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Understanding consumer acceptability of verjuice, its potential applications and sensory and chemical drivers of liking

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ABSTRACT

The wine sector is working to add value, enhance sustainability and reduce waste, yet often creating new products with unknown consumer acceptance. Verjuice, juice made from discarded unripe thinned grapes, is an example. Whilst verjuice has various culinary uses, its versatility in beverages continues to expand. However, its sensory drivers of liking when consumed as a drink, and their potential impact on its application remain unclear. Chemical drivers of sensory characteristics are also unknown representing a critical knowledge gap needed to guide product innovation. This study aimed to provide new knowledge regarding consumer acceptability of verjuice by identifying its sensory drivers of liking as a beverage, evaluating its potential use in different applications and identifying chemical drivers of its sensory characteristics. New Zealand consumers ($n = 93$) evaluated 13 verjuice samples from different countries. Furthermore, verjuice familiarity and its influence on emotional response was investigated to determine likely future consumer engagement. Sweetness was the most positive driver of liking in verjuice overall, followed by fruity and floral notes, smoothness, and to a lesser extent citrus flavour. Consumers expressed varied preferences for verjuice's sensory profile, with fruity, floral, and honey flavours driving beverage application, whilst winey and green apple notes were more associated with culinary scenarios. Some association between chemical parameters and sensory attributes were evident (e.g. sugars were highly associated with perceived sweetness, fruity, and floral attributes; these attributes also shared proximity with 1-hexanol and cyclohexanol). The general idea of verjuice elicited positive valence emotions, but consumers who were 'not familiar' felt more curious, and those 'familiar' felt happier and more satisfied. Findings highlight the potential to tailor verjuice for specific applications by understanding desired sensory profiles and related chemical parameters. Recognising the interplay between familiarity level and emotional response is crucial for positioning the product in the marketplace and fostering consumer engagement. Marketing initiatives are needed to increase verjuice familiarity and support product innovation, leading to increased product appeal.

1. Introduction

Verjuice, an acidic juice made from unripe and/or not fully ripe grapes, is commonly produced from wine grapes (Dupas de Matos et al., 2023).Typically described as a fresh, unfermented grape juice (Nikfardjam, 2008; Öncül and Karabiyikli, 2015; Dupas de Matos et al., 2017; Dupas de Matos et al., 2018), the English term 'verjuice' originates from the French 'vert jus' or 'verjus', referring to a juice characterised by a tart taste (Nikfardjam, 2008; Hayoglu et al., 2009). In Italy, 'agresto' refers to a traditional sour grape sauce (Simone et al., 2013), but it has also been called as verjuice, despite its production involving a heating/concentration step and sometimes slight fermentation. Similarly, 'abe ghureh' (in Iran), 'hosrum' (in Lebanon), 'koruk suyu' (in Turkey), and 'agraz' (in Spain) are used interchangeably with verjuice. Verjuice is considered a non-alcoholic product; however, some commercially available versions occasionally contain a low percentage of alcohol. Therefore, verjuice lacks an agreed-upon standard of identity or classification.

Verjuice has a long history, but its exact origin remains uncertain. Nevertheless, verjuice making seems to have originated from grape thinning, wherein bunches are removed to achieve a balanced yield in the vine whilst preventing overcropping (Ferree et al., 2003; Wang et al.,

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2018). This practice is conducted by some grapegrowers offering an opportunity for grape/winegrowers to maximise value of waste streams by converting wasted grapes, that are typically left to rot, into a high-value added product. Most grape and winegrowers consider the ideal grape picking time for verjuice making to be either before or at the beginning of veraison when acidity is pronounced, and sugar is absent or low (Dupas de Matos et al., 2017; Fia et al., 2022; Dupas de Matos et al., 2023). Typically, the evaluation of grape blocks requiring thinning or crop reduction is carried out prioritising the final quality of the wine, rather than specifically of verjuice (Dupas de Matos et al., 2023). Although this factor can reflect the variability found in verjuice currently available in the market, the pronounced acidity has been its main sensory signature.

Sensory characteristics of products are extensively recognised as crucial drivers of consumer preferences (Carrillo et al., 2011). Previous work has evaluated verjuice made from different grape varieties and preservatives, each harvested at different ripening stages (Dupas de Matos et al., 2017). With distinctive acidity and sugar levels, the authors found that verjuice taste was impacted by harvest time, sourness and bitterness to a greater extent, and saltiness and sweetness to a lesser extent. However, it did not appear to impact perceived aroma profile. Verjuice is rich in polyphenols, which include both flavonoid and non-flavonoid compounds (Nikfardjam, 2008). In wines, phenolic compounds have been associated with perceived bitterness, sourness, and astringency (Hufnagel & Hofmann, 2008). Previous studies on fruit juices showed that sugar level impacted perception of odours without changes in volatile concentrations (Von Sydow et al., 1974). Similar findings were observed later in Perng and McDaniel (1989)'s work, where sugar concentration increased fruity flavour perception, whilst high acidity lowered it.

From a flavour chemistry standpoint, it is crucial to uncover the volatile compounds driving perception of sensory characteristics. For instance, some C-6 compounds present in wines contribute to 'green' notes, and are often referred to as bell pepper (Parr, Sherlock and Green 2007). However, the volatile composition of verjuice products has not been reported in the literature. Thus, identifying compounds driving sensory characteristics is important to understand sensory product quality. In verjuice, the most common perceived aromas have been reported as herbaceous, fruity, and floral, with Merlot and Sauvignon blanc variants displaying greater intensities of perceived green apple and herbaceous aromas (Dupas de Matos et al., 2017). Other terms such as lemony, apple, winey, woody, fermented, astringent and smooth were commonly used by consumers (Dupas de Matos et al., 2023), but the extent to which these sensory characteristics are desirable in verjuice as a beverage and their potential impact on its use remains unknown. This is a critical knowledge gap in terms of product innovation.

Verjuice has been used as an alternative to lemon or lime juice and vinegar across diverse culinary applications. For instance, in appetisers (Hayoglu et al., 2009), salad dressings (Dupas de Matos et al., 2017; Dupas de Matos et al., 2023), cooking and deglazing (Dupas de Matos et al., 2023), and marinades (Sengun et al., 2019; Dupas de Matos et al., 2023). In recent years, verjuice has become popular as a mixer with other beverages, either alcoholic or non-alcoholic. Recently, Dupas de Matos et al. (2023) reported that consumers considered verjuice a suitable ingredient to be included in cocktails/mocktails, but also to be consumed as a beverage on its own. It was also reported that sweeter versions were generally preferred for drinking uses, whilst sourer ones were favoured for culinary uses, although exceptions existed across consumers due to interindividual preferences. Whilst the applications of verjuice continue to broaden, there is a gap in understanding the sensory drivers of verjuice liking as a beverage. Therefore, deeper exploration of consumer responses towards verjuice in specific use case scenarios is essential to fill the existing knowledge gap and to provide verjuice producers more certainty regarding where to target their efforts in producing verjuice for specific applications. This will support product diversification, thereby enhancing the revenue stream for the wine industry.

With the rapid proliferation of new products into the marketplace, understanding factors that influence purchase behaviour is needed. Emotional responses toward foods/beverages have been associated with purchasing behaviour (Spinelli et al., 2015), offering insights beyond traditional acceptance (liking) measures (Ng, Chaya and Hort, 2013). Exploring emotions can shed light on a product's market performance (Jaeger et al., 2019). Positive emotional associations enhance purchasing, whilst negative associations can prompt consumers to avoid a product (Mora et al., 2021; Samant & Seo, 2020). Previous product experience may also affect consumer responses to a product (Thomson & Crocker, 2015). It is likely that the more familiar a consumer is with a certain product, the more they can connect certain emotional responses to the product (Mielmann et al., 2022). However, consumer emotional engagement with verjuice is unknown, and understanding the interplay between familiarity and emotions is vital for strategies that can enhance verjuice's appeal and inform the wine industry regarding opportunities for potential future consumer engagement. To add to the knowledge base, the primary objective of this study was to determine verjuice acceptability and drivers of liking for its use in beverages compared to other potential applications; secondly to identify potential chemical drivers associated with key sensory characteristics; and finally to investigate how product familiarity impacted emotional response to verjuice.

2. Material and methods

2.1. Verjuice samples

A large sample set was established with respect to verjuice taste, flavour, and mouthfeel characteristics (Table 1). Selection was conducted by three in-house experienced research staff from the Food Experience and Sensory Testing (Feast) team with significant sensory evaluation experience to ensure a sample set representative of the verjuice sensory space. Products represented a range of countries of origin and grape varieties.

Products from the same batch were purchased directly from producers or online shops. All products were stored in the dark at ambient temperature (~20 °C) upon arrival.

2.2. Analytical characterisation

2.2.1. Oenological parameters

Oenological chemical analyses included soluble solids (Brix), pH, titratable acidity (TA), tartaric, malic and acetic acids, glucose and sucrose, total and free SO_2, and ethanol. Brix was determined by refractometer (Atago, Japan). The pH and TA were determined by autotitrator (Mettler Toledo T70, Columbus, Ohio, United States) with aqueous

Table 1
Verjuice samples used in the consumer study (n = 93 consumers).

Sample ID	Country of origin	Grape variety
NZ1	New Zealand	Cabernet Sauvignon
NZ2	New Zealand	Merlot, Cabernet Sauvignon, Syrah
NZ3	New Zealand	Chardonnay
NZ4	New Zealand	Chardonnay
NZ5	New Zealand	Riesling
AUS1	Australia	Information not available
AUS2	Australia	Semillon
CAN	Canada	Pinot Noir, Chardonnay
USA	United States	Chardonnay, Merlot
ENG	England	Pinot Menier, Pinot Noir, Chardonnay
AUT	Austria	Sauvignon Blanc, Moscatel, Riesling, Pinot Blanc, Chardonnay, Zweigelt
PRT	Portugal	Tinta Caiada, Touriga Nacional
IRN	Iran	Information not available

sodium hydroxide (0.1 M) as titrant. Tartaric, malic and acetic acids, glucose, fructose, free and total SO_2 were determined using a Biosystems Y15 auto-analyser (Barcelona, Spain). Alcohol was determined using an Anton Parr Wine Alcolyser (Graz, Austria). All measurements were made in duplicate.

2.2.2. Untargeted volatile analysis

The analysis of verjuice samples was carried out following the method described by Al-Dalali et al. (2019) with few modifications. Briefly, samples (4 mL) were placed in a 20 mL-vial, followed by 0.5 mL of NaCl (saturated solution) and 2 μL of 100 μg mL^{-1} 1,2-dichlorobenzene in methanol (added as an internal standard). The vial was placed in the GC–MS containing an autosampler (Shimadzu AOC-6000, Japan). The sample was stirred for 30 min at 250 rpm at 40 °C for the volatiles to reach equilibrium in the headspace. Extraction of volatile compounds was carried out using a solid-phase microextraction (SPME) fibre (DVB/CAR/PDMS, 50/30 μm, 1 cm) (Supelco, United States) exposed to the headspace for 30 min at 40 °C. During extraction, the sample was stirred continuously at 250 rpm. The volatile compounds were desorbed by direct insertion of the fibre into the injection port of the GC, which was operated in splitless mode at 220 °C for 1 min. Headspace volatile compounds were analysed using a GC system (Nexis GC-2030, Shimadzu, Japan) coupled to a mass spectrometer (MS QP 2020 NX, Shimadzu, Japan). The GC was equipped with a Stabilwax-DA column (30 m, 0.25 mm and 0.5 μm film thickness). Helium was used as the carrier gas at a constant pressure of 100 kPa. The initial temperature program employed was isothermal at 40 °C for 5 min, followed by elevation of the temperature to 180 °C at a rate of 3 °C/min, and then an increase to 230 °C at a rate of 10 °C/min and holding for 5 min at 230 °C. Mass spectra were obtained in the electron impact mode at an ionization voltage of 70 eV, and data were collected over a range of m/z 35 to 500.

Compound identification was carried out by spectra comparison using the Nist05 Library supported by calculated retention indices relative to a series of alkanes (C5-C24) compared to National Institutes of Standards and Technology retention index database. Due to some selected analytes coeluting with other compounds, selected masses (m/z) were used for peak integration to obtain the abundance of each compound. The relative standard deviation (RSD) that measures the precision of the average of the results was calculated for the abundance of the internal standard across the different samples. The RSD for the internal standard was 3.30 %, indicating a good precision of the analytical procedure used in this study. The GC–MS (untargeted) analysis was employed to explore key volatiles present in verjuice samples to inform future quantitative work, rather than for determining absolute concentrations of metabolites. Further, it aimed to study the relationships between their relative profiles (abundance) and other variables (sensory, liking, and oenological parameters) using multivariate techniques.

2.3. Consumer study

2.3.1. Participants

Participants (n = 93), recruited through the Feast consumer database, Palmerston North, New Zealand, met the following criteria: willing to taste new foods and/or beverages, willing to attend two one-hour research sessions one week apart, aged between 18 and 65 years old, not allergic or intolerant to any of the ingredients listed in the participant information sheet, not pregnant or lactating.

Information about stated drinking habits and use of particular ingredients when cooking or seasoning foods were also collected during recruitment.

2.3.2. Ethics approval

This study was assessed and considered low risk following the Massey University Human Ethics Committee process (Human Ethics Notification: 4000026188). Prior to study attendance, participants were asked to read an information sheet providing all study details and provide informed written consent. Participants were assigned a unique code to ensure anonymity. Upon study completion, participants were offered a snack treat and a supermarket voucher as compensation for their time.

2.3.3. Product evaluation sessions

Participants attended a central location test (individual tables in a neutral room (21 ± 1 °C)) at the Feast Laboratory in groups of up to 15 people. During recruitment many participants, as expected, indicated a lack of product familiarity and so a short introduction to verjuice was provided at session start covering its definition, origins as a viticultural by-product, and versatility as a food ingredient.

Before product tasting, familiarity with verjuice prior to hearing about the study, and emotional response towards verjuice having heard the introductory information, was collected. Both were scored on a 5-point scale from ‘not at all’ (0) to ‘extremely’ (4). For emotions, the EsSense 25 profile lexicon was used (Nestrud et al., 2016) with the removal of Pleasant (as its definition tends to overlap with Happy, e.g., King & Meiselman, 2010; Jaeger et al., 2019) and the addition of Curious (present in other emotional lexicons for different food/beverage categories, e.g., Mora et al., 2020) (for full list see **Table S2**). To minimise order bias, emotion terms were presented according to a randomised balanced design across consumers.

Three types of responses were obtained for each sample. Overall liking as a beverage/drink was rated on a 9-point hedonic scale from ’dislike extremely’ (1) to ’like extremely’ (9). Secondly, using a 5-point scale from ’not at all’ (0) to ’extremely’ (4), participants rated how likely they would be to use each sample as an ingredient in six different applications (cocktails, beverages, marinades, cooking/deglazing, salad dressings and sauces) suggested in a previous study (Dupas de Matos et al., 2023). Finally, participants characterised the samples using a CATA (check-all-that-apply) question including 29 sensory attributes identified in a previous consumer study (Dupas de Matos et al., 2023): 5 tastes (sweet, sour, bitter, salty, umami), 18 flavours (floral, unripe fruit, green apple, apple/pear, grapey/winey, tropical fruit, citrus/lemony, pomegranate, herbs, tea, piney, honey, dried fruit, nutty, earthy/musty, woody, fermented, chemical), and 6 texture/mouthfeel attributes (viscous, sticky, smooth, fizzy, astringent/dry, warm) (terms/definitions are provided in **Table S3**). Terms were presented as one list according to a randomised balanced design across consumers but in the same order for a consumer across samples.

Samples were poured, covered, and stored in a refrigerator (~4 ºC) overnight until the beginning of each session. Samples (15 mL) were served chilled (~5 ºC) in 30 mL clear, odour-free plastic cups covered with a lid, labelled with 3-digit random codes and evaluated under white lighting. Each participant received one cup to assess liking and use likelihood, and one cup for sensory profiling (CATA).

2.3.4. Experimental design

Evaluation of the 13 samples was divided across two sessions. Samples (7 in session 1 and 6 in session 2) were allocated to ensure each session set possessed a range of sensory characteristics. Samples were presented according to a Williams Latin Square within each session except that Portuguese (PRT) and Iranian (IRN) samples were presented as last sample in session 1 and 2 respectively, following concerns during study piloting that their strong acidity and flavour would, despite the use of palate cleansers, disproportionately influence ratings of subsequent samples.

Sample presentation was monadic with a forced minimum 2 min-break between each sample. To further minimise carryover effects participants were instructed to cleanse their palate before each sample in a consistent manner (bite of water cracker (Fine Food Holdings Pty Ltd, Victoria, Australia) followed by filtered water). Data was collected with tablets using Compusense® Cloud (version 23.0.25636, Compusense Inc., Guelph, Ontario, Canada).

2.4. Data analysis

Analyses were performed in XLSTAT version 2023.2.1414 (Lumivero, New York, United States). The heatmap was built using `pheatmap` package (version 1.0.12; Kolde, 2019) in R (version 4.0.3). The α-risk was set at 0.05.

One-way Analysis of Variance (ANOVA) followed by post hoc test (Tukey HSD) was applied to basic chemistry oenological parameters, specifying sample as a fixed effect, and Brix, pH, TA, tartaric acid, malic acid, glucose, fructose, total SO_2, free SO_2, and ethanol as response variables.

For volatiles, data were organised in a matrix where rows corresponded to samples and columns to volatile metabolites. The data were mean-centred and scaled for variance one in a column-wise direction to prevent the differences in scale of volatile metabolite abundances affecting assessment of samples differences (Liland, 2011). The order of columns and rows of the scaled data was determined with hierarchical cluster analysis with Euclidean distance and grouping with complete linkage. The reordered data were used to draw a heatmap, which was created using the R package heatmap.

Two-way ANOVA followed by Tukey HSD was carried out on liking and likelihood of usage for each application, with sample as a fixed factor and consumer as a random factor. Mean emotional responses were calculated and plotted to visualise consumers' initial response to verjuice in general.

Additionally, comparison amongst participants groups with different levels of familiarity ('not familiar' vs 'familiar') was performed. Mean emotional response scores were grouped by stated verjuice familiarity level, with 'not familiar' referring to consumers stating 'not at all' familiar with verjuice, and 'familiar' to those indicating some level of familiarity (from 'slightly' to 'extremely'). A two-way ANOVA was conducted to explore impact of familiarity on emotional responses (sample and familiarity as factors) and provide preliminary insights into potential consumer engagement and future utilisation of verjuice.

Following Meyners, Castura & Carr (2013), Cochran's Q tests were performed on each CATA term to determine differences in consumer perception of the evaluated samples, the Sheskin procedure was used for post-hoc comparisons. Correspondence Analysis (CA) (chi-square distances) was performed across all terms within the CATA question to provide a bidimensional representation of the samples and their relationship to the sensory characteristics. Contingency tables were formed by crossing samples (rows) and CATA terms (columns). Penalty-lift analysis, which identifies if the presence of an attribute leads to lower liking, no effect, or higher liking (Ares et al., 2014), was performed to determine the mean impact of sensory characteristic presence on overall liking. A threshold of 10 % citation frequency was used to test the significance of the mean impact.

Furthermore, multiple factor analysis (MFA) was used to integrate multiple datasets pertaining to the same set of products. To explore the relationship between sensory characteristics and their potential impact on verjuice usage, one MFA involved the mean ratings of sensory attributes (29 variables) and uses (6 variables). Then, a further MFA included liking (1 variable), sensory attributes (29 variables), oenological chemical parameters (11 variables) and volatiles (31 variables) to investigate chemical drivers of sensory characteristics and liking in verjuice.

3. Results

3.1. Analytical characterisation

3.1.1. Conventional oenological parameters

pH, tartaric, malic and acetic acids, titratable acidity, glucose, sucrose, Brix, total and free SO_2, and ethanol results are shown in Table 2. pH values ranged from 2.62 to 3.09, tartaric acid from 2.06 to 10.61 g/L, malic acid from 3.04 to 21.90 g/L, acetic acid from 0.01 to 0.04 mg/L, titratable acidity from 10.67 to 34.11 g/L, glucose from 0.14 to 72.44 g/L, fructose from 0.05 to 67.85 g/L, Brix from 3.90 to 15.70, total SO_2 from 1.00 to 327.00 mg/L, free SO_2 from 0.00 to 190.80 mg/L, and ethanol from 0.00 to 0.68 %.

Correlation analysis failed to establish a significant relationship between overall liking and sulphites, acetic acid, and ethanol content.

Table 2
Basic oenological chemical parameters for verjuice samples expressed as mean ± standard deviation. Different letter in the same column indicates significant differences according to Tukey's HSD (5 % level).

Sample	pH	Brix	Tartaric Acid (g/L)	Malic Acid (g/L)	Acetic Acid (g/L)	TA (g/L)	Glucose (g/L)	Fructose (g/L)	Total SO_2 (mg/L)	Free SO_2 (mg/L)	Ethanol (v/v%)
NZ1	2.92 ± 0.02^{cd}	13.85 ± 0.05^{c}	2.56 ± 0.06^{h}	4.64 ± 0.00^{g}	0.02 ± 0.00^{a}	10.67 ± 0.16^{i}	62.07 ± 0.30^{b}	61.30 ± 0.31^{abc}	82.50 ± 0.50^{b}	24.76 ± 0.51^{b}	0.16 ± 0.00^{c}
NZ2	3.04 ± 0.00^{ab}	14.65 ± 0.05^{b}	4.36 ± 0.02^{e}	8.98 ± 1.02^{ef}	0.03 ± 0.01^{a}	12.24 ± 0.00^{h}	68.75 ± 1.15^{a}	62.46 ± 1.71^{ab}	20.50 ± 0.50^{h}	1.27 ± 0.33^{f}	0.13 ± 0.00^{de}
NZ3	3.09 ± 0.00^{a}	13.45 ± 0.05^{d}	4.90 ± 0.02^{d}	10.44 ± 0.00^{cde}	0.03 ± 0.01^{a}	14.08 ± 0.01^{g}	57.80 ± 0.42^{b}	58.40 ± 2.70^{abcd}	27.50 ± 0.50^{g}	2.21 ± 0.38^{f}	0.14 ± 0.00^{d}
NZ4	2.72 ± 0.03^{ef}	13.05 ± 0.05^{e}	4.36 ± 0.02^{e}	11.06 ± 0.06^{cde}	0.01 ± 0.00^{a}	16.56 ± 0.01^{ef}	57.82 ± 1.03^{b}	50.00 ± 1.03^{cde}	45.00 ± 0.00^{e}	13.72 ± 0.15^{d}	0.08 ± 0.00^{f}
NZ5	2.63 ± 0.00^{g}	13.45 ± 0.05^{d}	6.76 ± 0.17^{b}	9.56 ± 0.04^{def}	0.02 ± 0.01^{a}	18.13 ± 0.09^{d}	59.21 ± 1.66^{b}	53.61 ± 3.47^{bcd}	49.00 ± 0.00^{d}	9.35 ± 0.01^{e}	0.44 ± 0.00^{b}
AUS1	2.85 ± 0.01^{d}	15.65 ± 0.05^{a}	2.06 ± 0.01^{i}	9.22 ± 0.02^{def}	0.02 ± 0.01^{a}	21.19 ± 0.04^{c}	72.43 ± 0.23^{a}	67.85 ± 0.20^{a}	79.50 ± 0.50^{c}	12.23 ± 0.04^{de}	0.17 ± 0.01^{c}
AUS2	2.96 ± 0.03^{bc}	9.85 ± 0.05^{h}	3.91 ± 0.01^{f}	12.94 ± 0.02^{bc}	0.02 ± 0.02^{a}	16.25 ± 0.04^{f}	43.18 ± 0.40^{d}	31.95 ± 0.31^{fg}	49.50 ± 0.00^{d}	20.19 ± 0.39^{c}	0.06 ± 0.00^{g}
CAN	2.74 ± 0.01^{e}	8.25 ± 0.05^{i}	5.32 ± 0.00^{c}	15.00 ± 0.10^{b}	0.04 ± 0.00^{a}	21.37 ± 0.01^{c}	31.67 ± 0.17^{e}	24.26 ± 0.22^{g}	22.00 ± 0.00^{h}	1.12 ± 0.19^{f}	0.44 ± 0.00^{b}
USA	3.03 ± 0.01^{ab}	14.45 ± 0.05^{b}	3.41 ± 0.05^{g}	7.80 ± 0.00^{f}	0.03 ± 0.01^{a}	11.92 ± 0.05^{h}	68.24 ± 2.39^{a}	60.12 ± 5.37^{abc}	37.50 ± 0.50^{f}	10.12 ± 0.18^{de}	0.17 ± 0.00^{c}
ENG	2.88 ± 0.00^{cd}	10.85 ± 0.05^{g}	3.97 ± 0.01^{f}	11.76 ± 0.0^{cd}	0.02 ± 0.00^{a}	17.03 ± 0.22^{e}	44.12 ± 0.54^{d}	39.79 ± 0.50^{ef}	327.00 ± 1.00^{a}	190.80 ± 2.22^{a}	0.68 ± 0.01^{a}
AUT	2.62 ± 0.01^{g}	11.65 ± 0.05^{f}	6.69 ± 0.07^{b}	3.04 ± 0.04^{g}	0.02 ± 0.00^{a}	16.71 ± 0.06^{ef}	49.69 ± 0.24^{c}	47.32 ± 0.64^{de}	1.00 ± 0.00^{i}	n.d.	0.13 ± 0.01^{e}
PRT	2.64 ± 0.03^{fg}	4.45 ± 0.05^{j}	10.61 ± 0.04^{a}	21.90 ± 0.30^{a}	0.02 ± 0.02^{a}	34.11 ± 0.00^{a}	5.53 ± 0.18^{f}	1.59 ± 0.15^{h}	1.00 ± 0.00^{i}	n.d.	n.d.
IRN	2.60 ± 0.01^{g}	3.85 ± 0.05^{k}	5.52 ± 0.02^{c}	21.95 ± 1.25^{a}	0.04 ± 0.00^{a}	31.58 ± 0.05^{b}	0.14 ± 0.10^{g}	0.05 ± 0.01^{h}	1.00 ± 0.00^{i}	n.d.	n.d.

TA: Titratable acidity. n.d.: not detected.

However, positive associations were established for Brix (r = 0.965), glucose (r = 0.969), fructose (r = 0.971) and pH (r = 0.696). For sugars, higher content drove higher liking scores. Negative associations were also established for titratable acidity (r = -0.912), malic (r = -0.868) and tartaric (r = -0.664) acids (data not shown). In the case of acidity, the association seemed to be primarily driven by high content in the more disliked samples. Further exploration of the relationship of these chemical parameters with other variables (liking, sensory attributes and volatiles) is reported in 3.7 section.

3.1.2. Volatile profile

A total of 31 metabolites were detected across the 13 verjuice samples (Fig. 1). Overall, 17 compounds were detected in all the verjuice samples, which belonged to various classes including alcohols, aldehydes, terpenes, alkanes, acids and methylbenzene (**Table S1**). Several compounds responsible for mostly herbaceous, vegetative and green odours (e.g., 3-hexen-1-ol (*E*), 3-hexen-1-ol (*Z*), 2-hexenal, etc) were detected across verjuice samples. Alcohols were identified in several samples, with higher ethanol levels detected in ENG, CAN and NZ5. Sulphur dioxide was found in all samples, except in AUT, PRT and IRN, and ENG was the verjuice with the highest level. ENG also showed higher levels for 1-octen-3-ol, isobutanol and 3-hexen-1-ol (*E*). AUT had higher concentrations of β-damascenone and nonanal, whereas acetic acid and toluene were more present in IRN. TDN (1,1,6-trimethyl-1,2-dihydronaphthalene) was detected in all samples, with NZ5 showing the highest level, where vitispirane A and B were mostly found. AUS1 showed higher concentrations of 2-octanol, 6-methyl-5-hepten-2-one, 2-methyl-butanal and 1-heptanol. Other compounds, such as 3-hexen-1-ol (*Z*), 2-ethyl-1-hexanol, 3-methyl-butanal, and furfural were mainly found in PRT compared to other verjuice samples (complete volatile profiles are available in **Table S1**).

3.2. Participants characteristics

Participants (n = 93) were predominantly female (78.5 %) with a mean age of 41.7 yrs ± 12.0. Participant drinking and cooking habits are summarised in Table 3. Participants declared liking to drink cocktails/mocktails, wine, cider, and kombucha to a higher extent (52–61 % of consumers) than gin, sour beverages, verjuice and non-alcoholic wine (32–39 %). As previous verjuice familiarity was not an eligibility criterion, rather a variable of interest, all participants were retained.

Table 3
Percentage of participants, in descending order, who agreed (#scored between 6 and 7) they like to drink various beverages and use particular ingredients when cooking or seasoning foods. Participants rated how strongly they agreed with each drinking/cooking statement on a 7-point scale from 'strongly disagree' (1) to 'strongly agree' (7).

Drinking habits *"I like to drink…"*	**Percentage** #
Cocktails/Mocktails	60.87
Wine	59.78
Cider	54.35
Kombucha	52.17
Gin	40.22
Sour beverages	39.13
Non-alcoholic wine	32.61
Verjuice	34.78
Cooking uses *"I like to use…when cooking and/or seasoning foods"*	**Percentage** #
Sauce/Dressing	86.96
Lemon Juice	77.17
Vinegar	69.57
Wine	56.52
Verjuice	25.00

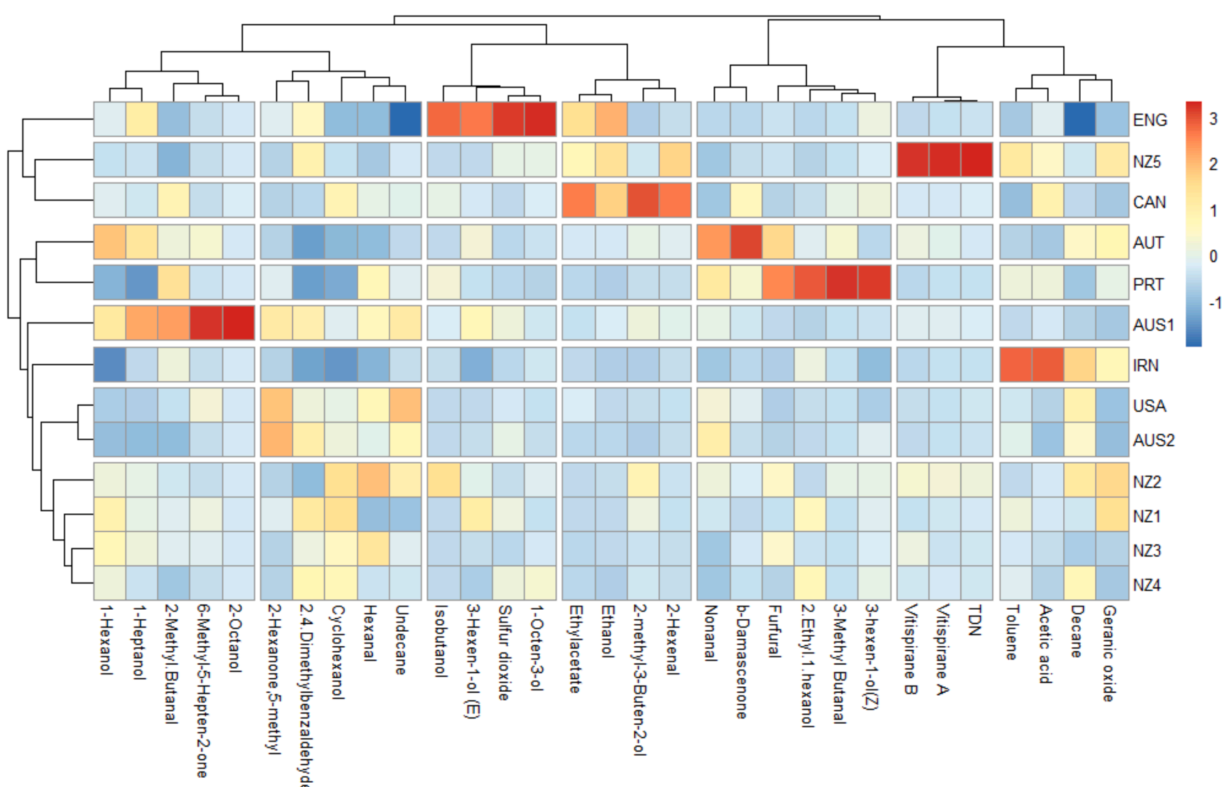

Fig. 1. Heatmap with hierarchical dendrograms of the volatile metabolites identified in the verjuice samples. Each column represents a metabolite, and each row represents a sample. For heatmap visualisation, the abundance of each metabolite was scaled to variance one. Negative values in the colour scale indicate that values are below the mean abundance for the corresponding metabolites, and positive values in the colour scales are higher than the corresponding mean abundance value.

Participants also declared they liked to use sauce/dressings when cooking and/or seasoning foods, specifically lemon juice (77 %), vinegar (70 %), wine (56 %) and less often verjuice (25 %).

3.3. Emotional response to verjuice product concept

Mean initial emotional response to the general idea of verjuice prior to tasting is shown in Fig. 2. Overall, verjuice elicited positive valence emotions in which six emotions were rated higher than 2 ('moderately'): interested (3.0/4.0), curious (2.9), enthusiastic (2.4), good (2.2), adventurous (2.1), happy (2.1). In terms of arousal (feeling of activation/deactivation), these positive emotions have medium–high level of arousal. Regarding valence (feeling of pleasure or displeasure), negative emotions such as aggressive, bored, disgusted, guilty, and worried received very low ratings (<0.2), suggesting that the product did not elicit negative feelings amongst consumers.

Comparison across 'not familiar' ($n = 55$) versus 'familiar' ($n = 38$) groups revealed only three emotions differed significantly by familiarity group. The "not familiar" group gave significantly higher ratings for curious, albeit only 0.58/5 scale points. On the other hand, the "familiar" group rated happy and satisfied higher, with a difference of 0.53 and 0.54 scale points, respectively (Table 4).

3.4. Verjuice liking as a beverage/drink

Mean liking ratings across verjuice samples as a beverage significantly differed ($p < 0.0001$) ranging between 1.75 and 7.31 (Table 5).

Five samples had mean ratings between 6 and 7 (respectively, 'like slightly' and 'like moderately'); they were from different countries – United States (USA), New Zealand (NZ1, NZ2, NZ3) and Australia (AUS1) – and were characterised by greater sweetness, fruity flavours, and smoothness. With mean scores between 5.1 and 5.7, three verjuice samples – two from New Zealand (NZ4, NZ5), one from Australia (AUS2) and one from Austria (AUT) – were more liked than disliked, on average. The most disliked samples to drink as a beverage were from Iran (IRN) and Portugal (PRT), possibly a reflection of their high acidity, but also other sensory notes such as bitter and salty.

3.5. Likelihood of verjuice usage in different applications

Mean ratings for sample usage likelihood by application (0: 'not at all' to 4: 'extremely') are presented in Fig. 3.

For beverage use (Fig. 3**A**), large variation was observed. USA, NZ1, NZ2, NZ3 and AUS1 received significantly higher rating scores for use in cocktails and in beverage mixtures than most other samples. NZ5, AUS2, ENG, CAN were scored less likely to be used in beverage applications, with PRT and IRN significantly receiving the lowest scores (<1, 'slightly'). For cooking (Fig. 3**B**), less score variation was evident – all received mean ratings 2 or below ('moderately') for usage in marinades and in cooking/deglazing. PRT and IRN received the lowest scores (≤ 1, 'slightly'). A similar pattern (Fig. 3**C**) was found in salad dressings and sauces. Specifically, AUS1, NZ3, AUS2, NZ4, USA, NZ1, NZ2, ENG, AUT, NZ5 and CAN samples were more likely to be used in salad dressings in comparison to others.

Table 4
Mean emotional response score (0: 'not at all' to 4: 'extremely') to verjuice grouped by stated verjuice familiarity level. Not familiar ('not at all'): $n = 55$, Familiar ('slightly' to 'extremely'): $n = 38$ participants. Emotion word which shares a letter were not significantly different according to Tukey's HSD (5 % level).

Emotion	Familiarity	
	Not familiar	Familiar
Active	1.33[a]	1.84[a]
Adventurous	2.05[a]	2.18[a]
Aggressive	0.05[a]	0.13[a]
Bored	0.16[a]	0.05[a]
Calm	1.25[a]	1.47[a]
Curious	3.16[a]	2.58[b]
Disgusted	0.09[a]	0.05[a]
Enthusiastic	2.38[a]	2.32[a]
Free	1.09[a]	1.18[a]
Good	2.11[a]	2.39[a]
Good-natured	1.44[a]	1.97[a]
Guilty	0.04[a]	0.08[a]
Happy	1.85[b]	2.39[a]
Interested	2.95[a]	3.18[a]
Joyful	1.53[a]	1.92[a]
Loving	0.69[a]	1.08[a]
Mild	1.09[a]	1.21[a]
Nostalgic	0.53[a]	0.58[a]
Satisfied	1.42[b]	1.95[a]
Secure	1.02[a]	1.03[a]
Tame	0.27[a]	0.50[a]
Understanding	1.09[a]	1.39[a]
Warm	1.25[a]	1.37[a]
Wild	0.75[a]	0.58[a]
Worried	0.27[a]	0.18[a]

[ab] Emotion scores with different superscript letter were significantly different between groups according to Tukey's HSD (5% level).

3.6. Verjuice sensory characterisation

Sensory attribute citation frequencies are shown in Table 6 with 26 of the 29 sensory terms significantly discriminating the samples.

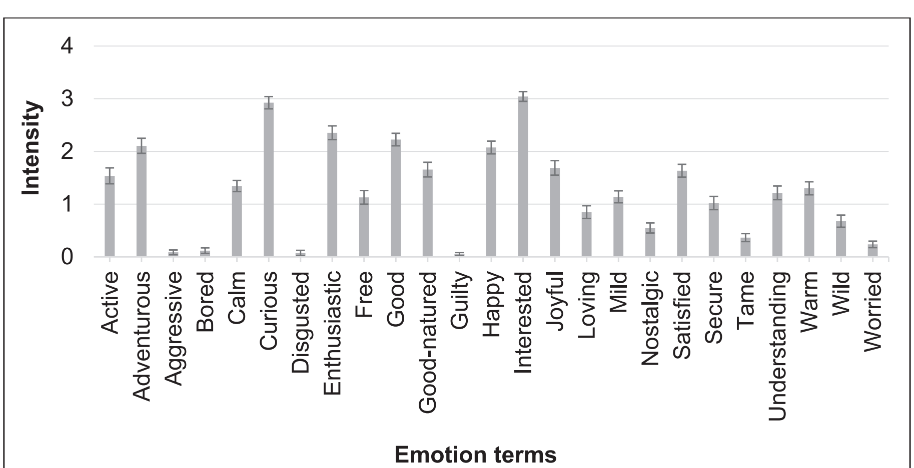

Fig. 2. Mean emotional response based on consumers' response to verjuice. Error bars represent standard error of the mean.

Table 5
Mean overall liking for verjuice samples (n = 13) in descending order.

Sample ID	Country of origin	Average	Std. Dev.
USA	United States	7.31[a]	1.14
NZ1	New Zealand	6.99[ab]	1.46
NZ2	New Zealand	6.82[ab]	1.38
NZ3	New Zealand	6.71[ab]	1.58
AUS1	Australia	6.53[b]	1.74
NZ4	New Zealand	5.74[c]	1.80
AUT	Austria	5.53[c]	1.83
NZ5	New Zealand	5.44[c]	1.83
AUS2	Australia	5.15 [cd]	1.89
ENG	England	4.65[d]	2.01
CAN	Canada	3.57[e]	2.00
PRT	Portugal	1.96[f]	1.44
IRN	Iran	1.75[f]	1.18

[a-f] Samples with different superscript letter are significantly different according to Tukey's HSD (5% level).

Penalty/lift analysis provided insight concerning attributes significantly driving liking for verjuice when drank on its own with positive values indicating a mean lift and negative values indicating a mean drop in overall liking. For taste, sweet was the largest positive driver of liking (2.37), whereas bitter (−2.13), salty (−1.87) and sour (−1.50) impacted mean liking negatively. For flavour, positive drivers of liking were tropical fruit (2.06), honey (2.06), floral (1.71), apple (1.68), green apple (1.12), winey (1.06), dried fruit (1.05) and citrus (0.31). Other flavours exerted a negative mean impact on sample liking: chemical (−2.39), fermented (−1.61), earthy (−1.49), woody (−1.01) and unripe fruit (−0.88). For texture/mouthfeel, smooth (1.69) impacted mean liking positively, whereas astringent/dry (−1.47) and warm (−1.05) penalised liking. Nine of 29 terms had low frequency citation (<10 %) and, therefore, significance testing was not performed for umami (−0.99), pomegranate (1.18), herbs (−0.49), tea (0.41), piney (−0.89), nutty (−0.31), viscous (0.46), sticky (0.41), and fizzy (0.08).

Fig. 4**A** presents the CA biplot showing the space spanned by the first and second dimensions. Collectively, they accounted for 90.52 % of the inertia in the data. F1 (38.23 %) mainly represented variation from sweet and fruity flavours to more, bitter, salty, and vegetal notes. F2 (16.18 %) captured variation from fizzy, unripe fruit, citrus notes to tea, nutty, woody, and earthy sensations. Accordingly, USA, NZ1 and NZ2 samples were associated with sweet, floral, tropical fruit, honey, dried fruit and smooth. NZ3 associated with apple and pomegranate, with AUS1 and NZ4 in a fairly similar space but more closely associated with winey and green apple. NZ5, AUT and ENG samples were characterised to the fairly central of the plot closer to sour, fermented, astringent/dry and warm. PRT was mainly associated with bitter and salty, and IRN with earthy and chemical notes. AUS2 was associated with unripe fruit, citrus, green apple and fizzy, and notably IRN also associated to attributes at the upper end of F2, in particular earthy (refer to **Table S4** for details on term frequency citation). Fig. 4**B** charts the significant Penalty Lift Analysis mean impact scores. Notably attributes with positive impact are positioned on the right side of CA biplot and those with negative impact are on the left side of biplot indicating liking increases from left to right.

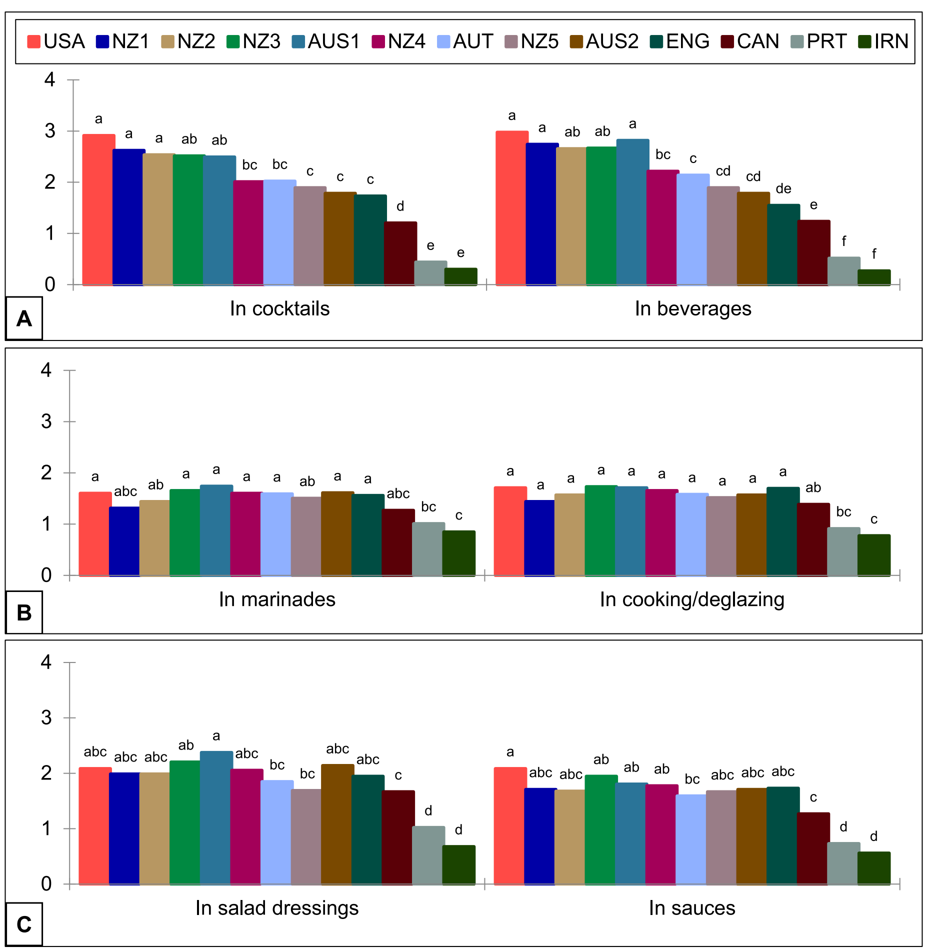

Fig. 3. Mean likelihood of verjuice use. **A)** Beverage use, **B)** Cooking use, **C)** Seasoning use. [a-f] Samples with different letter within each use/application are significantly different according to Tukey's HSD (5% level).

Table 6
P-values associated with Cochran's Q test for sample difference, average citation frequency (%) across verjuice samples, and mean impact on liking when CATA term was selected per sensory attribute.

Sensory term	P-value	Average citation frequency (%)	Mean impact on liking
Sweet	<0.0001	39.21	2.37 ***
Sour	<0.0001	80.65	−1.50 ***
Bitter	<0.0001	21.84	−2.13 ***
Salty	<0.0001	13.65	−1.87 ***
Umami	<0.0001	6.53	-0.99 n/a
Floral	<0.0001	17.45	1.71 ***
Unripe fruit	<0.0001	44.42	−0.88 ***
Green apple	<0.0001	49.71	1.12 ***
Apple/Pear	<0.0001	38.96	1.68 ***
Grapey/Winey	<0.0001	56.08	1.06 ***
Tropical fruit	<0.0001	14.72	2.06 ***
Citrus/ Lemony	<0.0001	43.92	0.31 *
Pomegranate	<0.0001	9.93	1.18 n/a
Herbs	<0.0001	9.84	-0.49 n/a
Tea	<0.0001	8.19	0.41 n/a
Piney	0.001	8.52	-0.89 n/a
Honey	<0.0001	26.47	2.06 ***
Dried fruit	<0.0001	14.89	1.05 ***
Nutty	0.290	2.65	-0.31 n/a
Earthy	<0.0001	12.32	−1.49 ***
Woody	<0.0001	17.95	−1.01 ***
Fermented	<0.0001	47.48	−1.61 ***
Chemical	<0.0001	14.89	−2.39 ***
Viscous	0.016	8.60	0.46 n/a
Sticky	0.736	7.03	0.41 n/a
Smooth	<0.0001	26.80	1.69 ***
Fizzy	0.053	9.26	0.08 n/a
Astringent/ Dry	<0.0001	48.80	−1.47 ***
Warm	<0.0001	24.40	−1.05 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.
n/a Significance test not performed if average citation frequency < 10 %.

3.7. Multiple factor analysis

3.7.1. Linking sensory characteristics to potential uses

The first MFA, considering sensory attributes (29 variables) and uses (6 variables), highlighted insights concerning the impact of sensory characteristics on potential verjuice use. Factor 1 (78.32 %) and Factor 2 (14.02 %) explained 92.34 % of the total variance in the dataset (Fig. 5). The MFA biplot showed that sweet, fruity flavours (apple, pomegranate, tropical fruit, dried fruit), honey and smooth were associated with drinking uses (in cocktails and with other beverages), whereas winey and green apple flavours were associated with cooking, marinades, salad dressings and sauces.

3.7.2. Chemical composition and sensory characteristics

The second MFA summarised the relationship between chemical composition (oenological parameters and volatiles), sensory attributes and liking in verjuice. Collectively, the first four dimensions/factors accounted for 72.15 % of total variance in the whole data set. The MFA biplot (F1: 38.23 % and F2: 16.18 %, Fig. 6A1) revealed close positioning of sugars alongside sensory attributes such as sweet, apple, pomegranate, floral, tropical fruit, dried fruit, and honey. Additionally, they also shared proximity with volatiles 1-hexanol and cyclohexanol. On the contrary, acidity parameters co-located with salty, bitter, umami, sour, fermented, chemical, woody, earthy, warm, astringent/dry, herbs and piney. These attributes opposed liking and co-located with acetic acid, 3-methyl-butanal, 2-ethyl-1-hexanol, and toluene. F3 (9.75 %) and F4 (7.99 %) explained a further 17.74 % (Fig. 6B1**)** of the variance in the data and showed mainly the separation of IRN and PRT samples. IRN was positioned on the negative pole of Factor 4 with predominately earthy, tea and nutty notes, and closer proximity to toluene, decane, and acetic acid. On the other hand, PRT was located on the positive pole of Factor 4 sharing proximity with other volatiles (e.g., 2-ethyl-1-hexanol, 3-hexen-1-ol (*E*), 3-hexen-1-ol (*Z*), 2-methyl-butanal).

4. Discussion

4.1. Chemical composition

Broad ranges of oenological parameters were observed (Table 2), probably because grapes typically exhibit quantitative and qualitative differences in chemical composition as a function of variety, maturity, growing region and year (Lamikanra, Inyang and Leong, 1995). Additionally, since verjuice lacks an agreed-upon standard of identity, this likely reflects the diverse chemical profile observed amongst the verjuice products, ranging from very sour to sweeter variants. In the present study, pH values ranged from 2.6 to 3.1 and Brix ranged from 3.9 to 15.7. Similar pH and Brix results were reported by previous verjuice studies (e.g., Hayoglu et al., 2009; Simone et al., 2013; Öncül & Karabiyikli, 2015; Dupas de Matos et al., 2017; Eddine et al., 2020). Dupas de Matos et al. (2017) analysed verjuice chemical composition from grapes harvested in stages 32–34 of Coombe's phenological classification (Combee, 1995). Earlier stages showed no pH and Brix differences, unlike later stages characterised by berry softening and rising Brix. In grapes, tartaric and malic acids are the primary organic acids, in which malic acid accumulates quickly in the berry, whilst the accumulation of tartaric acid is slower (e.g., Ribéreau-Gayon et al., 2021). Consistent with previous research (e.g., Dupas de Matos et al., 2017), findings showed malic acid concentrations (3.04–21.90 g/L) exceeded tartaric acid (2.06–10.61 g/L) in all verjuice samples, and sugar levels varied for glucose (0.14–72.44 g/L) and fructose (0.05–67.85 g/L). In green berries sampled at an early developmental stage, glucose constituted 85 % of the total sugar content, however, during veraison, there was a shift with fructose prevailing over glucose (Seymor, Taylor, and Tucker, 1993; Ribéreau-Gayon et al., 2021). Unexpectedly, due to verjuice's non-fermentative nature, traces of acetic acid and slight amounts of ethanol were found. Unlike the association between increased volatile acidity and reduced quality in wine, the traces of acetic acidity in verjuice may not necessarily indicate a decline in its quality. The verjuice samples assessed were commercial products and, therefore, complied with regulatory requirements which stipulate that they are not required to disclose their alcohol levels on the labels. The oenological analysis highlighted a significant diversity observed in verjuice available commercially, with similar values reported in previous literatures using experimental verjuice samples. This is unsurprising given the absence of an agreed-upon standard of identity. Further understanding of key chemical parameters can provide valuable insights to producers regarding product's composition and support improvements in its overall quality.

4.2. Sensory drivers of liking

Although 26 sensory attributes discriminated the verjuice samples (Table 6), only 10 attributes were identified as positive drivers of liking (refer to Fig. 4**B**). Sweetness was the most positive driver of liking in verjuice as a beverage, followed by fruity notes, floral, winey, smooth sensation, and to a lower extent citric/lemony. On the other hand, attributes associated with bitter, salty, sour, off-notes, woody, unripe fruit, dry and warm sensations penalised liking. Sweetness has been found to drive consumer liking of many products (Hutchings, Low and Keast, 2019). In fruit juices, sweet and fruity-related attributes drove liking in Barker, Moss & McSweeney (2021)'s work. Similarly, Meullenet et al. (2008) showed that grape juice perceived to be sweet was also associated with floral and apple/pear flavour, whilst green/unripe flavour was linked to sour and astringent juices, in line with present study. Also, Laaksonen, Ahola and Sandell (2013) indicated that low levels of sourness positively influenced preference for berry juices and products,

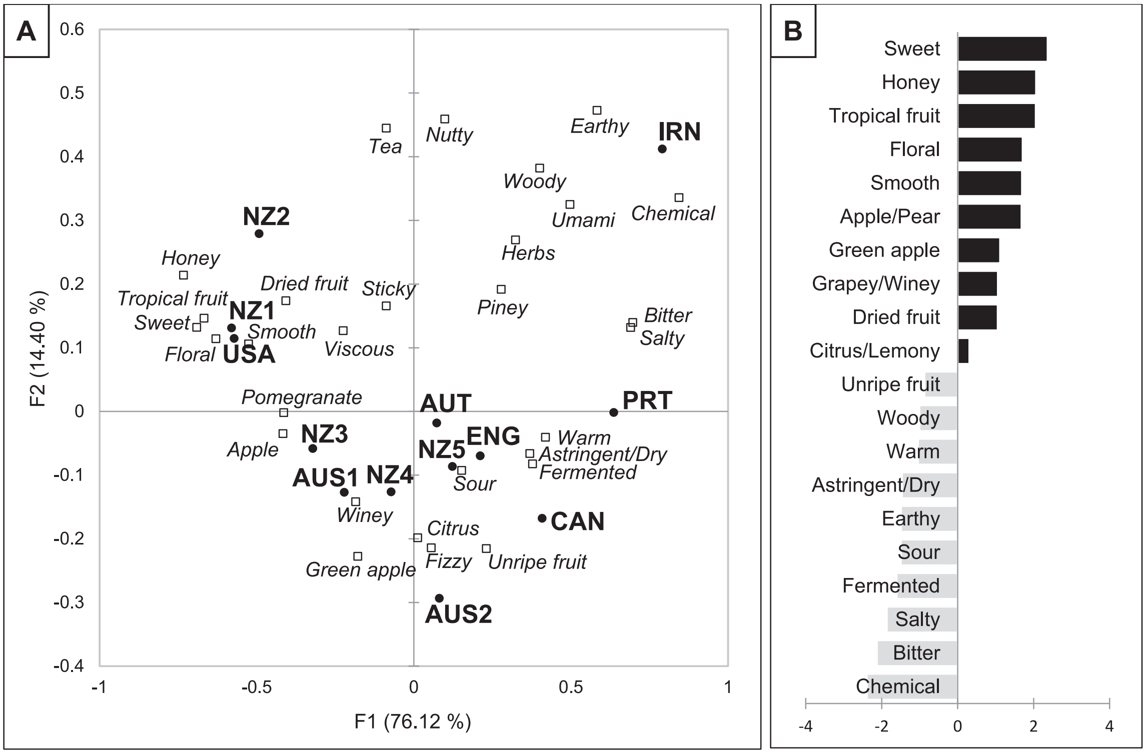

Fig. 4. A) Biplot from Correspondence Analysis of sensory terms. Space spanned by Dimensions 1 and 2. Samples are shown as black filled circles, whilst sensory terms are shown as unfilled squares with text in italic font. **B)** Penalty Lift Analysis based on the responses to the CATA question. Bars represent the mean impact on overall liking scores. Attributes with positive impact on liking are shown as black filled bars, whilst those with negative impact are shown in filled grey bars.

whereas strong bitterness, astringency and sourness are generally disliked sensations in most products. Whilst acidity was a distinctive feature of some verjuice samples, it was evident that balancing it with other sensory components such as sweet-related fruity notes enhanced drinkability and could attract a broader range of consumers. Finding the 'right balance' would leverage the desirable sensory characteristics in verjuice as a beverage, underscoring the importance of continued refinement and optimisation in its development for a pleasurable drinking experience. Considering that verjuice has no identity standard, there is a wide scope for producers to innovate given there is autonomy over grape picking time, production methods, and target end-uses (Dupas de Matos et al., 2023). This reflects the varied sensory experiences offered by the current range of verjuice on the market, potentially making it challenging for consumers to 'recognise' the product.

Whilst all acids in foods and beverages share the common sensory characteristic of sourness, its perceived intensity is influenced by the presence of other acids, sugars, their ratios, and other flavour compounds. In fruit beverages, the sourness of acids is often mitigated by the sweetness from sugars (Lawless and Heymann, 2010). Previous research has shown that term citation frequency serves as a proxy for perceived intensity, albeit not a direct measurement (Jaeger et al., 2023) and hence the results here only give an indication. It would be beneficial to identify optimal levels of sweetness, sourness, and other flavour and mouthfeel attributes in verjuice that align with consumer preferences for drinking it as a beverage to inform future product development strategies.

4.3. *Verjuice uses and sensory drivers in different applications*

A larger variation across products was observed in likelihood of using verjuice as a beverage or mixed in drinks, compared to its utilisation in culinary preparations such as marinades, cooking/deglazing, and to a lesser extent, in salad dressings and sauces. As expected, findings show that verjuice samples more liked as a beverage were also more inclined to be utilised for drinking rather than culinary purposes. Different verjuice samples were more suited for different applications. Specifically, fruity, floral & honey notes were preferred for drinking uses, whereas winey/grapey and green apple notes were favoured for culinary applications. Insights into the suitability of a product for various purposes can support market positioning to consumer segments (Cardello & Schutz, 1996). In Dupas de Matos study (2023)'s, consumers recognised verjuice's versatility as a non-alcoholic wine alternative, refreshing juice, as a shot or digestive drink, in particular the sourer versions. In the current study, the sourest samples were generally disliked regardless of their intended use. However, consumers did not assess verjuice samples in the suggested applications/uses, where other ingredients could potentially impact their responses, highlighting the importance of further consumer research in different applications.

Previous studies have explored verjuice's potential use as a salad dressing and for pickling vegetables. As pickling was not mentioned by consumers in earlier research, it was not investigated in this study. Dupas de Matos et al. (2018) indicated that verjuice and lemon juice were similarly liked as salad dressing, both characterised by lemon, high acidity, bitter, astringent, and runny viscosity. The subsequent study indicated that verjuice-pickled samples were equally appreciated as the commercial samples pickled in vinegar, with different levels of perceived sweetness, acidity, saltiness, and bitterness penalising liking (Dupas de Matos et al., 2019) indicating different sensory characteristics are sought in verjuice based on situational use. In fact, high acidity and other sensory aspects perceived as negative in the current study for use as a beverage, may be well-received when paired with other ingredients in a drink, such as cocktail or mocktail, or with other food matrices (like pickled-vegetables, salad dressings). Other studies have also highlighted differences in appropriateness for use within the same product category. For instance, Stolzenbach et al. (2016) showed that most liked apple juices received higher ratings for appropriateness across different use situations: sweet version was more suitable for breakfast, sour version more appropriate for special occasions. This highlights the importance

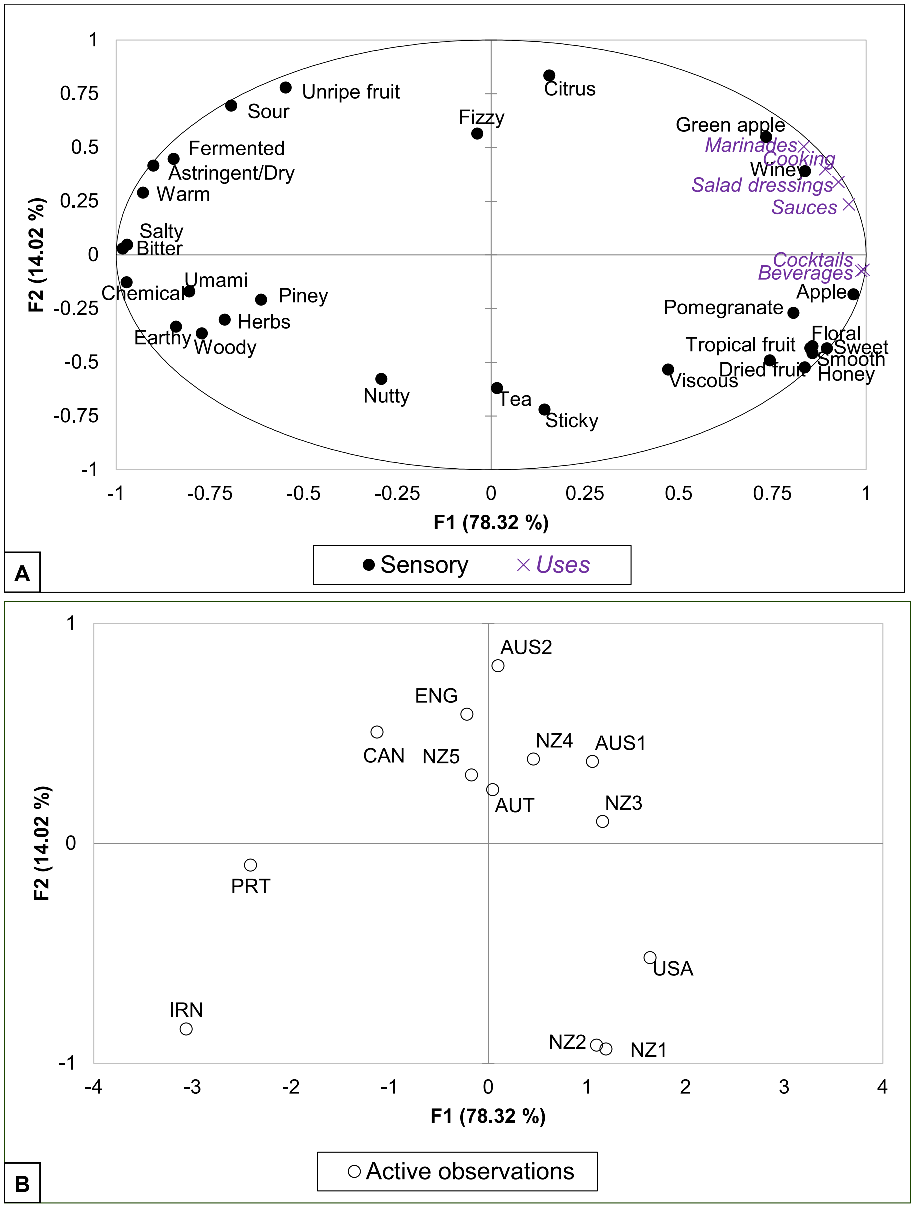

Fig. 5. **A)** Multiple Factor Analysis F1/F2 Biplot, accounting for 92.34% total variance across the first 2 factors. Sensory terms (black filled circle) and Uses (purple cross) loadings. **B)** Verjuice samples observations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of further research taking into consideration specific intended/situational uses when pinpointing ideal levels of acidity and other sensory attributes that influence consumer verjuice preferences. Moreover, connecting sensory characteristics to particular uses (e.g., culinary versus mixology) presents an avenue for clearer labelling, enhancing consumer understanding in which ways to utilise the product. This approach has the potential to broaden the scope of applications for verjuice enabling producers to enhance product positioning in the market and diversify their business even more. Additionally, future studies are needed to investigate the sensory drivers of liking in other use-case scenarios (e.g., in a cocktail or mocktail) more deeply to determine whether certain sensory attributes would influence liking differently when combined within another beverage or food matrix.

4.4. Consumer acceptability

This study indicated that variation in overall liking across verjuice samples was evident. The findings highlighted that verjuice could be favoured as a beverage if characterised by sweet-related fruity and floral flavours, and smooth mouthfeel. These characteristics did not seem to be linked to any particular grape, as the most liked samples were not associated with any specific grape variety or country of origin. Interestingly, these most liked verjuice products are marketed for culinary purposes, including marinades, cooking, deglazing and sauces, serving as alternatives to vinegar and lemon juice, missing an opportunity for producers to consider and promote their verjuice for a more diverse range of applications beyond current culinary uses.

The correlation and penalty/lift analysis validated a link between higher sugar content and increased liking scores, aligning with qualitative consumer feedback reported in Dupas de Matos et al. (2023)'s previous work, where sweeter verjuice was typically preferred for drinking purposes, sourer ones for cooking applications. The present research showed that certain sensory attributes were not favourable for drinking as a beverage (e.g., salty, bitter, herbs, high acidity), but could be justly marketed for culinary applications. Previous work has shown that perceived bitterness, sourness, and astringency were associated

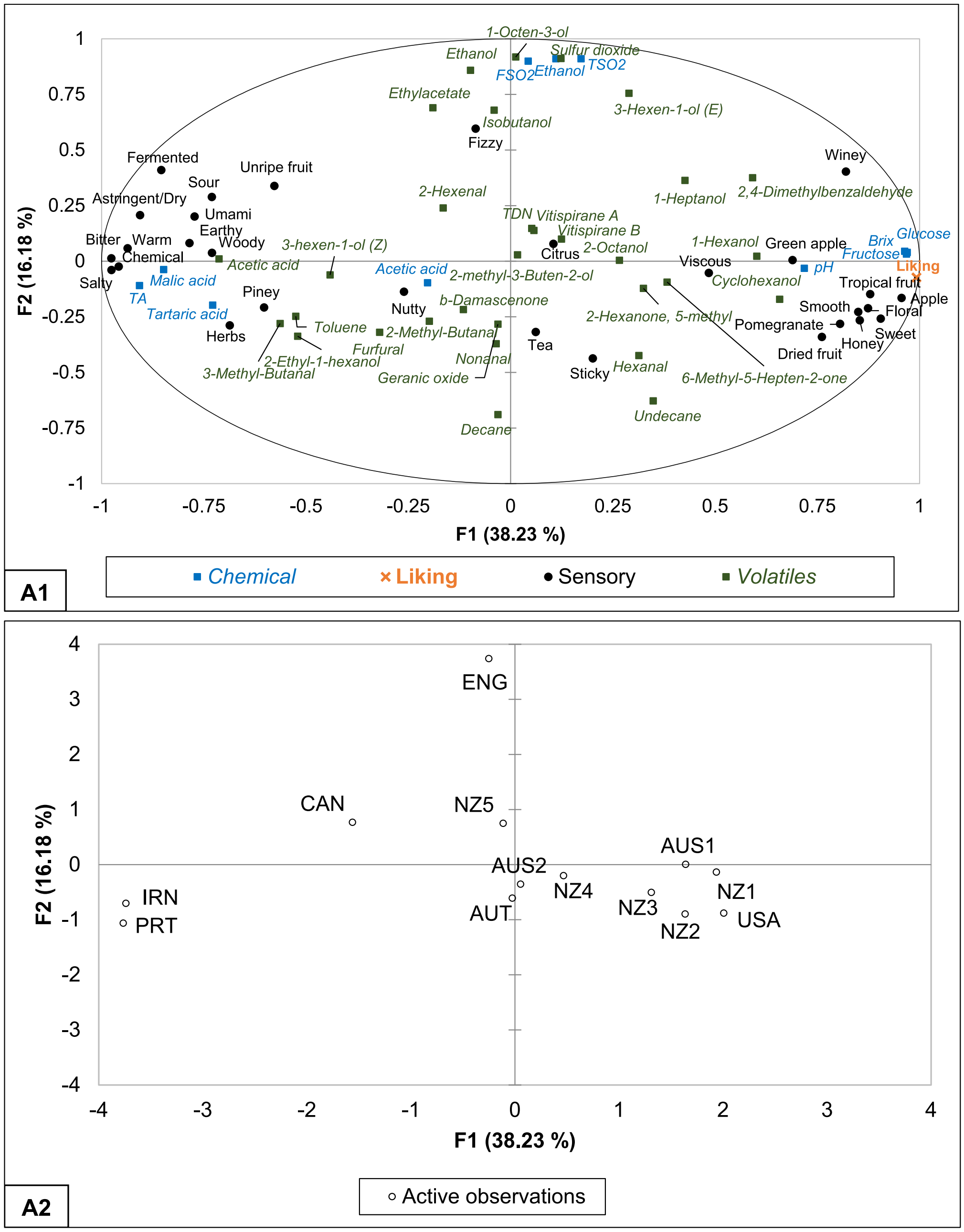

Fig. 6A1. Multiple Factor Analysis F1/F2 Biplot, accounting for 54.41% total variance across the factor 1 and 2. Liking (orange cross), Sensory attributes (black filled circle), Chemical (blue filled square), and Volatiles (green filled square) loadings. **A2)** Verjuice samples observations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

with phenolic compounds (Hufnagel & Hofmann, 2008). In fact, verjuice is rich in polyphenols, which include both flavonoid and non-flavonoid groups (Nikfardjam, 2008). Some of the flavour attributes penalising liking of verjuice as-is (e.g., woody, earthy) could be linked to these compounds (Ferrer-Gallego et al., 2014), although further investigation is required to confirm this association.

The correlation between liking scores and acidity appeared to be primarily influenced by the high acidity content in the less liked samples. In fact, the packaging directed consumers to such uses, for instance PRT is suggested for use in culinary applications, but also can be used as a tart ingredient in cocktails. However, the only verjuice (AUT) where packaging suggested it should be consumed as a drink was not well liked as a beverage and was characterised by attributes more associated to culinary uses. It was apparent that, in general, uses indicated on product labels (cooking vs drinking) did not necessarily align with product sensory characteristics. This is an important aspect to be considered by verjuice producers to better communicate product sensory signatures with consumers.

4.5. Emotional engagement

The study of emotions is increasingly important to develop more effective strategies for product innovation and optimisation (Spinelli & Jaeger, 2019), in other words, there is a need to go "beyond liking". The general idea of verjuice evoked positive, not negative, emotions amongst consumers (Fig. 2). The emotions evoked by the idea of verjuice had different levels of arousal/activation, varying between medium (good, happy, interested) and high (adventurous, curious, enthusiastic) arousal/activation (Jaeger et al., 2018). Baker et al. (1992) indicated that happiness and excitement positively correlate with willingness to

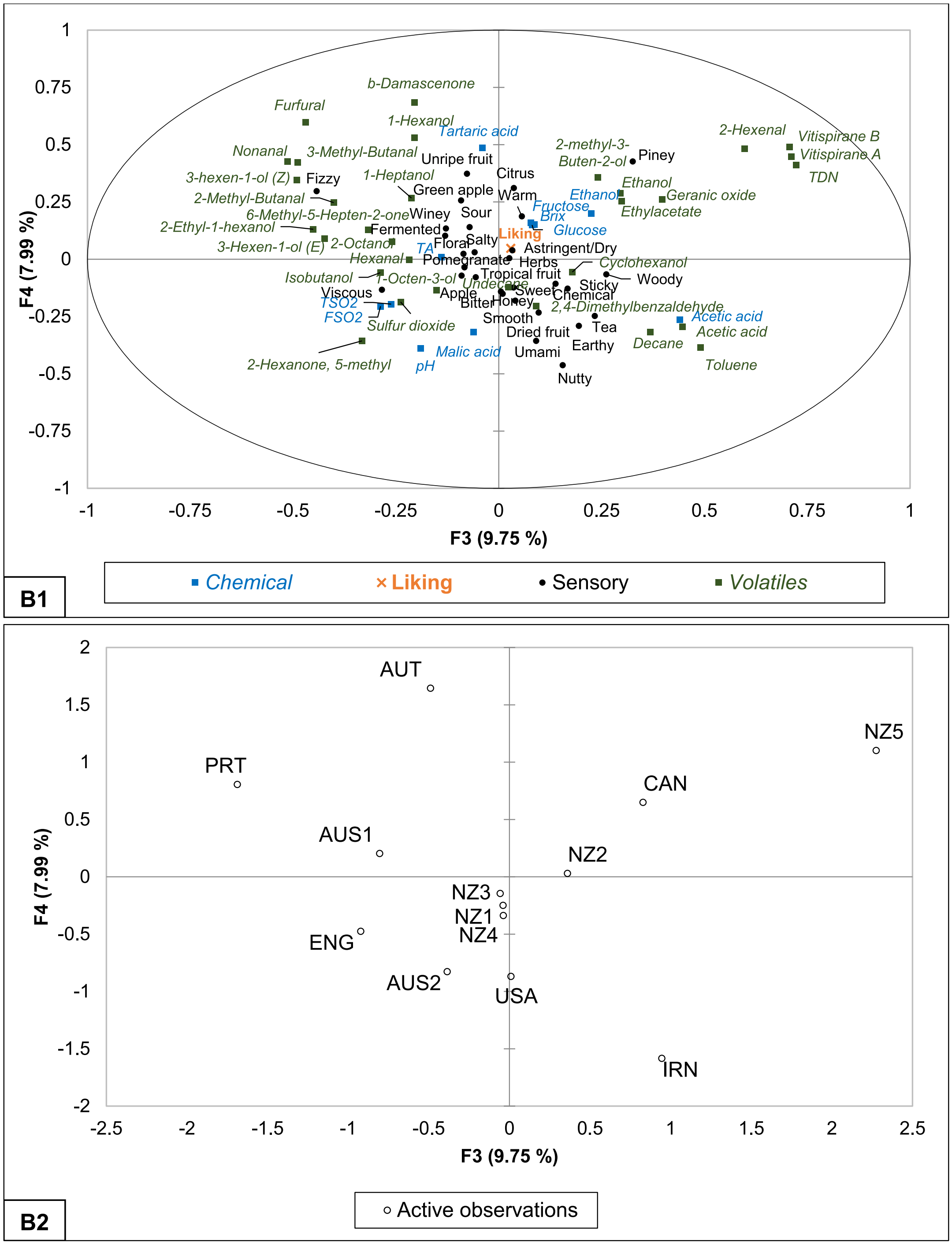

Fig. 6B1. Multiple Factor Analysis F3/F4 Biplot, accounting for 17.74% total variance across factor 3 and 4. Liking (orange cross), Sensory attributes (black filled circle), Chemical (blue filled square), and Volatiles (green filled square) loadings. **B2)** Verjuice samples observation.

purchase. The emotions indicated that consumers would be likely to purchase verjuice albeit dependent on the price. However, forthcoming research is needed to evaluate emotional responses across various verjuice products, elucidating the correlation between sensory characteristics and evoked emotions. Establishing associations with positive emotions can greatly strengthen consumer purchasing behaviour, whilst connections with negative emotions can lead consumers to avoid a product (Mora et al., 2021; Samant & Seo, 2020). Therefore, the findings here can support industry in incorporating emotion words in marketing campaigns to help create products that are emotionally engaging (e.g., curious, enthusiastic), influencing purchase decisions and supporting verjuice innovation. In the case of wine and the drinking experience, it seems that people predominantly use words associated with enjoyment/pleasure, rather than words that suggest displeasure (Ferrarini et al., 2010). In the current study, consumers who were previously familiar with verjuice exhibited a positive emotional response in general to the verjuice product idea. Consumers who were not familiar felt more curious, whereas those with some level of familiarity felt happier and more satisfied. Previous studies have observed this effect in other product categories (e.g., Desmet & Schifferstein, 2008; Mielmann et al., 2022), therefore understanding the effects of familiarity can inform the wine industry on potential future consumer engagement with verjuice and is vital for enhancing verjuice appeal.

Previous studies reported that verjuice is still relatively unknown in many countries, but a specific percentage has not been provided in consumers studies and may not have been a study question. Additionally, consumers generally lack awareness of verjuice's incorporation into dishes and beverages (Dupas de Matos et al., 2023). In the present study, 25 % to 35 % of consumers stated they had used verjuice for cooking/seasoning foods and drinking, respectively, whereas more participants were familiar with verjuice in Dupas de Matos et al. (2023)'s work. Communication efforts aimed at raising awareness, educating consumers, and building positive associations will contribute to increase familiarity with verjuice. Also, leveraging emotional responses to verjuice will be important for enhancing product positioning in the marketplace and generating consumer interest. For unfamiliar users, producers could focus on educational content to introduce them to verjuice basics, for example, what verjuice is, how it is made highlighting its use of waste materials in grape/wine production, and its versatile applications in cooking and mixology by highlighting unique sensory characteristics to spark consumers' curiosity and interest across different channels. Additionally, tasting events could offer a firsthand experience to increase familiarity, as could promotion through chef/cook shows, food/beverages fairs, as well as cellar door visits – which has previously been adopted by verjuice producers (Dupas de Matos et al., 2023). Instead, for familiar users, producers could emphasise verjuice's versatility in terms of application by providing appealing recipes on social media, winery websites, and food/drink-related magazines as a way to diversify use-case scenarios. Verjuice consumers are typically perceived as those who enjoy experimenting with new products, foodies, and cocktail and/or mocktail lovers (Dupas de Matos et al., 2023). Utilising storytelling (Hall, Harrison and Obilo, 2023) could strategically position verjuice, enhance consumer engagement and market penetration, and influence consumption experiences, for both unfamiliar and familiar users. Indeed, evaluating emotional responses beyond the general idea as a product is pivotal for gaining deeper insights into consumer preferences and behaviours.

4.6. Chemical composition driving sensory characteristics in verjuice

Findings highlighted the potential to tailor verjuice for specific uses by understanding the chemical parameters linked to desired sensory profiles. Higher sugar contents were closely linked with sweet-related notes, such as fruity and floral, which also co-occurred with 1-hexanol and cyclohexanol. The volatile 1-hexanol is known to contribute to sweet, fruity and floral notes (e.g., Lu et al., 2023), and cyclohexanol is responsible for fruity, minty, camphor-like nuances (e.g., Burdock, 2010; Negri et al., 2015). On the other hand, the volatile acetic acid was co-located with earthy, woody and chemical notes, opposed to liking. The compounds 3-methyl-butanal, 2-ethyl-1-hexanol, and toluene, known for burnt (Isogai & Wise, 2016), earthy (Rettinger et al., 1991), chemical/benzene-like odours (Burdock, 2010), respectively, were co-located with piney and herbs more likely to be accepted in culinary/cooking uses. Perng and McDaniel (1989) showed that sugar concentration improved fruity flavour perception, whilst high acidity lowered it, in line with current study. For instance, the verjuice from the USA, characterised by notably higher levels of glucose and lower levels of malic acid (as shown in Table 2), was perceived as having one of the most pronounced sweetness and apple flavour intensities (78.5 % and 61.3 % citation, respectively, **Table S3**). Understanding the link between chemical composition and sensory profiles is essential for understanding product quality and allows for the creation of verjuice styles with targeted sensory characteristics. If intended for drinking, consumers sought sweeter fruity, floral and honey notes; whereas for culinary uses (e.g., salad dressings, marinades) preferences leaned towards winey-like, green apple, and sourness. Knowledge concerning the link between chemical composition and perceived sensory characteristics can help producers better optimise verjuice quality to enhance the overall product experience for the consumers. Furthermore, this understanding will help them to link sensory attributes of their products to consumer desired applications. In wines, achieving the right balance between fruity and green characteristics is challenging due to enhancing and masking effects between different compounds (Deed, Fedrizzi and Gardner, 2017). Ribéreau-Gayon et al. (2021)'s book elaborates that not all volatile compounds equally impact wine aroma. Abundance of compounds typically influences the perceived intensity of aromas. Moreover, some compounds, even in trace quantities, may significantly influence aroma, whilst others may only slightly contribute. In this study, metabolites were not quantified for odour activity value determination but provide guidance for future work to further understand key compounds driving sensory perception.

In previous work by Niimi et al. (2017), astringency was demonstrated to comprise the absence of softness and smoothness, and the presence of dryness, puckering, burning and bitterness. The authors also showed that increased astringency decreased liking in wines, in agreement with current study where warm/burning sensation in verjuice was perceived more in PRT and IRN samples (41 % citation frequency, **Table S4**), despite no ethanol, and was associated with astringency, sourness and bitterness, overall. Dupas de Matos et al. (2023) observed that participants expressed uncertainty regarding the non-alcoholic nature of some verjuice samples assessed. Interestingly, participants also used words like woody/oaky to describe samples, even though barrel aging is not part of the verjuice making process. In fact, this was confirmed in the current study, where such attribute was mainly present in IRN sample (46 % citation frequency, **Table S4**), even though barrel step/aging is not part of any verjuice making process. In verjuice, consumers have previously noted sensory traits reminiscent of white wine or Riesling grapes (Dupas de Matos et al., 2023). The sample NZ5, derived from Riesling grapes, exhibited the highest level of TDN. Whilst low levels of TDN are desirable, excessive concentrations of this compound can introduce undesirable sensory characteristics, potentially leading to consumer rejection (Sacks et al., 2012). Although quantification of this compound was not conducted, this observation can advise producers to have caution regarding the presence of TDN in verjuice to be consumed as-is, but it could be fine if in a drink mixture (e.g., cocktail) or with other food matrixes. Overall, the interplay of acids, sugars and volatiles collectively can provide a better understanding on product quality to shape the sensory characteristics of verjuice.

5. Conclusion

The consumer-centric approach identified the sensory drivers of liking, which can serve as a guide to verjuice developers, mainly wine/grapegrowers, highlighting key sensory attributes when tailoring verjuice for beverage (as-is) consumption. The findings highlighted the potential to tailor verjuice for different uses, showing the importance of considering distinct sensory characteristics for the intended use. Considering the versatility of verjuice in multiple scenarios, it represents a product with promising economic potential. This applies to current verjuice producers but also for those in the wine sector seeking non-alcoholic options considering the fast-growing no-alcohol and/or low-alcohol sector.

Some chemical compounds linked to sensory attributes were identified. Volatiles 1-hexanol and cyclohexanol were associated with desired sensory attributes perceived by consumers, whilst acetic acid, 3-methyl-butanal, 2-ethyl-1-hexanol, and toluene likely contributed to less desired notes in verjuice as a beverage. Higher sugar content enhanced perceived sweet-related fruit and floral notes, which can direct producers to make informed decisions during production processes (e.g., picking grapes a bit later for more residual sugar content) catering to consumer preferences as a beverage. Conversely, acidity parameters and less desirable sensory attributes for drinking may be accepted in other applications, e.g., cooking, marinades, and salad dressings.

By tapping into consumer emotions towards verjuice, marketing campaigns can create a stronger emotional connection between consumers and verjuice, leading to increased product appeal. Moreover, verjuice promotion is crucial to increase consumer familiarity and awareness, expanding its market demand and leading to increased opportunities for growth in the grape and wine sector driving product diversification and revenue expansion, whilst aligning with the wine industry's sustainability goals.

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CRediT authorship contribution statement

Amanda Dupas de Matos: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mariza Gomes Reis:** Visualization, Formal analysis, Data curation. **Robyn Maggs:** Investigation. **Joanne Hort:** Writing – review & editing, Supervision, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary material

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