Research article

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Quantitative sensory characterisation of, and distinction between, Argentine ciders

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This work reports the quantitative sensorial characterisation of Argentine ciders from the Patagonia and Cuyo regions. Argentine cider has been undervalued by consumers in recent years - a challenge to which the academic and manufacturing sectors have risen. Sensory analysis characterised 17 large scale ('industrial') and one small scale ('artisanal') Argentine ciders. Some of the ciders had a fruity aroma with predominant apple notes, whereas others had unwanted sediment and sulphite odours. Based on the quantitative aroma results, the ciders were distinguished by principal components analysis (PCA) with two groups discriminated by the apple and sediment descriptors. The ciders were similarly characterised and distinguished by flavour. The work reported here can be used by cider producers to improve their products.

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Keywords: Argentine ciders; Patagonia; Upper Valley of the Río Negro and Neuquén; sensory analysis

Introduction

This work provides a quantitative analysis of the sensory quality of Argentine ciders - information that might be used by manufacturers to improve the quality of their products. Argentine cider has been undervalued by consumers in recent years. Consumers disliked Argentine ciders in the last ten or fifteen years as its quality had decreased due to the use of defective apples and the lack of strict controls during cider making. Consequently, consumers prefer other beverages, such as champagne, wine and beer.

While beer and wine are the most consumed alcoholic beverages in Argentina *(1)*, the cider industry produced some 900,000 hL of cider in 2017. In comparison, production in Europe - which is focussed on carbonated cider – is dominated by the UK with 5,800,000 hL, followed by France (1,300,000 hL), Germany (1,100,000 hL) and Spain (800,000 hL) *(2)*. In the USA, production in 2015 was 2,000,000 hL *(3)*. Argentina mostly produces carbonated cider while in other countries with a longer cider making tradition (such as Spain), natural cider – cider with just endogenous carbon dioxide - is produced *(2)*. Cider consumption in Argentina is significant during the Christmas holidays, with larger producers seeking to promote the consumption of cider throughout the year *(2)*. The cider consumed in Argentina is mainly produced at a large, industrial scale with artisanal cider boosted by entrepreneurs new to the sector *(2)*.

Research in cider production, composition and product improvement has existed for many years. Uthurry et al. *(2)* characterised Argentine ciders physicochemically and sensorially from a *qualitative* viewpoint, but there are no reports on the *quantitative* sensorial analysis of Argentine ciders. The cider produced in other countries, however, has been the subject of much quantitative analysis. For example, Leguérinel et al. *(4)* developed a method of evaluating ciders based on instrumental analyses and used multiple linear regression models to correlate sensory profile data with the concentration of glucose, fructose, malic, lactic and acetic acids, ethanol, fusel alcohols, isobutanol, ethyl acetate, 2,3-butandiol and the titratable acidity. In further work, the same authors assessed the role of the yeast strain in the formation of flavour components, as well as the influence of the fermentation temperature on flavour development *(5)*. Antón et al. *(6)* studied the aromatic profile of Asturian ciders (from northern Spain) using gas chromatography and olfactometry and other sensory analyses. Zhao et al. *(7)* studied the volatile composition of ciders after alcoholic fermentation and detected several compounds that contributed to their fruity notes *(8–10)*. Symoneaux et al. *(11)* studied the effect of the concentration and degree of polymerisation of apple procyanidins in ciders since these compounds are responsible for the perception of astringency. Alonso-Salces et al. *(12)* reported that procyanidins and their degree of polymerisation to be responsible for bitterness, and Song et al. *(13)* that their enzymatic oxidation affects the colour of cider. According to Lea, hydroxycinnamic acids can be precursors of volatile molecules involved in cider aroma *(14)*. Symoneaux et al. studied the influence of cider aroma on flavour sensations *(15)* and the effect of carbon dioxide on different cider matrix components (fructose, organic acids, phenols and ethanol) on sensory impression *(16)*. Le Quéré et al. *(17)* characterised French ciders in terms of their sensorial, chemical and technological features, while Qin et al. *(18)* studied the flavour profiles of UK and Scandinavian apple ciders using sensory profiling and the analysis of their volatile and non-volatile components. In other work Tarko et al. *(19)* studied the influence of apple tree cultivar

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and fermentation yeasts used on the composition of volatile organic compounds in ciders, and on their sensory properties. They reported that ciders obtained from Rubin and Topaz apples using distillery yeasts returned the poorest sensory evaluation with wine and cider yeasts performing the best.

Wei et al *(20)* studied the enhancement of flavour complexity of cider fermented by non-*Saccharomyces* yeast species with *Pichia kluyveri*, *Hanseniaspora vineae*, *Hanseniaspora uvarum* and *Torulaspora quercum* used for apple juice fermentations in single and mixed cultures. Esters such as 3-methylbutyl acetate, 2-methylbutyl acetate, ethyl hexanoate, ethyl octanoate and β- damascenone were found to contribute to fruity, floral and sweet notes, while acetate esters contributed to roasted and cooked notes. Wei et al. *(21)* also studied the fermentation of apple juice using *Hanseniaspora osmophila* and *Torulaspora quercum* in pure, simultaneous and sequential culture, and noted that ethyl esters and terpenes contributed to the dominant temperate fruity aroma. Finally, Wang et al. *(22)* used recombinant fusant yeast strains (obtained by protoplast fusion of *Saccharomyces cerevisiae* and *Candida ethanolica*) for the production of cider with low alcohol content and enhanced aroma. Two fusants, R_5 and R_6, produced ciders with excellent sensory scores.

The work reported here describes the first quantitative sensorial analysis of the country's ciders, along with new physicochemical data, that could be used to help producers improve the quality of these beverages.

Materials and methods

Samples

Eighteen Argentine ciders were examined (six bottles of each cider from the same production batch), 17 from the Upper Valley area (Patagonia), and one from the Province of Mendoza (Cuyo region). Two of the 18 ciders were carbonated by secondary fermentation using the Champenoise method ('sparkling' ciders), whereas the remaining ciders were carbonated under pressure with exogenous carbon dioxide ('carbonated' ciders). Nine were purchased in supermarkets and nine were provided by producers. All were stored at 4°C until analysis.

Physicochemical analyses

Physicochemical analyses were performed according to Argentine National Institute of Viniculture (INV) standard methods; these are based on the norms of the Office Internationale de la Vigne et du Vin [OIV, Paris] *(23)* for alcoholic beverages. Titratable acidity was measured by titration with a 0.1 N NaOH solution with bromothymol blue as the indicator. Free and total sulphur dioxide were analysed by the Ripper method, volatile acidity by the Jaulmes method, pH by potentiometry, and reducing sugars by the Fehling method. The alcohol content was determined using distillation and measuring the density of the distillate. The dried extract content was determined by heating in a boiling water bath and weighing the dry residue. The reduced dried extract content was determined by subtracting reducing sugars from the dry residue, and the ash content by heating the cider at 525°C and weighing the final product. All measurements were made in (at least) duplicate.

The total polyphenol index (TPI) was measured (in triplicate) using the Folin-Ciocalteau method of Waterhouse *(24)*, with a slight modification, based on that used by Slinkard and Singleton *(25)*. Cider (20 μL) was added to 1.58 mL of distilled water and 100 μL of Folin-Ciocalteau reagent and mixed well. After 8 minutes, 300 μL of saturated sodium carbonate solution was added. The mixture was shaken, and then left at 40°C for 30 minutes. The absorbance was measured at 765 nm using a UV-VIS spectrophotometer to determine the total phenols content (expressed as mg gallic acid/L) against a corresponding calibration curve.

Sensory analysis

Panel training. Nine trained assessors from academia and industry were further trained in quantitative sensory evaluation at the National Institute of Industrial Technology following the recommendations of the Argentine Institute of Rationalization of Materials (Norm IRAM 20005-2: Sensorial analysis. Complete guide for the selection, training and monitoring of the evaluators. Part 2: Expert evaluators).

The volunteers were asked to confirm that they drank cider, and details were recorded on their diet, any medications taken, possible illness, and lifestyle. They were then presented with odour standards of different intensity score as follows: low (mineral water) = 0, medium (powdered grapefruit juice reduced in sugars) = 6, and high (ground menthol tablets) = 12. This provided them a scale on which to later judge the intensity of the cider aroma variables. The panel members were also presented with commercial odour standards for amyl alcohols (n-butanol), acetaldehyde, solvent/ketone (ethyl acetate), almond, alcoholic (6% v/v ethanol in water), cider alcohol (spirit obtained by base cider distillation) and dairy (diluted lactic acid) in 30 mL screw-cap, brown bottles. They were also presented with other in-house produced natural standards of fresh Red Delicious apple, over-ripe Red Delicious apple, fresh Granny Smith apple, pear, pineapple, grass, soil, yeast, apple stalk, apple seeds, highly sulphited base cider, and cider lees. In later tests with cider, these odours were given odour intensity scores based on the intensity of the compounds used to produce the above 0-12 scale. Finally, the panel members were introduced to off-aromas such as hydrogen sulphide and sulphite, which in tests would also be graded on the same 0-12 scale (Table 1 shows all the above 27 descriptors).

The panel members were trained to recognise basic tastes (sweet, sour, salty and bitter), non-basic tastes (e.g., metallic) and mouthfeel attributes (e.g., astringent), using solutions of anhydrous caffeine (*purissimum*; bitter taste), sodium chloride (analytical grade; salty taste), ferrous sulphate 7-hydrate (analytical grade; metallic taste), aluminium sulphate 18-hydrate (analytical grade; astringent attribute), anhydrous citric acid (analytical grade; sour taste) (all purchased from Biopack, Buenos Aires, Argentina) and commercial sucrose (sweet taste) (Ingeniero Ledesma SAAI, Jujuy, Argentina). Their consensus scores for different concentrations of the compounds providing these tastes were then recorded to provide a 1-12 scale for each.

Sweet: 1 (4.0 g/L); 7 (20.0 g/L); 9 (25.0 g/L)
Sour: 2 (0.25 g/L); 8 (1.0 g/L); 10 (1.5 g/L)
Salty: 1.5 (1.25 g/L); 7 (5.0 g/L); 11 (8.0 g/L)
Bitter: 1 (0.125 g/L); 7 (0.5 g/L); 9 (0.8 g/L)
Astringent: 1.5 (0.25 g/L); 8 (1.0 g/L); 12 (1.5 g/L)
Metallic: 1 (0.005 g/L); 6 (0.02 g/L); 8 (0.04 g/L)

The panel members were given 30 taste standards (see Table 2) which in tests would also be graded on the same 0-12 taste scale. Six of these taste standards corresponded exactly to the six

Table 1. Aroma descriptors used in the quantitative sensory analysis

Class	Descriptor	Descriptor (Spanish term)	Recognition of descriptor via
Alcohol/solvent odours	amyl alcohol	alcoholes amílicos	pure compound
	cider alcohol	alcohol de sidra	sample test
	ethanol	etanol, alcohol	pure compound
	ketone	cetónico	pure compound
	sherry	Jerez	sample test
Fermented odours	lactic, lactic acid, dairy	lácteo	pure compound
	yeast, bread	levadura, pan	natural standard
Flowery/fruity odours	apple	manzana	natural standard
	banana	banana	natural standard
	fermented apple juice	jugo de manzana fermentado	sample test
	fruity	frutal	sample test
	geranium	geranio	natural standard
	pear	pera	natural standard
	pineapple	ananá, piña	natural standard
Heavy/chemical odours	acetaldehyde	acetaldehído	pure compound
	sediment	borras, fondos de pileta	sample test
	oxidation	oxidación, jugo oxidado	sample test
	reduction, hydrogen sulphide	reducción, sulfuro de hidrógeno	sample test
	sulphite, sulphur dioxide	sulfuroso	sample test
Moisture odours	fungi	hongo, humedad	sample test
	soil	suelo, tierra mojada	natural standard
Vegetal odours	apple seed	semilla de manzana	natural standard
	apple stalk	pedúnculo de manzana	natural standard
	almond	almendra	natural standard
	grass	pasto, césped	natural standard
	herbaceous	herbáceo, leñoso	natural standard
Vinegary odours	acetic, acetic acid	acético, vinagre	pure compound

Note: Pure compound: pure substance in aqueous solution. Natural standard: in-house produced standards using fresh material. Sample test: cider samples showing the corresponding descriptors. For cider alcohol, distilled cider alcohol was used.

training standards (sweet, sour, bitter, salty, astringent and metallic). Body, persistence and equilibrium were measured on a scale of 0-10 based on the results of tasting preliminary cider samples.

Finally, the panellists were trained to recognise the visual characteristics of cider such as sparkling, foam, bubble size, colour, brightness and clarity as outlined in the above Argentine standard. Sparkling relates to the bubbles provided by carbonation, foam is the white upper layer of gas formed on pouring, and bubble size was reported considering the typical bubbles of soft drinks. For colour comparison, the panellists used the following scale: light green, pale, light, gold and amber. Brightness is the ability of a cider to reflect light, and clarity describes the presence of either suspended particles or hazy components. The evaluation of colour, brightness and clarity was qualitative whereas sparkling, foam and bubble size varied widely with the same cider sample and accordingly were not reported.

Panellist performance. Three ciders were assessed in quadruplicate by all nine panel members – who tested each cider sample in one single sensory session - and their results subjected to analysis of variance (ANOVA) to examine the influence of the interaction *panellist x sample* on the scores they returned for all variables. Significance was set at $P<0.05$. Those panellists who returned outlying results for certain variables received assistance to improve their performance.

The descriptors for which significant differences were recorded between cider samples in the above test were subjected to another ANOVA analysis involving the results of all panellists, contemplating the 'sample' as the fixed factor. This one-way ANOVA was performed for each panellist with sample (cider) as fixed factor. This analysis allowed the identification of panellists who recorded significant differences between samples for a descriptor. Significance was set at $P<0.30$ (a statistical requirement to take into account the variable nature of panellist subjectivity) *(26, 27)*. This test identified those panellists who could distinguish between samples with respect to a determined descriptor. These analyses allowed descriptors that scored consistently high values from most panellists to be discarded from the final evaluation if they were not able to distinguish between cider samples. Pungency was dropped for this reason and does not appear in the descriptor list. In flavour analysis, cider alcohol and reduction (hydrogen sulphide) were dropped as they were never detected by the panellists.

Finally, a generalised Procrustean analysis (see Statistical Analysis) was performed to examine the behaviour of each panellist with respect to the consensus use of the descriptors.

Assessment of 18 ciders. The panel members tested the 18 different ciders at 12–13°C in standard wine glasses, recording their results for the different descriptors. The sample randomisation design was a stratified random sampling as both industrial and artisanal ciders were studied. Both sample groups were selected on

Table 2. Flavour descriptors used in the quantitative sensory analysis

Class	Descriptor	Descriptor (Spanish term)	Recognition of descriptor via
Alcohol/solvent flavours	amyl alcohol	alcoholes amílicos	pure compound
	cider alcohol	alcohol de sidra	sample test
	ethanol	etanol, alcohol	pure compound
	ketone	cetónico	pure compound
	sherry	Jerez	sample test
Fermented flavours	lactic acid, dairy	lácteo	pure compound
Flowery/fruity flavours	apple	manzana	natural standard
	fruity	frutal	sample test
	pear	pera	natural standard
	pineapple	ananá, piña	natural standard
Heavy/chemical flavours	acrid	rancio, agrio	sample test
	sediment	borras, fondos de pileta	sample test
	oxidation	oxidación, jugo oxidado	sample test
	reduction, hydrogen sulphide	reducción, sulfuro de hidrégeno	sample test
	sulphite, sulphur dioxide	sulfuroso	sample test
Moisture flavours	soil	suelo, tierra mojada	natural standard
Mouthfeel attributes	astringent	astringente	pure compound
Mouthfeel features	body	cuerpo	sample test
	persistence	persistencia	sample test
Sensorial quality/balance	equilibrium	equilibrio, balance	sample test
Tastes	sweet	dulce	pure compound
	sour	ácido	pure compound
	salty	salado	pure compound
	bitter	amargo	pure compound
	metallic	metálico	pure compound
Vegetal flavours	apple seed	semilla de manzana	natural standard
	apple stalk	pedúnculo de manzana	natural standard
	grass	pasto, césped	natural standard
	herbaceous	herbáceo, leñoso	natural standard
Vinegary flavours	vinegar, acetic acid	acético, vinagre	pure compound

Note: Pure compound: pure substance in aqueous solution. Natural standard: in-house produced standards using fresh material. Sample test: cider samples showing the corresponding descriptors. For cider alcohol, distilled cider alcohol was used.
Definitions of mouthfeel features: **Body**: mouthfeel characteristic connected with the ability of cider to move and flow inside the mouth. A scale of 0 – 10 was used, based on sample tests with different bodied ciders; the body of mineral water was considered 0. **Persistence**: mouthfeel characteristic related to the time the sensorial attributes of a cider persist after tasting a sample. A scale of 0 – 10 was used, based on tests with ciders of different persistence.

the basis that industrial ciders are produced at a larger scale (than artisanal ciders), they are not generally bottled on site and are sweetened prior to bottling. Sensory testing temperature was performed at 12-13°C because - although Argentine ciders are consumed cold (7-8°C) - their sensory attributes are more easily detected. The order of the attributes in the evaluation was a) Visual: sparkling features (carbonation), foam, colour, brightness and clarity; b) Aroma: intensity, fruity, apple, pear, pineapple, banana, herbaceous, grass, apple stalk, apple seed, almond, sulphite, sediment, ethanol, amyl alcohol, cider alcohol, reduction, ketone, acetaldehyde, geranium, vinegar, lactic, oxidation, sherry, soil, fungi, yeast and fermented apple juice; c) Flavour: fruity, apple, pear, pineapple, herbaceous, grass, apple stalk, apple seed, sweetness, sourness, bitterness, astringency, salty, metallic, sulphite, sediment, oxidation, sherry, ethanol, amyl alcohol, cider alcohol, ketone, lactic, vinegar, acrid, reduction and soil; d) Mouthfeel texture attributes: body and persistence; e) Overall score: equilibrium.

Three to four samples were evaluated per session and some ciders were repeated 3-4 times without the panellist's knowledge, which allowed the variation of the results to be examined. The panellists cleansed their palates by drinking low-sodium mineral water and eating salt free crackers between samples. Odour standards of medium intensity *(6)* were available for checking to all panellists throughout the test. Such standards reminded panellists of aroma intensity for any descriptor and were provided during full evaluation because the panellists training had focused on aroma/odour recognition and intensity references were needed for scoring the aroma descriptors.

The test facility at the National Institute of Industrial Technology has sensory analysis booths, a large room with natural daylight and air conditioning. This is in line with the requirements for sensory analysis and were used throughout the testing of ciders.

Statistical analysis

The physicochemical data was subjected to PCA and cluster analysis (using the nearest neighbour conglomeration method).

Treatment of sensory data. The mean sensorial scores for each cider were calculated as follows:

$$\text{Average score of descriptor} = \frac{\sum_{i=1}^{n}(\text{Score given by panellist})_i}{n}$$

where n represents the total number of panellists (n = 9). The mean scores for the aroma descriptors provided a final data matrix of 24 ciders (ciders SD3, 14, 16, 17 were evaluated twice whereas cider SD5 was evaluated in triplicate) x 28 variables (the 27 descriptors plus an estimate of the aroma intensity). The mean scores for the flavour descriptors produced a data matrix of 30 variables for the 24 ciders.

The average values of the descriptors determined for each cider generated its sensory profile.

The sensory data was subjected to two-way ANOVA tests (panellist x sample, using panellist as random factor), and PCA. A two-way ANOVA (panellist x sample, panellist as random factor) was performed because no replicates were tested for the 18 ciders subjected to sensory analysis. The 'post-hoc' test used to identify significant effects when pairwise comparing the samples has been the Fisher´s Least Significance Difference (LSD). Partial least squares regression (PLSR) was used to study the correlations between the physicochemical and the sensorial data.

ANOVA tests, PCA, cluster analysis performed and Pearson correlations between variables were determined using Statgraphics Centurion XVII software (Statgraphics Technologies, Inc., The Plains, Virginia, USA). PLSR regression analyses were performed using Genstat Statistical Software 20th Edition (VSN International, Rothamstead, UK). Generalised Procrustean analysis was performed using XLSTAT 2019 software (Addinsoft, Paris, France).

Results and discussion

Panellist performance

Details of panellist performance are given in Supplementary Information. Generalised Procrustean analysis showed that, for the aroma analysis, two of the nine panellists (22.2%) returned outlying results and received further training. Sulphite and aroma intensity were more consistently recorded by the panellists, whereas apple and fruity showed a lack of consistency, probably due to the difficulty in discriminating the different fruity notes of apple, pear and pineapple. The panellists easily discriminated cider SD5 from ciders SD12 and SD13 (the three tested) as it returned higher scores for sulphite.

The analysis of the flavour data showed that three of the nine panellists (33.3%) returned outlying results and received further training. For sweetness, sourness, body and equilibrium the panellists generally scored the ciders according to the consensus. The panellists received further training before the full evaluation sessions. As these were weekly, performance was checked after each session to detect outlying scores.

Physicochemical evaluation of ciders

Table 3 shows the physicochemical data recorded for the ciders. None exceeded the legal volatile acidity limit (2.50 g/L) (all values were $\leq$ 0.93 g/L). The alcohol content complied with the Argentine Food Code (4.0-6.0% v/v for carbonated ciders and 6.4–6.9% v/v for sparkling ciders) and all complied with the regulations for ash content *(28)*. In addition, all the samples met the legal requirements for free and total sulphur dioxide content, and 89% met those for reduced dried extract content *(28)*. Among the variables not subject to legislation by the Argentine Food Code, the reducing sugar concentration was higher in the industrial ciders (mean 68.3 g/L) than in the artisanal cider (18.1 g/L). Titratable acidity ranged from 3.6 to 5.2 g/L, and the pH from 3.6 to 3.9, values in accordance with those expected for Argentine ciders. The total phenol content ranged from 180 mg/L to 496 mg/L.

Principal component analysis extracted five components that explained 87.8% of the variance and revealed 10 of the 18 ciders (55.6%) to be similar (SD1, 4 and 8, SD2 and 9, SD3, 5, 10, 13 and 16). This analysis clearly identified the sparkling ciders (Fig. 1) - SD15 (industrial) and SD18 (artisanal) - which also had the lowest concentration of reducing sugar (31.7 and 18.1 g/L) and the highest alcohol content (6.9 and 6.4% v/v) (Table 3). Cider SD7 was distinguished in terms of its high free sulphur dioxide content (102 mg/L).

The strongest correlations between parameters were for reducing sugar and alcohol (r = -0.83), and volatile acidity and total phenols (r = -0.70) ($P<0.05$). As previously reported *(1)*, the correlation between the reducing sugar and alcohol content was inverse. The negative correlation can be explained by the high alcohol and low reducing sugar contents of sparkling ciders SD15 and SD18, together with the insight that the sweetness of both carbonated ciders SD11 and SD12 are being intentionally reduced to increase quality. The volatile acidity and the total phenol contents also exhibited a moderate inverse correlation, with the industrial, carbonated ciders SD7 and SD17 having the highest volatile acidity (0.93 and 0.92 g/L) and relatively low concentrations of phenols. The remaining ciders revealed little correlation between these variables. Indeed, the high volatile acidity and low phenol contents of ciders SD7 and SD17 may suggest the interference of sulphur dioxide in the determination of the total phenol content using the Folin–Ciocalteau method *(24, 29–31)*. Indeed, Nardini and Garaguso *(29)* demonstrated that sulphites added to organic white wines overestimated the content of total polyphenols determined by the Folin–Ciocalteau method. Somers and Ziemelis *(30)* also reported that total phenol measurement using this method may be enhanced by sulphur dioxide, due to an artefact formed between sulphur dioxide and o – dihydroxy phenols. Moreover, Saucier and Waterhouse *(31)* proposed a synergistic mechanism between catechin and sulphur dioxide to explain this interference; they suggested that phenolic quinones – as former oxidation products of the Folin–Ciocalteau reaction – might be reduced to the phenol by the oxidation of sulphite to sulphate. This suggests that the lower the phenol content the lower the sulphur dioxide concentration, resulting in the cider being unprotected against microbial spoilage, which would raise its volatile acidity. However, the highest level of free sulphur dioxide was seen in cider SD7 (102 mg/L), which had an intermediate total phenol content (284.4 mg/L). This suggests this cider was strongly sulphited to prevent its volatile acidity content exceeding the legal limit. Cider SD17, which also had low free sulphur dioxide content (4.6 mg/L), had the lowest phenol content (179.7 mg/L); its volatile acidity may have increased due to lack of protection against microbial spoilage.

Cluster analysis using the nearest neighbour conglomeration method produced two clusters of ciders, best distinguished by their reducing sugar and alcohol contents (Fig. 2). Cluster 1

Table 3. Values for physicochemical variables for the different ciders

Variable	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
Titratable acidity (g. malic acid/L)	3.75 ± 0.00	3.88 ± 0.19	3.72 ± 0.14	4.62 ± 0.09	4.52 ± 0.05	4.35 ± 0.09	5.06 ± 0.05	3.72 ± 0.14
Free sulphur dioxide (mg/L)	51.7 ± 0.0	20.5 ± 1.3	32.1 ± 0.0	68.6 ± 1.3	16.9 ± 1.3	57.1 ± 2.5	102.0 ± 0.9	20.4 ± 0.0
Bound sulphur dioxide (mg/L)	40.1 ± 1.3	35.7 ± 5.0	69.5 ± 2.5	18.7 ± 3.8	54.4 ± 1.3	14.3 ± 0.0	172.1 ± 2.6	40.0 ± 1.3
Total sulphur dioxide (mg/L)	91.8 ± 1.3	56.2 ± 3.8	101.6 ± 2.5	87.4 ± 2.5	71.3 ± 2.5	71.3 ± 2.5	274.1 ± 1.7	60.4 ± 1.3
Volatile acidity (g. acetic acid/L)	0.03 ± 0.01	0.34 ± 0.07	0.24 ± 0.09	0.24 ± 0.09	0.74 ± 0.07	0.09 ± 0.01	0.93 ± 0.07	0.18 ± 0.01
Reducing sugar (g/L)	71.97 ± 3.65	93.97 ± 1.38	72.16 ± 0.00	87.65 ± 3.61	85.10 ± 1.14	69.92 ± 0.00	77.12 ± 1.86	65.11 ± 5.30
pH	3.62 ± 0.01	3.80 ± 0.01	3.77 ± 0.01	3.69 ± 0.00	3.76 ± 0.01	3.85 ± 0.02	3.69 ± 0.00	3.70 ± 0.01
Alcohol content (% v/v)	4.0 ± 0.0	4.0 ± 0.1	4.7 ± 0.1	4.1 ± 0.1	4.5 ± 0.0	5.4 ± 0.4	4.3 ± 0.2	4.7 ± 0.1
Dried extract (g/L)	93.89 ± 0.78	114.75 ± 4.51	87.62 ± 0.45	131.44 ± 1.91	108.19 ± 3.85	100.44 ± 4.38	99.54 ± 1.35	88.01 ± 0.54
Reduced dried extract (g/L)	21.92 ± 2.86	20.78 ± 3.13	15.46 ± 0.45	43.79 ± 1.70	23.09 ± 4.98	30.51 ± 4.38	22.42 ± 0.51	22.90 ± 4.76
Ash (g/L)	2.17 ± 0.27	2.91 ± 0.63	2.26 ± 0.13	3.59 ± 0.33	2.30 ± 0.11	4.10 ± 0.69	2.43 ± 0.11	2.29 ± 0.32
Total phenol index (mg gallic acid/L)	413.8 ± 12.5	415.0 ± 38.6	236.8 ± 65.5	415.1 ± 28.5	341.0 ± 28.3	367.3 ± 29.7	284.4 ± 18.0	463.2 ± 27.4

* SD18 is artisanal.

Table 3. *(Continued)*

Variable	SD9	SD10	SD11	SD12	SD13	SD14	SD15	SD16	SD17	SD18*
Titratable acidity (g. malic acid/L)	3.78 ± 0.14	4.39 ± 0.14	4.29 ± 0.19	3.85 ± 0.05	3.62 ± 0.19	3.85 ± 0.05	4.89 ± 0.09	3.85 ± 0.24	4.32 ± 0.05	5.16 ± 0.19
Free sulphur dioxide (mg/L)	7.4 ± 0.0	33.5 ± 2.6	3.7 ± 0.0	2.8 ± 1.3	4.6 ± 1.3	47.4 ± 1.3	45.5 ± 1.3	25.1 ± 1.3	4.6 ± 1.3	27.9 ± 0.0
Bound sulphur dioxide (mg/L)	43.7 ± 1.3	39.0 ± 2.6	77.1 ± 1.3	81.8 ± 5.3	83.6 ± 0.0	34.4 ± 3.9	74.3 ± 2.6	61.3 ± 0.0	25.1 ± 1.3	19.5 ± 1.3
Total sulphur dioxide (mg/L)	51.1 ± 1.3	72.5 ± 0.0	80.8 ± 1.3	84.6 ± 3.9	88.3 ± 1.3	81.8 ± 2.6	119.9 ± 1.3	86.4 ± 1.3	29.7 ± 0.0	47.4 ± 1.3
Volatile acidity (g. acetic acid/L)	0.31 ± 0.01	0.25 ± 0.03	0.38 ± 0.10	0.64 ± 0.08	0.46 ± 0.00	0.02 ± 0.03	n.d.	0.31 ± 0.04	0.92 ± 0.04	n.d.
Reducing sugar (g/L)	83.55 ± 2.19	73.35 ± 1.69	25.48 ± 0.31	29.33 ± 0.07	63.09 ± 1.25	81.32 ± 3.11	31.66 ± 0.79	79.98 ± 5.00	69.89 ± 5.72	18.06 ± 0.03
pH	3.65 ± 0.01	3.88 ± 0.01	3.76 ± 0.00	3.76 ± 0.01	3.65 ± 0.01	3.72 ± 0.02	3.72 ± 0.00	3.76 ± 0.01	3.76 ± 0.00	3.67 ± 0.01
Alcohol content (% v/v)	4.6 ± 0.0	5.8 ± 0.0	6.0 ± 0.1	5.8 ± 0.2	4.5 ± 0.3	5.0 ± 0.0	6.9 ± 0.3	4.6 ± 0.3	4.7 ± 0.1	6.4 ± 0.2
Dried extract (g/L)	108.07 ± 0.38	104.09 ± 15.90	106.95 ± 4.61	126.35 ± 3.93	98.09 ± 0.52	94.20 ± 0.88	52.53 ± 0.29	113.39 ± 0.69	106.32 ± 2.79	34.00 ± 0.39
Reduced dried extract (g/L)	24.52 ± 1.81	30.74 ± 17.58	81.47 ± 4.92	97.07 ± 4.00	35.00 ± 0.73	12.88 ± 3.99	20.87 ± 0.50	33.41 ± 4.32	36.43 ± 2.93	15.94 ± 0.41
Ash (g/L)	3.31 ± 0.13	2.14 ± 0.78	2.69 ± 0.34	2.40 ± 0.03	1.98 ± 0.00	2.62 ± 0.40	3.24 ± 0.10	2.29 ± 0.01	2.11 ± 0.04	2.75 ± 0.16
Total phenol index (mg gallic acid/L)	326.3 ± 36.2	394.5 ± 46.0	268.3 ± 15.4	353.8 ± 13.3	293.3 ± 53.3	496.0 ± 68.8	432.2 ± 15.6	374.6 ± 62.1	179.7 ± 33.7	446.8 ± 38.7

* SD18 is artisanal.

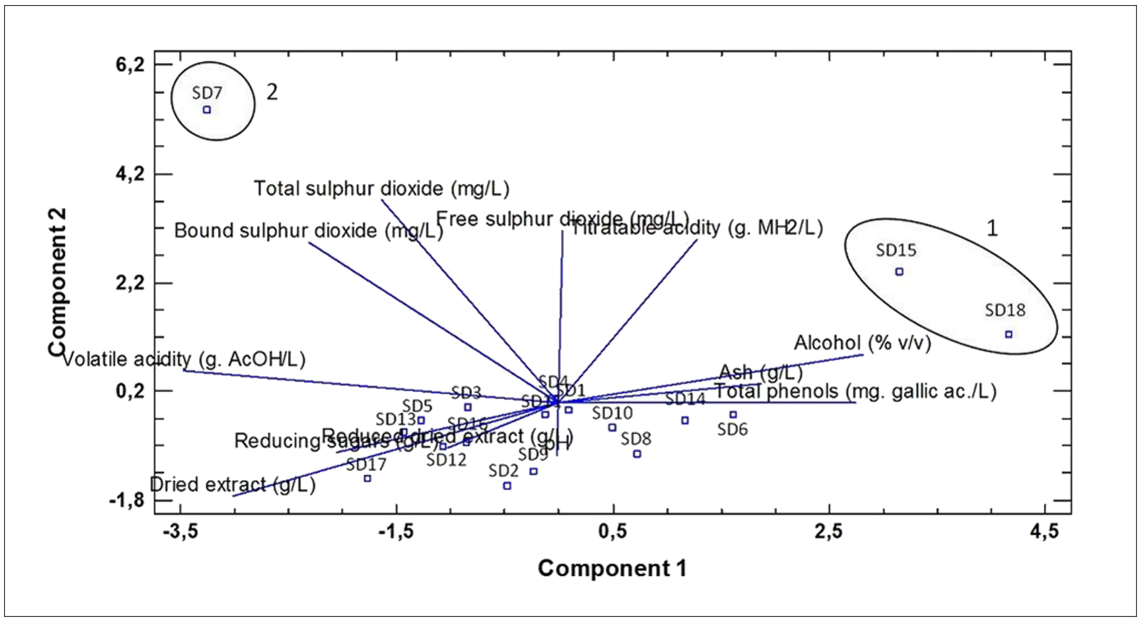

Figure 1. Principal component analysis grouping the sparkling (1) and highly sulphited ciders (2). [Colour figure can be viewed at wileyonlinelibrary.com]

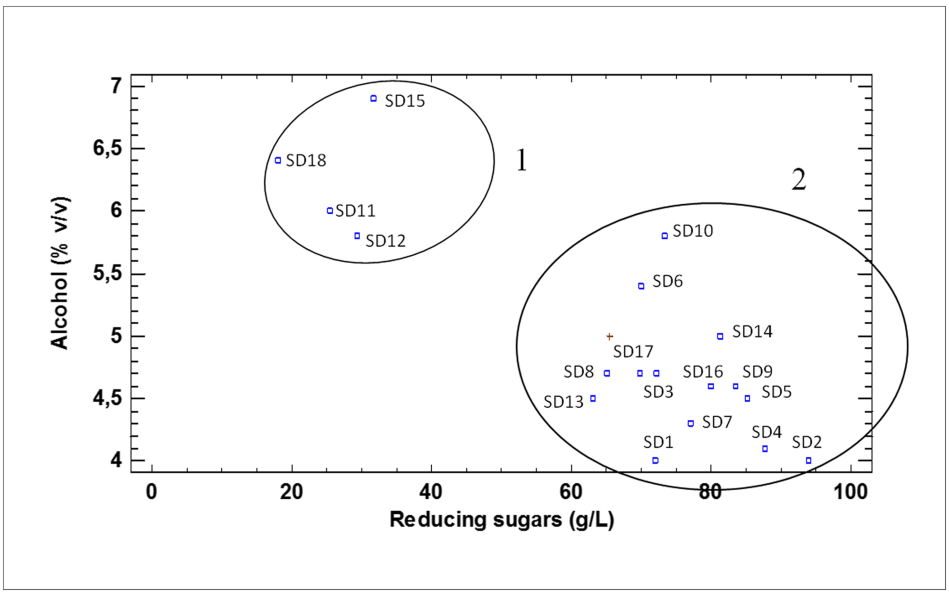

Figure 2. Cluster scattering showing two groups of ciders in terms of their physicochemical properties. [Colour figure can be viewed at wileyonlinelibrary.com]

comprised three industrial ciders (SD11, 12, 15) and the artisanal cider (SD18) with the lowest reducing sugar and higher alcohol contents. Ciders SD11 and SD12 were also distinguished by the low concentration of reducing sugar (25.5 and 29.3 g/L) and high alcohol content (6.0 and 5.8% v/v) (Table 3). Cluster 2 comprised 14 ciders with the highest reducing sugar and the lowest alcohol contents (SD1-10, 13, 14, 16, 17).

Sensory evaluation

As previously reported *(2)*, colour, brightness and clarity were more consistent parameters as foam and bubble size varied widely within the same sample. For more than 50% of the panellists, only one of the 24 ciders (SD3) was light green, seven (SD2, 5, 5-A, 5-B, 13, 17, 17-A) were gold, six (SD3, 4, 8, 14, 16, 18) were considered pale to light, four (SD9, 14-A, 15, 16-A) were light, and one (SD10) was pale. Eighteen ciders were bright for all panellists and six were assessed to be 100% clear by all panellists. Eleven ciders were considered to be either hazy or cloudy. Here, the haze found in some ciders reflected a lack of processing by some cider makers. For example, a lack of filtration, careless racking, the lack or insufficient use of clarifying agents (e.g. bentonite), the presence of yeasts (especially in sparkling ciders made by the Champenoise method – ciders SD15 and SD18-), and treatments such as 'framboisé' *(32)*.

A two-way ANOVA (panellist x sample, with panellist as random factor) was performed for the 24 ciders x 28 aroma descriptors data matrix. Nine of the 28 variables were significant for sample

($p < 0.10$): fruity, apple, almond, sulphite, sediment, amyl alcohol, reduction, acetic and sherry.

Principal components analysis (PCA) extracted three components that explained 64.9 % of the variance and revealed six of the 24 ciders (25.0%) to be similar (SD1, 4, 6, 8, 10, 15) with high sulphite, reduction and sediment scores (Fig. 3) (1.3-3.8, 0-0.9 and 0.4-1.6 respectively) (Table 4). In contrast, seven of the 24 ciders (29.0%) showed an apple and fruity aroma (SD2, 3-A, 5-B, 11, 16, 17, 17-A) (Fig. 3) (scoring 2.9-4.3 and 3.9-5.0 respectively) (Table 4). Marked correlations were for fruity and apple (r = 0.90), lactic and soil (r = 0.71), banana and grass (r = 0.70), sediment and reduction (r = 0.66), apple and sediment (r = - 0.64), and fruity and reduction (r = - 0.63). The correlation between fruity and apple was highly positive since apple contributed most to the fruity aroma of the ciders. This result agrees with that found by Le Quéré et al. in their research on the characterisation of French ciders *(17)*. The correlation between lactic and soil was surprisingly high since both descriptors returned very low scores and the lactic note was often detected together with soil. Banana and grass also showed a similar correlation because they also returned low scores thus explaining this unexpected result. Moreover, many zero values were recorded for most ciders.

The correlation between sediment and reduction (hydrogen sulphide) was important because sediments can contribute unpleasant aromas to cider. After alcoholic fermentation, ciders are left so that suspended particles (apple tissues, apple pomace and yeasts) settle out. Generally, this operation takes place in concrete vessels before racking the clariofied base cider. These vessels must be cleaned to avoid microbial spoilage. Apple and sediment showed a moderate negative correlation as the panellists considered sediment detrimental to the apple and fruity aroma, in agreement with Le Quéré et al. *(17)*. Sediment has a high content of vegetable matter and dead yeast which can be fermented by lactic and acetic bacteria, spoiling the cider. The higher the sediment score, the worse the sensory quality of a cider *(6)*. Fruity and reduction showed a similar correlation to that of apple and sediment because reduction is also detrimental to the fruity aroma.

A two-way ANOVA (panellist x sample, with panellist as random factor) was performed for the 24 ciders x 28 flavour descriptors data matrix. 14 out of the 28 variables were found to be significant for sample ($p < 0.10$): fruity, apple, herbaceous, apple stalk, sweetness, sourness, bitterness, astringency, sediment, salty, vinegar, body, persistence and equilibrium.

PCA of the variables extracted three components that explained 70.7% of the variance and revealed two of the 24 ciders (8.3%) to be similar (SD6, 10) with high sediment and low fruit scores (Fig. 4) (0.9-1.0 and 3.0-3.1 respectively) (Table 5). This agrees with the aroma analysis as panellists recorded high sediment scores for these ciders. Ciders SD15 and SD18 were revealed to be similar with high astringency and bitterness scores (Fig. 4) (1.6 – 1.7 and 2.1 – 2.2 respectively) (Table 5). Two of the 24 ciders (8.3%) were also shown to be similar (SD2, 16) (Fig. 4) with remarkably high fruit scores (5.4 and 5.3 respectively) (Table 5). This also agrees with the results of the aroma study since the panellists detected marked apple and fruity notes in these ciders.

The strongest correlations were seen between fruity and apple (r = 0.82), fruity and sweetness (r = 0.83), fruity and sediment (r = - 0.75), fruity and body (r = 0.74), fruity and equilibrium (r = 0.78), fruity and astringency (r = - 0.72), grass and herbaceous (r = 0.77), apple and equilibrium (r = 0.76), apple and sediment (r = - 0.74), sweetness and astringency (r = - 0.73), sourness and astringency (r = 0.72), bitterness and body (r = - 0.74), bitterness and equilibrium (r = - 0.70), and equilibrium and sediment (r = - 0.69). Fruity and apple showed a strong positive correlation since apple was the descriptor that mostly contributed to the fruity flavour of the ciders, and both descriptors are desirable fruity attributes *(16)*. The correlation between fruity and sweetness was strong, and this result agrees with the findings of Le Quéré et al. for French sweet ciders *(17)*. The reducing sugar content of 14 of the 18 ciders ranged from 63.1 to 94.0 g/L, above the limit of 35.0 g/L used to distinguish between bitter and sweet French ciders. The correlation between fruity and sediment was strongly inverse since sediment is a negative descriptor.

Body is a property of mouthfeel reflecting the flow of cider inside the mouth, the more body the heavier the cider flows. As reported by Gawel et al. *(33)*, it is a characteristic used in the wine sector with terms such as 'watery' – low in body, viscosity, and hence, easy to flow in mouth - and 'full' – a pressure against the tongue and surfaces, and difficult to flow in mouth. It closely connected to the term viscous described by the same authors

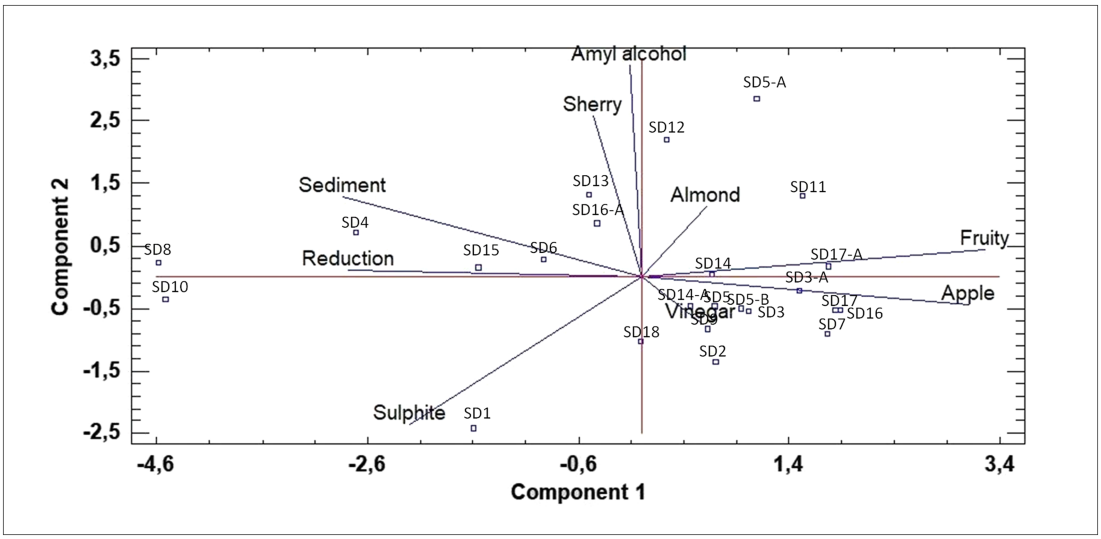

Figure 3. Principal component analysis of cider aroma showing fruity and sulphited ciders with sediment notes. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 4. Mean scores (n = 9) for the aroma variables for the different ciders

Variable	SD1	SD2	SD3	SD3-A	SD4	SD5	SD5-A	SD5-B	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	SD14	SD14-A	SD15	SD16	SD16-A	SD17	SD17-A	SD18*
Intensity	5.4	5.3	5.2	5.3	5.4	6.2	6.0	5.3	5.2	6.2	5.6	5.3	5.8	5.9	5.8	5.9	5.2	5.0	6.2	5.6	5.3	5.4	5.4	6.1
Fruity	2.9	3.9	3.7	4.8	3.2	4.1	5.0	4.8	3.3	5.2	2.3	4.1	1.7	4.8	4.0	3.1	4.2	4.1	3.4	5.0	3.6	4.9	4.6	3.9
Apple	2.7	3.4	3.4	3.7	2.3	3.3	4.1	4.2	2.1	4.1	1.4	3.0	1.3	2.9	2.9	2.4	3.1	2.8	2.2	4.1	2.3	4.3	4.2	3.1
Pear	0.2	0.7	0.3	0.2	0.0	0.2	0.7	0.3	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.2	0.1	0.2	0.1	0.2	0.3	0.1	0.1	0.0
Pineapple	0.1	0.0	0.2	0.1	0.0	0.4	0.0	0.0	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.3	0.0	0.1	0.2	0.0	0.0	0.3
Banana	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Herbaceous	1.0	0.1	0.6	1.1	1.0	0.8	1.3	0.8	1.0	0.9	1.3	1.1	0.9	0.9	1.1	0.4	0.8	0.6	1.1	0.8	0.9	0.7	0.4	0.8
Grass	0.0	0.0	0.0	0.7	0.2	0.1	0.0	0.1	0.1	0.0	0.3	0.0	0.1	0.1	0.2	0.0	0.2	0.3	0.4	0.1	0.2	0.3	0.2	0.2
Apple stalk	0.5	0.0	0.3	0.1	0.3	0.0	1.0	0.7	0.2	0.7	0.7	0.3	0.7	0.3	0.9	0.2	0.2	0.0	0.4	0.4	0.7	0.2	0.0	0.2
Apple seed	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.3	0.1	0.0	0.1	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.2
Almond	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulphite	3.8	1.8	0.9	1.1	2.0	1.1	0.6	1.6	1.3	1.9	2.6	1.2	2.0	1.0	1.2	1.0	1.2	1.2	2.2	0.8	0.8	0.9	0.9	1.6
Sediment	0.4	0.0	0.0	0.2	1.0	0.7	1.0	0.8	0.8	0.3	1.6	0.3	1.4	0.2	0.4	0.4	0.3	0.3	1.1	0.3	0.8	0.1	0.1	0.4
Ethanol	0.1	0.8	0.4	0.8	0.1	0.4	1.4	0.8	1.2	0.8	0.7	1.1	0.3	1.2	0.9	0.4	0.3	0.2	0.4	0.4	0.6	0.8	0.6	0.9
Amyl alcohol	0.0	0.0	0.1	0.2	0.6	0.2	0.7	0.1	0.3	0.3	0.0	0.0	0.1	0.2	0.9	0.1	0.3	0.1	0.4	0.0	0.4	0.1	0.0	0.0
Cider alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.3	0.0
Reduction	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2
Ketone	0.1	0.1	0.0	0.3	0.3	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0
Acetaldehyde	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.0
Geranium	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vinegar	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.7	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Lactic	0.0	0.0	0.0	0.4	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.0
Oxidation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.4	0.2	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
Sherry	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.7	0.0	0.0	0.2	0.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Soil	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Fungi	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0
Yeast	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Fermented apple juice	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: the cider marked with an asterisk is artisanal.

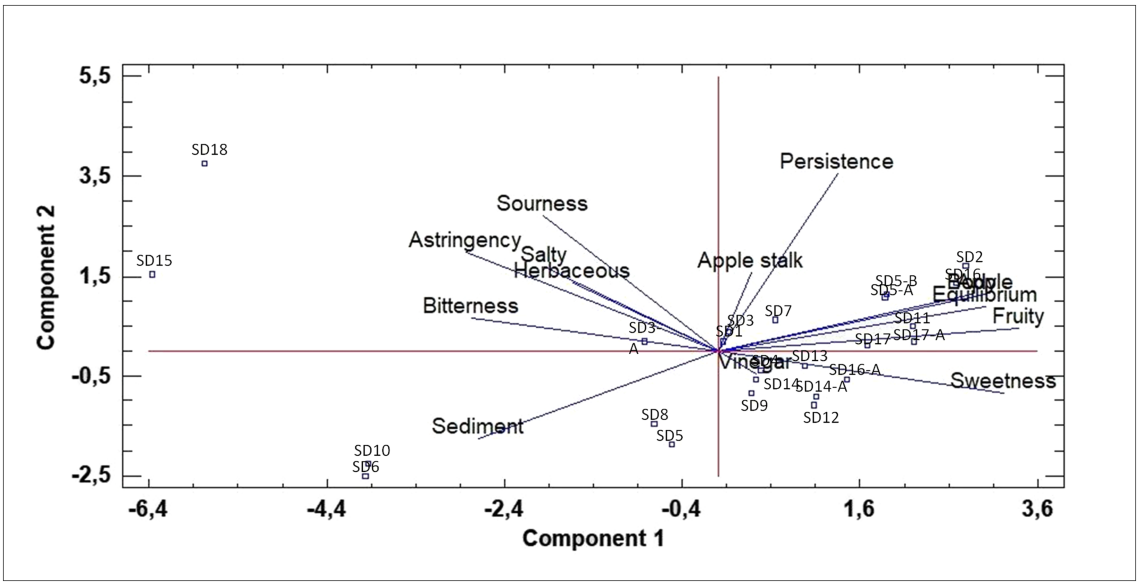

Figure 4. Principal component analysis of cider flavour showing fruity and ciders with sediment notes. [Colour figure can be viewed at wileyonlinelibrary.com]

for wine, as an apparent thickness which results in a pressure required to move the cider around the mouth *(33)*. Fruity and body - both variables of quality in ciders - showed a strong positive correlation. Equilibrium provides an overall assessment of a cider, taking into account its visual, aroma, flavour and mouthfeel characteristics. This term describes the balance between the sensory attributes of ciders, not only if balance is perceived between taste notes such as sour and sweet *(17)*, but also considers the presence of negative descriptors. Accordingly, the higher the equilibrium the higher the sensory quality of the cider. The strong correlation between fruity and equilibrium clearly highlights the positive contribution of the fruity character to a favourable overall assessment. Fruity and astringency showed a negative correlation since panellists found that astringent ciders revealed a lower fruity character; this result is in accordance with studies of French ciders *(17)* and UK and Scandinavian ciders *(18)*, which reported that ciders made using pure apple juice are characterised by astringency. It is noteworthy that Argentine cider is made from natural apple juice *(2)*. Grass and herbaceous showed a strong positive correlation since grass notes contribute to the herbaceous taste of ciders. The strong positive correlation between apple and equilibrium can be explained by the strong correlation between fruity and equilibrium. Apple and sediment showed a negative correlation similar to that shown by fruity and sediment. As explained above, apple mostly contributed to the fruity flavour of the ciders. Sweetness and astringency showed a strong negative correlation since ciders with lower sugar contents are usually more astringent, a consequence of the seeds and peel crushed during the processing of the apples. Moreover, the apple variety used can impart astringent and bitter tastes to ciders *(34)* depending upon the content of polyphenols *(35)*. The correlation between sourness and astringency was strong and positive. The synergistic effect between sourness and astringency has been previously reported in wine by Guinard et al. *(36)* and Kallithraka et al. *(37)*. Body showed an inverse correlation with bitterness since the more bitter ciders were found to be less rounded with less mouthfeel. The negative correlation between equilibrium and bitterness agrees with the results discussed above. Finally, the correlation between equilibrium and sediment was inverse as well since ciders with sediment tastes were regarded unacceptable by the panellists.

Correlations between flavour descriptor scores and physicochemical data were examined using PLSR2, with both X and Y multivariate. The 18 samples x 12 physicochemical variables were the X-matrix and the 18-samples x 14 flavour descriptors (those with $P<10\%$ significance level in separating samples) was the Y-matrix. Osten's cross-validation test *(38)* was used to determine that the first two PLS components were significant. The first PLS component explained 43% and 22% of the variance of the Y and X matrixes, respectively; and the second PLS component explained 9% and 23% of the Y and X matrixes, respectively. Thus, the first two components explained a total of 52% of the variance of the sensory Y-matrix, taking the physicochemical X-matrix as explanatory. Figure 5 shows the plotted correlation coefficients of the physicochemical and flavour variables for the first two PLSR dimensions. On PLS1, the sensory variables sour, astringent, salty and bitter and to a lesser extent herbaceous and sediment, were correlated with high alcohol content. On PLS2, vinegar flavour was correlated with total and bound sulphur dioxide, and to a lesser degree with volatile acidity and free sulphur dioxide. The relationship between vinegar flavour with volatile acidity was expected *(17)*. A combination of PLS1 and PLS2 correlated sour and astringent flavours with titratable acidity. Sourness and astringency have a synergistic interaction as the higher the titratable acidity the higher the perception of sourness, and the astringency is enhanced *(36)*. This correlation between the titratable acidity and sourness is in accordance with the report of Le Quéré et al. for sweet French ciders *(17)*. Sweetness and dried extract were explained by high negative values on the first component (-0.87 and -0.83) since sugars contribute strongly to the dried extract content of ciders, and sweetness increases with the sugar content. Sourness and dried extract were explained by the first component but showed an inverse correlation since sourness was found less by panellists in sweet ciders containing high dried extract values. Astringency and dried extract showed a similar inverse correlation by the first component as astringency in ciders is generally due to the apple procyanidins *(11)* and can be hidden by sweetening.

Table 5. Mean scores (n = 9) for the flavour variables for the different ciders

Variable	SD1	SD2	SD3	SD3-A	SD4	SD5	SD5-A	SD5-B	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	SD14	SD14-A	SD15	SD16	SD16-A	SD17	SD17-A	SD18*
Fruity	4.7	5.4	4.1	4.7	4.2	4.6	5.7	5.6	3.1	5.1	4.6	4.4	3.0	5.6	4.7	5.1	5.0	4.7	2.3	5.3	4.8	5.2	5.0	3.0
Apple	4.3	5.1	4.4	3.9	3.2	3.0	4.2	4.6	2.1	3.3	3.2	2.8	2.3	3.9	3.2	3.0	3.8	3.4	1.7	4.3	3.8	4.1	4.1	2.1
Pear	0.2	0.8	0.2	0.2	0.1	0.2	0.3	0.6	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.8	0.1	0.3	0.1	0.2	0.2	0.3	0.1	0.0
Pineapple	0.3	1.0	0.4	0.1	0.1	0.1	0.0	0.2	0.0	0.2	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.2	0.2	0.1	0.1	0.3
Herbaceous	0.1	0.1	0.1	1.3	0.2	0.1	0.4	0.6	0.7	0.1	0.2	0.1	0.1	0.4	0.4	0.3	0.0	0.0	0.9	0.3	0.1	0.1	0.3	0.7
Grass	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0
Apple stalk	0.1	0.1	0.0	0.1	0.0	0.0	0.4	0.8	0.1	0.1	0.0	0.1	0.2	0.4	0.3	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.3
Apple seed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweetness	4.2	5.7	3.6	4.0	4.9	4.3	5.6	5.8	3.3	5.1	4.6	5.2	3.2	5.2	6.4	3.9	4.1	4.2	1.4	5.1	5.3	5.4	5.6	1.1
Sourness	3.2	2.6	3.2	1.7	2.3	2.7	3.3	1.8	2.6	3.4	2.1	1.7	1.6	1.7	0.9	1.9	2.2	2.4	4.1	2.2	1.4	2.2	1.9	5.4
Bitterness	2.0	0.7	1.4	1.7	0.6	0.9	0.3	1.4	1.3	1.1	1.4	0.9	2.1	0.7	0.7	0.4	0.2	0.3	2.1	0.3	0.6	0.7	0.2	2.2
Astringency	0.1	0.3	0.3	0.3	0.4	0.3	0.4	0.3	0.7	0.8	0.3	0.6	0.6	0.1	0.2	0.3	0.2	0.2	1.7	0.4	0.1	0.6	0.3	1.6
Salty	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.2	0.1	0.1	0.0	0.0	0.3
Metallic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulphite	0.7	0.4	0.4	1.7	0.9	0.7	1.2	1.1	0.9	0.9	0.7	0.7	1.4	0.3	0.8	0.7	0.8	0.7	0.8	0.6	0.6	0.4	0.7	0.6
Sediment	0.0	0.0	0.0	0.2	0.4	0.7	0.2	0.2	1.0	0.0	0.2	0.1	0.9	0.0	0.2	0.1	0.1	0.2	0.7	0.1	0.1	0.1	0.1	0.4
Oxidation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Sherry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethanol	0.0	0.3	0.3	0.3	0.0	0.0	0.3	0.4	0.0	0.3	0.7	0.4	0.7	0.4	0.7	0.4	0.0	0.0	0.1	0.2	0.0	0.1	0.1	0.4
Amyl alcohol	0.0	0.0	0.0	0.2	0.0	0.3	0.3	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.1	0.2	0.0	0.1	0.0	0.0	0.0
Ketone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lactic	0.3	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vinegar	0.0	0.0	0.0	0.0	0.2	1.0	0.2	0.2	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0
Acrid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Body	4.9	5.4	4.7	4.6	5.6	5.2	5.4	5.4	4.1	5.2	4.4	4.9	4.2	5.3	4.9	5.7	5.0	5.3	4.6	6.0	5.4	5.6	5.4	4.4
Persistence	5.6	6.8	5.7	5.3	5.9	5.1	5.8	5.7	4.4	5.8	5.2	5.4	4.9	5.9	5.6	5.7	4.9	5.3	5.6	6.1	5.6	5.7	6.0	6.3
Equilibrium	4.9	6.0	5.9	5.8	5.3	4.9	5.9	5.9	4.7	5.6	4.7	5.9	3.9	6.0	5.2	5.1	5.8	6.1	3.9	7.1	5.4	5.6	6.1	4.3

Note: the cider marked with an asterisk is artisanal.

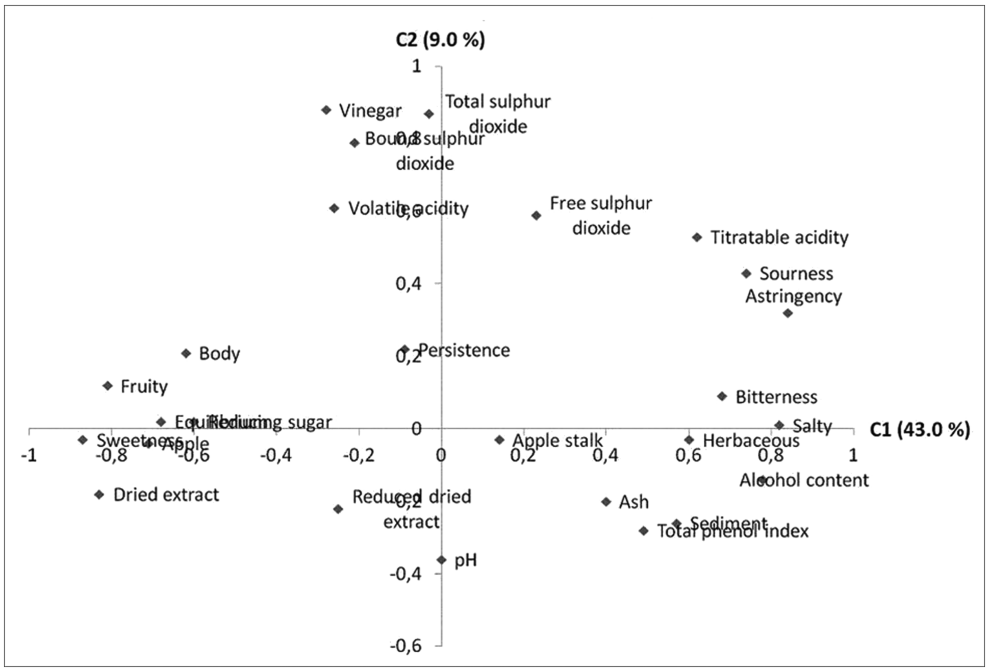

Figure 5. Partial least squares regression analysis of physicochemical variables and flavour descriptors.

Correlations were also found between the aroma descriptor scores and the physicochemical data. PLS regression analysis of the ciders was performed using the 12 physicochemical variables as the X-matrix and the nine most significant (P<10%) aroma descriptors as the Y-matrix. The first two PLS regression components only accounted for 28% of the variance in the sensory Y-matrix; and it was concluded that sensory aroma descriptors were not correlated with physicochemical variables.

In summary, the reported results show that sparkling ciders can be differentiated from carbonated ciders in terms of their physicochemical composition, the most discriminating variables being reducing sugar and the alcohol content. The sensory panellists were able to differentiate ciders with off-flavours such as sediment, reduction and sulphite, from those with apple and fruity characteristics. With flavour analysis, the panellists were able to differentiate defective ciders with sediment from fruity ciders with a predominantly apple character. These results agree with those of the aroma study. This work is the first quantitative sensory analysis of Argentine ciders and provides new physicochemical data that could help producers improve the quality of cider.

Author contributions

Carlos A. Uthurry - conceptualisation, software, formal analysis, investigation, writing – original draft, supervision, project administration, funding acquisition.
Ana M. Caponi - methodology, validation, resources, data curation, supervision.
Guillermo E. Hough - methodology, software, validation, formal analysis.

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Conflict of interest

The authors declare there are no conflicts of interest.

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