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Murcott Mandarin Ferment Beverage: Study of its Physicochemical, Biochemical, and Microbiological Properties

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Abstract

The aim of this work is to continue the analysis of a fermented product obtained from the Murcott mandarin, a fruit widely grown in Brazil. The methodology included physicochemical analyses (pH, acidity, alcohol content, and dry extract), colorimetric characterization (CIELab), identification of volatile compounds by gas chromatography coupled with mass spectrometry, and evaluation of bioactive properties and microbiological safety. The results indicated a product with an alcohol content of 13°GL and a pH of 3.54, with low volatile acidity (2.0 meq/L) and no methanol, which confirms the appropriate sanitary conditions and the safety of the product. The colorimetric analysis showed a bright appearance ($L^* = 91.90$), similar to young white wines. Seventeen volatile compounds were identified, with a predominance of fruity aromas, and there was no D-Limonene in the final fermentate. Potassium (2.36 g/L) was the most abundant mineral. The product showed good antioxidant capacity, and microbiological analysis indicated its quality, with pathogens below regulatory limits. The conclusion is that Murcott mandarin fermentate is safe, has physico-chemical and sensory characteristics reminiscent of the fruit, adds value to its production chain, and meets the growing demand for functional and sustainable products.

Keywords: alcoholic fermented beverage; saccharomyces cerevisiae; physicochemical characterization.

Practical Application: This study characterized an alcoholic Murcott mandarin fermentate, revealing a safe product (13°GL of alcohol, pH 3.54, no methanol, and low volatile acidity) with guaranteed microbiological quality. The colorimetric analysis showed similarities with white wines, while the profile of volatile compounds highlighted fruity and floral aromas. Rich in minerals such as potassium and with good antioxidant capacity, the research confirms the viability and added value of this fermented product, in line with the demand for functional and sustainable products.

1 INTRODUCTION

The global beverage market shows a growing inclination toward functional foods with sensory characteristics and nutritional value that meet the demands of the consumer market (Han et al., 2023; Mahato et al., 2021).

Brazil's prominent position in global citrus production results in a significant availability of fruit, representing a strategic opportunity for innovation and diversification in the fermented beverage segment (Cinardi et al., 2025). The development of products from citrus fruits not only meets consumer market demand but also strengthens the production chain, adding value to primary production (Guiné et al., 2021).

In this sense, several studies have explored the production of fermented fruit drinks. Relevant examples include fermented cagaita (Oliveira et al., 2011), Umbu (Paula et al., 2012), cajá (Dias et al., 2003), mangaba (Almeida et al., 2020), blackberry (Gao et al., 2022), yacon (Brandão et al., 2019), jackfruit (Asquieri et al., 2008), jaboticaba (Asquieri, Damiani et al., 2004), and baru (Silva et al., 2021), among many other relevant works.

The aim of this article is to continue the analysis of an alcoholic fermented Murcott mandarin, with an emphasis on the physicochemical and bioactive characterization of the product obtained from the technological process described in the previous study.

1.1 Relevance of work

This study characterized an alcoholic Murcott mandarin fermentate, revealing a safe product (13°GL of alcohol, pH 3.54, no methanol, and low volatile acidity) with guaranteed microbiological quality. The colorimetric analysis showed similarities with white wines, while the profile of volatile compounds highlighted fruity and floral aromas. Rich in minerals

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such as potassium and with good antioxidant capacity, the research confirms the viability and added value of this fermented product, in line with the demand for functional and sustainable products.

2 MATERIAL AND METHODS

The analysis of the Murcott mandarin ferment was carried out at the Food Chemistry and Biochemistry Research Laboratory (LPQBA) of the Faculty of Pharmacy (FF) of the Federal University of Goiás (UFG) and at the Food Quality Control Laboratory (LABFOOD/PPGCTA/EA/UFG). The technological process followed the flowchart shown in Figure 1, which is the object of analysis in this article.

2.1 Physico-chemical analysis

After packaging the fermentate (Figure 2), the analyses to characterize the ferment were carried out in triplicate.

2.1.1 Density

Carried out according to AOAC 950.28.

2.1.2 pH

Determined using the methods described in AOAC 981.12.

2.1.3 Total acidity (fixed and volatile)

Total acidity was determined by titration with 0.1N NaOH. Volatile acidity was obtained by steam distillation and then titration with 0.1N NaOH (Instituto Adolfo Lutz [IAL], 2008), and fixed acidity, the difference between total and volatile acidity (Amerine & Ough, 1976).

2.1.4 Reducing sugars

The 3,5-dinitrosalicylic acid (DNS) method according to Miller (1959). When the DNS reagent comes into contact with sugars in the sample under boiling water conditions, it reacts with the sugars present in the sample, forming 3-amino-5-nitrosalicylic acid with a dark brown color, allowing it to be read using a spectrophotometer.

2.1.5 Sucrose

According to Miller's (1959) method, with modifications made by Silva et al. (2003).

Figure 2. Murcott mandarin fermentate.

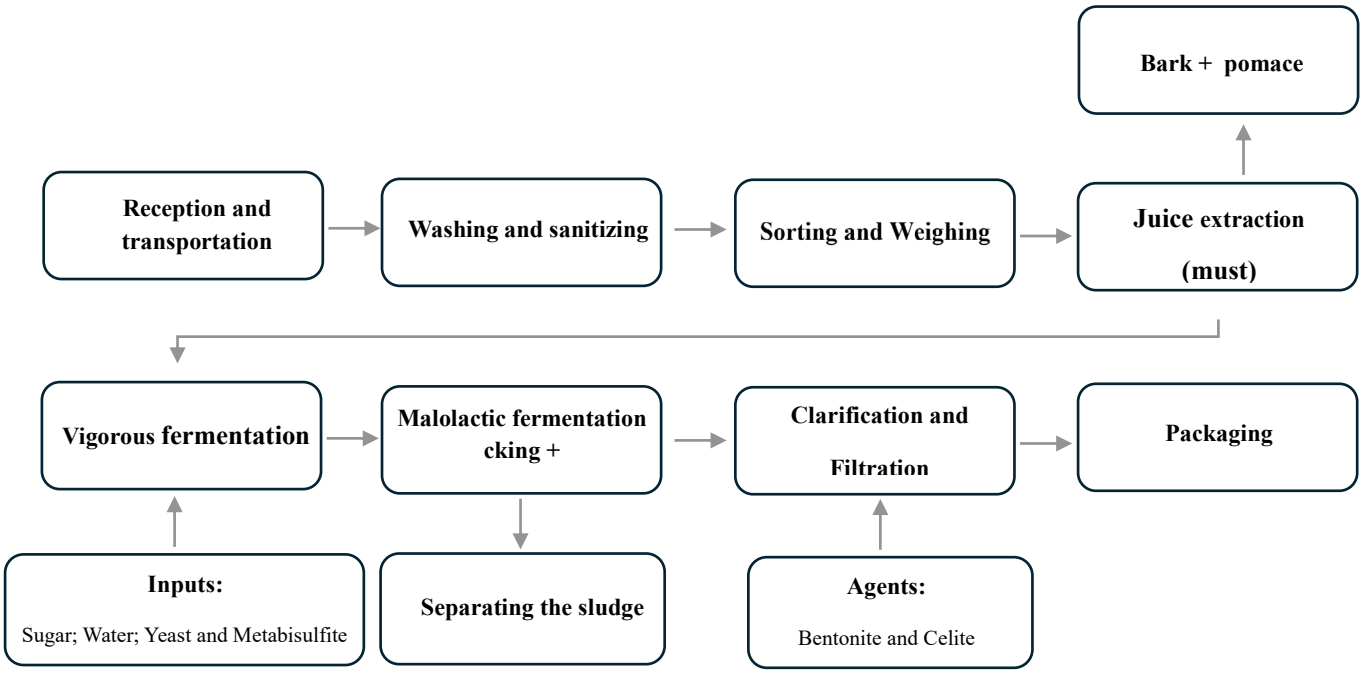

Figure 1. Flowchart of the technological process for making the fermented product.

2.1.6 Alcoholic strength

Determined by the density of the distillate using a Gay-Lussac alcoholmeter inserted directly into 250 mL of distillate at 20°C (IAL, 2008).

2.1.7 Dry extract

Determined by evaporation in an oven at 105°C until constant weight. The reduced extract was determined by the difference between the dry extract value and the amount of sugar in the fermented product (IAL, 2008).

2.1.8 Potassium sulfate

Potassium sulfate was determined according to Canecchio Filho (1972).

2.1.9 Potassium bitartrate

The Berthelot-Fleurieu technique was used (Canecchio Filho, 1972).

2.1.10 Chlorides

Determined using the methods described by Moretto et al. (1988).

2.1.11 Tannins

Determined by spectrophotometry using the Folin-Denis reagent, as described by Canecchio Filho(1972).

2.1.12 Sulfur dioxide (SO_2)

Determined according to Ribéreau-Gayon (1982). The levels of free and total sulfur dioxide were expressed in mg/L.

2.1.13 Acetaldehyde

According to Amerine and Ough (1976).

2.1.14 Proteins

In the de-alcoholized fermentate, they were determined according to the Biuret method (Vilella et al., 1973).

2.2 Volatile organic compounds

The analysis of volatile organic compounds was carried out using 5 mL of the sample, stored in vials suitable for gas chromatography coupled to mass spectrometry (GC-MS), using a Nexis GC-2030 system coupled to a Nexis QP2020 mass spectrometer, both from Shimadzu (Kyoto, Japan). Detection was carried out in Scan mode using an SH-Stabilwax-MS column (30 m × 0.25 mm × 0.25 μm). The extraction of volatiles followed the headspace method, with the sample incubated at 60°C and the syringe temperature set at 70°C. During this process, agitation was maintained at 300 rpm, with a pre-purge time of 5 s, an injection flow rate of 10 mL/min, and a total analysis time of 60 min. The chromatographic conditions included an initial oven temperature of 40°C and an injection temperature of 250°C in split mode. Flow control was maintained at linear velocity, with a pressure of 45.1 kPa, total flow of 13.4 mL/min, column flow of 0.94 mL/min, linear velocity of 35 cm/s, and purge flow of 3.0 mL/min (Cabral, Briceno, et al., 2025).

2.3 Microbiological characterization of the beverage

The microbiological analyses of the fermented beverage were carried out at the Food Quality Control Laboratory of the Faculty of Pharmacy at UFG, following the parameters established by Ordinance No. 64 of April 23, 2008 (Brasil, 2008). The following microbiological criteria were evaluated: enumeration of *Escherichia coli*, coagulase-positive *Staphylococcus*, standard count of viable aerobic mesophilic microorganisms, and mold and yeast count, according to the methodology described by Downes and Ito (2001).

2.4 Statistical analysis

The analyses of the physicochemical and biochemical characterization of the juice and fermented fruit were carried out in triplicate. Significant differences between the means of the fresh juice and the fermented product were assessed using Student's t-test, with a significance level of $p < .05$ for all comparisons.

3 RESULTS AND DISCUSSION

Table 1 shows the results of the chemical and mineral analyses carried out on the mandarin fermented juice.

The results of the Student's t-test indicated significant differences between mandarin juice and fermented juice for all the parameters analyzed, reflecting the impact of the fermentation process on the physicochemical properties of the drink.

The tangerine fermentate had a total sugar content of 0.54% (5.4 g/L), composed mainly of reducing sugars. According to Decree 6.871/2009, art. 44, § 3 (Brasil, 2009), which requires the designation "sweet" or "mild" for sugar contents above 3 g/L, this fermented product should be classified as mild.

The tangerine fermentate had a tannin content of 9 mg/L (or 0.90 mg/100 mL). This value is significantly lower than those found in red wines (194 to 3,619 mg/L) by Kassara et al. (2022). However, the result is consistent with the nature of mandarin, which, like yacon (70 mg/100 mL), is not a fruit rich in tannins (Brandão et al., 2019). Tannins are important for aroma, astringency, and stability in wines.

The sulfate and chloride anions in Murcott mandarin fermentate were 0.7 and 0.00 g/L, respectively, which is in line with Brazilian legislation that allows a maximum of 1.0 g/L and 200 mg/L (Brasil, 2008). Sulfates result from the oxidation of sulfur dioxide, which is used in some wines for microbiological control and to prevent oxidation (Asquieri, Assis, et al., 2004). These values differ from those found by Santos et al. (2016) (0.53 and 0.33 g/L) and in jaboticaba fermented wine (Asquieri, Assis, et al., 2004).

The concentration of free sulfur dioxide (free SO_2) was 13.65 ± 0.74 mg/L, and that of acetaldehyde was 40.62 ± 1.11 mg/L. A low concentration of free SO_2 is desirable to avoid allergenic reactions, reflecting an efficient use of sulfur in processing (Leonardi & Azevedo, 2018). Although in grape wines free SO_2 is typically around 20 mg/L, higher concentrations act as enzyme inactivators and antimicrobials (Leonardi & Azevedo, 2018).

The value of 13.65 mg/L of free SO_2 is within the legal limits (< 350 mg/L) (Brasil, 2012). However, there is an imbalance: Garcia et al. (2022) indicate that 30 mg/L of free SO_2 would be needed to complex around 20 mg/L of acetaldehyde. With only 13.65 mg/L of free SO_2, the amount is insufficient to stabilize the 40.62 mg/L of acetaldehyde, resulting in a higher proportion of unbound acetaldehyde. Despite this, the total acetaldehyde value (40.62 mg/L) is lower than the average for white wines (around 80 mg/L), which can limit undesirable sensory impacts.

Most red wines undergo malolactic fermentation after alcoholic fermentation, converting malic acid into lactic acid and reducing acidity. This process, conducted by lactic acid bacteria, also degrades carbonyls such as pyruvic acid and acetaldehyde (Aquarone et al., 2001; Jackowetz & Mira de Orduña, 2013). Lachenmeier and Sohnius (2008) reported an average of 34 mg/L of acetaldehyde in white and red wines.

Ash, which corresponds to the minerals in wine and represents around 10% of the reduced dry extract (Rizzon & Miele, 2002), showed a value of 0.35%. It was not possible

Table 1. The results of the chemical, mineral, and microbiological characterization of Murcott mandarin fermentate.

Component	Mean fermented value ± SD	Mean juice value ± SD
Reducing sugars (%)	0.51 ± 0.01	5.99 ± 0.11
Sucrose (%)	0.03 ± 0.00	4.97 ± 0.41
Total sugar (%)	0.54 ± 0.01	10.96 ± 0.48
Soluble solids (ºbrix)	5.1 ± 0.1	10.46 ± 0.46
Ph	3.54 ± 0.01	3.8 ± 0.01
Total acidity (meq/L)	127.66 ± 0.57	108.0 ± 1.10
Volatile acidity (meq/L)	2.0 ± 0.00	108.0 ± 1.10
Fixed acidity (meq/L)	125.66 ± 0.57	—
Tannins mg/100 mL	0.09 ± 0.002	0.22 ± 0.01
Protein	ND	0.45 ± 0.02
Ash (%)	0.35 ± 0.002	1.29 ± 0.06
Potassium (g/L)	2.36 ± 0.05	—
Calcium (g/L)	0.8 ± 0.00	—
Magnesium (g/L)	0.2 ± 0.00	—
Phosphorus (g/L)	0.3 ± 0.00	—
Alcohol content °GL (%V/V)	13.0 ± 0.00	—
Temperature (°C)	24 ± 0.00	—
Sulfates (g/L)	0.7 ± 0.00	—
Chlorides (g/L)	0.00 ± 0.00	—
Dry extract (g/L)	31.0 ± 0.018	—
Reduced dry extract (g/L)	26.6 ± 0.17	—
Alcohol/ESR ratio (g/L)	3.91 ± 0.03	—
Density (g/mL)	0.99 ± 0.0001	—
Free sulfur dioxide (mg/L)	13.65 ± 0.74	—
Acetaldehyde (mg/L)	40.62 ± 1.11	—
Potassium bitartrate (g/L)	0.55 ± 0.04	—
Methanol	ND	ND
Escherichia coli (CFU/mL)	< 1.0	—
Aerobic mesophilic bacteria (CFU/mL)	6.5 × 10	—
Molds and yeasts (CFU/mL)	< 1.0	—
Coagulase-positive staphylococci (CFU/mL)	< 1.0	—

ND: not detected.

to detect protein after malolactic fermentation, an expected result given that the original mandarin juice contains only 0.45% protein.

The mineral composition has a significant impact on the quality of fruit-fermented products. In Murcott mandarin fermentate, potassium was the most abundant element (2.36 g/L), followed by calcium (0.8 g/L), phosphorus (0.3 g/L), and magnesium (0.2 g/L). These concentrations are comparable to studies by Mercanti et al. (2025) (K: 1.98 ± 0.17 g/L; Ca: 494 ± 235 mg/L; Mg: 536 ± 273 mg/L), but higher than those of papaya and banana fermented products (Awe et al., 2013). The high concentration of potassium, which can vary depending on the type of fruit and the preparation of the fresh juice (Ageyeva et al., 2024), corroborates the fact that potassium is the predominant cation (approximately 50% of the ash).

Potassium (2.36 g/L) is vital for fermentate stability and pH regulation, and is influenced by the fermentation process, where potassium metabisulfite or bitartrate is used for microbiological control and oxidation prevention (Bosso et al., 2020; Obhodaš et al., 2021). This mineral is essential for cardiovascular health, blood pressure regulation, and bone and kidney support (Weaver, 2012).

Calcium (800 mg/L) is important for bone and dental health (Krall et al., 2001) and for stabilizing tartaric acid in the fermented wine, preventing post-bottling calcium bitartrate precipitates (Bosso et al., 2020; Cosme et al., 2024).

Magnesium (200 mg/L) is essential for yeast growth and metabolism, crucial for ethanol production and tolerance to alcoholic stress (Birch et al., 2003), while phosphorus (300 mg/L) is important for raw material cultivation and beverage quality (Rodrigues et al., 2011).

The stability of potassium bitartrate is crucial for wine clarity (Geveke & Runnebaum, 2020). High concentrations of potassium can lead to the loss of tartaric acid, complicating and making pH adjustment more expensive (Daudt & Fogaça, 2008). The tangerine fermentate had 0.55 g/L of potassium bitartrate, a value similar to the 0.61 g/L found by Daudt and Fogaça (2008). The small difference of 0.06 g/L could be the result of variations in fermentation.

The volatile acidity of the Murcott mandarin fermentate was 2.0 meq/L for fermented fruit (Brasil, 2008). Low volatile acidity values indicate good sanitary conditions (Aquarone et al., 2001) and are comparable to fermented passion fruit (5.53–6.67 meq/L) (Santos et al., 2021), jackfruit (6.0 meq/L) (Asquieri et al., 2008), and carambola (5.4 ± 2.0 meq/L) (Valim et al., 2016). Well-treated wines, with adequate addition of sulfur dioxide, tend to have low volatile acidity, while spoiled fruit results in high total acidity (Aquarone et al., 2001).

The total acidity of the fermentate, expressed as citric acid, was 127.66 ± 0.57 meq/L, within the legal limits for fruit ferment (55–130 meq/L) (Brasil, 2008). This value is similar to that of jaboticaba fermented fruit (122.3 and 129 meq/L) (Asquieri, Damiani et al., 2004), but higher than that of H. lemaire (63.6 meq/L) (Sales et al., 2021) and carambola (48.8 ± 7.7 meq/L) (Valim et al., 2016).

The alcohol content of Murcott mandarin fermentate was 13°GL, meeting the standards for fermented fruit products and surpassing the values of other fruit fermented fruit, such as umbu (11.20°GL) (Paula et al., 2012), carambola (11.15°GL) (Valim et al., 2016), and mulberry (11.15°GL) (Jung et al., 2005). These variations in alcohol content are directly linked to the conditions and choices of the fermentation process in each study.

Tangerine fermentate had an average density of 0.99 g/mL, reflecting the relationship between alcohol and soluble solids, with density generally decreasing with alcohol and increasing with sugars (Manfroi et al., 2010). The dry extract was 31.0 g/L, indicating a full-bodied drink, according to Castilhos and Del Bianchi (2011), who consider above 30 g/L as such. In comparison, Santos et al. (2021) observed 131–145 g/L in passion fruit fermented in the caatinga. The concentration of dry extract influences the texture and mouthfeel of the drink.

Table 1 shows the results of the microbiological analysis of Murcott mandarin fermentate fruit. Ordinance No. 64 of April 23, 2008 (Brazil, 2008), which establishes the standards of identity and quality for fruit-fermented products, does not specify microbiological parameters for these products. However, the regulation requires production establishments to comply with the hygienic and sanitary conditions of the standards in force.

The determination of *Escherichia coli* was less than 1.0 UFC/mL, meeting the standard of up to 103 UFC/g of ANVISA/MS Resolution RDC No. 218/2005 (Brasil, 2005), indicating the effectiveness of hygiene and processing practices. The absence of *E. coli* suggests satisfactory food safety conditions, guaranteeing the quality and safety of the product. The results for *Staphylococcus spp.* and *E. coli* were also lower than 1.0 CFU/mL, showing efficiency in microbiological control, as reported by Kim et al. (2014), who observed the elimination of pathogens in wines. The mold and yeast count was less than 1.0 CFU/mL, in line with the ANVISA microbiological standard, reflecting the quality of the raw material and the strict control of processing and pasteurization.

The color analysis of the Murcott mandarin fermentate, carried out using the CIELab colorimetric system, found in Table 2, showed significant differences between the juice and the fermented product, especially in terms of luminosity (L*), hue (a* and b*) and other chromatic parameters.

Table 2. Color parameters of the CIELab colorimetric system of tangerine fermented juice with mean and standard deviation.

	L	a	b	C	h °
Juice	54.99 ± 0.01	18.0 ± 0.01	72.55 ± 0.02	74.75 ± 0.02	76.06 ± 0.01
Fermented	91.90 ± 0.1	−1.48 ± 0.02	16.16 ± 0.03	16.22 ± 0.04	95.25 ± 0.04

L: luminosity; a: green-red axis; b: blue-yellow axis; c: chroma/saturation; h: hue angle.

The luminosity (L*) of the Murcott mandarin fermentate remained high (91.79–91.98), with values similar to those of white wines (Cejudo-Bastante et al., 2011; Minkova et al., 2023). The a* parameter changed from positive in the juice (18.0) to negative in the fermentate (−1.50 to −1.46), suggesting greenish tones, similar to Chardonnay. The b* parameter decreased from 72.55 in the juice to 16.16 in the fermentate, indicating a reduction in yellow intensity. The changes in C* (juice: 74.75; fermented: 16.22) and h° (juice: 76.06; fermented: 95.25) reinforce the transformation in the color profile, typical of fermented citrus drinks, bringing the fermented closer to white wines.

Tangerine fermentate contains 3.2 mg GAE/100 mL of phenolic compounds, a typical value for citrus drinks. This concentration is notably lower than that of other fermented beverages, such as karanda (184.32 mg GAE/100 g) (Minh, 2021). The difference occurs because, in mandarin, phenolics are more concentrated in the peel and pomace than in the juice.

The Murcott mandarin fermentate exhibited of 1.13 μM/mL (ABTS [(2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid]) and 2.42 ± 0.08 μM/mL (FRAP [Ferric Reduction Antioxidant Power]), according to Table 3. Antioxidant stability is crucial, as fruits such as passion fruit from the Caatinga can lose it during ripening (Santos et al., 2021). The reduction in this activity in prolonged fermentations is attributed to the oxidation and degradation of polyphenols (Guo et al., 2023).

The Murcott mandarin fermentate showed of 0.42 ± 0.00 μM Trolox/mL, indicating its ability to fight free radicals. However, this activity is lower than that of other fermented wines, such as red pitahaya wine (65.4%, 2,2'-diphenyl-1-picrylhydrazyl [DPPH] radical scavenging, Anh et al., 2025) and mango wines (30–91% radical scavenging, Varakumar et al., 2011).

Fermentation of the Murcott mandarin juice reduces β-carotene by 1% due to its degradation, similar to what occurs in mango wines (losses of 15.3–26.5%). Despite this, the process releases bioactive compounds, such as phenolics, from food residues (Anh et al., 2025; Varakumar et al., 2011). The ferment retained its antioxidant properties, although studies by Gupta et al. (2024) indicate a reduction in free radical scavenging activity throughout fermentation.

GC-MS analysis identified 19 volatile compounds in mandarin juice, must and fermentate, with ethanol being the only one common to all phases. The greatest similarity was observed between must and fermentate, with six compounds shared. The aromatic complexity of the drink is influenced by alcohols, esters, and terpenes, with the alcohols giving it a fruity and pungent profile, with the fruity attribute being the most predominant.

Table 3. Antioxidant activity of Murcott mandarin ferment with standard deviation.

Component	Unit	Mean value ± SD
DPPH	μM trolox/mL	0.42 ± 0.00
ABTS	μM trolox/mL	1.13 ± 0.16
FRAP	μM ferrous sulfate/mL	2.42 ± 0.08
Phenolics	mg EAG/100 mL	3.2 ± 0.1
Beta carotene	%	1% protection

DPPH: 2,2-Diphenyl-1-picrylhydrazyl; ABTS: 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonate); FRAP: ferric reducing antioxidant power.

GC-MS analysis identified 19 volatile compounds in mandarin juice (Table 4), with ethanol being the only one common to all phases. The greatest similarity was observed between the must and the fermentate. The aromatic complexity of the beverage is influenced by alcohols and esters, where alcohols contribute to a fruity and slightly pungent profile, with the fruity attribute being the most predominant. Figure 3 illustrates the chromatographic profiles obtained for the juice, must, and fermentate, showing qualitative variations in volatile composition throughout the process.

Although 1-butanol can influence consumer acceptance, its odor is often imperceptible at normal concentrations (Heo et al., 2020; Wang et al., 2020). In contrast, Phenylethyl Alcohol offers a mild and warm aroma, similar to rose honey, with moderate to low tenacity (Scognamiglio et al., 2012).

Linalool, a crucial volatile, was identified in the Murcott mandarin fermentate. It has a strong positive correlation with fermentation aroma (Chi et al., 2025) and confers notes of freshness, making it an important aromatic component in natural and fermented foods.

The absence of octanal in must and fermentate is beneficial for sensory attributes. This compound, identified only in juice, is associated with "green" and oily notes, undesirable characteristics in fermented products. The transformation or decomposition of these compounds during fermentation contributes to a more balanced and pleasant sensory profile, Murcott mandarin fermentate (Vurro et al., 2024).

Terpenes play a crucial role in the sensory profile of Murcott mandarin fermentate. α-pinene, identified in the product, brings a fresh forest aroma (Adamski & Adamska, 2021). D-limonene, typical of citrus juices, was detected in the juice (S), but absent in the FM and F treatments, due to volatile transformations during fermentation (International Agency for Research on Cancer, 1993). α-phellandrene contributes herbal and woody notes (Radice et al., 2022), while β-myrcene offers fruity and earthy touches, with sweet and spicy notes (Surendran et al., 2021). γ-terpinene, which has a woody character in this study, is associated with citrus and floral scents in essential oils (Asikin et al., 2018).

Ethyl esters of C7–C18 fatty acids, not detected in the juice (S), were identified in the FM and F treatments, conferring fruity and complex notes (Peinado et al., 2006; García-Carpintero et al., 2011a). 3-methylbutyl acetate offers a banana aroma, ethyl hexanoate adds notes of green apple, banana, and tropical fruit, while ethyl octanoate contributes aromas of banana, pear, and brandy. Ethyl decanoate reinforces fruity and vinous notes, and long-chain esters (ethyl dodecanoate, ethyl hexadecanoate) soften the sensory profile with waxy nuances.

The absence of esters in the juice and their subsequent formation and increase during fermentation demonstrate the

importance of this process for the synthesis of these compounds, which are crucial for the final sensory quality of the product. The combination of medium-chain esters (more volatile and fruity) with long-chain esters (more subtle and unctuous) creates a balanced, complex, and pleasant aromatic profile, typical of fermented fruit drinks (García-Carpintero et al., 2011b; Peinado et al., 2004, 2006; Wu et al., 2011).

4 CONCLUSIONS

This investigation confirmed the technical feasibility of producing an alcoholic Murcott mandarin fermentate, taking advantage of the surplus of this fruit, which is widely grown in Brazil. The physical–chemical characterization of the product showed highly desirable parameters and complied with Brazilian

Table 4. 19 volatile compounds identified.

Volatile Organic compounds	S		FM		F		Chemical formula	Functional group	Contribution
	RT	Area%	RT	Area%	RT	Area%			
Ethanol	3.402	6.21	3.705	87.78	3.762	87.04	C_2H_6O	Alcohol	Pungent
1-Butanol	ND	ND	9.282	0.07	9.064	0.08	$C_4H_{10}O$	Alcohol	Fruity
1-Butanol, 3-methyl-(Isoamyl Alcohol)	ND	ND	11.037	9.36	10.944	10.82	$C_5H_{12}O$	Alcohol	Fruity
1-Propanol, 2-methyl-(Isobutanol)	ND	ND	7.571	1.22	7.563	1.62	$C_4H_{10}O$	Alcohol	Pungent
Linalool	20.404	0.06	ND	ND	ND	ND	$C_{10}H_{18}O$	Alcohol	Floral and citrus
Phenylethyl alcohol	ND	ND	28.597	0.35	28.616	0.09	$C_8H_{10}O$	Alcohol	Soft and warm
α-Pinene	9.574	3.15	ND	ND	ND	ND	$C_{10}H_{16}$	Terpene	Fresh notes
α-Phellandrene	9.958	1.73	ND	ND	ND	ND	$C_{10}H_{16}$	Terpene	Green notes
β-Myrcene	10.292	1.71	ND	ND	ND	ND	$C_{10}H_{16}$	Terpene	Fruity, earthy
γ-Terpinene	10.865	0.98	ND	ND	ND	ND	$C_{10}H_{16}$	Terpene	Woody and fruity
D-Limonene	10.115	89.39	9.683	0.05	ND	ND	$C_{10}H_{16}$	Terpene	Fruity
3-Methylbutyl acetate	ND	ND	7.841	0.31	7.871	0.31	$C_7H_{14}O_2$	Ester	Fruity aroma, banana
Ethyl hexanoate	ND	ND	11.342	0.05	ND	ND	$C_8H_{16}O_2$	Ester	Fruity, green apple
Ethyl octanoate	ND	ND	17.263	0.34	ND	ND	$C_{10}H_{20}O_2$	Ester	Fruity, sweet
Ethyl decanoate	ND	ND	22.517	0.38	ND	ND	$C_{12}H_{24}O_2$	Ester	Fruity, heavy
Ethyl dodecanoate	ND	ND	27.201	0.07	ND	ND	$C_{14}H_{28}O_2$	Ester	Fruity, waxy
Ethyl hexadecanoate	ND	ND	33.819	0.04	ND	ND	$C_{16}H_{32}O_2$	Ester	Fruity
Ethyl 9-hexadecenoate	ND	ND	34.092	0.03	ND	ND	$C_{18}H_{34}O_2$	Ester	Fruity
Octanal	11.524	0.3	ND	ND	ND	ND	$C_8H_{16}O$	Aldehyde	Citric, fatty

S: juice; FM: must on the sixth day of fermentation; F: mandarin ferment; RT: retention time, in minutes; Area%: percentage area of the chromatographic peaks of the samples; ND: not detected.

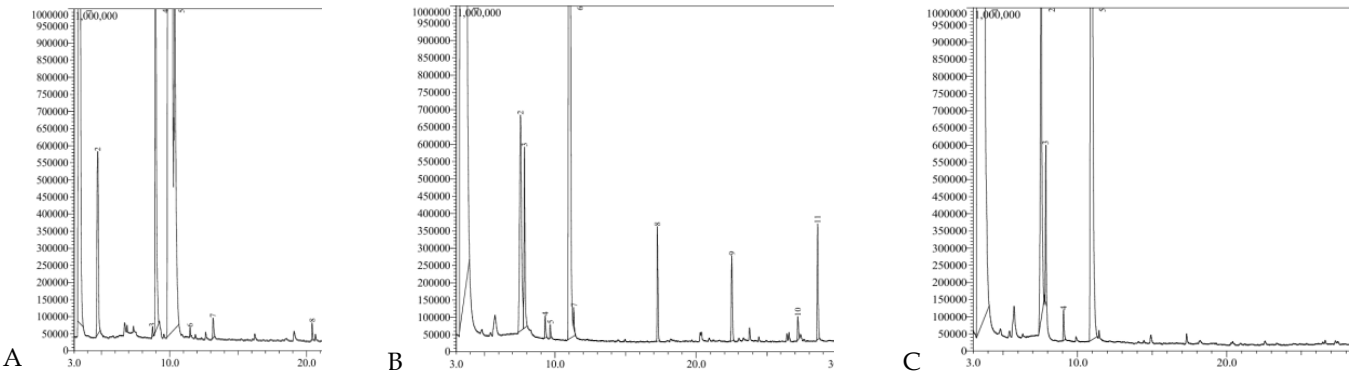

Figure 3. Chromatograms of the volatile compounds identified. (A) tangerine juice, (B) sixth day must, and (C) tangerine ferment.

legislation, including the absence of methanol, guaranteeing food safety, and sanitary rigor in the production process implemented.

The colorimetric analysis revealed a drink with high luminosity and shades similar to those of young, fresh white wines. The mineral composition, especially rich in potassium, calcium, phosphorus, and magnesium, gave the product chemical and microbiological stability.

The profile of volatile compounds identified gave the fermentate sensory complexity, highlighting fruity and floral aromas provided by alcohols and terpenes, as well as demonstrating significant transformations during fermentation, especially with the reduction of D-limonene. In addition, beneficial antioxidant properties were maintained, providing additional health benefits to consumers.

In addition, the production of this fermentate adds value to the mandarin production chain, especially for surplus production, with a positive impact on reducing waste and diversifying the beverage market. The research contributes to the advancement of food technology by exploring fruits that are little used in the industry and presents fermentation as an effective tool for creating products with added value, meeting the growing demand for functional and sustainable foods.

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