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ORIGINAL ARTICLE

Chemical and sensory effects of brewing hot trub incorporation during winemaking of BRS Vitória hybrid grapes

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Abstract
The aim of this study was to analyze the physicochemical and sensory profiles of the BRS Vitória wine produced using hot trub during the alcoholic fermentation. Seven types of wine were produced: control wine (only BRS Vitória grapes), wines with 5%, 10% and 15% of hot trub incorporation (INC5%, INC10%, and INC15%), and wines with 5%, 10% and 15% of hot trub replacement (SUB5%, SUB10%, and SUB15%). Alcohol content, pH, total and volatile acidity, dry extract, reducing sugars, total phenolic content, and color indexes were influenced by the addition of hot trub to the grape must. Among all the wines analyzed, control wine showed the highest value for phenolic content (801 mg/L), followed by the INC5% wine with 580 mg/L. The control sample was sensorially described as red color, fruity taste, sweet taste and grape aroma, showing high overall acceptance. However, the wines produced with hot trub showed statistically similar overall acceptance in comparison to the control wine. The low sensory acceptance of the SUB15% sample was determined by the high scores for bitterness, acidity, astringency and persistence. The wines produced using an innovative approach involving low insertion of hot trub showed their potential in the field of winemaking.

Keywords Winemaking · Hot trub · BRS Vitória grape · Chemical compounds · Sensory analysis

Introduction

Wine, defined as the beverage obtained from the alcoholic fermentation of the simple must of healthy, fresh and ripe grapes (Brasil 2018), has numerous benefits for consumers, primarily related to health, as it is a beverage rich in compounds with antioxidant activity from phenolic compounds (anthocyanins, flavones, flavonols, flavan-3-ols, alkylphenols, tyrosols, phenolic acids, lignans and stilbenes such as resveratrol) (Jackson 2020). Di Renzo et al. (2014) studied the effect of the combined consumption of wine with different types of meals and found that the consumption of 250 mL of wine together with a Mediterranean meal significantly reduced the oxidation of low-density lipoprotein (LDL) cholesterol.

The phenolic concentration in wines is influenced by their quality and can be described by a large number of factors such as terroir, the place where the grape is grown, vine management, soil chemical and mineral composition, grape sanitary conditions, winemaking technology and others (De Castilhos et al. 2013). All these factors can change the chemical properties of the wine and influence its sensory quality.

In Brazil, grape production is divided into two groups: one made up of *Vitis labrusca* or hybrids, known as common rustic or American grapes, and the other made up of fine or European grapes (*Vitis vinifera*) (De Castilhos et al. 2016; Jackson 2020). Among the American grapes, those from the Brazilian Agricultural Research Company (EMBRAPA) Grape and Wine Genetic Improvement Program stand out, the BRS type grapes, which have a greater deeper purplish color, aroma and fruity flavors, features appreciated by Brazilian consumers. BRS Vitória is an example of these grapes and it is the result of a cross between CNPUV 681−29 [Arkansas 1976 x CNPUV 147-3 ('Niágara Branca' x 'Vênus')] and 'BRS Linda'. The berries are spherical,

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blue-black in color, with thick, resistant skin, good tolerance to tissue cracking, which allows the bunches to be transported over long distances, colorless pulp, slightly firm flesh and a taste reminiscent of raspberry, which makes it pleasant to the palate (Maia et al. 2014).

The importance and need to optimize the management of the waste generated by its expansion is growing (Brasil et al. 2021), including malt bagasse, which is the largest in terms of volume, trub (the sediment left by hops after boiling and by dormant yeast after fermentation) and yeast (yeast cells), as well as broken bottles and sludge from wastewater treatment plants. Hot trub is the second solid waste produced in the brewing process, during the wort boiling stage. It results primarily from the coagulation of proteins, with other substances present due to their participation in the formation of these complexes or due to dragging during sedimentation. Another factor that can influence trub formation is the presence of cations, mainly Ca2+, hop compounds with low solubilization efficiency, polyphenols and carbohydrates that are not completely hydrolyzed in the mash (Priest and Stewart 2006).

In the brewery, between 200 and 400 g of hot trub (80–90% moisture) is produced for every hectolitre of beer produced, and it is characterized as an agglomeration of insoluble proteins, complex carbohydrates, lipids, tannins, minerals and hop components. It also contains about 40 to 70% protein, 7 to 32% bitter substances, 20 to 30% organic substances such as polyphenols (5 to 10%) and 5% ash (Mathias et al. 2014; Kühbeck et al. 2007). The composition of trub can be influenced by the type of malt, the type of milling, the type and concentration of hops, the processes used in the production of the beverage, and its use in food and beverages. Asevedo et al. (2020) evaluated the effect of trub addition on the fermentation of a Pilsner-style beer and concluded that trub may not be as detrimental in terms of reducing extract and consequent alcohol production, as well as not affecting yeast growth. However, the study showed the need for further investigation of the detrimental effects of trub on yeast activity, considering the effects of introducing higher trub concentrations and changes in the sensory characteristics of the beverage.

In this context, the present work aimed to produce BRS Vitória red wines using the hot brewing trub to evaluate the influence of the presence of this residue during the alcoholic fermentation on the physicochemical and sensory profiles. The use of the hot brewing trub will minimize the formation of waste, with the expectation that the use of the residue will add value to the beverage, possibly enhancing the phenolic content, promoting regional features and market potential.

Materials and methods

Grapes and alcoholic fermentation

The wines were produced from grapes of the BRS Vitória variety, grown in the city of Jales, São Paulo (latitude 20º 16′ 06″ South, longitude 50º 32′ 56″ West), at an altitude of 486 m. The grapes were harvested in November 2023 and then stored in a refrigerated environment (between 1 and 2 °C) at the State University of Minas Gerais - Frutal Unit for approximately three days. After this time, the grapes were submitted to the winemaking process. The hot trub was provided by the company Beco do Malte, located in the municipality of São José do Rio Preto, São Paulo, (latitude: 20° 49′ 13″ South, longitude: 49° 22′ 47″ West), at an altitude of 510 m, and stored in a refrigerated environment (between 1 and 2 °C) for approximately three days at the State University of Minas Gerais - Frutal Unit, after this time, the hot trub was used in the winemaking process. Other materials used were fermentation reactors consisting of white non-toxic plastic containers with valves at the bottom to allow the wine to be removed by dejuicing. In addition, active dry yeast *Saccharomyces cerevisiae* (strain Y904 Mauri from Burns Philp®, Australia) and potassium metabisulfite from Amazon Group Coatec®, Rio Grande do Sul, were used.

Seven types of wine were made in two repetitions: wine with the BRS Vitória grape (control); wine incorporating hot trub at 5% (m/m) (INC5%); wine incorporating hot trub at 10% (m/m) (INC10%), wine incorporating hot trub at 15% (m/m) (INC15%), wine replacing the grapes with hot trub at 5% (m/m) (SUB5%); wine replacing grapes with hot trub at 10% (m/m) (SUB10%), and wine replacing grapes with hot trub at 15% (m/m) (SUB15%). The incorporation method consisted of adding a certain amount of hot trub without removing the amount of grapes from the fermentation must. The substitution method consisted of replacing a certain amount of grapes with hot trub. Both the incorporation and hot trub replacement methods were performed before yeast inoculation, i.e., before alcoholic fermentation.

The percentages of hot trub added were specified in %mass/mass (Table 1), i.e., based on the total initial mass of grapes, the mass of hot trub to be added or replaced was calculated. For example: using 5 Kg of grapes for winemaking, for the INC5% treatment, 250 g of hot trub were added to the 5 Kg of grapes; for the SUB5% treatment, 250 g of grapes were removed and replaced with 250 g of hot trub.

All treatments followed the winemaking process according to De Castilhos et al. (2015) with modifications (Table 1). The grapes, approximately 5 Kg for each treatment, were destemmed and crushed to obtain the must. The must was placed in 5 L fermentation flasks, and the alcoholic

Table 1 Experimental design for winemaking

Wines[1]	Grapes (%m/m)[2]	Hot brewing trub (%m/m)
Control	100	0
INC5%	100	5
INC10%	100	10
INC15%	100	15
SUB5%	95	5
SUB10%	90	10
SUB15%	85	15

[1]INC5%: wines with 5% hot trub incorporated; INC10%: wines with 10% hot trub incorporated; INC15%: wines with 15% hot trub incorporated; SUB5%: wines with 5% grapes replaced by hot trub; SUB10%: wines with 10% grapes replaced by hot trub; SUB15%: wines with 15% grapes replaced by hot trub. [2] (%mass/mass)

fermentation procedure was carried out with the addition of 15 g of potassium metabisulfite per 100 kg of grapes as a selective antimicrobial agent, which is 0.75 g for each treatment, and the inoculation of active dried *Saccharomyces cerevisiae* yeasts at the rate of 20 g per 100 L of must. The yeasts were activated using a volume 10 times greater than the yeast mass calculated for the must at a temperature of 37 °C, according to the manufacturer's instructions.After inoculation of the yeasts, the musts were fermented for seven days at 25 °C, with pumping over twice a day until the 5th day of the alcoholic fermentation. After this fermentation, the wines were racked and chaptalized to 9% v/v. The beverages were racked three times at 10-day intervals. After 10 days from the third racking, the beverages were vacuum filtered, bottled and allowed to stabilize for 90 days horizontally in a control room temperature at 18 °C.

Conventional enological parameters

The following physicochemical parameters were carried out according to AOAC (2005): Alcoholic content (%v/v) (ALC) using an oenological distiller Super DEE and hydrostatic balance (Gibertini®), reducing sugar (RSG) according to the Lane-Eynon method using a Redutec determinator (Tecnal TE0861®), total acidity (TAC) as tartaric acid equivalent and volatile acidity (VAC) as acetic acid equivalent using a pH meter and a distiller (Tecnal TE0363®), titration and a distiller (Tecnal TE0363®), dry extract (EXT) using porcelain capsules and a thermostatic bath at 100 °C, total phenolic content (PHEN) using an absorbance spectrophotometer at 765 nm and CIELab color indices using absorbance spectrophotometers at 450, 520, 570 and 630 nm. CIELab parameters were determined using MSCV 7.1 software (Ayala et al. 2012). All the physicochemical parameters were analyzed in triplicate.

Sensory analysis

The sensory analysis evaluated the seven BRS Vitória wines using a descriptive and a sensory acceptance test. All the sensory analyses were carried out at the Sensory Analysis Laboratory of the State University of Minas Gerais, Frutal, Minas Gerais, Brazil.

The descriptive sensory analysis was determined by applying the RATA (Rate All That Apply) technique (Sabino et al. 2023), which consisted of a survey of sensory descriptors for red wines through a targeted literature search addressing sensory descriptors of appearance, aroma, texture and flavor. For each sensory descriptor, an unstructured 9-point scale was used, anchored by the boundaries of "not applicable" and "applicable". The sensory descriptors rated by consumers were: pink color, transparency, grape aroma, alcohol aroma, floral aroma, sweet taste, bitter taste, sour taste, fruity flavor, astringency, body, and persistence.

Sensory acceptability was assessed using a nine-point verbal hedonic scale (1 = extremely disliked, 5 = neither liked nor disliked, and 9 = extremely liked) by rating appearance, aroma, body, taste, and overall acceptability. In addition, purchase intention was assessed using a five-point hedonic scale (1 = definitely would not buy, 5 = definitely would buy).

The descriptive and sensory acceptability tests were conducted in individual booths at room temperature (23–25 °C) under white light. The samples were presented in 30 mL transparent plastic cups containing 15 mL of a sample at 18 °C with a cup of water for mouth rinsing. A full block experimental design was used for both analyses, i.e. all consumers rated all the samples. The samples were presented monadically, in a randomized order coded with three random digits to avoid carry-over effects (Meilgaard et al. 2006).

The Ethics approved the Ethical Issues regarding sensory acceptability in the Minas Gerais University Research Committee (process CAAE number 78820724.3.0000.5115) and the panelists that smoke or use medications that negatively influenced the taste/oral or olfactive perception were excluded from the sensory analysis.

Data analysis

All the results were expressed as mean values ± standard deviation, and the physicochemical parameters and sensory data were treated with the application of Analysis of Variance (ANOVA) test to observe significant differences between the wines. When significant differences were observed ($P < 0.05$) the Tukey's posthoc test was performed using the Minitab 17 software (Minitab Inc.). A sensometric approach was applied to determine the relationship between the descriptive and sensory acceptance attributes with the physicochemical properties by applying the Principal Component Analysis (PCA) using Statistica 12 software (StatSoft Inc.).

Results and discussion

Grape musts, hot brewing trub and alcoholic fermentation parameters

The soluble solids content of the must ranged from 13.7 (SUB15%) to 15.5 Brix (control), the pH from 3.86 (INC15%) to 4.93 (INC5%), and all wines were properly chaptalized by the addition of 30.2 g (control) to 45.5 g (SUB15%) sucrose per liter of must. The pH of the hot trub was 4.73 ± 0.09, with 80.8 ± 0.19% moisture, 3.7 ± 0.23 total acidity and 2,156 ± 293 total phenolic content. The result obtained for the alcoholic fermentation yield (L of wine/Kg of grapes in percentage) ranged from 48.0% (INC10%) to 51.0% (control).

Physicochemical parameters

The BRS Vitória grape used in the winemaking process presented the following physicochemical characteristics: average soluble solids content of 15.1 ± 0.3°Brix, average pH of 4.09 ± 0.14, average total acidity of 3.9 ± 0.08 g/L and 412 ± 5.33 mg/L of total phenolics.

The pH of the INC15% wine was significantly higher than the others, at 4.19, and was not different from the control and SUB15% wines (Table 2). With a direct influence on the total acidity and consequently on the sensory characteristics of the wine, the higher the acidity, the lower the pH, which affects the freshness of the wine, as more acidic wines are fresher on the palate (Jackson 2020). Wurz et al. (2021) found values between 2.91 and 3.4 when characterizing table wines from the Planalto Norte Catarinense region, vintage 2019. With an ideal pH range of 3.0 to 3.8 (Rizzon 2010), the wines in this study ranged from 3.94 to 4.19, which is slightly above the recommended range.

The wines presented alcohol content ranged from 8.25% (SUB5%) to 9.5% (v/v) (Control), with the control having a significantly higher value than the other samples. Since the law prescribes a range of 8.6% to 14% (v/v) for table wines, only the SUB5% sample was below the recommended parameter.

There was a significant difference in the total acidity parameter, with the treatments showing lower values compared to the control group, except for the INC5% treatment, which showed a total acidity value statistically similar to that of the control wine. The total acidity of the samples ranged from 4.71 g/L (SUB10%) to 5.97 g/L (control). There was a significant difference in the volatile acidity parameter between the control sample and the other treatments, with the control wine showing the highest volatile acidity. The results presented a trend that increasing the percentage of hot trub added to or substituted for the fermenting must decreased the total and volatile acidity, i.e., the greater the

Table 2 Mean±standard deviation of the physicochemical properties of the BRS Vitória wines

Physicochemical properties	Control	INC5%	INC10%	INC15%	SUB5%	SUB10%	SUB15%	P value[1]
ALC (%v/v)	9.50 ± 0.18 a	8.60 ± 0.07 d	8.92 ± 0.40 bcd	8.88 ± 0.21 cd	8.25 ± 0.05 e	9.26 ± 0.07 ab	9.08 ± 0.03 bc	< 0.001
pH	4.13 ± 0.06 ab	3.95 ± 0.06 d	4.05 ± 0.01 bcd	4.19 ± 0.15 a	3.93 ± 0.03 d	3.99 ± 0.05 cd	4.09 ± 0.02 abc	< 0.001
TAC (g/L)	5.97 ± 0.15 a	5.84 ± 0.07 a	5.31 ± 0.25 bc	5.47 ± 0.14 b	5.09 ± 0.07 cd	4.71 ± 0.09 e	5.04 ± 0.04 d	< 0.001
VAC (g/L)	1.11 ± 0.07 a	0.81 ± 0.25 bc	0.59 ± 0.14 bcd	0.85 ± 0.13 b	0.56 ± 0.17 cd	0.45 ± 0.05 d	0.39 ± 0.07 d	< 0.001
EXT (g/L)	23.5 ± 0.,5 b	24.5 ± 0.4 b	26.9 ± 0.2 a	27.4 ± 0.3 a	23.9 ± 1.1 b	27.6 ± 0.7 a	27.0 ± 0.3 a	< 0.001
RSG (g/L)	1.63 ± 0.04 d	1.83 ± 0.10 c	2.43 ± 0.03 a	2.06 ± 0.03 b	1.98 ± 0.02 b	1.85 ± 0.04 c	1.85 ± 0.01 c	< 0.001
PHEN (mg/L)	801 ± 15 a	580 ± 17 b	517 ± 20 c	499 ± 22 cd	557 ± 31 b	462 ± 11 de	457 ± 22 e	< 0.001
L*	45.48 ± 0.28 b	1.78 ± 0.15 e	36.45 ± 3.39 c	18.87 ± 6.46 d	4.35 ± 0.91 e	5.97 ± 0.61 e	55.62 ± 0.51 a	< 0.001
C*	50.24 ± 0.38 a	7.22 ± 0.56 f	34.17 ± 0.82 b	28.69 ± 4.26 c	11.55 ± 1.53 e	14.94 ± 1.09 d	33.02 ± 0.42 b	< 0.001
h*	39.68 ± 0.36 c	20.99 ± 1.27 e	46.68 ± 2.11 b	39.78 ± 0.41 c	25.42 ± 1.46 d	23.46 ± 1.13 d	51.60 ± 1.38 a	< 0.001
a*	38.67 ± 0.41 a	6.74 ± 0.52 f	23.43 ± 1.08 b	22.04 ± 3.16 bc	10.42 ± 1.25 e	13.70 ± 0.94 d	20.51 ± 0.58 c	< 0.001
b*	32.08 ± 0.28 a	2.58 ± 0.25 e	24.85 ± 1.05 b	18.37 ± 2.86 c	4.99 ± 0.94 d	5.96 ± 0.63 d	25.87 ± 0.69 b	< 0.001
INT	3.09 ± 0.02 d	9.43 ± 0.16 a	3.64 ± 0.27 d	5.42 ± 0.83 c	7.66 ± 0.29 b	7.07 ± 0.15 b	2.26 ± 0.04 e	< 0.001
TON	0.99 ± 0.01 de	1.03 ± 0.04 c	1.13 ± 0.02 b	1.05 ± 0.02 c	1.02 ± 0.02 cd	0.95 ± 0.01 e	1.25 ± 0.03 a	< 0.001

[1]INC5%: wines with 5% hot trub incorporated; INC10%: wines with 10% hot trub incorporated; INC15%: wines with 15% hot trub incorporated; SUB5%: wines with 5% grapes replaced by hot trub; SUB10%: wines with 10% grapes replaced by hot trub; SUB15%: wines with 15% grapes replaced by hot trub. ALC: alcohol content; TAC: total acidity; VAC: volatile acidity; EXT: dry extract; RSG: reducing sugars; PHEN: total phenolic content; L*: luminosity; C*: Chroma; h*: hue angle; a*: coordinate a; b*: coordinate b; INT: color intensity; TON: tonality. [1]P-value referred to Analysis of Variance (ANOVA) at $P < 0.05$. Different letters in the same line significantly differ by the application of Tukey's post-hoc multiple comparison test at $P < 0.05$

amount of hot trub added to the alcoholic fermentation, the lower the total and volatile acidity of the wines produced.

In both cases, all the wines had acidity parameters in accordance with Brazilian legislation (Brasil 2018), i.e. from 40 to 130 meq/L of total acidity, corresponding to 3 to 9.75 g/L of tartaric acid equivalents; and values of less than 20 meq/L of volatile acidity, corresponding to 1.2 g/L of acetic acid equivalents. The fact that all the wines had volatile acidity below the maximum limit indicates that they are all free of microbial contamination and safe to drink. Nevertheless, Jackson (2020) hypothesized that this divergence between table wines for these determinations may be related to the winemaking process and the use of different grape varieties in their production.

The dry extract showed a significant difference between the samples, with the samples with 10% or 15% hot trub in the formulation, regardless of whether it was incorporated or replaced, showing a significantly higher dry extract compared to the 5% and control samples. Therefore, it can be assumed that the incorporation or substitution of more than 10% hot trub in the fermenting must increases the dry extract of the wine produced. All wines were classified as light on the palate, as they had a dry extract below 30 g/L (Jackson 2020; De Castilhos et al. 2015). It was observed that the wines produced had dry extract values between 23.56 and 27.65 g/L, and these values are in line with the minimum limit established by the legislation for red wines, which is 21 g/L (Brasil 2018). Similar results were obtained in the study of De Castilhos et al. (2015), who reported that the dry extract of BRS Rúbea and BRC Cora red wines were close to 25 g/L.

The results obtained for the reducing sugar content showed significant differences, with the INC10% treatment presenting a significantly higher value than the other treatments. These values indicate that the wines produced were classified as dry, since the residual sugar was less than 4 g/L (Brasil 2018). De Castilhos et al. (2019) found similar values in samples of wines produced by BRS Carmem hybrid grapes, which averaged 2.90 g/L to 3.61 g/L, indicating that they were legally classified as dry wines. The same study also reported that the wines produced from BRS Violeta hybrid grapes presented residual sugar content between 2.92 and 4.28 g/L, even using the chaptalization process to standardize the final wine alcohol content.

The total phenolic content of the control wine was significantly higher than that of the other wines. Studies by De Castilhos et al. (2015) presented the total phenolic content of wines produced from some BRS grapes, showing that the concentration of this parameter varied according to the grape variety. The authors reported total phenolic concentrations of between 706 and 975 mg/L for BRS Rúbea grape wines, and 366 to 380 mg/L for BRS Cora grape wines. The wines produced in this study showed concentrations close to those observed in the BRS Rúbea wine.

Looking at the results obtained, there is a tendency to consider that the greater the amount of hot trub used in winemaking, the lower the total phenolic content in the wine. Despite the control, the wines with 5% hot trub by incorporation and by substitution had the highest concentrations of total phenolics, indicating that the higher the concentration of hot trub added to the fermenting must, the lower the concentration of total phenolics in the wine. However, when comparing the total phenolic value of the BRS Vitória juice with all the samples in the study, the values obtained were higher.

Considering the luminosity (L*), hue angle (h*) and tonality (TON) parameters, the SUB15% treatment showed significantly higher values when compared to the other samples. The control wine showed significantly higher values for chroma (C*), a-coordinate (a*) and b-coordinate (b*). The color intensity was significantly higher for the INC5% sample.

The Chroma (C*) parameter characterizes the concentration or saturation of the overall color of the wine. Considering all the samples together, the control had the highest chroma, which means a purer, more saturated color. The others had lower Chroma, which indicates paler, less saturated colors. The a* and b* coordinates showed significant differences when comparing the treatments, indicating that the control sample had a higher value for both coordinates. In all the wines, the a* value was higher than the b* value, except for the INC10% and INC15% samples, indicating a more intense red color than the yellow color.

The color intensity profile of each of the samples showed a significant difference, with the INC5% treatment having the highest color intensity and the SUB15% treatment having the lowest. This increase in color intensity is associated with a decrease in brightness. This result assumes that color intensity is inversely proportional to the brightness of the beverage.

The hue shows the evolution of color in yellow pigments as a result of oxidation and/or reduction of anthocyanins, increasing in hue with aging, i.e. lower hue values indicate a greater ratio of red coloration to yellow/orange coloration. The samples showed significant differences, with values ranging from 0.95 to 1.25. Some factors may have influenced these results, such as the vineyard management system, which did not allow enough sunlight into the vineyard to reach the ideal phenolic ripeness of the grapes, providing a wine with more color and tone, characteristics that add value and structure to the beverage (Santos et al. 2017).

Sensory analysis

Descriptive sensory analysis

A panel of 100 untrained consumers (52 men, 52.0%) with an average age of 26.3 years (minimum 18 and maximum 64 years) assessed all the fermented beverages.

For the pink color attributes, there was a significant difference between the samples, whose values ranged from 5.13 to 2.52, with the control wine having the highest pink color score and the SUB15% wine having the lowest score (Table 3). This color can be influenced by the grape variety, ripeness, winemaking techniques and ripeness followed by aging (Leonardi 2022). It can be assumed that the addition of hot trub to the fermenting must had a negative influence on the color of the wine.

All the wines differed significantly in all the olfactory attributes (grape aroma, alcohol aroma and floral aroma). In the grape aroma attribute, the control wine had the highest score and the SUB15% wine had the lowest intensity. From the treatments analyzed, it can be assumed that the addition of hot trub to the fermentation must reduce the grape aroma scores, with the wines produced from substitution showing the lowest scores for this attribute. In terms of alcohol aroma, the INC5% wine was more intense, while the control wine had the lowest score for this attribute, and in terms of floral aroma, the difference was between the SUB15% and SUB5% samples, with the former having significantly higher scores. In general, wines contain aromatic compounds in different concentrations and degrees of volatilization, making them more or less easily perceivable (Leonardi 2022).

Taste and flavor attributes varied among the samples. The control wine scored higher for sweet taste and fruity flavor. The sweet taste showed lower scores for wines made with 15% hot trub in the composition, regardless of how it was added (incorporated or substituted). For the fruity taste, the control wine stood out from the INC15%, SUB5% and SUB10% wines. The SUB15% wine was more intense in terms of bitterness and did not differ significantly from the INC5% and SUB10% wines. All the wines made with hot trub, regardless of how it was added, had high acid taste scores, and showed significant differences from the control wine, i.e. the presence of hot trub in the wine formulation was responsible for determining higher acid taste scores in the wines.

Hot brewing trub is mostly composed of insoluble high molecular weight proteins, wort, hops, and malt particles which are discarded from the process before the inoculation of yeast responsible for promoting the alcoholic fermentation (Santos and Martins 2024). The carbohydrate and tannin content in the hot brewing trub residue favor browning processes, such as caramelization and Maillard reaction, and bitterness, the last mostly due to the hop's presence (Santos and Martins 2024). Hot trub is formed after boiling the wort, at which point hops are added. At this stage, the secondary hop metabolites are converted into bittering compounds and about 85% of the hop constituents are not solubilized in the wort and are discarded in the hot trub, including lupulin and α acids. These acids are responsible for determining the expressive acidity of the hot trub, which, when added to the fermenting must for winemaking, is incorporated into the beverage (Durello et al. 2019). This may explain why wines made with hot trub have higher acid taste scores than control wines.

There was no significant difference in the astringency and body attributes. Finally, in terms of persistence, the wines made with hot trub were more persistent in the mouth, with

Table 3 Mean±standard deviation of the descriptive sensory attributes of the BRS Vitória wines

Sensory descriptive attributes	Control	INC5%	INC10%	INC15%	SUB5%	SUB10%	SUB15%	P value[1]
Pink color	5.13 ± 2.10 a	4.83 ± 2.24 ab	4.64 ± 2.09 ab	4.07 ± 2.05 bc	3.59 ± 1.85 c	4.63 ± 2.18 ab	2.52 ± 1.94 d	< 0.001
Grape aroma	4.70 ± 2.35 a	3.79 ± 2.15 b	3.80 ± 2.17 b	3.48 ± 2.01 bc	3.12 ± 1.94 bc	3.14 ± 1.98 bc	2.83 ± 1.99 c	< 0.001
Alcohol aroma	2.56 ± 1.89 d	4.34 ± 2.14 a	3.83 ± 2.14 abc	4.26 ± 2.20 ab	4.17 ± 2.29 abc	3.30 ± 1.92 cd	3.41 ± 2.17 bcd	< 0.001
Floral aroma	4.19 ± 2.26 ab	3.40 ± 1.86 ab	3.60 ± 1.80 ab	3.51 ± 2.15 ab	3.33 ± 2.04 b	4.03 ± 2.41 ab	4.22 ± 2.37 a	0.007
Sweet taste	3.12 ± 2.41 a	2.57 ± 2.06 ab	2.57 ± 2.16 ab	2.17 ± 1.92 b	2.27 ± 1.88 ab	2.35 ± 2.02 ab	1.84 ± 1.77 b	0.001
Bitter taste	3.89 ± 2.35 c	4.90 ± 2.28 ab	4.32 ± 2.39 bc	4.57 ± 2.53 bc	4.58 ± 2.50 bc	4.83 ± 2.35 abc	5.73 ± 2.40 a	< 0.001
Sour taste	3.46 ± 2.14 b	4.40 ± 2.32 a	3.79 ± 2.22 ab	4.21 ± 2.19 a	4.17 ± 2.24 a	4.31 ± 2.29 a	4.12 ± 2.42 a	0.050
Fruity flavor	4.33 ± 2.45 a	3.50 ± 2.17 ab	3.43 ± 2.03 ab	3.34 ± 2.18 b	3.25 ± 1.98 b	3.31 ± 2.18 b	3.41 ± 2.37 ab	0.010
Astringency	3.01 ± 2.05 a	3.62 ± 2.00 a	3.54 ± 1.93 a	3.63 ± 2.15 a	3.50 ± 2.06 a	3.56 ± 2.06 a	3.87 ± 2.36 a	0.154
Body	4.14 ± 2.03 a	4.29 ± 1.96 a	4.05 ± 2.14 a	4.07 ± 2.12 a	4.08 ± 2.10 a	4.29 ± 2.03 a	4.30 ± 2.31 a	0.932
Persistence	4.40 ± 2.09 b	5.07 ± 1.94 ab	4.69 ± 2.08 ab	4.75 ± 2.23 ab	4.54 ± 2.13 ab	5.07 ± 2.04 ab	5.24 ± 2.23 a	0.043

[1]INC5%: wines with 5% hot trub incorporated; INC10%: wines with 10% hot trub incorporated; INC15%: wines with 15% hot trub incorporated; SUB5%: wines with 5% grapes replaced by hot trub; SUB10%: wines with 10% grapes replaced by hot trub; SUB15%: wines with 15% grapes replaced by hot trub. [1]P-value referred to Analysis of Variance (ANOVA) at $P < 0.05$. Different letters in the same line significantly differ by the application of Tukey's post-hoc multiple comparison test at $P < 0.05$

a significant difference between the SUB15% and the control wines. Usually associated with quality, the persistence of flavor is expected to be long and balanced.

Acceptance sensory analysis

Significant differences were observed in the acceptance of the samples in terms of appearance, aroma, body, flavor, overall acceptance and purchase intention (Table 4). In all the sensory acceptance attributes, the control sample stood out as the one with the highest scores, differing significantly from some samples in certain attributes.

In terms of appearance, the control wine did not differ significantly from the INC5%, INC10%, INC15% and SUB10% samples, but it did differ significantly from the SUB5% and SUB15% samples. As it is directly related to the appearance of the wine, color is the panelists' first contact and one of the most important attributes, allowing them to speculate about possible defects in the beverage, while also having a strong influence on the perception of other sensory attributes, such as aroma and sweet taste (Oliveira et al. 2011).

In terms of aroma acceptance, the control wine, which presented the highest score, was not significantly different from the wines obtained by incorporating hot trub, while the wines obtained by replacing grapes with hot trub had the lowest scores for this attribute. The average score for the aroma attribute of the control wines was 6.77, and features such as growing soil, grape type, pH and others influence the perception of different aromas for each wine, i.e. no wine will have the same aroma or flavor, as this is differentiated either at the time of winery practice or in the changes made during the fermentation process (Jackson 2020).

The body acceptance showed that the significant difference was between the control wine and the SUB15% wine, i.e. the wine produced from replacing grapes with 15% hot trub had the lowest body acceptance. The control wine presented the highest taste acceptance score, with an average of 5.82, but it was not significantly different from the INC10% (score 5.06), INC15% (score 4.90) and SUB10% (score 4.92) samples, showing the potential for taste acceptance in wines produced from hot trub. De Castilhos (2016), who performed a sensory analysis of wines produced form *Vitis labrusca* and hybrid grapes from a subtropical region, obtained flavor acceptance average scores ranging from 3.35 to 5.17.

All wines showed statistically similar overall acceptance, with the exception of the SUB15% wine, which had the lowest overall acceptance score and was significantly different from the control wine sample. The purchase intention of the hot trub wines was significantly lower than that of the control wine.

Sensometric approach

The sensometric approach aimed to relate the physicochemical properties to the sensory descriptive and acceptance parameters for all wines. The Principal Component Analysis (PCA) is a multivariate tool that provides relevant information that is not noticed in the univariate approach, and this statistical analysis is commonly used in several sensory studies with consumers (De Castilhos et al. 2015; Valentim et al. 2016).

According to the PCA results (Fig. 1), PC1 explained 52.44%, and PC2 explained 24.82% of the total variance. Both PC1 and PC2 explained 77.26% of the total variance. Two groups of variables explained the PC1 (Fig. 1A). The first group (PC1 positive axis) was composed by bitter taste, sour taste, astringency and persistence and they were related to the SUB15% wine. The second group (PC1 negative axis) of variables was composed by total acidity (TAC), volatile acidity (VAC), total phenolic content (PHEN), coordinate a (a*), pink color, grape aroma, sweet taste, fruity flavor and all the acceptance attributes (appearance, aroma, body,

Table 4 Mean ± standard deviation of the sensory acceptance attributes of the BRS Vitória wines

Wines[1]	Sensory attributes[2]					
	Appearance	Aroma	Body	Flavor	Overall acceptance	Purchase intention
Control	7.19 ± 1.53 a	6.77 ± 1.77 a	6.03 ± 1.74 a	5.82 ± 2.17 a	6.05 ± 1.90 a	3.32 ± 1.17 a
INC5%	6.66 ± 1.79 ab	5.98 ± 1.95 abc	5.51 ± 1.87 ab	4.87 ± 2.33 b	5.33 ± 2.04 ab	2.73 ± 1.22 b
INC10%	6.66 ± 1.80 ab	6.32 ± 1.94 ab	5.63 ± 1.75 ab	5.06 ± 2.28 ab	5.35 ± 2.15 ab	2.78 ± 1.12 b
INC15%	6.49 ± 1.71 ab	5.99 ± 1.77 abc	5.54 ± 1.87 ab	4.90 ± 2.29 ab	5.26 ± 2.18 ab	2.64 ± 1.23 b
SUB5%	6.21 ± 1.73 b	5.48 ± 1.86 cd	5.47 ± 1.94 ab	4.72 ± 2.20 b	5.21 ± 1.99 ab	2.66 ± 1.24 b
SUB10%	6.87 ± 1.70 ab	5.89 ± 1.99 bcd	5.67 ± 1.60 ab	4.92 ± 2.24 ab	5.36 ± 2.22 ab	2.72 ± 1.26 b
SUB15%	5.41 ± 2.21 c	5.11 ± 2.26 d	5.07 ± 1.94 b	4.41 ± 2.35 b	4.50 ± 2.25 b	2.35 ± 1.23 b
P value[2]	< 0.001	< 0.001	0.023	0.001	< 0.001	< 0.001

[1]INC5%: wines with 5% hot trub incorporated; INC10%: wines with 10% hot trub incorporated; INC15%: wines with 15% hot trub incorporated; SUB5%: wines with 5% grapes replaced by hot trub; SUB10%: wines with 10% grapes replaced by hot trub; SUB15%: wines with 15% grapes replaced by hot trub. [1]P-value referred to Analysis of Variance (ANOVA) at $P < 0.05$. Different letters in the same column significantly differ by the application of Tukey's post-hoc multiple comparison test at $P < 0.05$. [2]The attributes of appearance, aroma, body, flavor and overall acceptance were evaluated using a structured scale of 1 to 9 points. Purchase intention was evaluated using a structured scale of 1 to 5 points

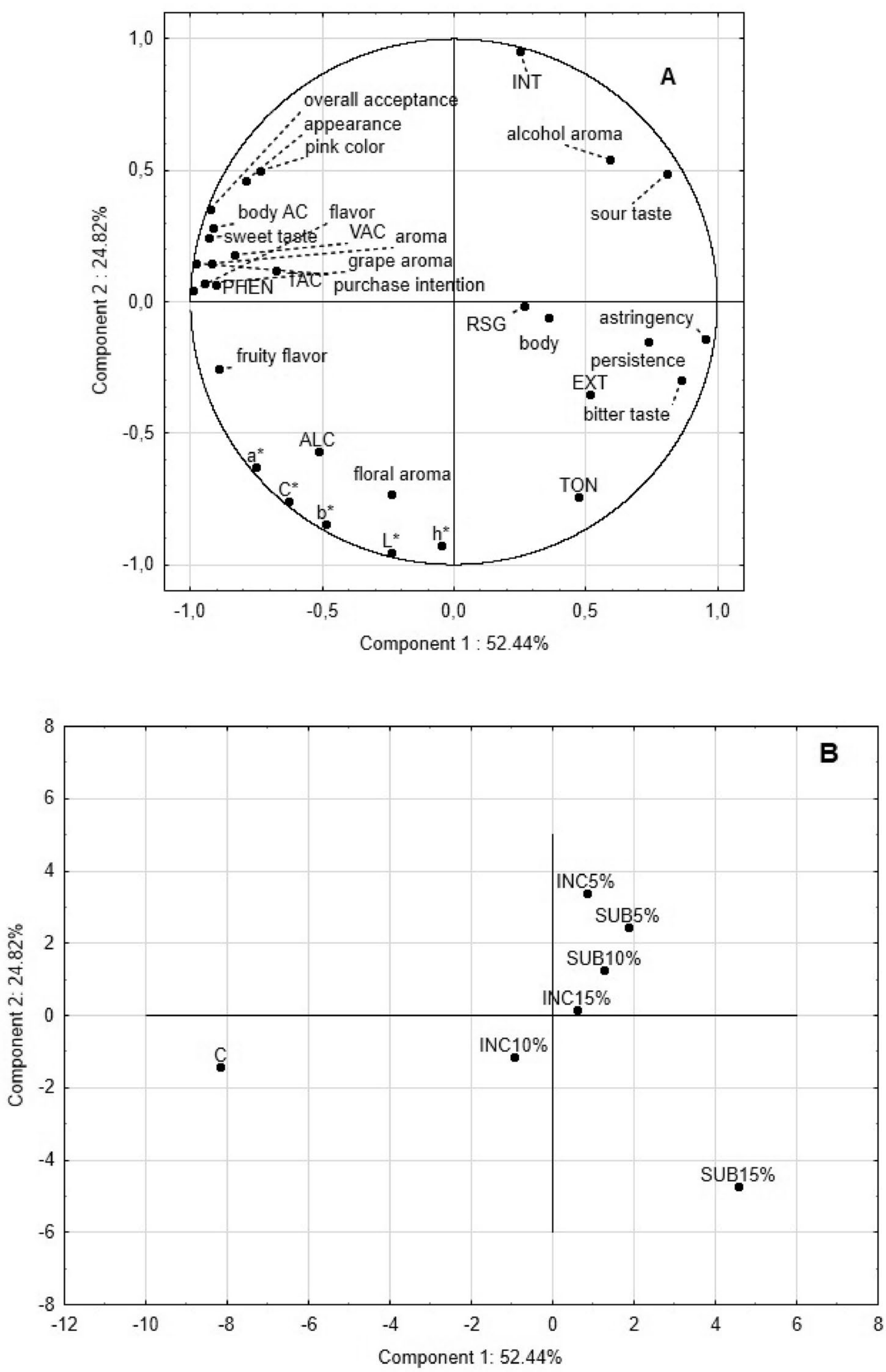

Fig. 1 Projection of the physicochemical parameters, sensory descriptive, sensory acceptance attributes **A** and the wine samples **B** according to the Principal Component Analysis (PCA) multivariate technique. ALC: alcoholic content; TAC: total acidity; VAC: volatile acidity; RSG: reducing sugars; EXT: dry extract; PHEN: total phenolic compounds; L*: luminosity; C*: Chroma; h*: hue angle; a*: coordinate red/green; b*: coordinate yellow/blue; INT: color intensity; TON: tonality. INC5%: wines with 5% hot trub incorporated; INC10%: wines with 10% hot trub incorporated; INC15%: wines with 15% hot trub incorporated; SUB5%: wines with 5% grapes replaced by hot trub; SUB10%: wines with 10% grapes replaced by hot trub; SUB15%: wines with 15% grapes replaced by hot trub

flavor, and overall acceptance) as well as purchase intention. All these attributes were related to the control wine. Two groups of variables explained the PC2. The first group (PC2 positive axis) was composed only by the color intensity, related to the INC5% wine. The second group (PC2 negative axis) of variables was composed by luminosity (L*), Chroma (C*), hue angle (h*), coordinate b (b*), tonality, and floral aroma, all of them directly related with SUB15%.

The control sample stood out from the other samples as it had the highest sensory acceptance scores for all the evaluated attributes. In addition, descriptors such as pink color, grape aroma, sweet taste and fruity taste were associated with this sample, showing the preference of Brazilian consumers for sweeter and more fruity wines.

The sensory acceptance and descriptive attributes were related to the high acidity of the control sample and the high concentration of total phenolics. Total phenolics in wine play an important role in wine quality because they are directly related to color and appearance through the presence of anthocyanins. Anthocyanins, as well as other phenolic compounds involved in copigmentation reactions, are positively responsible for the high acceptance of the appearance of wines and for the high color, since the control wine was related to the descriptor pink color and with high positive values of the a* coordinate (red color). Compounds such as flavan-3-ols contribute to the body and texture of wine (De Castilhos et al. 2015). Acidity is a chemical parameter that is directly related to palatability, especially the volatile acidity of the wine, which optimizes the release of aromatic compounds that have a positive impact on the acceptance of the wine's aroma and flavor (De Castilhos et al. 2016).

The SUB15% sample showed the lowest sensory acceptance among the samples analyzed due to its relationship with the descriptors bitter taste, acid taste, astringency and persistence (positive PC1) and luminosity (L*), Chroma (C*), hue angle (h*), b coordinate (b*), hue and floral aroma (negative PC2). The SUB15% sample was sensory described as a sample with a high bitter taste, acid taste, astringency and persistence, attributes that are not well accepted by Brazilian wine consumers. The sample also showed high luminosity and saturation with the highest hue angle and b-coordinate (b*) showing more obvious yellow tones than the other samples. The floral aroma also described the SUB15% sample, and this is a descriptor that may be related to the low acceptance of the sample. Zampini et al. (2007) reported that visual features can have a direct influence on the high wine acceptability; however, in this study it was possible to observe that only the coordinate a (a*) had a positive influence on the acceptability, which does not agree with the results obtained in the aforementioned study.

The INC5% sample presented a higher color intensity; however, this attribute was not significantly related to the physicochemical and sensory profiles. In general, we observed that the incorporation of hot trub in the winemaking did not lead to a high acceptance by the consumers who participated in the sensory evaluation, since the control sample stood out from the other samples. Despite the presence of the control sample, the wines obtained from the incorporation of hot trub showed the highest overall acceptance, also highlighting the wines obtained from the grape substitution with hot trub at 5% and 10% (m/m). The SUB15% sample was the least accepted of all the samples evaluated.

Conclusions

Based on the obtained results, all the physicochemical properties were influenced by the insertion of hot trub in the winemaking process, highlighting the hot trub incorporation wines (INC), which showed higher values in some relevant physicochemical properties such as total acidity and volatile acidity when compared with the hot trub substitution wines (SUB). The lower percentage of hot trub incorporation (INC5%) and substitution (SUB5%) wines presented higher values for dry extract, phenolic compounds, and color intensity, despite the control wine. The control wine presented the highest phenolic content, followed by the INC5% and SUB 5%, showing the need for further studies to evaluate the behavior of the hot trub insertion influence on wine total phenolic concentration. Also, the control sample was the wine that showed the highest overall acceptance, presenting no significant differences when compared to the wines produced from incorporation of hot trub, regardless its percentage, and substitution of hot trub in 5% and 10%. The descriptors of bitter taste, sour taste, astringency and persistence were responsible for determining the lower acceptability of the SUB15% sample, according to PCA. In addition, grape aroma, floral aroma, sweet taste, and fruity flavor were the sensory descriptors that presumably influenced the higher acceptance for control wine. The results obtained in this project served as a basis for elucidating the potential of using low concentrations of hot trub brewing residue as a fermentation aid in the winemaking process for American grape red wines. The use of hot trub in winemaking significantly affected some of the sensory acceptance parameters. Despite the higher acceptance for control wine, no significant differences were observed for body overall acceptance when control wine was compared with the INC wines and SUB wines, except for SUB15%. Using a high concentration of hot trub in winemaking produced no positive results in terms of the relationship between the sensory description and acceptance, indicating the need for further research into the influence of this residue in winemaking. The results showed that the use of the residue in low concentrations has the potential to produce wines with specific features, and it is an alternative for the reuse of this brewery residue.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability All the statistical data were performed using the trial version of the statistical softwares.

Declarations

Ethics approval The Ethics approved the Ethical Issues regarding sensory acceptability in the Minas Gerais University Research Committee (process CAAE number 78820724.3.0000.5115).

Consent to participate I, as the corresponding author, and on behalf of the other authors, agree to participate in the submission of the following article titled "Impact of the use of brewing waste in the winemaking of BRS Vitória hybrid grape: relationship between the chemical and sensory profiles" for appreciation of Journal of Food Science and Technology.

Consent for publication I, as the corresponding author, and on behalf of the other authors, agree to all the information regarding the publication on Journal of Food Science and Technology and all the images and data provided in the manuscript were original and created by the authors.

Conflict of interest The authors state no conflict of interest.

References

Asevedo SML, Fontoura CRO, Santos LMR (2020) Evaluation of the effects of Trub addition in the fermentation of a pilsen beer. Cadernos UniFOA 15:3085. https://doi.org/10.47385/cadunifoa.v15.n42.3085

Association of Official Analytical Chemists (AOAC) (2005) Official methods of analysis of the AOAC International. Washington

Ayala F, Echavarri JF, Negueruela AI (2012) MSCV 7.1 software [Computer software]

Brasil (2018) Normative instruction number 48 of August 31, 2018. Provides for the production, circulation and marketing of wine and grape and wine derivatives. DOU, Brasília

Brasil VCB, Guimarães BP, Evaristo RBW, Carmo TS, Ghesti GF (2021) Buckwheat (*Fagopyrum esculentum moench*) characterization as adjunct in beer brewing. Food Sci Technol 41:265–272. https://doi.org/10.1590/fst.15920

De Castilhos MBM, Cattlean MG, Conti-Silva AC, Del Bianchi VL (2013) Influence of two different vinification procedures on the physicochemical and sensory properties of Brazilian non-*Vitis vinifera* red wines. LWT-Food Sci Technol 54:360–366. https://doi.org/10.1016/j.lwt.2013.06.020

De Castilhos MBM, Corrêa OLS, Zanus MC, Maia JDG, Gómez-Alonso S, García-Romero E, Del Bianchi VL, Hermosín-Gutiérrez I (2015) Pre-drying and submerged cap winemaking: effects on polyphenolic compounds and sensory descriptors. Part I: BRS Rúbea and BRS Cora. Food Res Int 75:374–384. https://doi.org/10.1016/j.foodres.2015.05.056

De Castilhos MBM, Maia JDG, Gómez-Alonso S, Del Bianchi VL, Hermosín-Gutiérrez I (2016) Sensory acceptance drivers of pre-fermentation dehydration and submerged cap red wines produced from *Vitis Labrusca* hybrid grapes. LWT – Food Sci Technol 69:82–90. https://doi.org/10.1016/j.lwt.2016.01.043

Di Renzo L, Carraro A, Valente R, Iacopino L, Colica C, De Lorenzo A (2014) Intake of red wine in different meals modulates oxidized LDL level, oxidative and inflammatory gene expression in healthy people: a randomized crossover trial. Oxid Med Cell Longev 2014(681318). https://doi.org/10.1155/2014/681318

Durello R, Silva L, Bogusz S Jr (2019) Hop chemistry. Quim Nova 42:900–919. https://doi.org/10.21577/0100-4042.20170412

Jackson RS (2020) Wine science: principles and applications. Academic, San Diego

Kühbeck F, Müller M, Back W, Kurz T, Krottenthaler M (2007) Effect of hot Trub and particle addition on fermentation performance of *Saccharomyces cerevisiae*. Enzyme Microb Tech 41:711–720. https://doi.org/10.1016/j.enzmictec.2007.06.007

Leonardi MR (2022) Vinhos, Arte e ciência Da degustação. Missão Sommelier, Florianópolis

Maia JDG, Ritschel OS, Camargo UA, Souza RT, Fajardo TVM, Naves RDL, Girardi CL (2014) BRS Vitória' – a novel seedless table grape cultivar exhibiting. Crop Breed Appl Biot 14:204–206. https://doi.org/10.1590/1984-70332014v14n3a31

Mathias TRS, Mello PPM, Sérvulo EFC (2014) Solid wastes in brewing process: a review. J Brew Dist 5:1–9. https://doi.org/10.5897/JBD2014.0043

Meilgaard M, Civille GV, Caar BT (2006) Sensory evaluation techniques. Boca CRC, Boca Raton

Oliveira LCD, Souza SOD, Mamede MEO (2011) Evaluation of physicochemical and colorimetric characteristics of fine wines from two main vineyards regions of Brazil. Rev Inst Adolfo Lutz 70:158–167. https://doi.org/10.53393/rial.2011.v70.32566

Priest FG, Stewart GG (2006) Handbook of brewing. CRC Press and Taylor & Francis Group, Florida

Rizzon LA (2010) Metodologia Para análise de Vinho. Embrapa, Brasília

Sabino LL, Silva MFO, De Castilhos MBM (2023) Production of fermented beverage using pineapple residue as an alcoholic fermentation substrate: a physicochemical and sensory approach. Eur Food Res Technol 249:387–396. https://doi.org/10.1007/s00217-022-04124-6

Santos LG, Martins VG (2024) Functional, thermal, bioactive and antihypertensive properties of hot Trub derived from brewing waste as an alternative source of protein. Food Hydrocolloid 146:109292. https://doi.org/10.1016/j.foodhyd.2023.109292

Santos FLD, Costa RRD, Lima CAMD (2017) Qualidade Durante a maturação Da Uva "BRS magna" cultivada sobre o porta-enxerto ''IAC313": quarto Ciclo de produção. In Jornada de Integração da Pós-Graduação da Embrapa Semiárido.

Valentin D, Parr WV, Peyron D, Grose C, Ballester J (2016) Colour as a driver of Pinot Noir wine quality judgments: an investigation involving French and new Zealand wine professionals. Food

Qual Prefer 48:251–261. https://doi.org/10.1016/j.foodqual.2015.10.003

Wurz DA, Jastrombek JM, Maciel TAS, Almeida RS, Kowal NA (2021) Physico-chemical characterization of red table wines made in the planalto Norte catarinense region, harvest 2019. Rev Cien Inov 7:1–16. https://doi.org/10.26669/2448-4091.2021.312

Zampini M, Sanabria D, Phillips N, Spence C (2007) The multisensory perception of flavor: assessing the influence of color cues on flavor discrimination responses. Food Qual Prefer 18:975–984. https://doi.org/10.1016/j.foodqual.2007.04.001