analysis was performed. No significant differences were found.

addition of clarifiers (bentonite + alginate) in the Traditional method did not influence the fermentation kinetics and the physicochemical characteristics of the wines (Figure 1). Overall, there was no significant difference between the methods in the physicochemical parameters at the end of the second fermentation (Figure 1C).

2. The evolution of sparkling wines during ageing

2.1. Physicochemical parameters

Table 2 shows the physicochemical analyses commonly performed for wine quality control. These analyses were performed after 4, 9, 12, 16, and 22 months, the same periods in which the sensory analyses were performed. As can be seen in Table 2, there were slight differences between the wines obtained by the Charmat and Traditional methods during ageing. Significant differences between the methods were detected only in the sugar concentration that was higher in Charmat sparkling wines, the concentration of SO_2 and tint at some point during ageing, and the turbidity that was higher in Charmat wines at 9 and 12 months. These differences in turbidity are related to the difference between the filtration performed before bottling in the Charmat method and the *dégorgement* in the Traditional method.

Parameters like ethanol concentration (12.4 ± 0.2 %), total acidity (3.9 ± 0.1 g/L), pH (3.3) and volatile acidity (0.3 ± 0 g/L) did not show significant differences between processes or along maturation. In the same way, the yellow colour (Abs 420 nm) and colour intensity did not vary significantly. Regarding the internal pressure of the sparkling wines, there were no significant differences between the methods. Care was taken at all stages of corking to ensure that the pressures were kept close together and did not impair the sensory analysis. All the values are within the quality standards used to classify this type of product (Togores, 2018).

2.2. Volatile compounds

The volatile compounds found, which are responsible for the aromas of the sparkling wines, had almost no significant variations between the methods (Figure 2). The only compound that varied between the two methods was diethyl succinate, which had an early increase in the Traditional method, while the other compounds maintained their concentration over time.

The greatest differences occurred between the base wine and sparkling wines regardless of the method and the maturation on their lees (Figure 2). After the second fermentation, there

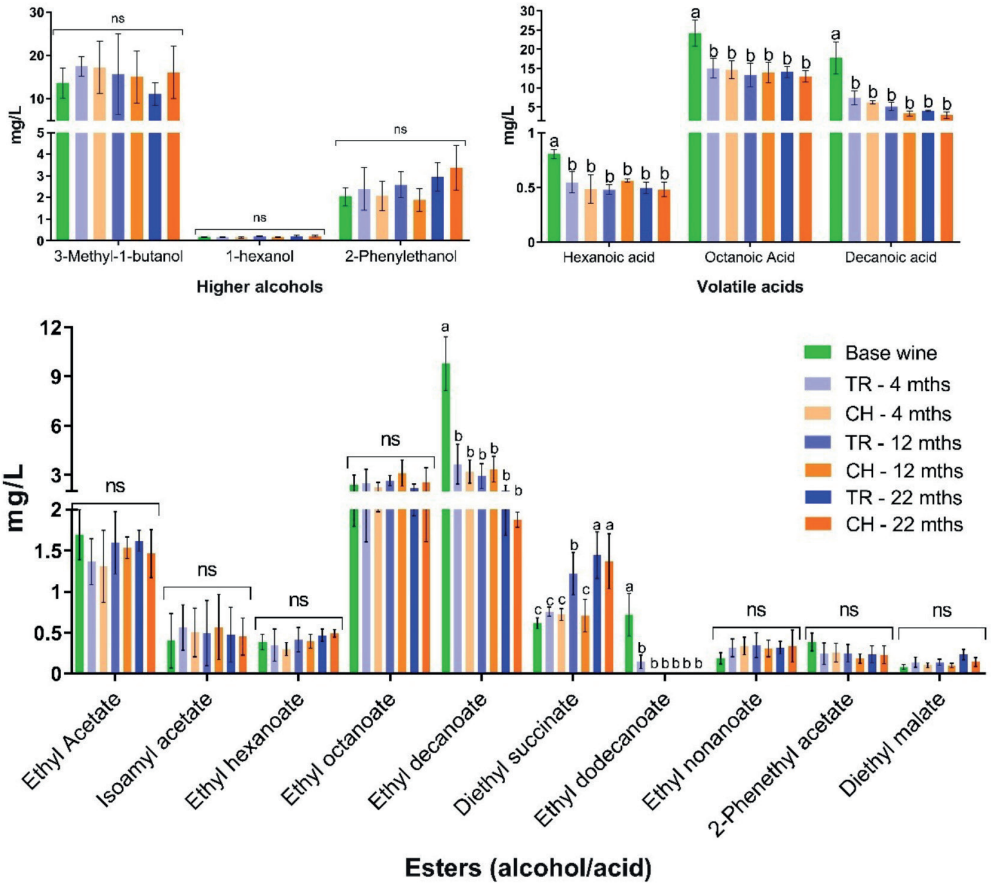


FIGURE 2. Analysis of volatile compounds. Gas chromatography with solid phase microextraction (SPME) with polyacrylate fibre. Different letters at each time indicate statistical differences in One-way ANOVA followed by Tukey's test ($p < 0.05$). ns = not significant.

TABLE 2. Oenological analysis of sparkling wines (means ± standard deviation).

Time with lees	4 months		9 months		12 months		16 months		22 months		22 months (Brut)	
Method	Charmat	Traditional	Charmat	Traditional	Charmat	Traditional	Charmat	Traditional	Charmat	Traditional	Charmat	Traditional
Ethanol (% v/v.)	12.3 ± 0.1	12.4 ± 0.1	12.5 ± 0.1	12.5 ± 0.1	12.4 ± 0.1	12.4 ± 0.1	12.4 ± 0	12.5 ± 0.1	12.5 ± 0.1	12.4 ± 0.1	12.2 ± 0.1	12.1 ± 0.1
Reducing sugars (g/L)	2.1 ± 0*	1.5 ± 0*	1.9 ± 0*	1.3 ± 0.1*	1.9 ± 0*	1.2 ± 0.1*	2.1 ± 0.1*	1 ± 0*	1.8 ± 0.2*	1 ± 0*	10 ± 0.2	10 ± 0.1
Pressure (atm at 20 °C)	6.1 ± 0.1	6.5 ± 0.1	5.8 ± 0.2	5.8 ± 0.1	5.8 ± 0.1	6.2 ± 0.2	6.9 ± 0.1	6.8 ± 0.2	6.3 ± 0.1	6.5 ± 0.1	5.8 ± 0.1	6.3 ± 0.2
pH	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0	3.3 ± 0
Total acidity (g/L)	3.9 ± 0	3.9 ± 0	3.9 ± 0	3.9 ± 0	3.9 ± 0	3.9 ± 0	3.9 ± 0	3.9 ± 0	3.8 ± 0	3.9 ± 0	3.8 ± 0	3.9 ± 0.1
Volatile acidity (g/L)	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0	0.3 ± 0
SO_2 free (mg/L)	13.2 ± 2.5	14.8 ± 1.1	10.3 ± 1.2*	15.7 ± 0.6*	9.8 ± 0	12.6 ± 1	8.3 ± 0.3*	13.9 ± 1*	13.4 ± 1.5	14.1 ± 0	10.3 ± 1.5	12.3 ± 0.6
SO_2 total (mg/L)	108.8 ± 3.8	108.8 ± 2.5	97.7 ± 1.5*	107.3 ± 2.5*	99.1 ± 1.4	102.4 ± 4.9	99.1 ± 2.2	105.9 ± 5.5	106.5 ± 1	105.2 ± 2	102 ± 1	103.6 ± 2.3
Abs 420 nm	0.102 ± 0	0.109 ± 0	0.103 ± 0	0.104 ± 0	0.106 ± 0	0.103 ± 0	0.107 ± 0	0.111 ± 0	0.098 ± 0	0.107 ± 0	0.105 ± 0	0.120 ± 0
Abs 520 nm	0.028 ± 0	0.034 ± 0	0.030 ± 0	0.025 ± 0	0.034 ± 0	0.027 ± 0	0.031 ± 0	0.028 ± 0	0.024 ± 0	0.021 ± 0	0.028 ± 0	0.033 ± 0
Abs 620 nm	0.009 ± 0	0.015 ± 0	0.011 ± 0	0.006 ± 0	0.016 ± 0	0.006 ± 0	0.013 ± 0*	0.007 ± 0*	0.006 ± 0	0.010 ± 0	0.008 ± 0	0.010 ± 0
Colour Intensity (Abs 420+420+620)	0.139 ± 0	0.157 ± 0	0.145 ± 0	0.135 ± 0	0.156 ± 0	0.137 ± 0	0.151 ± 0	0.145 ± 0	0.127 ± 0	0.138 ± 0	0.142 ± 0	0.164 ± 0
Tint (Abs 420/520)	3.6 ± 0.3	3.2 ± 0	3.4 ± 0.2*	4.2 ± 0.1*	3.2 ± 0.3	3.8 ± 0.2	3.4 ± 0.2	4 ± 0.1	4.1 ± 0.4	5.1 ± 0.1	3.8 ± 0.2	3.6 ± 0.1
Nephelometric Turbidity Unit	1 ± 0.1	0.9 ± 0.1	1.9 ± 0.1*	0.8 ± 0.1*	2.2 ± 0.3*	0.8 ± 0*	0.8 ± 0.1	1.1 ± 0.1	1.2 ± 0.2	1 ± 0.1	0.6 ± 0.1	1.2 ± 0.2

Single comparisons were performed between the methods with unpaired two-tailed t-tests between treatments at each stage (* significant differences $p < 0.05$).

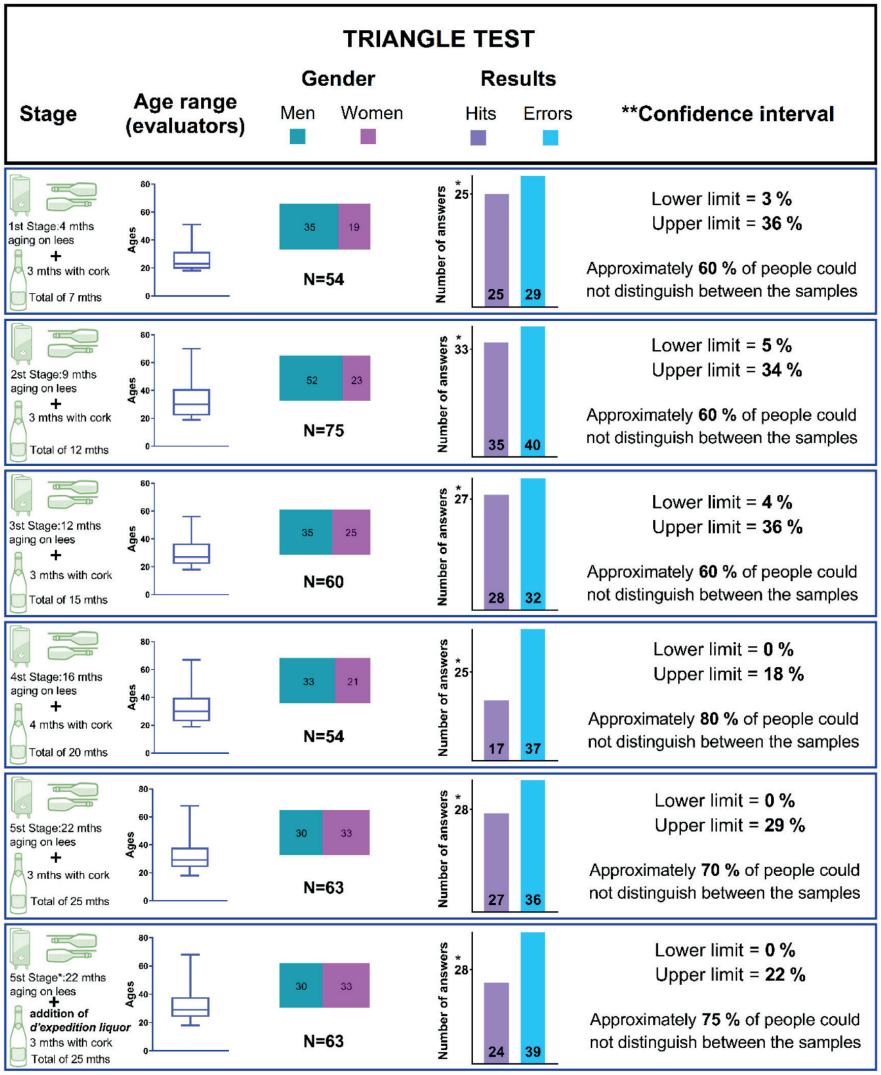


FIGURE 3. Triangular test conducted at different ageing times of sparkling wines. All statistical results were obtained based on ISO 4120 (ISO, 2004).

N = the number of evaluators in each period. Stage = time of contact with lees and time whit cork. *Critical value of correct answer = the minimum number of correct answers to conclude that there are differences at the tested level, 95 % confidence level whit α risk of 5 % to 1 % (indicates moderate evidence that the difference was apparent). **Confidence interval = (95 % confidence level) the proportion of the population that can distinguish the samples is between the lower and upper confidence limit.

was a significant reduction in the concentration of volatile acids: hexanoic acid, octanoic acid, and decanoic acid, which a responsible for leafy, wood, vanish, butter, almond, and caramel aromas, as well as the concentration of decanoate and dodecanoate ethyl esters, that are described to contribute with fruity, fatty, sweet, floral, cream, and other pleasant and fresh aromas (Hu *et al*., 2018). Interestingly, we did not detect a significant reduction in the concentration of acetate esters or an increase in higher alcohols during ageing in either method. The absence of significant differences between the sparkling wines obtained by the Charmat and Traditional methods showed that the method did not influence these parameters.

3. Sensory evaluation

Figure 3 shows the results of all periods in which the sensory analyses were performed regarding the triangle test. As can be observed, the data shows the ageing time of the sparkling wines, the average age, gender, and the number of correct and incorrect answers of the participants in each period. Next to each tasting time is a summary of the statistical analysis and the result of the confidence interval calculation in percentage.

In general, the data showed that there is a higher percentage of correct answers and a higher confidence interval (higher number of judges capable of distinguishing the samples) in the first months in which the test was applied (4, 9, and 12 months of contact with lees). However, in the tests applied after one year (16 and 22 months of contact with the lees), the percentage of judges who were able to distinguish between the samples decreased together with the confidence interval. In all stages, more than half of the judges were not able to differentiate the sparkling wines and distinguish the elaboration methods. The addition of expedition liqueur at 22 months seemed to make it even more difficult for the judges to differentiate the samples.

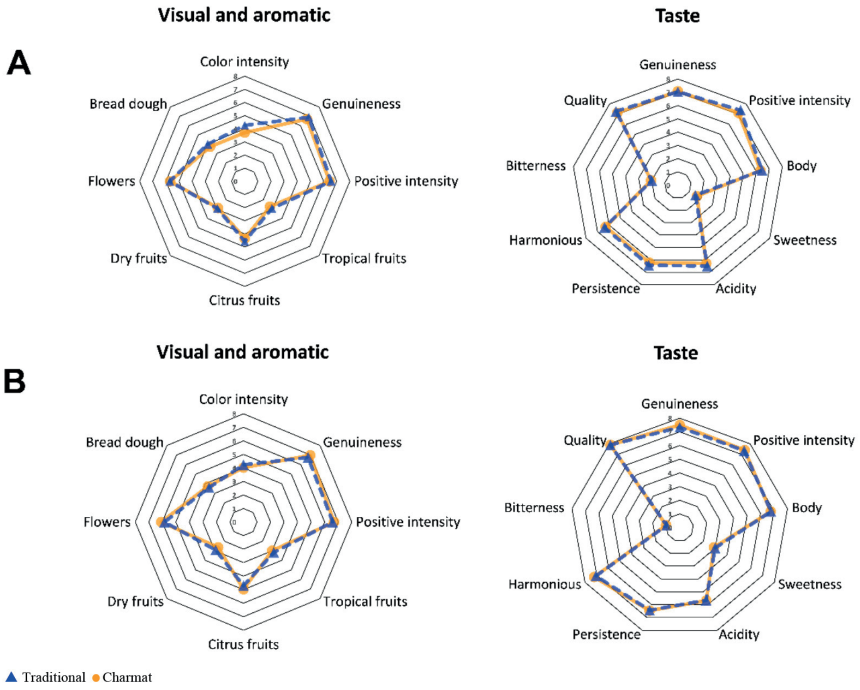


FIGURE 4. Quantitative Descriptive Analysis (QDA).

A = Sparkling nature (without expedition liqueur); B = Sparkling Brut (dosage of 10 g/L of sugar in the expedition liqueur). The results were obtained by a trained panel of 12 tasters. The graphics were separated into visual, aromatic, and taste. There were no significant differences between the method (One-way ANOVA followed by Tukey's test $P < 0.05$).

In the last stage of sparkling wine evaluation (22 months of contact with the lees), a panel of trained tasters (oenologists specialising in sparkling wine elaboration) performed a quantitative analysis of the attributes commonly described in sparkling wines (Figure 4). In all the attributes quantified, the two methods did not present differences that were possible to discriminate between the elaboration methods, the values on most attributes being close. The only differences found were between sparkling wines with and without expedition liqueur, regardless of the method. The sparkling wines with the addition of liquor were considered sweeter, less acidic, more harmonious, and of better quality.

DISCUSSION

Although the methods of making Traditional or Charmat sparkling wines have technological characteristics, the physicochemical, volatile, and sensory differences of sparkling wines are controversial. Our study shows that the sparkling wines produced from the same base wine, inoculum, and ageing time on lees, do not differ much in their chemical (Figures 1 and 2, and Table 2) and sensory (Figures 3 and 4) characteristics to the point of being able to differentiate or identify the method that was used.

Even though are already some studies in the literature on the same subject with contrary conclusions, they all differ from our study in that either the comparisons between the methods were made with commercial sparkling wines (Culbert *et al*., 2017; Ubeda *et al*., 2016), or the sparkling wines had different fermentation temperatures or different contact times with the lees depending on the method (Caliari *et al*., 2015; Vecchio *et al*., 2018), which makes it difficult to compare the methods properly. In our study, the comparison between the Traditional and Charmat methods sought to respect as much as possible the techniques normally applied in each of the methods on an industrial scale, the main variable being the method used to conduct the second fermentation. The base wine, inoculum, and fermentation temperature form the same, and the two methods have similar fermentation kinetics (Figure 1). Despite the differences in ageing temperature between the methods in our study (Charmat method of 6 °C and Traditional methods of 10 °C), during the follow-up time of our study (approximately 2 years), we saw that this difference did not cause noticeable changes in the overall characteristics of the products. It is interesting to comment that in one study evaluating the same base wine aged with and without contact with the lees and the sparkling wine from this base wine aged on its fewer for 24 months (Sawyer *et al*., 2021), the researchers found no significant differences in the aromatic profile of the wines, concluding that the quality of the base wine used and the oxy-reductive phenomena occurring during ageing are more important in this process than ageing on lees. According to our results, this is also true for the method of making Charmat and Traditional sparkling wines for a period of fewer than 24 months. For, in our comparison using the same base wine for the two methods, we identified few differences in the volatile compounds, where only the compound diethyl succinate varied statistically over time at 12 months (Figure 2). Whereas in a study conducted in Chile (Ubeda *et al*., 2016) comparing the aromatic profile of commercial sparkling wines

made by the Charmat and Traditional methods (16 Chilean sparkling wines, 8 of each method), the main difference between the sparkling wines was the higher presence of ethyl esters in Traditional method sparkling wines and higher amounts of acetic esters and ketones in Charmat sparkling wines. These two classes of esters (ethyl esters and acetate esters) are respectively related to characteristics of aged wines and young wines (Waterhouse *et al*., 2016). This case shows an example of the types of products that are normally made with each method (young Charmat sparkling wines and Traditional aged sparkling wines), but by no means do these characteristics come exclusively from the type of method used to conduct the second fermentation of the sparkling wines.

An important fact that occurs when we talk about sparkling wine-making methods is the expectation effect that occurs whit the people. An interesting study was conducted to understand the effect on quality expectations and how information about the method by which the sparkling wine was made influences the consumer (Vecchio *et al*., 2018). Although the sensory comparisons between the methods were made with sparkling wines fermented at different temperatures and with different times of contact with the lees (Traditional 15 months in contact with lees Charmat 4 months in contact with lees), which may impair the comparison between the methods, the researchers carried out a hedonic evaluation of the products without tasting, only through the label with detailed information about each production method. Sparkling wines produced by the Traditional method were preferred in this hedonic choice. In this case, the information about the method created expectations of taste and quality without the assessors having tried the products. This may be because the Traditional method is related to "Champagne" sparkling wines, which have a formidable reputation acquired over time and a strong collective territorial brand (Charters and Spielmann, 2014), which is probably why to this day, there is this myth that one method is better than the other.

In our sensory analyses concerning the triangle test over time, we saw that a greater number of judges were able to identify the samples in the first months of evaluation (Figure 3). It may be that in this period, the autophagic and autolytic phenomena of yeasts that differ between the methods (Cisilotto *et al*., 2023), may modify some organoleptic sensations. However, in any case, if there are slight differences, they are very subtle because, in addition to the chemical analyses being similar (Figure 1 and 2), in all the tastings, more than half of the judges were not able to identify the different sparkling wine (Figure 3). Added to this, we saw that in the quantitative descriptive sensory analysis conducted with the professionals (Figure 4), the characteristics of the sparkling wines that were quantified did not have statistical differences, which further strengthens our argument that the method does not define the main characteristics and quality.

All these results show that although there is marketing that praises the quality of sparkling wines made with the Traditional method, sparkling wines made with the Charmat method can have the same level of quality and ageing capacity. However, in most cases, sparkling wines made using the Charmat method go to market much younger than those made using the Traditional method, assuming this identity and relation with young and fruity products. In our understanding, the quality of the base wine used plays a key role in this process, and with both methods, it is possible to make both sparkling wines with characteristics of young and fruity wines, with less time of contact with the lees, or more aged with characteristics related to the evolution of wines. This is a fact known by many winemakers, but this knowledge is still not clear to many professionals and especially to the final consumer.

Our study is the first one that used the same base wine and inoculum and treated the ageing time with the lees equally in both methods, performing regular tastings with care to be as faithful as possible to the industrial reality. Under these conditions presented, in general, the methods are similar, having a similar behaviour over time, and as we have seen, most people cannot differentiate the method employed in the second fermentation of sparkling wines. This shows that regardless of the method used to conduct the second fermentation of the sparkling wines, in both methods, it is possible to obtain similar sparkling wines and that the methods do not define the main characteristics and the final quality of the sparkling wines.

CONCLUSIONS

From the same base wine and inoculum, with the wines ageing the same amount of time on their lees, the sparkling wines made by the Charmat and Traditional methods are similar in every aspect. The differences found in sparkling wines made by Charmat and Traditional methods are subtle and do not cause major changes capable of modulating the overall characteristics of the products. The longer the sparkling wines age, the more difficult it becomes to only differentiate the products sensorially by the method used in the second fermentation. The method used to perform the second fermentation does not define the quality of the sparkling wines, and it is possible to assume that there are other factors that precede the second fermentation that can have more impact on the product.

ACKNOWLEDGEMENTS

This study was supported by the Federal Institute of Education, Science and Technology of Rio Grande do Sul (IFRS), the University of Caxias do Sul (UCS), and the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brasil* (CAPES)—Finance Code 001. We would like to thank Philippe Mevel, Juliano Perin, Graciele Tomazi, Andressa Cattani, Jandir Furlanetto, Eudes Fernando Trombini and the winery Chandon Brazil for their support, partnership, and exchange of knowledge during the project.

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