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Regionality of Australian Apple Cider: A Sensory, Chemical and Climate Study

Madeleine L. Way [1,*], Joanna E. Jones [1], Rocco Longo [1,†], Robert G. Dambergs [1,2] and Nigel D. Swarts [1]

[1] Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 98 Sandy Bay, Tasmania, TAS 7001, Australia
[2] National Wine and Grape Industry Centre, Charles Sturt University, Wagga Wagga, NSW 2650, Australia
* Correspondence: madeleine.way@utas.edu.au
† Current address: Winequip, Dudley Park, Adelaide, SA 5008, Australia.

Abstract: Terroir is an important concept linking sensory attributes to geographically specific environmental conditions. Whilst typically applied to wine, the concept of terroir could be applied to cider. To investigate the influence of the production region on base cider total phenolic content and sensory attributes, ciders were made using 'Fuji' apples sourced from three major apple growing regions in Australia. Total Phenolic Content was measured using a spectrophotometry method recently validated for use in cider. A trained panel performed descriptive sensory analysis by scoring the intensity of 12 pre-determined attributes across the ciders. The intensity of sensory attributes were found to vary significantly between regions. For instance, cider made from apples grown in Stanthorpe was scored significantly higher than ciders made from apples sourced from Batlow and Huon Valley for the attribute 'Alcoholic'. Cider made with apples from Batlow was scored significantly higher for the attribute 'Yeasty' compared to cider made using apples from the Huon Valley. Cider made with apples from Stanthorpe had significantly greater total phenolic content, titratable acidity, sugar content and alcohol by volume than the two other locations. These results suggest that terroir can influence apple cider, as ciders were able to be differentiated by sensory analysis based on the geographical region from where the apples were grown.

Keywords: region; cider; total phenolic content; terroir

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1. Introduction

Terroir is a French expression which describes the relationship between a combination of non-biological factors related to a production area such as aspect, soil, climate, and elevation, with biological factors of grapes and how that translates into particular sensory attributes [1–3]. Many studies have considered the evidence for terroir using sensory and other quality measures for wine [1–4]. There is limited literature however on how terroir may influence apple cider. Sousa et al. [5] found that geographical origin and climate conditions such as precipitation and temperature had a significant effect on the volatile fingerprint of apple cider made in different regions of Madeira Island, Portugal. Specifically, a decreased mean annual precipitation was found to correlate with an increase in concentrations of esters, alcohols, acids and volatile phenols [5]. Ubalde et al. [6] found similar results when studying the effects of soil and climatic conditions on wine quality, finding an increase in phenolic compound accumulation in response to limited water in the driest year of the study. Alexander et al. [7] compared regional variation in juice quality characteristics including total soluble solids (TSS), specific gravity, pH, titratable acidity (TA) and tannin, of four cider apple varieties from Washington, US. No significant findings were found between juice quality and region, nor any interactions between region, cultivar and or season [7]. Instead, as many studies have shown, regardless of what factors are being analysed, apple variety generally had the greatest influence on quality, followed by variations within and between seasons [7,8].

Differentiation of beverage qualities can be achieved through sensory analysis, by engaging a panel of trained tasters [9,10]. Quantitative descriptive analysis (QDA) uses the ability to train a panel to rate particular attributes of a specific product to create comparable comprehensive data which can be repeated and statistically analysed [11,12]. QDA allows a panel to score the intensity of a range of attributes for multiple samples at a time. QDA is differentiated from other methods as it is able to profile samples on any or all of its perceived sensory characteristics [13]. Previous studies have applied descriptive analysis to characterize the flavour profile of ciders comparing between those produces in the United Kingdom and Scandinavian region [14]. Others have used descriptive analysis to examine the effect of blending different types of apple varieties [15].

Apples are grown in Australia across a wide range of latitudes from the Huon Valley 43° S, Tasmania in the South (65 m above sea level), to Stanthorpe 29° S, Queensland in the North (872 m above sea level) [16]. As cider producers are increasingly sourcing apples from these regions to make premium quality ('craft') ciders, as an alternative to imported apple concentrate, there is a need to determine if provenance or 'terroir' influences differentiation between ciders. In this study, the authors tested the hypothesis that apples made from the same variety, originating from different regions would have different base cider chemistry and sensory attributes. To address this hypothesis, they explored sensory properties of ciders made from a dessert apple 'Fuji', grown in three major Australian apple growing regions. Base cider characteristics were analysed including total phenolic content using the absorbance at A280 method described in Way et al. [17]. These analyses were used to identify if there was consistency between sensory and base cider chemistry attributes with climatic data to investigate the influence of region on sensory properties of apple cider.

2. Materials and Methods

2.1. Cider Making

In April 2019, 'Fuji' apples were sourced from three Australian apple growing regions: Stanthorpe in Queensland, Batlow in New South Wales and the Huon Valley in Tasmania. Apples were transported and stored at 4 °C (Table 1). Apples were milled, pressed and fermented into base cider as in Way et al. [17]. The variety 'Fuji' was selected as it is a popular eating apple, is readily available across Australia and is commonly used as a dessert variety filler in cider making. The three regions were selected to provide the broadest range in latitude representing the greatest geographical and climate distribution within the Australian apple production regions. For each region, three representative orchards were selected to source apples for cider making. From each orchard, cider was made in four 500 mL Schott bottles, creating four replicates.

Table 1. Apple growing region geographical information.

Apple Growing Region	State	Coordinates	Closest Weather Station	Elevation (m)
Huon Valley	Tasmania	43.0295° S, 147.0580° E	Grove (Research Station)	65 m
Batlow	New South Wales	35.5167° S, 148.1500° E	Tumbarumba Post Office	645 m
Stanthorpe	Queensland	28.6600° S, 151.9376° E	Applethorpe	872 m

2.2. Sensory Analysis

A descriptive sensory analysis technique with a trained panel was used to differentiate ciders, following the same procedure as Way et al. [17], excluding the attribute "chemical", originally adapted from Qin et al. [14]. The panel included ten volunteers (aged 25 to 65 years old, six male, four female). Over five, daily 1 h sessions, the panel were trained to recognize a list of attributes and rate their intensity. During the initial training session, using cider samples, panelists selected the most common attributes either creating their own or choosing from the provided A4 piece of paper listing potential attributes as in

Qin et al. [14]. The attributes chosen are reported in Table 2 with the associated reference standard. During the formal analysis, the panel were asked to rate the intensity of each attribute from 0 to 9 on a 9 cm evaluation scale, 0 being attribute absent and 9 being high intensity of attribute. Freshly opened bottles of cider, which had been refrigerated for 10 months, were used for all training and formal analysis sessions.

Table 2. Sensory attributes tested as chosen by sensory panel in initial sensory assessment and corresponding reference standards compositions.

Attribute	Reference Standard [a]
Odor	
Floral	120 mL elderflower juice
Fresh apple	1 chopped fresh apple, 50 mL apple juice
Cooked apple	1 chopped fresh apple in boiling water for 5 min
Pear	1 chopped fresh pear, 50 mL pear juice
Citrus	50 mL juice and half of one chopped fresh grapefruit and one half of one chopped lemon
Tropical fruit	1 cup of fresh chopped pineapple, 1/2 cup of chopped melon
Earthy	1 chopped large potato, 4 chopped cup mushrooms
Yeasty	1.5 g of commercial yeast (Lalvin EC1118)
Taste	
Sweet	15 g sugar
Sour	50 mL apple cider vinegar
Astringent	20 mL commercial winemaking tannin
Alcoholic	10 mL of 95% ethanol

[a] In 500 mL of 50:50 filtered water: base cider (made from 'Fuji'apples, fermented by EC1118 cider) to have 30 mL poured into an ISO/INAO clear glass for each panelist.

The panel assessed nine (30 mL) samples on three separate occasions (three regions × three orchards × three replicates = total 27 samples per panelist). Samples were presented in 215 mL ISO/INAO covered clear wine glasses, labelled with three-digit random number generated by by Compusense® (ver. 5.0.49; Guelph, ON, Canada) as in Longo et al. [18]). Formal evaluations were conducted an open-plan room where panelists were seated at individual desks spaced 1.5 m apart. Data was collected on paper based ballots.

Social science ethics approval for the collection of tasting data was obtained from the University of Tasmania's Social Sciences Human Research Ethics Committee (Ref No: H0018534).

2.3. Juice and Base Cider Analysis

Totals Soluble Solids (TSS; °Brix), Titratable Acidity (TA; g/L), pH and Total Phenolic Content (TPC; TPI) were measured as described in Way et al. [17]. The specific gravity (to estimate the alcohol content) of the juice and cider was measured using a DMA 35 portable density meter (Anton Parr, Graz, Austria). Alcohol by Volume (ABV) was estimated using the equation: ABV = (Original specific gravity − final specific gravity) × 131.25.

2.4. Climate Data

All climate data was collected using the Australian Bureau of Meteorology website [19]. The closest weather stations to the orchards used were selected (as reported in Table 1) and the data for monthly mean, maximum and minimum temperature, and monthly mean solar exposure was gathered. To calculate growing degree days (GDD), the daily mean temperature was calculated by adding the mean daily maximum temperature to the mean daily minimum temperature and dividing the result by two then subtracting 10 (GDD = [(daily maximum temperature + daily minimum temperature/2) − 10 °C]). Rainfall was not considered in this study as apple growers irrigate to ensure adequate soil water content.

2.5. Statistical Analysis

SPSS (IBM SPSS Statistics Version 24, IBM Corp, Armonk, NY, USA) was used to analyse base cider chemistry results with a multivariate general linear model approach to determine differences between regions. Region and climate were considered as main effects. A two-way Analysis of Variance in SPSS was used to determine significant differences between regions for each of the analytical methods at p less than equal to 0.05. A Tukey's—B post hoc test was used to determine differences between groups of samples. Sensory results were analysed using JMP (ver. 14, SAS Institute, Cary, NC, USA) to determine difference between sensory analysis results using a two-way ANOVA with panelist and region as main factors. Using The Unscrambler (The Unscrambler X, V. 10.2, CAMO software, Magnolia, TX, USA), principal component analysis (PCA) was used to determine the major drivers for sensory attributes related to region, and to determine the major drivers for base chemical parameters related to region.

3. Results

3.1. Sensory

The attribute 'Alcoholic' was significantly ($p < 0.5$) higher for the sensory profile of cider made from Stanthorpe grown apples as observed in both Table 3 and the PCA plot (Figure 1). The panel were able to detect the intensity of alcohol (Table 3) in the same order as the actual alcohol content determined analytically (Table 4). Base cider made from Stanthorpe produced apples, scored the highest for the attributes 'Cooked Apples', 'Floral', 'Earthy', and 'Astringent' although these intensity ratings were not statistically significantly different from the other regions. Cider made from apples grown in Batlow was scored significantly higher than the other regions to the North and South of Batlow for the attribute 'Yeasty'. The actual intensity however remained below 2, so while there was a detectable difference, it still scored low. Although not statistically significant, Batlow cider also scored the highest for sweetness. For Huon Valley cider, although no significant differences were determined for any attributes, it was scored the highest for both 'Sour' and 'Fresh Apple' (Table 3).

Table 3. Sensory profiles of "Fuji" cider made from apples grown from three different regions represented by mean aroma and taste intensities ± standard error of the mean for each attribute (n = 9). Different letters denote significant differences between means at $p \leq 0.05$.

	Huon Valley		**Batlow**		**Stanthorpe**	
Fresh Apple	4.03	±0.68	3.33	±0.55	2.93	±0.72
Citrus	1.26	±0.40	1.34	±0.34	1.06	±0.29
Tropical Fruit	1.88	±0.53	1.58	±0.63	1.59	±0.55
Cooked Apple	2.01	±0.60	1.98	±0.37	2.67	±0.72
Floral	1.89	±0.55	1.94	±0.30	2.17	±0.52
Earthy	1.14	±0.29	1.56	±0.32	1.82	±0.78
Yeasty	0.62	±0.739 [a]	1.39	±0.24 [b]	1.09	±0.58 [ab]
Pear	2.10	±0.50	1.91	±0.19	2.17	±0.44
Sour	3.58	±0.34	2.88	±0.49	3.26	±0.26
Astringent	3.06	±0.37	3.09	±0.35	3.49	±0.43
Alcoholic	3.08	±0.41 [a]	3.96	±0.38 [b]	5.04	±0.55 [c]
Sweet	2.28	±0.48	2.71	±0.49	2.53	±0.32

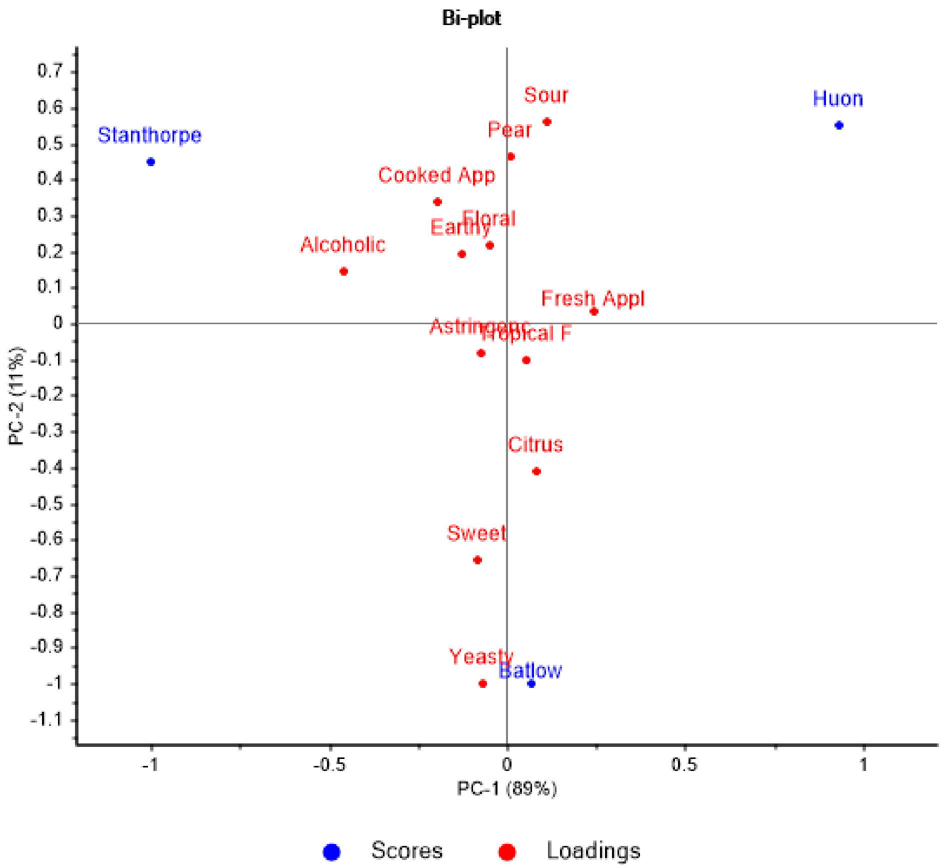


Figure 1. Scores plot for principal component analysis (PCA) of sensory attributes analysed on ciders made using "Fuji" apples from Huon Valley, Batlow and Stanthorpe (n = 48 per region).

Table 4. TPC (TPI), pH, TA (malic acid mg/mL), TSS (°Brix) and alcohol by volume (ABV) results for Fuji apples from all three regions for both juice and cider. Different letters denote significant differences between means at $p \leq 0.05$. (No significant difference is denoted by "NS", ** is p = 0.001–0.01 and *** $p \leq 0.001$).

	TPC		pH		TA		TSS	ABV
	Juice	Cider	Juice	Cider	Juice	Cider	Juice	Cider
Huon Valley	15.93 ± 3.69 ^{b}	8.55 ±0.45 ^{a}	3.83 ± 0.07	3.62 ± 0.48	2.72 ± 0.59	3.44 ±0.49 ^{a}	12.67 ± 3.25 ^{ab}	7 ± 1.19 ^{a}
Batlow	5.15 ± 2.01 ^{a}	7.75 ± 0.69 $_{a}$	3.80 ± 0.11	3.97 ± 0.08	2.54 ± 0.27	4.04 ± 0.55 ^{ab}	12.47 ± 1.43 ^{a}	8.14 ± 0.39 ^{a}
Stanthorpe	11.35 ± 1.08 ^{b}	11.6 ± 0.43 ^{b}	3.87 ± 0.13	4.08 ± 0.02	2.34 ± 0.48	4.50 ±0.27 ^{b}	17.37 ± 1.97 ^{b}	9.98 ± 0.93 ^{b}
Significance	***	***	NS	NS	NS	**	**	**

Interestingly, 89% of the variance in the descriptive analysis results can be explained by the difference between cider made using apples from Huon Valley and cider made from using apples from Stanthorpe as displayed along the X axis. According to PCA, 11% of the variance can be explained by the difference on the Y axis between the region Batlow and the other two regions, Huon Valley and Stanthorpe ciders together (Figure 1).

The PCA (Figure 1) also illustrates clusters of attributes for each region. According to the PCA, Huon Valley was found to be influenced the strongest by 'Fresh Apple', 'Sour', and 'Pear'. Batlow was projected in the same region of the 'Yeasty', 'Sweet', 'Citrus', 'Tropical Fruit' and 'Astringent' attributes. The attributes associated with Stanthorpe according to the PCA were 'Alcoholic', 'Cooked Apple', 'Floral' and 'Earthy'. A significant panelist effect was found at $p < 0.01$ for 'Earthy' and 'Yeasty'. All other attributes were $p < 0.05$ however, this effect was small in comparison with the region effect.

3.2. Analytical Assessment of Ciders

Significant differences for TPC and TSS were observed in base ciders made from each of the three growing regions. Juice from Huon Valley 'Fuji' apples had the highest TPC followed by Stanthorpe 'Fuji', and both were significantly higher (p value) than Batlow 'Fuji', as shown in Table 4. Juice from Stanthorpe 'Fuji' apples had significantly higher TSS than juice from both Huon Valley and Batlow apples.

Stanthorpe cider had a significantly higher TPC compared to cider made with apples from Huon Valley and Batlow regions. When comparing the TPC result between juice and cider, for Huon Valley 'Fuji', the cider TPC was nearly half the value of juice TPC, whilst TPC from Batlow cider was higher than juice, and for Stanthorpe, TPC for cider and juice were not different.

Ciders made from 'Fuji' apples sourced from Stanthorpe had significantly greater alcohol content compared to ciders from Batlow apples. Cider made from Huon Valley apples had significantly lower TA than cider from Stanthorpe apples, and cider made from Batlow apples was not significantly different to either of the other regions.

PCA observing the relationship between region and base cider chemical parameters (Figure 2) determined 76% of variation between the results of each region can be explained along the X axis, and 16% along the Y axis. This PCA shows the parameters cluster together to represent each region, albeit of varying degrees. Results from Stanthorpe are shown to be clearly separated from those from Batlow and Huon Valley. Results from Huon valley are shown to also be clustered together although simultaneously overlapped by results from Batlow.

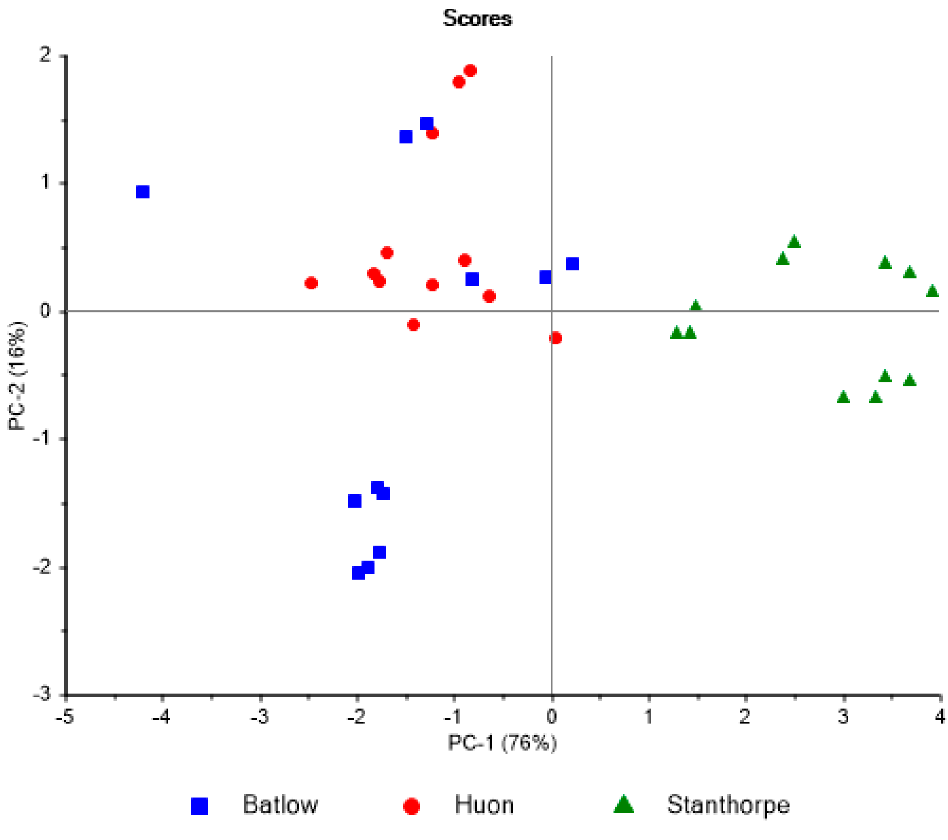
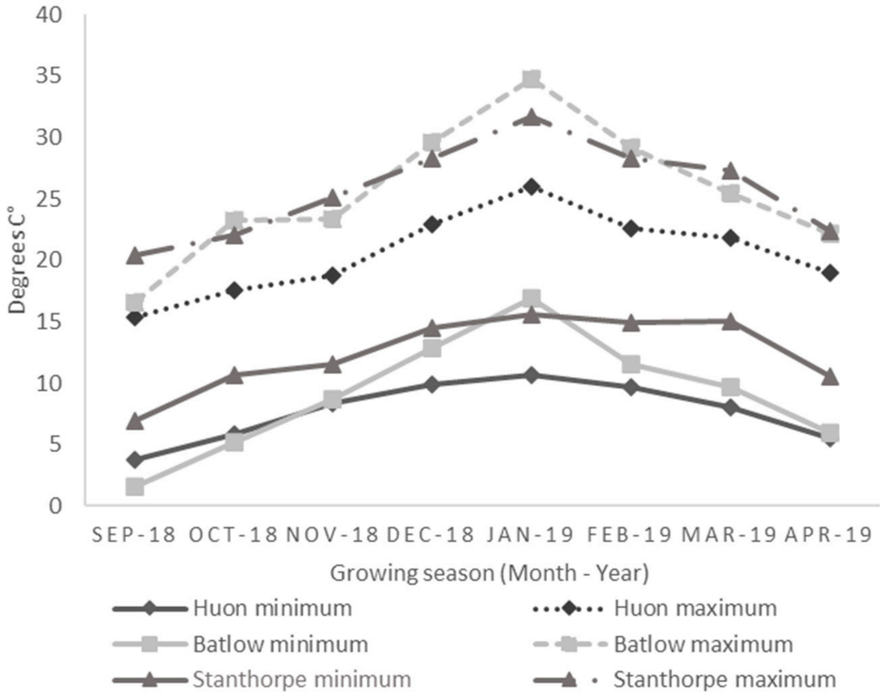


Figure 2. Scores plot for principal component analysis (PCA) for all four base chemical parameters of ciders made using "Fuji" apples from Huon Valley, Batlow and Stanthorpe (n = 12 per region, per parameter).

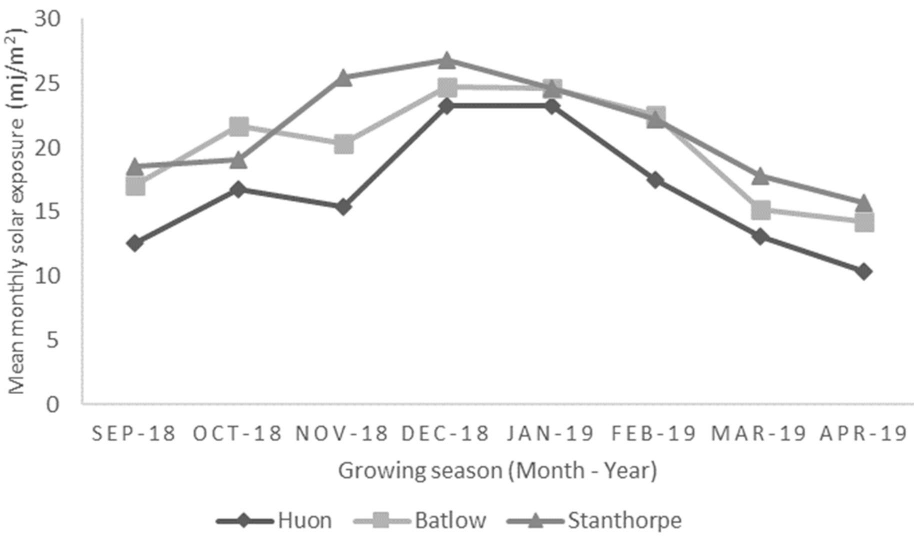
3.3. Climate

In the 2018/19 growing season, Stanthorpe had the highest solar exposure overall across the growing regions, excluding October when Batlow surpassed Stanthorpe, and in January and February, Batlow matched Stanthorpe's solar exposure for those months. Throughout the growing season, the Huon Valley had less solar exposure than both Stanthorpe and Batlow.

Throughout the growing season, Stanthorpe consistently accumulated the greatest GDD days, followed by Batlow with the Huon Valley having the lowest GDD overall. Whilst Batlow had the highest mean monthly maximum and minimum in January 2019, in general Batlow and Stanthorpe had similar maximum mean monthly temperature, with the Huon Valley being substantially colder throughout the growing season (Figure 3). Stanthorpe had generally warmer mean m+inimum monthly temperatures with the Huon Valley again having consistently colder minimum temperatures throughout the growing season.

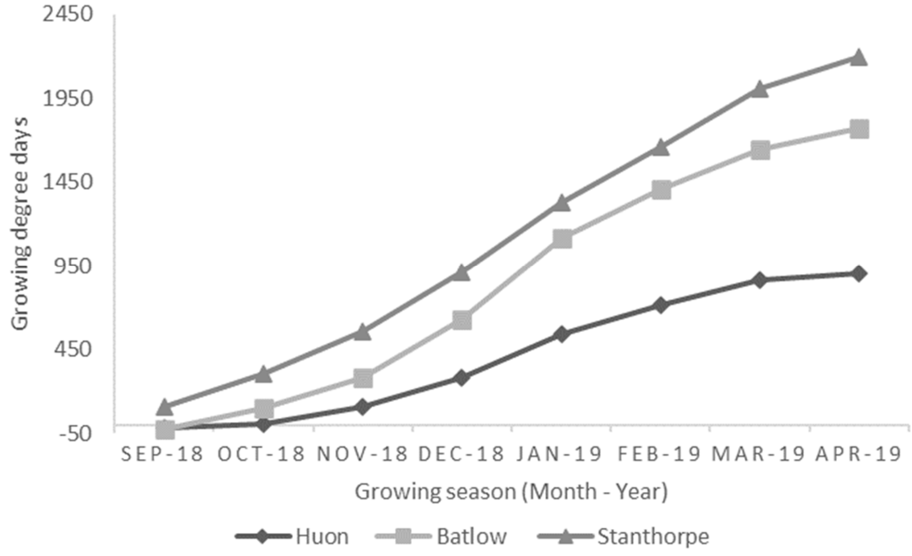


(**a**)



(**b**)

Figure 3. *Cont.*



(**c**)

Figure 3. Weather data for each growing region during the 2018/2019 growing season including; monthly mean minimum and maximum temperature (°C) (**a**), mean monthly solar exposure (MJ/m^2) (**b**) and accumulated growing degree days (base 10 degrees) (**c**).

4. Discussion

4.1. Sensory

Using descriptive analysis, the three regions were differentiated by some of the sensory attributes tested. The influence of environmental factors on sensory quality is commonly reported in wine research [20–23]. Sadras et al. [20] elevated the temperature of the grapevine to simulate increased region temperatures and found for Semillon, green and citrus aromas were reduced while tropical flavours and rich mouth feel was enhanced. This contrasts with findings from this study where the lowest mean maximum monthly temperatures (Huon Valley) where apples were grown produced cider that was more closely associated with the characteristics 'Citrus' and 'Tropical Fruit'. Huon Valley was the coldest region and received the least solar exposure. Using the PCA (Figure 1) cider made using apples grown in Huon Valley, was associated with 'Fresh Apple', could be loosely associated with 'Citrus', according to the X axis and was the least likely region to be associated with "Earthy". This demonstrates the influence that regions, through differences in climate conditions, influence the quality of fermented beverages as determined by sensory analysis. A similar result was found upon investigating the regional effects on sensory in wine, Schlosser et al. [21] discovered when there were colder temperatures during berry maturation, and less solar exposure, the wine could be characterised by 'Apple', 'Melon', and 'Citrus' and 'Acidity', and low in 'Grassy' and 'Earthy'.

'Alcohol', 'earthy', 'floral' and 'cooked apples', were all attributes clustered closest to Stanthorpe in Figure 1. This is also similar to results found by Schlosser et al. [21] Where the warmer region, with the greatest number of GDD, produced wines that were lacking fruit characteristics, compared to the cooler regions. This was attributed to the fact that cooler longer ripening periods have been associated with a higher concentration of compounds such as monoterpenes, which and have been linked to attributes such as 'Fruity', 'Apple', and 'Citrus' [21].

Yeasts can impact on the organoleptic qualities of apple cider [24,25]. They contribute to the overall flavour profile with esters and volatile phenols [26]. He et al. [27] have however characterised *S. cerevisiae* as producing 'alcoholic' and 'yeasty' characteristics. An explanation for the 'Yeasty' flavour being significantly greater for Batlow may be due to the lack of phenolic compounds in both the juice and the cider. Although the juice for Batlow apples had the lowest TSS, samples were scored as the sweetest of the ciders by the sensory panel. As phenolic compounds are mostly responsible for the organoleptic properties in cider [28], the lack of the flavour contributing factors may allow other compounds in the solution to contribute to the flavour such as residual sugars and yeasty flavours. Further research is needed to compare range of TPC to flavour profiles.

4.2. Base Cider Chemistry

Phenolic compounds are organic compounds present in all plants and are found in the highest concentration in apples in the skin and seeds [29,30]. It is these phenolic compounds that drive the key sensory attributes in cider; colour, aroma and mouthfeel including bitterness and astringency [29–31]. Sweetness and sourness are also influenced by phenolic compounds, proving their significant impact on flavour profiles [31,32]. Riekstina-Dolge et al. [10] found variation in cider sensory properties was dependent on physicochemical compositions of the apples used including Total Soluble Sugars (TSS) and Titratable Acidity (TA). Riekstina-Dolge et al. [10] also suggested knowledge of the apple variety phenolic profile provides information on their sensory properties such as bitterness and astringency and their potential to influence the quality of the final product.

As yeast coverts sugar to alcohol, a high sugar content juice is likely to result in cider with higher alcohol content [33]. The high sugar content could be caused by a range of factors. The storage time during transport from Stanthorpe to Hobart may have increased fruit respiration, ripening and therefore increased the sugar content [34]. Although all apples were assumed to be collected at the same level of maturity (at commercial harvest timing), there may have been some variability due to outside influences on fruit maturity at harvest such as target markets or picked for long term storage. We mitigated this risk by conducting analysis on the fresh juice as well as cider.

It is clear that climate conditions varied across the regions and contributed to the differentiation between base cider chemistry. Stanthorpe had the greatest GDD of all three regions and greatest solar exposure. This could have directly influenced the carbohydrate accumulation in the fruit as seen by high TSS and facilitated faster ripening [28]. A study in 1994 comparing apple juices from 11 varieties and 3 growing regions in Ontario, found growing region did not affect sugar content [35]. Another author found apple juice °Brix content varied significantly between eight American states, stating the climatic difference between the eight states was far greater than the difference in climates across the Ontario growing regions [36]. High sugar content can cause microbial stress as high sugar content encourages yeasts to produce acetaldehyde, which in high concentrations can lead to stuck ferments [37]. In wine, this has been reported to increase during hot years and negatively affect wine quality [33]. It's likely this would affect cider quality in a similar way. In this study, the only organoleptic impact the high sugar content found in the Stanthorpe apple juice had, was a strong "Alcoholic" taste, as observed by the sensory panel (Table 3) and confirmed by ABV analysis (Table 4).

Ackermann et al. [38] found apple malic acid content decreases during maturation and in storage. Comparing malic acid content across the three regions, the juice results showed no statistical difference. However, the TA of cider made using apples from Huon Valley was significantly lower than cider made using apples from Stanthorpe. Huon Valley apples produced cider with significantly lower TPC and TA compared to cider produced by Stanthorpe grown apples (Table 4), this is not novel as in cherries, Serrano et al. [39] found a strong correlation between TPC and TA throughout different ripening stages. For all three regions, TA increased during fermentation. Malic acid is one of the major organic acids in both apple juice and cider and can bring a harsh flavour to cider in too larger quantities [40]. Malic acid is influenced by nitrogen and vitamins contained in the apple juice and can either be formed or broken down by yeasts during the fermentation process [40]. In this study, greater content of malic acid increasing compounds in the 'Fuji' apples from Stanthorpe may have caused the increase in TA after fermentation compared to the southern regions, especially the Huon Valley. Ye et al. [40] found malic acid to increase significantly after fermentation when compared to apple juice, consistent with our findings here.

Apples grown in Stanthorpe produced cider with more TPC than those made from apples grown in Batlow or Huon Valley due to greater GDD and solar exposure experienced in Stanthorpe compared to the more southern regions [41]. A study by Alexander et al. [7] examined regional variation in juice quality characteristics of four cider apple cultivars in Northwest and Central Washington. Four years of climate data showed a trend for all varieties, an increased GDD lead to a reduction in anthocyanins and tannins and therefore a decrease in bitterness [7]. Stanthorpe had the greatest cumulative GDD, the highest TPC in cider.

The TPC variation across regions may also be affected by altitude and therefore solar exposure, where high altitude fruit receives greater solar ultraviolet-B (UV-B). Alonso et al. [42] found, increased solar ultraviolet-B produced Malbec grapes with increased TPC, largely the flavanols astilbin, quercetin and kaempferol. This finding aligns with the results where Stanthorpe is located at the highest altitude, 872 m, followed by Batlow at 645 m and Huon Valley at 65 m (Table 1), which is the same order as greatest measured cider TPC to lowest (Table 4).

Other studies have found solar exposure to be crucial for anthocyanin development in fruit [43]. Stanthorpe and Batlow alternate throughout the year in receiving the greatest solar exposure, while Huon Valley did not receive as much solar exposure as either of the more northern regions in any given month. If the TPC results were driven mostly by solar exposure, it would be expected that juice and cider from Huon Valley would have a detectable lack of TPC when compared to that of Stanthorpe and Batlow. However, this is not the case for juice made from apples grown in the Huon valley. TPC analysis of apple juice from the Huon Valley had the greatest TPC results followed by Stanthorpe, both of which had significantly greater TPC than juice made from apples grown in Batlow. During fermentation, for ciders made from apples grown in each region, TPC reduced substantially for Huon Valley, increased for Batlow and remained mostly unchanged for Stanthorpe. These differences may be related to the concentration of individual phenolic compounds that make up the TPC. The apples grown in Huon Valley may have had a different combination of phenolic compounds that allowed a large amount to be extracted during juicing, that then bind during fermentation.

Differences between cider and dessert apple varieties for TPC, as seen in Way et al. [8], may also help explain the differences observed in our study. Cider apple varieties are known have significantly greater TPC than those found in dessert apple varieties and TPC varies significantly between cider apple varieties [8,17]. Cider apples having greater TPC, may have enabled clearer differentiation between regions and climatic conditions compared to results here using dessert apples [7].

5. Conclusions

Ciders made using ‘Fuji’ apples grown in three different apple growing regions in Australia in the same year, using the same yeast, processed by the same method were able to be differentiated both analytically and sensorially. Climate factors were shown to play a role in region differentiation and were found to likely be major drivers for variation in sensory attributes as well as base chemical parameters such as TPC, TA, TSS and ABV. These results provide evidence for the influence of terroir and validate its relevance for Australian cider. Future studies should incorporate other varieties and regions and investigate the origins of key aromas using gas chromatography-mass spectrometry.

Author Contributions: Conceptualization and methodology of this research were carried out by M.L.W., J.E.J. and N.D.S.; formal analysis, investigation, and data curations by M.L.W., R.L. and R.G.D.; writing—original draft preparation by M.L.W.; writing—review and editing was a joint effort between M.L.W., J.E.J., R.L., R.G.D. and N.D.S. The research was supervised by J.E.J. and N.D.S. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Re-search integrity and Ethics Unit of University of Tasmania (protocol code H0018534 and 13 December 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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