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# **Chemometric and Sensory Characterisation of New Zealand Craft Ciders – A Preliminary Study**

A thesis presented in partial fulfilment of the requirements for the degree of

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## **Abstract**

The New Zealand craft cider industry is growing, but its unique sensory characteristics and chemical components are not yet fully scientifically understood. This study aimed to understand the key components and sensory attributes that define selected New Zealand craft ciders through the integration of chemometrics and sensory characterisation.

Seventeen craft cider samples were collected from New Zealand cider regions and characterized for their chemical parameters, including pH, titratable acidity, tannin content and colour. Volatile components were identified and quantified using headspace solid-phase microextraction (HS-SPME) combined with gas chromatography-mass spectrometry (GC-MS).

One focus group (n=5) was organised to generate consumer-oriented descriptors for ciders. This was followed by quantitative sensory evaluation using a 9-point hedonic scale for liking of sensory attributes and Check-All-That-Apply (CATA) to characterise the samples.

The results of the data analysis showed that there were significant differences ( $p < 0.05$ ) in chemical parameters and volatile components among the samples. Principal component analysis (PCA) revealed that tannin, pH and colour ( $a^*$  and  $b^*$  values) were the chemical parameters that contributed to high variability among the samples. The key volatile compounds identified in the samples were ethyl octanoate, isoamyl octanoate, and 1-octanol.

According to sensory assessments, ciders from the North Island were mainly described as "fruity," whereas those from the South Island were primarily described as "bitter" and "dry." Additionally, the study showed that while bitterness and astringency were negative drivers, fruitiness and sweetness were positive drivers of acceptance for the samples.

Moreover, the North Island's ciders displayed higher levels of similarity, whilst the South Island's ciders displayed higher levels of chemical variety. This finding implies that production techniques and apple varieties may be significant variables in determining the sensory and chemical profiles of the samples. This has implications for the importance of understanding the impact of geographical factors on the chemical and sensory characteristics of craft ciders.

This study not only revealed differences in chemical and sensory characteristics of New Zealand craft cider but also provided valuable insights for producers. Future research could further explore the effects of apple variety, production methods and regional characteristics on cider quality, thereby contributing to the sustainable development of the New Zealand craft cider industry.

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## List of Abbreviations

<b>a*</b>	Red-green colour component
<b>AHC</b>	Agglomerative Hierarchical Clustering
<b>AICV</b>	European Cider and Fruit Wine Association
<b>ANOVA</b>	One-way Analysis of Variance
<b>AOAC</b>	Association of Official Analytical Chemists
<b>b*</b>	Yellow-blue colour component
<b>BJCP</b>	The Beer Judges Certification Programme
<b>CAR</b>	Carboxen
<b>CATA</b>	Check-All-That-Apply
<b>DVB</b>	Divinylbenzene
<b>EDIPM</b>	Euclidean Distance Ideal Point Mapping
<b>GC-MS</b>	Gas Chromatography-Mass Spectrometry
<b>GC-O</b>	Gas Chromatography-Olfactometry
<b>HCA</b>	Hierarchical Cluster Analysis
<b>HPLC</b>	High-performance Liquid Chromatography
<b>HS-SPME</b>	Headspace Solid-Phase Microextraction
<b>L*</b>	Colour brightness
<b>MDF</b>	Multidimensional Preference Mapping
<b>MDGC</b>	Multidimensional Gas Chromatography
<b>NMR</b>	Nuclear Magnetic Resonance
<b>PCA</b>	Principal Components Analysis
<b>PCoA</b>	Principal Coordinate Analysis
<b>PDMS</b>	Polydimethylsiloxane
<b>PLS-DA</b>	Partial Least Squares Discriminant Analysis
<b>RATA</b>	Rate-All-That-Apply
<b>TA</b>	Titrateable Acidity
<b>TOF</b>	Time of Flight

**VOCs**

**Volatile Organic Compounds**

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## Chapter 1 Introduction

### 1.1 Background

The production and consumption of cider have experienced a surge in popularity in recent years, with the United Kingdom boasting Europe's highest per capita consumption and the presence of the largest cider-producing companies (Le Fur & Outreville, 2022). According to statistics from the European Cider and Fruit Wine Association (AICV), between 2017 and 2022, the UK has the highest share of cider consumption at 8,140,361 litres compared to other European nations (AICV, 2023). In the United States, the total retail volume sales of cider in 2018 reached nearly 2 million litres (Snyder, 2022).

Following the global trends in cider consumption, consumers have become increasingly interested in artisanal and locally produced beverages in recent years, driving significant growth in the New Zealand craft cider industry. In New Zealand, cider is categorised as a fruit wine, and the rules regarding the definition of cider need to be clarified. There is not even a minimum amount of apple juice in cider in the official standards (Industries, 2003). Unlike traditional cider, which is usually sweeter and made from dessert apples, New Zealand's craft ciders are made using a variety of apple varieties (including cider-specific varieties) and use a range of fermentation techniques and ageing processes.

Craft cider represents a unique, crafted method that does not necessarily align with traditional, modern, fruity or speciality classifications. Key characteristics of craft cider include region-specific apple varieties, including cider-specific varieties. Emphasis on terroir, reflecting a sense of place/origin. Use of unique small batch fermentation and ageing techniques. A focus on producing unique, complex-flavoured products. Craft cider is a unique style that does not fit neatly into the existing categorisation (Calvert et al., 2023; Jolicoeur, 2013; Merwin et al., 2008).

Therefore, New Zealand ciders encompass a broad spectrum of sensory characteristics. Thus, as the popularity of craft drinks increases, it is necessary to establish a clear classification of craft cider in New Zealand (Pando Bedriñana et al., 2023).

To understand these craft ciders' quality characteristics and their precise chemical profiles, it is crucial to apply scientific techniques such as chemometrics and sensory analysis (Moss et al., 2021). This will help in identifying the basic components and the sensory profiles of different ciders to enhance the production of ciders and expand the cider market in New Zealand.

New Zealand is famous for producing quality apples in the market as it is currently known today (Lorck, 2016). While it is documented that sensory characteristics and chemometrics' role in cider production are well understood, there is limited literature on New Zealand craft cider in these areas. Chemometric analysis and concentration on sensory properties allow the creation of New Zealand-specific premium craft ciders with specific sensory attributes.

The colour, aroma, flavour and taste attributes are central to the quality of cider and consumer preferences. These attributes affect the consumers' decisions and are vital to the craft cider in the marketplace. Recognising consumers' sensory preferences through sensory research can aid New Zealand craft cider producers in creating ciders with consumable sensory characteristics. It aids in making the product unique in the market and satisfies consumers' expectations for quality craft cider (Calvert et al., 2023; Riekstina-Dolge et al., 2012; Walker et al., 2016).

Multivariate data analysis and other chemometric methods are significant for the investigation of the link between the chemical composition of cider and its organoleptic properties about phenolic compounds and volatile components in particular. Thus, chemometric analysis will enable cider producers to gain a better understanding of the

effect of producing regions' geographical location and terroirs, apple variety, fermentation process, and production techniques on the sensory profile of the cider (Alonso-Salces et al., 2006; Blanco-Gomis et al., 1998; Calvert et al., 2023; Mangas et al., 1999; Riekstina-Dolge et al., 2012). This knowledge is useful when choosing the apple varieties and fine-tuning production procedures to get the right sensory attributes desired for New Zealand's specific terroir and thus helps cider makers harness the potential of their region for crafting ciders with their unique characteristics.

However, despite the popularity of cider, there is little information on the combination of chemometric analysis and sensory evaluation of New Zealand craft cider. This study is important as it aims to fill existing knowledge gaps through detailed chemometric and sensory characterisation of New Zealand craft cider. This information is invaluable to producers seeking to improve product quality and consistency. Secondly, this research will contribute to the wider field of food science by demonstrating the application of advanced analytical techniques to the characterisation of complex beverages. Finally, the results of this study have the potential to contribute to the development of the New Zealand craft cider industry by providing insights that can be used to more effectively market products and fulfil consumer preferences.

## **1.2 Objective of the Study**

The main objective of this study was to gain a comprehensive understanding of New Zealand craft cider's chemical and sensory characteristics. The specific objectives are as follows:

1. To analyse the chemical composition of New Zealand craft cider, focusing on key parameters such as sugar content, acidity, tannins and volatile components.

2. To conduct a focus group and consumer sensory evaluation to characterise the ciders and determine drivers of acceptance
3. Use chemometric techniques to determine the relationship between chemical parameters and sensory attributes.
4. To determine the similarity in ciders from the North and South Islands based on chemical parameters and volatile components.

### **1.3 Structure of the Thesis**

Chapter 1 describes the background of this study and explains the importance of this study to craft ciders in New Zealand. It also describes what the objectives of this study are, and the specific structure of the thesis.

Chapter 2 reviews the literature on cider chemometrics and sensory analysis, as well as environmental and production factors affecting cider quality.

Chapter 3 outlines the research methodology, including the selection of cider samples, chemical analysis techniques and sensory evaluation methods.

Chapter 4 presents the results of the chemical and sensory analyses, highlighting the main findings and their implications.

Chapter 5 discusses the results in the context of the available literature, providing a detailed interpretation of the findings and their significance.

Chapter 6 summarises the key findings and limitations of the study and makes recommendations for future research.

## Chapter 2 Literature Review

### 2.1 Introduction of Cider and New Zealand Craft Cider

Sensory characteristics of cider include colour, intensity of aroma, taste, and texture or mouth feel. These attributes may further depend on the type of apple used, the type of fermentation that has been used, and the other fruits or spices that may be used (Picchi et al., 2023). Cider can be categorized into various categories which include traditional cider, modern cider, and fruity cider all of which possess different sensory attributes (Cole et al., 2022).

Traditional cider is usually produced according to traditional techniques. Several specific apple varieties are used to make cider. Among them, Ellis Bitter is a bitter apple, while Dabinett and Kingston Black are bittersweet apples. They can be still or sparkling, with flavours ranging from sweet to dry (Merwin et al., 2008).

In contrast, modern cider is produced on a larger production scale and with more emphasis placed on the standardization of the product as opposed to traditional cider. Most current ciders are not as hazy and not as coloured as the original ciders. They may be produced from any kind of apples including cooked ones. Modern cider is generally less bitter for the consumer and has less variation between one production run and the next (Jolicoeur, 2013; Lea & Drilleau, 2003).

Ciders that contain other flavours (such as spices or other fruit flavours) are categorised as fruity and flavoured ciders (Lea & Drilleau, 2003). Berries, cherries, or tropical fruits can bring more sweetness and depth of flavour to fruity ciders.

Speciality ciders come in many varieties and use unusual ingredients or production techniques (Lea & Drilleau, 2003; Picchi et al., 2023). For example, ice cider is fermented from naturally frozen, high-sugar (approximately 9% to 12.73% sugar content) apples (New Zealand Apples and Pears, n.d.). This method gives the cider a

better flavour and makes it sweeter. Barrel-aged cider is a type of cider that is aged in wooden barrels to add flavours such as smoke, vanilla, or oak. Herbs and spices can be added to botanical ciders to create unique flavours and aromas. Depending on the ingredients and the style of the cider maker, these ciders vary in sweetness, alcohol content and flavour (Rose, 2006).

Many chemical reactions occur during cider fermentation, producing a complex organic mixture of alcohols, acids, esters and phenolic compounds (Picchi et al., 2023). The relative proportions of these compounds can vary considerably from product to product, resulting in differences in the sensory attributes of ciders (Lorenzini et al., 2019; Peng et al., 2009).

Craft cider represents a unique method that does not necessarily align with traditional, modern, fruity or speciality classifications. Key characteristics of craft cider include region-specific apple varieties, including cider-specific varieties. Emphasis on terroir, reflecting a sense of place/origin. Use of unique small batch fermentation and ageing techniques. A focus on producing unique, complex-flavoured products. Craft cider is a unique style that does not fit neatly into the existing categorisation (Calvert et al., 2023; Jolicoeur, 2013; Merwin et al., 2008).

Cider making in New Zealand started in the late 1800s when farmers capitalised on the perfect climatic conditions for the production of cider (Oszajca, 2018). In the early twentieth century, cider emerged as one of New Zealand's most popular alcoholic drinks. Beer and wine consumption, accompanied by the variety of available products in the late twentieth century, caused a decline in cider consumption (Oszajca, 2018).

In New Zealand, cider is categorised as a fruit wine, and there is no specific requirement for the minimum amount of apple juice in cider in the official standards (Industries, 2003). This is not different from other countries as each country has different standards.

While there are requirements in countries such as Sweden which requires at least 15% apple juice, other European countries such as Germany have no official standards like New Zealand. Unlike traditional cider, which is usually sweeter and made from dessert apples, New Zealand's craft ciders are made using many apple varieties (including cider-specific varieties) and use a range of fermentation techniques and ageing processes.

Growing interest in craft brewing is boosting interest in New Zealand craft cider. Producers have started paying attention to the quality of cider by using fresh and better-quality apples sourced locally, and the traditional method of production has also started drawing attention to making better-quality cider (Cider New, 2021; West, 2015).

New Zealand cider-making is now one of the local cultural products, increasingly evoking demand from people in the country and other countries. According to preliminary market research, the apples used in New Zealand's cider production usually include several varieties, such as Braeburn, Gala, Fuji, Pacific Rose, and Jazz. These varieties of apples are usually high in sugar content with the average sugar content ranging between 10 and 12.7/100g. They are also high in acidity, resulting in rich, fresh, tart cider with a distinctive fruity flavour and aroma (Sedghi, 2019; West, 2015).

Another opportunity that the cider market can leverage is apple production in New Zealand as the country is famous for producing quality apples in the market as it is currently known today (Lorck, 2016). For example, Braeburn and Royal Gala apples possess a crisp texture and a moderate level of sweetness and sourness, which are suitable for balancing the flavour of cider and making the ciders more refreshing. It should be noted that the crisp texture and moderate sweetness and sourness are the taste sensory characteristics of the apples. However, due to the fermentation and special brewing process of cider, the sensory characteristics of the cider will differ from those of a single apple during the tasting process. While it is documented that sensory characteristics and chemometrics' role in cider production are well understood, there is

limited literature on New Zealand craft cider in these areas. Therefore, New Zealand ciders encompass a broad spectrum of sensory characteristics. Thus, as the popularity of craft ciders increases, it is necessary to establish a clear classification of craft cider in New Zealand (Pando Bedriñana et al., 2023).

To understand the quality characteristics and their precise chemical profiles these craft ciders, it is crucial to apply scientific techniques such as chemometrics and sensory analysis (Moss et al., 2021). This will help in identifying the basic components and the sensory profiles of different ciders to enhance the production of ciders and expand the cider market in New Zealand.

## **2.2 Chemometrics Analysis of Cider**

Chemometrics is the branch of chemistry that extracts information from chemical data by mathematical and statistical methods. It has become an important tool in many areas of analytical chemistry, including food analysis (Roberts & Cozzolino, 2016). As Li et al. (2019) mentioned before, chemometrics is an exciting and rapidly growing research area that could greatly benefit food science and technology. Combining chemometrics with food science is promising because it directly connects to chemistry, analytical chemistry, and, increasingly, process analytical methods (PAT) and chemometric applications (Aleixandre-Tudo et al., 2022).

Using chemometrics can provide more comprehensive data and analysis, which can be useful in improving the quality of craft cider. Chemometrics techniques can offer several practical implications for experiments. First, regarding sample selection for the analysis of New Zealand craft cider, chemometric considerations are essential. By employing chemometric methods, a representative subset of cider can be identified that captures the largest variations in chemical composition. This is accomplished through techniques

such as cluster analysis, which groups similar ciders together, ensuring that the sample set encompasses the characteristics of all ciders on the market.

Second, the choice of analytical techniques, such as gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), and headspace solid phase microextraction (HS-SPME), is directly related to chemometric analysis. These techniques are selected because they provide a detailed chemical profile of cider suitable for chemometric treatment. For instance, high-resolution data obtained from GC-MS can be used as input for principal component analysis (PCA) to identify key chemical components that contribute to differences in cider quality and sensory characteristics.

In the process of data analysis, chemometric techniques play a crucial role. After collecting chemical data from various analytical methods, a chemometric algorithm is applied. Principal component analysis is used to reduce the dimensionality of the data and visualize the relationship between different chemical variables and cider samples. This allows for an understanding of how changes in the chemical composition of cider affect their sensory perception and ultimately enables the optimization of the cider production process based on these relationships. However, applying chemometrics comes with challenges, like needing advanced technical support from experts in this specialised area.

Even though chemometrics offers potential advantages, it still needs to work on establishing itself as a solid research field. The lack of long-term funding for chemometrics projects may be because industries are hesitant to investing too much in labour costs to train personnel has resulted in a shortage of experienced chemometricians, and statisticians see chemometrics as inferior to pure statistics. Plus, chemists often try to do chemometrics tasks themselves instead of working with trained chemometricians. These limitations highlight chemometrics' difficulties during the

analytical process, which could prevent it from fully realising its capabilities (Brereton, 2013).

Volatile organic compounds (VOCs) are essential to the quality of cider. Cider aroma is influenced by various fermentation-related factors (Bingman et al., 2020). As New Zealand ciders vary in origin, their apples' variety, provenance, and maturity, as well as the way they are made, affect the type and content of volatile habitat substances. Direct sampling can contaminate the gas chamber and column because non-distilled cider contains many difficult-to-volatilise components such as sugars, polyacids and polyphenols. Therefore, a suitable separation technique must be selected to separate the flavours from the cider. Standard separation techniques include distillation, liquid-liquid extraction, super condensate extraction, static (dynamic) headspace extraction and the recently developed solid-phase microextraction.

Various analytical techniques commonly used in chemometrics include gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), headspace solid-phase microextraction (HS-SPME) and nuclear magnetic resonance (NMR) spectroscopy. Gas chromatography-mass spectrometry (GC-MS) involves the separating volatile compounds based on their boiling points and identifying them by measuring their mass-to-charge ratio. HPLC, a liquid - based separation method, analyzes the components of a sample by passing it through a column filled with an adsorbent, thus enabling the identification and quantification of various substances. HS-SPME, as a sample preparation technique, utilizes coated fibers to extract volatile and semi-volatile compounds from the headspace above the sample, thereby enhancing detection limits before GC analysis. Finally, NMR spectroscopy utilizes the magnetic properties of atomic nuclei to measure their resonant frequencies within a magnetic field, thus providing detailed information regarding the structure of a molecule.

In a previous study, Antón et al. analysed the aromatic profile of nine Asturias ciders using chemical quantification, gas chromatography-olfactometry (GC-O) and sensory analysis (2016). Their results showed that volatile organic compounds such as 3-methyl-2-butenol, 2-phenylethanol, ethyl 2-methylbutyrate, ethyl caproate, ethyl caprylate, octanoic acid, ethyl 2-phenylethyl acetate, 4-ethylguaiacol, and 4-ethylphenol are considered as part of the aromatic structure of cider. The production of these compounds is primarily attributed to the fermentation conditions during the cider - fermentation process, which differentiates it from the fruity aroma generated solely by apples. For instance, during the cider - fermentation process, esters are produced, introducing other fruity aromas and other aromatic substances. Therefore, the overall aroma profile in cider distinct from that of apples.

However, so many volatile chemicals can be found in foods and beverages. Only a fraction of the substances discovered using experimental approaches are involved in perceiving a product's scent or fragrance. Because of variances in concentrations and detection thresholds, specific volatiles are non-odourants, whereas odourants do not contribute equally to the overall odour of the product. Therefore, gas chromatography-mass spectrometry is needed to determine volatile compounds. Furthermore, when researching highly complex goods like fermented foods or drinks, samples might be even more complicated than expected (Valles et al., 2007).

However, as mentioned above, craft cider is a fermented beverage, and its samples are significantly complex. Analysis by GC-MS alone may lead to an overlap of individual volatile peaks.

Previous studies have shown that MDGC and GC × GC can provide high separation capability. With GC × GC-TOF-MS, compounds in eight other odour categories were identified. By combining these two techniques, they could elucidate 80% of the odour

categories (Eyres et al., 2007). These techniques improve the separation and identification of complex mixtures and ease the analysis of volatile organic compounds. MDGC uses multiple GC columns with different separation mechanisms for better separation. GC×GC applies two columns of different stationary phases to separate compounds by two properties, greatly enhancing peak capacity and resolution. The combination of TOF - MS and GC×GC enables quick analysis and offers detailed mass spectral data, facilitating the identification of multiple components in one run. These multidimensional techniques complement HS - SPME combined with GC - MS. Although HS - SPME combined with GC - MS is effective in extracting volatile compounds from samples, it may encounter difficulties when handling complex matrices. The enhanced separation capabilities of the MDGC and GC×GC methods are exploited to isolate and identify volatile compounds, making them valuable tools within comprehensive analytical workflows alongside HS - SPME/GC - MS.

In the study conducted by Perestrelo et al, the HS-SPME/GC-MS was applied as an analysis tool for the separation of volatile compounds present in cider. In analyzing the excessive data that arises from the method of HS-SPME/GC-MS analysis, chemometrics was applied in this study. For chemometrics, they used statistical tools like Principal Component Analysis (PCA), and Hierarchical Cluster Analysis (HCA) in a bid to estimate patterns and clusters in this data. It also found significant differences in terms of volatile compounds between ciders of different geographical origins and the results suggested the usability of the HS-SPME/GC-MS, as well as chemometrics studies, applied in this research for cider classification and quality control purposes (2019). Thus, this article illustrates the potential of the chemometrics, more specifically the HS-SPME / GC-MS approach for the analysis of cider volatiles and offers useful insights for cider making and quality assurance.

In another study, Nešpor et al. employed HS-SPME-GC-MS to determine the aroma profile of 34 European ciders and found that 4 fatty acids, 6 higher alcohols and 12

esters were identified using HS-SPME technique by CAR/PDMS fibres (2019). Kliks et al. employed gas chromatography and mass spectrometry on 32 ciders and identified thirty-two volatile chemicals (2021) This experiment primarily utilized HS - SPME - GC - MS for the identification of fatty acids, higher alcohols, and esters as specific volatile compounds. The preceding experiment focused on the wide range of volatile compounds in the cider samples in order to understand the aroma profile.

From the above research, it can be seen that chemometrics can be used for analysing and evaluating the chemical profile of the cider. Chemometrics can be applied to determine chemical elements that influence the change in the flavour, aroma and other qualitative characteristics of craft cider. It can also identify patterns and trends in large-scale datasets, as evidenced by analysing the many factors that can affect the quality of craft cider (e.g. the type of apples used, the fermentation process, and the ageing process). This way, the researchers also got an understanding of the compositional space of chemometrics of craft cider and how different components influence the cider, which is crucial information for cider makers who want to enhance their cider.

Consequently, the application of HS-SPME/GC-MS is considered efficient in the measurement of cider or apple cider vinegar at this stage of studying. The approach in this paper will, therefore, follow previous literature to establish the best methods for the detection of volatiles in New Zealand cider.

One of the most widely used coating on the fibers for the extraction of volatile compounds is the DVB (Divinylbenzene)/CAR (Carboxen)/PDMS (Polydimethylsiloxane) coating. The DVB/CAR/PDMS coatings combine liquid polymers and porous particles, with molecular weights ranging from 40 to 275. These coatings consist of macropores ( $>500 \text{ \AA}$ ), mesopores ( $20\text{-}500 \text{ \AA}$ ), and micropores ( $2\text{-}20 \text{ \AA}$ ), and have bipolar properties. The adsorption and absorption of the stationary phase act synergistically, resulting in a high retention capacity (Perestrelo et al., 2019).

### 2.3 Sensory Analysis of Cider

Bitterness, astringency, sweetness and acidity are a few of the basic elements that constitute the flavour of cider, just as in wine (Jolicoeur, 2013). The taste, aroma, "body," dryness, and bitterness of the cider communicate these traits to the customer (Tozer et al., 2015). Although craft cider production in New Zealand is expanding, consumer knowledge of cider and their sensory preferences for cider, including the choice of flavours, is limited. Wine and cider are "experience" items because they do not benefit the user until consumed (Ashton, 2014). Only after opening the package and examining, smelling, and tasting them can they be assessed and discussed. Therefore, documenting and understanding the sensory profiles of craft ciders will be useful in promoting the ciders as has been done for wines.

There are many methods of sensory profiling which broadly include conventional profiling and rapid profiling. Rapid sensory profiling methods are valuable for quickly capturing consumer perceptions of product attributes. These methods are instrumental in the early stages of product development when time and resources are limited. Some of the rapid sensory profiling methods that have been used include Free-Choice Profiling, Flash Profile, Check-All-That-Apply (CATA), and Rate-All-That-Apply (RATA) (Liu et al., 2018). In consumer surveys, check-all-that-apply (CATA) questions on consumer-perceived product qualities have been used to assess what sensory attributes may be unique to a particular product (Dooley et al., 2010). Rate-All-That-Apply (RATA) questions vary from Check-All-That-Apply (CATA) questions. Compared to standard CATA questions, RATA questions ask participants to score the intensity of particular attributes, resulting in a more thorough assessment. When semi-trained assessors are involved in the review process, this approach is constructive (Giacalone & Hedelund, 2016). The structure of the CATA questions allowed participants to select all possible features to describe the test item from the list provided. In addition, the choice of descriptors available is not limited to the sensory attributes of the product, but may also relate to the use of the product or conceptual fit (Dooley et al., 2010).

Therefore, the CATA technique is easy to teach and can be applied easily and quickly by participants or patients. It could be a better method than intensity measurement for creating consumer-driven products. Knowledge questions and CATA answers are directly connected with the customer's perception of the product. Hence, it can be employed essentially as additional data that increases the chances of acceptability of the target product (Dooley et al., 2010). According to the data analyzed by CATA, the consumers can define which attributes and how those attributes influence total liking (Stone & Sidel, 2007).

Preference mapping analysis graphs can be obtained after CATA analysis, and preference mapping is crucial in the connection between the consumer and sensory aspects. In a set of commonly applied multivariate statistical techniques, preference mapping is defined as the process of optimising products based on the correlation between customer preference and sensory data and identifying the preferred drivers (Faye et al., 2006). The EDIPM method is, in fact, the extension of the MDF method, which is a new technique for density analysis concerning the ideal product location of a single customer in the product configuration space (J.-F. Meullenet et al., 2008). This technique involves determining the position with the least ratio of the Euclidean distance and the hedonic score of the product in question relative to the consumer profile (Dooley et al., 2010).

Another optimisation mapping technique is Danzat's Response Surface Model (RSM), which expands on external preference mapping (Dooley et al., 2010). Sensory (or external) data constructs a vector of sensory inputs. Individual consumer data is then regressed against product coordinates in sensory space to determine the optimal location of individuals and groups (J. F. Meullenet et al., 2008).

Many producers are producing and commercialising craft cider in New Zealand. To compete in this highly competitive market, craft cider makers must understand their products' strengths and weaknesses and the impact of consumer attitudes and preference patterns on their development.

## **2.4 Chemical Components in Craft Cider**

Cider's taste and aroma ultimately make it successful; the sensory experience is what counts. The unique smells and tastes of craft ciders result from their chemical composition. Variations in ciders from various locations that affect the sensory aspects can be identified through chemical component analysis. To fully appreciate cider's sensory attributes, one must comprehend its chemistry (Calvert et al., 2023).

The polyphenol compounds in cider apples are crucial. Procyanidins are the only true tannins, but other phenolics act as aroma precursors. Most craft ciders blend cider apples with dessert apples to balance tannins, acids, and sugars (Riekstina-Dolge et al., 2014).

Polyphenols are plant compounds that give cider its colour, bitterness, astringency, and stability (Mainente et al., 2023). They come in various forms, like catechins, procyanidins (polymers of catechins), and phenolic acids. Some cider apple varieties are high in highly polymerized tannins. Tannins are essential for cider flavour - they provide the astringency and bitterness that lingers after drinking. The tannin level must be suitable for an enjoyable cider experience (PricklyCider, 2020). Traditional ciders tend to have higher tannins than commercial ones.

Cider contains many esters, which are the source of the aroma of cider. 2-phenyl ethanol, propanol, butanol, hexanol, 2-methyl-propanol, 2-methyl-butanol, 3-methyl-butanol, 2,3-butanediol, and glycerol are the most significant alcohols in cider. The sensory nature of these compounds is often warm or sweet. Hexyl acetate, which has a

green apple fragrance, is one of the esters that considerably influences the final sensory features (Villière et al., 2012), ethyl 2-methyl butyrate with a yellow apple aroma (Fan et al., 2011), ethyl lactate, ethyl butyrate, ethyl caproate, ethyl octanoate, and diethyl succinate are examples of isoamyl acetate, which has a banana flavour (Buglass, 2011).

Acids are essential in cider production and the finished product's flavour. They may be found in apples and ciders, giving acidity and a peppery flavour to both (Garcia-Medina, 1981). Formic acid, acetic acid, lactic acid, citric acid, fumaric acid, pyruvic acid, and malic acid are the most concentrated organic acids. These acids usually give the cider citric acid, known for its lemon flavour (Zhao et al., 2014). Malic acid contributes to the tart and acidic taste in cider, typically in 4.5 to 7.5 grams per litre.

This shows that cider polyphenols and esters are similar to those of wine. Therefore, it is possible to make a bold deduction that ciders from different regions of New Zealand have some variation in the number of polyphenols and esters in their cider due to the environment or terroir (Jolicoeur, 2013). Apple ripeness is also determined by malic acid content, which drops as the fruit ripens (Gomis et al., 1988). During fermentation, most of the natural sugars in apples are transformed into alcohol and carbon dioxide. If the fermentation continues, the cider will dry with no apparent residual sugar (Le Quéré et al., 2006). This indicates that the cider is not sweet and may have a higher bitterness or acidity.

## **2.5 Environmental Influences on the Phenolics Content Apples**

The composition of phenolic compounds in apples can vary significantly across growing regions due to differences in environmental conditions, particularly climate. New Zealand's major apple production areas of Hawkes Bay and Central Otago exemplify these regional contrasts.

Hawkes Bay experiences a warm climate with relatively low rainfall and humidity (Lowe, 2011). Over millennia, the region's rivers have carved valleys and terraces with fertile soils ranging from clay loams to limestone-derived types and well-draining coarse gravels. In contrast, Central Otago has a continental semi-arid climate with hot, dry summers and cold winters (Brash & Beecroft, 1987; Leamy, 1966). The soils consist of loess and alluvial silts over gravelly subsoils, providing excellent drainage but poor water retention capacity (Brash & Beecroft, 1987; Leamy, 1966).

While few studies directly examine climate impacts on apple polyphenols, research on grapes with a similar polyphenolic profile offers insights. Water deficits can hinder shoot and berry growth, altering the biosynthesis of secondary metabolites like polyphenols (anthocyanins, tannins), aroma compounds, and precursors vital for high-quality wines (Mansour et al., 2022; Savoi et al., 2020). It can be inferred that humidity limitations in Central Otago may affect apple growth and development, including polyphenol accumulation, which may result in regional differences in these compounds (Mansour et al., 2022; Savoi et al., 2020).

The effects of environmental factors such as temperature and water availability on polyphenol metabolism in grapes have been widely studied (Arias et al., 2022; Butkeviciute et al., 2022; Francini & Sebastiani, 2013; Gillingham, 2008; Monis Hussain et al., 2021). For example, it has been mentioned in the past literature that high temperatures reduce anthocyanin concentrations, while moderate water deprivation tends to increase phenolic content (Arias et al., 2022; Monis Hussain et al., 2021). However, the intensity and duration of water deficit conditions are critical, and the impact of moisture varies across species and phenological stages (Gambetta et al., 2020; Gillingham, 2008).

In apples' case, it was ascertained that factors like light intensity and duration, relative humidity and temperature influenced phenolic profiles (Francini & Sebastiani, 2013; Li

et al., 2021). Nevertheless, regarding altitude, latitude, and microclimate influences on apple polyphenols, the existing research shall be further advanced (Li et al., 2021). Therefore, there is a need for more research on how certain environmental factors affect the phenolic content coupled with quality attributes of apples in different growing regions, such as the case of Hawkes Bay and Central Otago.

## **2.6 Effect of Vinification Method on the Phenolic Content of Cider**

First, there is a need to investigate the disparities in the chemical composition between the various types of apples. Certainly, brewer's yeast can generate ciders with comparable levels of non-volatile organic acids such as lactic, succinic as well as acetic acids. In contrast, the concentration of volatile compounds, such as methanol and 1-butanol, varies by apple variety.

One of two ways is commonly used to squeeze apple juice. The cider mill's earliest and most fundamental form was the enclosure, where the apples were ground with a massive wooden pestle and mortar. Each craft cider producer has a different selection of pressing equipment and different pressing rates, which can lead to differences in the chemical content of the juice. Cider fermentation can be done not only with apple juice but also with apple puree or pomace.

Previous research has found that the fermentation substrate substantially impacts the methanol concentration of cider, with fruit juice ciders having the lowest methanol content, followed by fruit puree ciders and pomace ciders having the most peak methanol content. Methanol is a vital sign of cider safety, and adding pectinase to the pre-fermentation process might result in a rise in methanol levels, which can impair the flavour of the cider and possibly compromise food safety. Also, the fermentation method chosen by each producer varies, with some choosing wild fermentation and others inoculating the yeast.

Fermentation of cider takes place through a mechanism very similar to that of wine fermentation. The conversion of simple sugars characterises alcoholic fermentation into ethanol by yeast, particularly *Saccharomyces cerevisiae* (Boudreau et al., 2016). "Wild fermentation" happens when indigenous yeasts are allowed to ferment. The cidemaker does not need to introduce more yeast strains; the local yeast will begin fermentation independently. Indigenous yeasts are wild yeast strains unique to the specific location where the cider is produced. The distinct cider strain contributes to the apple flavour.

*Saccharomyces*, *Candida*, *Bilobacterium*, *Pseudomonas*, and *Metschnikowia* are commonly found in wild yeast communities (Valles et al., 2007). Climatic circumstances influence the population dynamics of Indigenous yeast strains, apple types, geographical location, and the cider-making procedures utilised (Pando Bedriñana et al., 2010). As a result of these factors, various locations host distinct populations of indigenous yeasts. The particular features of ciders produced in specific places are due to the unique makeup of indigenous yeast strains and the activity of the yeast during fermentation (Morrissey et al., 2004). Other indigenous yeast populations can contribute different components of volatile flavour compounds, resulting in diverse flavours, smells, and textures in the final cider (Rita et al., 2011).

Other producers will choose to inoculate the yeast for fermentation, while non-yeast will be added to release other compounds that the taste will produce. This can also result in differences in the chemical content of the cider made by each cider producer.

## **2.7 Conclusion**

Chemometric analysis can be used in New Zealand craft cider production to increase quality as it will enable producers to better understand the variation of the chemicals in

production. One can easily use chemometric analysis to help the consumer distinguish different craft ciders from various regions, as one does with wine selection factors.

Second, sensory analyses can enhance consumer knowledge about the attributes and characteristics of cider, which in turn should enhance the likelihood of consumers' purchase of cider. The examination of New Zealand craft cider has been limited in prior studies. However, recent experiments have contributed a wealth of empirical evidence.

Nevertheless, cider production exhibits considerable variation, which may result in inconsistencies in the obtained data. By integrating chemometrics and sensory profiling, a coherent lexicon may be established, facilitating the identification of favourable or unfavourable sensory attributes throughout the cider production process. This approach ultimately contributes to enhancing the quality of craft cider production in New Zealand. The implementation of this approach has the potential to catalyze a significant advancement in the progression of the craft cider industry in New Zealand.

## **Chapter 3 Materials and Methods**

### **3.1 Cider Samples**

Based on the convenience sampling principle, commercial craft cider samples (n = 17) were purchased from retail outlets in Auckland, New Zealand, and characterised using physicochemical and sensory methods. Sample selection was based on segmentation between the North (n = 12) and South (n = 5) Islands of the country to allow the determination of the chemical and sensory differences between the samples from these two regions. The alcohol content of the samples ranged from 4.5% to 8.0%. More information on the samples is provided in Appendix E.

### **3.2 Chemical Analysis**

The pH, titratable acidity, residual sugar, tannins, and colour measurements were determined on each sample. The procedure for each analysis is briefly summarised below.

#### **3.2.1 pH**

The pH of the sample was taken in triplicate using a pH meter by submerging the electrode in about 40 ml of the sample and reading off the value after the reading was stabilised (Pakale et al., 2018). The pH meter was calibrated with buffer standard solutions at pH=4 and pH=7. The electrode was rinsed with deionised water and patted dry with tissue paper between samples (Cheng & Zhu, 2005; Hayley, 2020).

#### **3.2.2 Titratable Acidity (TA)**

The AOAC technique was used to determine titratable acidity (Abid et al., 2013). 90 mL of distilled water and 10 mL of the sample were put into a 250 mL beaker. The solution was titrated against a standardised solution of 0.1 M NaOH to the endpoint (pH  $8.2 \pm 0.1$ ) and constantly swirled by a magnetic stirrer. Following the conversion of the volume of NaOH to the amount of malic acid (in grammes) per 100 mL of juice, the

titratable acidity was estimated using an equation involving the concentration and the volume of NaOH at the endpoint (Appendix A).

### **3.2.3 Residual Sugar**

According to the manufacturer's instructions, residual sugar (°Brix %) was determined using a handheld digital refractometer. Briefly, the instrument was zeroed using distilled water by adding about 0.3 ml of distilled water onto the prism surface using a pipette. The distilled water was carefully cleaned from the prism surface with a tissue after the zero setting was obtained. The residual sugar content of each sample was obtained by placing about 0.3 ml sample on the prism surface and pressing the start key. Distilled water to clean the refractometer between readings (Jaywant et al., 2022). Readings were done in triplicates.

### **3.2.4 Tannin Assay**

To carry out the tannin assay, the spectrophotometer was warmed up for 30 minutes and set to an absorbance value of 750nm, zeroing it with 3mL of distilled water in two cuvettes as blanks. Gallic acid standard solutions were prepared at concentrations of 25mg/L, 50mg/L, 75mg/L, and 100mg/L, and transferred into 3mL of each to cuvettes. The absorbance of each standard solution was measured three times. The values were plotted to generate a standard curve and a regression equation to quantify tannin concentration. to determine the cider samples' tannin content, 1 mL of gallic acid was first mixed with 1 mL of cider sample. The supernatant was extracted and transferred into clean cuvettes. An amount of 1 mL of Folin-Ciocalteu reagent was added to the supernatant, thoroughly mixed, and allowed to stand for 30 minutes for colour development. The absorbance of the sample was measured at 750 nm, and the regression equation was used to calculate the tannin content (Monteleone et al., 2004; Sommer et al., 2022). The assay was carried out in triplicates.

### **3.2.5 Colour Measurement**

Colour measurement was done using the Minolta Chroma Meter (KONICA MINOLTA, Tokyo, Japan). It was first calibrated according to the manufacturer's instructions by determining the colour of the white colour standard by positioning the measuring head in the centre of the white standard plate and reading the colour. To determine the colour of the cider samples, a clean petri dish was nearly filled with cider and covered with another petri dish. The measuring head of the chroma meter was then positioned on the petri dish and the colour in the L\*, a\*, b\* space was determined. Measurements were done in triplicates (Techakanon & Venkatachalam, 2021). The formula used for the calculation of delta E ( $\Delta E$ ) is shown in Appendix A.

### **3.3 Volatile Compounds**

#### **3.3.1 Reagents and Standard**

VOC standards for the identification of target compounds were purchased from Sigma-Aldrich (Madrid, Spain). Octanol (internal standard, IS, purity  $\geq 99\%$ ) was purchased from Sigma-Aldrich (Madrid, Spain), and divinylbenzene/carbon/polydimethylsiloxane (DVB/CAR/PDMS) fibres and SPME apparatus were purchased from Supelco (Bellefonte, PA, USA).

#### **3.3.2 Sample Preparation**

Before the analysis, all cider samples were stored at 4 °C. Samples were brought to ambient temperature before analysis. To reduce the amount of CO<sub>2</sub> in the samples, a volume of 200 mL of cider sample was shaken on a shaker for 7 min (frequency 175/min). After the shaking, a volume of 10 mL of sample spiked with 10  $\mu$ L octanol (IS) was mixed in a 20 mL colourless vial, sealed and agitated for 1 minute on a vortex mixer (Nešpor et al., 2019).

### 3.3.3 Extraction of Volatile Compounds

Volatile compounds were extracted using the Head Space - Solid Phase Microextraction (HS-SPME) technique. (Nešpor et al., 2018) The vial was capped with a PTFE-faced silicone septum and placed in an AOC 5000 PLA Autosampler (Shimadzu, Kyoto, Japan) with continuous magnetic stirring at 50 °C for 30 minutes while exposing the DVB/CAR/PDMS fibre to the headspace. After the 30 minutes had elapsed, the DVB/CAR/PDMS fibres were retracted into the SPME needle, removed from the vial and immediately introduced into the GC injection port for 30 minutes of thermal desorption of the analytes at 265 °C. Extractions were performed in triplicate.

### 3.3.4 Gas Chromatography-mass Spectrometry

Chromatographic separations were performed on a GC-2010 and GCMS-QP2010 plus (Shimadzu, Kyoto, Japan) gas chromatograph system using an RTX-5 (30 m × 0.53 mm i.d. × 3.00 µm film thickness) fused silica capillary column with helium as the carrier gas at a flow rate of 0.99 mL min<sup>-1</sup>. The injector temperature was fixed at 265 °C. The temperature programme was set as follows: an initial temperature of 50 °C, followed by an increase to 230 °C at a rate of 3 °C per minute, and a final constant temperature of 5 minutes. The ion energy used for electron impact (EI) was 70 eV, and the source temperature was 200 °C. The electron multiplier was set to an auto-tuning program. The mass acquisition range was 50-500 m/z in full scan mode. Identification of volatile compounds was done in the total ion mode, scanning a mass-to-charge ratio (m/z) range between 50 – 500. Further identification was obtained using a probability-based matching with mass spectra in the NIST library. Quantification of the compounds was done using relative peak areas by dividing the sample peaks by the internal standard peak.

### **3.4 Sensory Methods**

Qualitative and quantitative sensory approaches were used to understand how cider consumers describe New Zealand apple ciders and to determine the sensory differences in the selected apple ciders used in this study. Before commencing the study, ethical approval was obtained from Massey University's Human Ethics Committee (Reference No. OM1 23/37).

#### **3.4.1 Focus Groups**

One focus group discussion was conducted to gain insights into consumer perceptions and preferences for New Zealand craft ciders. Participant recruitment was facilitated through a Qualtrics questionnaire (Appendix C, Figure C1) shared via social media platforms and university email lists, targeting individuals who regularly consumed apple cider and aligned with the desired demographic profile. Printed flyers (Appendix C, Figure C2 and C3) were also displayed around the university campus for recruitment.

Potential participants were provided with a comprehensive information sheet detailing the study's objectives, procedures, and their rights as voluntary participants (Appendix C, Figure C4). Those who wished to participate in the discussion completed a consent form acknowledging their voluntary participation and allowing the discussion to be audio recorded (Appendix C, Figure C5).

A semi-structured focus group discussion guide was designed to guide the conversations. Five participants tasted six New Zealand craft ciders during the session (Appendix C, Table C1). The six craft ciders selected to participate in the focus group discussion were three from the North Island and three from the South Island. Their alcohol levels and brewing styles also varied to collect enough vocabulary to construct a complete CATA questionnaire for use in the subsequent Consumer Panel Discussion. Several open-ended questions were posed to the participants for an in-depth discussion

of their perceptions, preferences, and overall impressions of the cider samples. The open-ended questions and other prompt questions helped to explore the topic from multiple perspectives. The audio recording was transcribed and the key points from the discussion were summarised (Alexander & Valliere, 2020).

### **3.42 Sensory Evaluation**

Quantitative sensory assessments of the cider samples were conducted using the Check-All-That-Apply (CATA) methodology to complement the qualitative insights gained from the focus groups. One CATA questionnaire was developed with a list of 27 sensory attributes for participants to choose from to characterise each cider sample. A list of attributes and their definition was provided to the participants during the tasting session. (Appendix D).

Three sensory sessions were carried out, with each session having 30 participants. Participants were allowed to attend multiple sessions. Participants tasted 6 samples in the first and second sessions, followed by 5 samples in the third session for 17 samples (Appendix C, Table C2). Samples were grouped to adhere to the ethics requirement of alcohol consumed during a session not exceeding 1 standard drink for health and safety reasons. Other criteria for grouping the samples were representation between the North and South Islands, brewing methods, and apple varieties. About 20 mL of samples were served in 35 mL plastic cups labelled with three-digit random codes (Stone et al., 2020).

Participants were provided with a spit cup to spit the sample after tasting. They were also provided with water and unsalted crackers for palate cleansing. Participants were asked first to indicate their overall liking for the samples on a 9-point hedonic scale (1= dislike extremely to 9 = like extremely). They were then after being presented with a list of 26 attributes (including some of the attributes generated from the focus group and asked to select as many attributes as possible that describe the sample they have tasted

(Appendix F). Data was collected using Compusense<sup>®</sup> on accessed through an iPad (from Massey University).

The sensory assessment was carried out in individual booths in the sensory facility at Massey University, Auckland campus. Lighting and temperature are maintained at the same level, in line with standard practice for sensory testing (Kemp et al., 2011).

### **3.5 Data Analysis**

Statistical analyses were carried out to assess the differences and similarities among the various cider samples. A one-way analysis of variance (ANOVA) was initially used to evaluate the differences among the means of the chemical and volatile component data for the cider samples. The variables were °Brix % (sugar content), pH, TA (titratable acidity), tannin concentration, L\* (brightness), a\* (red-green colour component), b\* (yellow-blue colour component) and delta E (colour difference) as well as 20 volatile compounds obtained from HS-GC-MS. The factors were the 17 cider samples. The choice of one-way ANOVA was based on the fact that it enables the comparison of the means of the different populations. Significance between means was established at  $p < 0.05$ .

A Tukey test, a post hoc test, was carried out to determine the samples that significantly differed. This process aided in categorizing distinct subgroups from the data set that were statistically different in terms of °Brix %, pH, TA, tannin content, L\*, a\*, b\*, and delta E.

Principal components analysis (PCA) was used to visualise the relationship between the samples and chemical parameters. Before applying PCA, all the variables are standardized to normalize the variance and, thus, the statistical significance of the

variables (Alberti et al., 2016). Principal coordinate analysis (PCoA) was used to visualise the relationship between the samples and their sensory attributes.

Agglomerative Hierarchical Clustering (AHC) employing Euclidean distance and Ward linkage was used to explore differences and similarities among the samples based on their chemical composition and volatile compounds. The AHC is an efficient clustering algorithm that constructs a tree structure called a dendrogram through the successive linkage of the most similar samples. The intra-cluster cohesion and inter-cluster separation were automatically used by the software to determine the ideal number of clusters.

CATA analysis of the attributes present in each cider sample was conducted using Cochran's Q test where the significance level was set at  $p < 0.05$ . The pairwise differences between the cider samples were evaluated using the Sheskin procedure. The contingency table of CATA counts was analysed using correspondence analysis and visualised in a symmetric plot in which samples and attributes were overlaid in a biplot.

Partial least square discriminant analysis (PLSDA) was used to classify cider samples based on the location of the cidery (North or South Island). The classification was conducted on the chemical composition data and the volatile components data. A confusion matrix was generated to show the number of correct and incorrect classifications. Data analysis was conducted using XLSTAT and RStudio.

## Chapter 4 Results

### 4.1 Chemical Parameters

The chemical parameters of the craft ciders are presented in Table 1.

Table 1: Mean values of chemical parameters of New Zealand craft ciders (n=17).

Sample No.	Island	°Brix %	pH	TA (g/L)	Tannins (mg/100ml)	L*	a*	b*	▲ E
Cider 1	North	7.33 <sup>b</sup>	3.73 <sup>b</sup>	6.95 <sup>b</sup>	1.02 <sup>b</sup>	33.66 <sup>de</sup>	-0.35 <sup>k</sup>	3.56 <sup>a</sup>	4.84 <sup>ab</sup>
Cider 2	North	5.67 <sup>h</sup>	3.66 <sup>c</sup>	6.80 <sup>c</sup>	0.31 <sup>j</sup>	33.71 <sup>cde</sup>	0.25 <sup>gh</sup>	1.44 <sup>f</sup>	2.76 <sup>h</sup>
Cider 3	North	6.23 <sup>f</sup>	3.65 <sup>cd</sup>	6.75 <sup>c</sup>	0.50 <sup>f</sup>	33.71 <sup>cde</sup>	0.14 <sup>h</sup>	1.86 <sup>d</sup>	3.20 <sup>f</sup>
Cider 4	North	5.57 <sup>hi</sup>	3.65 <sup>cd</sup>	6.13 <sup>f</sup>	2.77 <sup>a</sup>	33.01 <sup>hi</sup>	0.02 <sup>i</sup>	2.94 <sup>b</sup>	4.42 <sup>d</sup>
Cider 5	North	7.20 <sup>b</sup>	3.46 <sup>h</sup>	5.90 <sup>g</sup>	0.45 <sup>h</sup>	31.51 <sup>k</sup>	0.28 <sup>g</sup>	1.95 <sup>d</sup>	4.56 <sup>c</sup>
Cider 6	North	6.90 <sup>c</sup>	3.50 <sup>g</sup>	5.30 <sup>h</sup>	0.23 <sup>l</sup>	33.81 <sup>cd</sup>	0.78 <sup>d</sup>	-0.70 <sup>k</sup>	1.22 <sup>l</sup>
Cider 7	North	6.43 <sup>e</sup>	3.56 <sup>f</sup>	7.50 <sup>a</sup>	0.91 <sup>c</sup>	33.51 <sup>ef</sup>	0.50 <sup>e</sup>	0.35 <sup>h</sup>	2.00 <sup>k</sup>
Cider 8	North	6.33 <sup>ef</sup>	3.71 <sup>b</sup>	5.83 <sup>g</sup>	0.40 <sup>i</sup>	33.21 <sup>gh</sup>	0.35 <sup>fg</sup>	1.71 <sup>e</sup>	3.23 <sup>f</sup>
Cider 9	North	7.27 <sup>b</sup>	3.70 <sup>b</sup>	7.08 <sup>b</sup>	0.46 <sup>gh</sup>	32.96 <sup>hi</sup>	0.16 <sup>h</sup>	3.48 <sup>a</sup>	4.90 <sup>a</sup>
Cider 10	North	4.40 <sup>k</sup>	3.62 <sup>e</sup>	6.28 <sup>e</sup>	0.28 <sup>k</sup>	32.31 <sup>j</sup>	0.79 <sup>d</sup>	0.05 <sup>i</sup>	2.87 <sup>g</sup>
Cider 11	South	6.03 <sup>g</sup>	3.63 <sup>cde</sup>	3.63 <sup>k</sup>	0.29 <sup>jk</sup>	31.36 <sup>k</sup>	3.40 <sup>a</sup>	0.87 <sup>g</sup>	4.80 <sup>b</sup>
Cider 12	South	5.90 <sup>g</sup>	3.62 <sup>de</sup>	6.50 <sup>d</sup>	0.46 <sup>h</sup>	32.42 <sup>j</sup>	0.94 <sup>c</sup>	-0.28 <sup>j</sup>	2.66 <sup>i</sup>
Cider 13	South	6.70 <sup>d</sup>	3.74 <sup>b</sup>	6.73 <sup>c</sup>	0.61 <sup>e</sup>	33.36 <sup>fg</sup>	0.70 <sup>d</sup>	0.28 <sup>h</sup>	2.05 <sup>k</sup>
Cider 14	South	8.93 <sup>a</sup>	3.40 <sup>i</sup>	5.15 <sup>i</sup>	0.19 <sup>m</sup>	32.91 <sup>i</sup>	1.12 <sup>b</sup>	-0.33 <sup>j</sup>	2.20 <sup>j</sup>
Cider 15	North	5.40 <sup>j</sup>	3.84 <sup>a</sup>	4.83 <sup>j</sup>	0.48 <sup>fg</sup>	34.52 <sup>a</sup>	0.46 <sup>ef</sup>	0.09 <sup>i</sup>	1.18 <sup>l</sup>
Cider 16	North	5.57 <sup>hi</sup>	3.83 <sup>a</sup>	5.78 <sup>g</sup>	0.59 <sup>e</sup>	33.94 <sup>c</sup>	0.02 <sup>i</sup>	1.38 <sup>f</sup>	2.67 <sup>hi</sup>
Cider 17	North	5.50 <sup>ij</sup>	3.83 <sup>a</sup>	5.23 <sup>hi</sup>	0.69 <sup>d</sup>	34.22 <sup>b</sup>	-0.10 <sup>j</sup>	2.27 <sup>c</sup>	3.42 <sup>e</sup>

<sup>a,b,c...l</sup> Means with the different letters in a column indicate significant differences based on Tukey's test ( $p < 0.05$ ).

Each cider sample was described by seven parameters – °Brix % (brix), pH, TA (titratable acidity), Tannins (tannin content), L\*, a\*, b\* (colour parameters), and ▲ E (colour difference). Significant differences ( $p < 0.05$ ) were observed among the samples for all the parameters tested. The °Brix % values, reflecting sugar content, range between 4.4 and 8.93%, with Cider 14 recording the highest and Cider 10 being the lowest. The pH values spanned a narrow range from 3.46 for Cider 5 to 3.84 for Cider 15, which was not statistically significant for Cider 16 and 17. Titratable acidity shows greater variability, with statistically significant differences observed among the samples. Cider 7 had the highest titratable acidity of 7.50 mol/g, while the lowest titratable acidity of 3.63 mol/g was observed in Cider 11. Also, a wide range of tannin concentrations was observed among the cider samples, ranging from 2.77 mg/100ml for Cider 4 to 0.19 mg/100ml for Cider 14.

No distinct patterns of disparity emerge concerning the brightness parameter (L\*) among the cider samples. However, examining the a\* (red-green) and b\* (blue-yellow) values reveals noteworthy observations. Specifically, Cider 11 showed an exceptionally high a\* value of 3.40, while Cider 1 was characterised by a low a\* value of -0.35 and the highest b\* value of 3.56. The delta E (colour difference) is determined based on distilled water as the reference point for the calculation. The values ranged from 4.90 for Cider 9 to 1.18 for Cider 15. Cider 1 does not exhibit statistically significant differences in colour compared to Cider 9 and 11.

Principal components analysis (PCA) was used to visualise the relationship between samples and chemical parameters in the first three dimensions. Figure 1 shows the PCA

biplot for principal components 1 and 2, while Figure 2 shows the biplot for principal components 2 and 3.

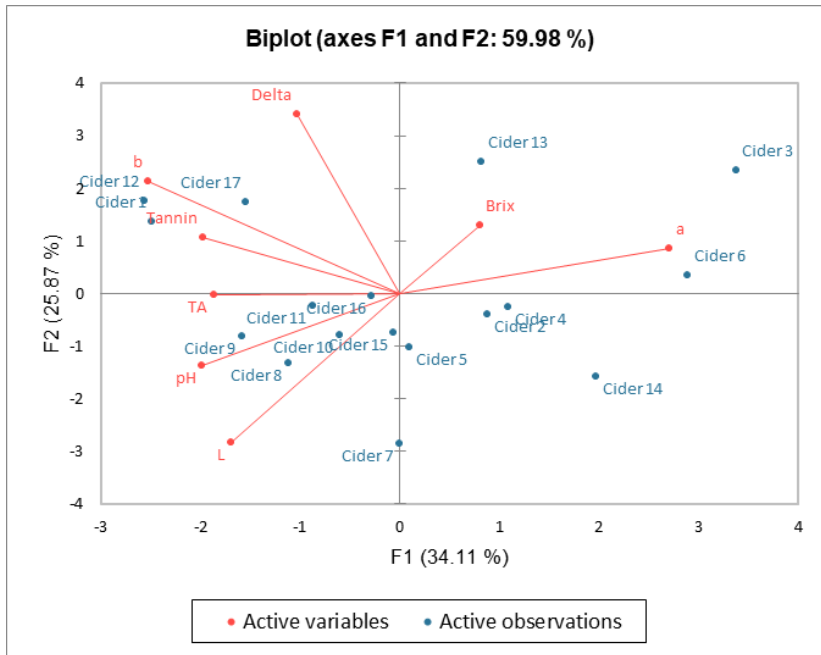


Figure 1: PCA biplot of chemical parameters for craft ciders from New Zealand for principal components 1 and 2.

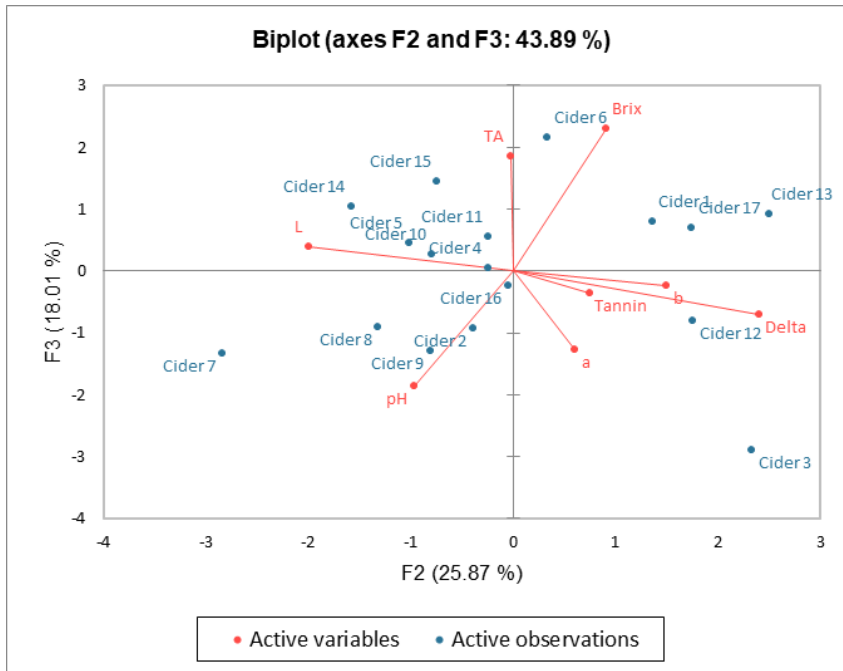


Figure 2: PCA biplot of chemical parameters for craft ciders from New Zealand for principal components 2 and 3.

The first two principal components (F1 and F2) account for 59.98% of the total variation explained. The third principal component (F3) (accounts for 18.01% of the variation. Thus, the first three principal components explain about 77.99% of the total variation observed in chemical parameters data.

In PCA Biplot plots, the magnitude and direction of the angle between the variable vectors and the principal component axes are important for interpreting the correlation and contribution of the variables in the principal component space. The magnitude of the angle reflects the correlation between the variable and the principal component. The small angle indicates that the variable has a high correlation with that component based on the square of the cosine of the angle. In contrast, a 90-degree angle suggests that there is no correlation between the variable and the principal component. In addition, the direction of the variable vector is important for interpretation. A vector pointing in the positive direction indicates that the samples will have high values for those variable increases. On the contrary, if a sample is in the opposite direction vector, that sample will have a low value for that variable. In addition, the length of the vector shows the extent of the variable's contribution in the direction of the principal component, with longer lengths indicating that the variable has more weight on the main component (Greenacre et al., 2022).

For example, Figure 1 is a PCA Biplot plot with 59.98% of the total variance explained on the F1 and F2 principal component axes. Delta E, b\*, Tannins, TA, pH and L\* on the Y-axis (F2) were loaded on the left side of F1, while °Brix % and a\* were on the right. Despite the variable loadings observed, the most important variables on each principal component are seen from the squared cosine angle (Table A3 in the appendix). It is evident from Figure 1 that pH, tannin, a\* and b\* have the highest cosine angles, hence these are heavily loaded on F1. Since pH and tannin are loaded on the negative side, while a\* and b\* are on the right side, this implies that F1 contrasts pH and tannin with a\* and b\*. Similarly, F2 is a contrast between lightness (L\*) and delta E. However, F3

has both °Brix % and TA on the same side of the principal component. Samples plotted close variables on the biplot tend to have high values for those variables, while the farther away samples are from variables, the smaller their value for those variables.

The PCA Biplot plots were examined in detail to explore the relationship between the positions of sample points in the plots and the vectors of variables. Some sample points are grouped in the graph between the vectors of variables.

Both made using modern processes, Cider 3 and Cider 6 are in very different locations on the graph (Appendix E). Cider 3, produced in Hawke's Bay and made from French cider apples, is located on the far right of the graph, indicating a high value for the “a\*” variable, representing a strong red and green colour component. Cider 6, on the other hand, is more centrally positioned and shows reasonable values for most variables. It is prepared on the West Coast utilising Granny Smith apples grown exclusively in New Zealand. Despite equal production processes, this discrepancy emphasises the impact of regional circumstances and apple variety on cider characteristics.

Cider 13 is located at the top of the plot and is closely related to the “°Brix %” variable. This Nelson-produced cider was made using the traditional method (rubbing of mixed apples) and showed the highest average °Brix % value (8.67%) of all the samples (Appendix E). Its particular location highlights how conventional methods can provide unique ciders.

Cider 7, in comparison, is towards the bottom of the figure and has a lower value for the “L\*” variable, which could mean that it has a lighter colour. This extra-dry cider (Appendix E), prepared by Hamilton using multiple types of cooking apples, shows how production methods can significantly affect the organoleptic characteristics of cider.

Moreover, except for the aggregated sample points mentioned above, the other samples were relatively dispersed on the biplot, with no obvious aggregation pattern. This suggests that these sample points may have more significant variability in the variables examined, possibly due to differences in brewing processes, ingredient combinations, or other factors.

Hierarchical clustering analysis (AHC) was performed to determine similarity among samples based on cluster membership (Figure 3).

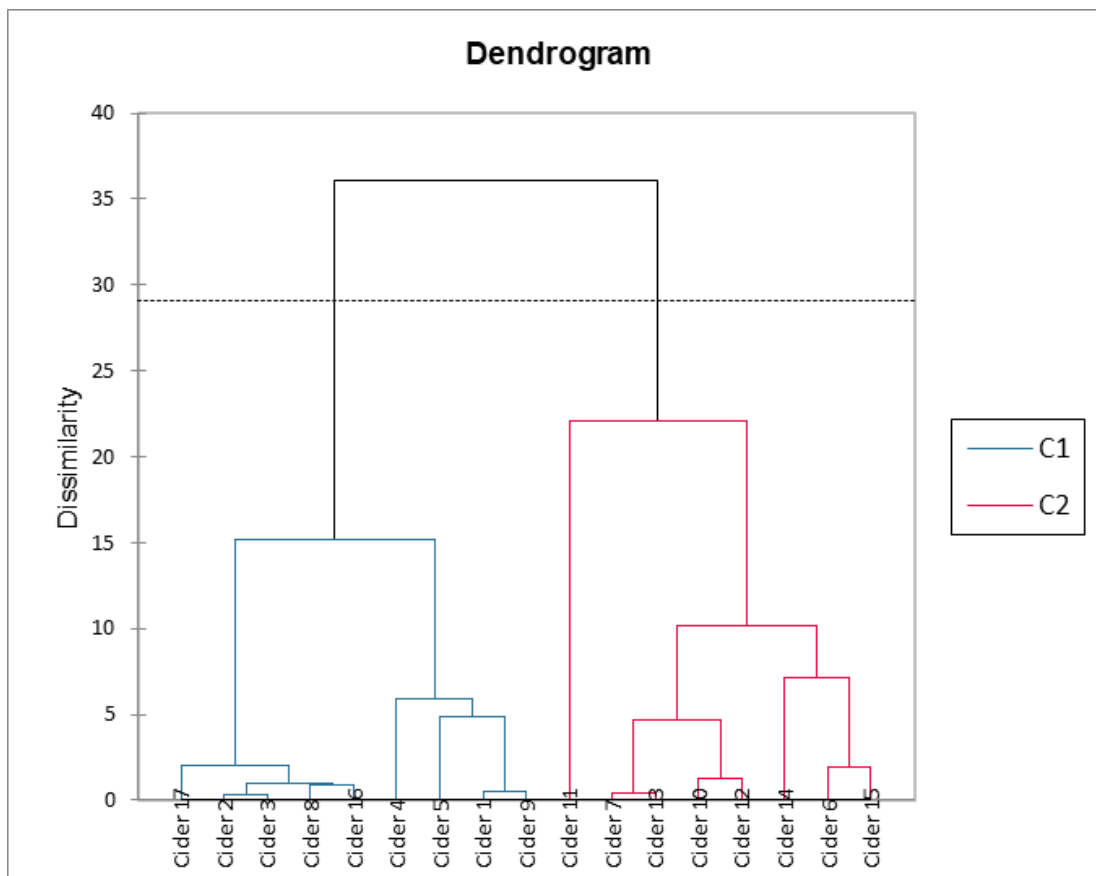


Figure 3: Dendrogram for New Zealand craft ciders based on chemical parameters and Euclidean distance with Ward linkage.

The dataset was divided into two groups using the hierarchical clustering (AHC) method with a threshold of 29, as shown by the dendrogram. The dendrogram's first branch,

which has a height of 15, denotes the creation of a more extensive cluster (Group 1) of data points that share specific characteristics or traits and show some resemblance.

Observation of the profile plot (Appendix A, Figure A2) reveals that the °Brix % and pH values are similar for both clusters, indicating that the samples have comparable levels of sugar content and acidity. However, the TA values were slightly different with slightly higher acidity in cluster 1. Tannin content was low in both clusters, indicating that tannin was not an important differentiating factor. The most significant difference was in the brightness ( $L^*$ ) parameter, with cluster 2 showing a clear peak, indicating higher brightness values. The differences in the colour parameters  $a^*$  and  $b^*$  were smaller, with slightly higher values in group 2. The overall colour difference ( $\Delta E$ ) between the clusters is small.

Further analysis of Group 1's data points reveals recurring themes, such as using Kingston apples as a primary ingredient in Cider 5 and Cider 16's brewing processes. However, a significant divergence within this wider grouping emerged due to the sole use of an ageing procedure by Cider16 in the brewing process (Appendix E).

On the other hand, the dendrogram's second branch, which has a height of 22, shows the creation of a smaller clustering group (Group 2). Compared to those in Group 1, the data points in Group 2 show various traits and features. Examples of ciders with different sugar contents include Cider12, which is a semi-dry cider, and Cider16, which is a dry cider.



The relationship between volatile components and selected New Zealand craft ciders is depicted in the PCA biplot shown in Figure 4. The two axes, F1 and F2, form the basis of the biplot, accounting for 44.39% of the total variation explained.

From the squared cosine angles (Table B3 in Appendix B), the significant variables of F1 are 1-octanol (0.713), ethyl octanoate (0.763), ethyl 9-decenoate (0.738), isoamyl octanoate (0.916), and ethyl dodecanoate (0.573), all of which are on the positive side of F1. Thus, these compounds determine a large amount of the variation explained by principal component 1. The angle between each variable vector and the principal component axis indicates the correlation between that volatile compound and the two principal components F1 and F2. A smaller angle indicates a stronger positive correlation (Jolliffe, 2002). For example, ethyl octanoate has a high squared cosine value (0.763) with F1, indicating that it is positively correlated with this principal component. On the contrary, acetic acid has a higher squared cosine value (0.374) on the F2 axis than on the F1 axis (0.016), indicating a stronger correlation with F2. This is consistent with the position of acetic acid on the biplot, where the vector of acetic acid is closer to the F2 axis.

The direction of the variable vectors shows which principal component the volatile increases or decreases along. Compounds like 1-hexanol and ethyl decanoate point in the positive F1 direction, increasing along that axis. Sample located close to these compounds will have high values compared to those on the opposite side on the plot.

The length of the vector visualises the weight or influence of each volatile on the principal components. Longer vectors like ethyl octanoate and isoamyl acetate have higher weightings, while shorter vectors like 1-octanol have less impact on these two components.

From the biplot, several clusters of ciders with similar aromatic profiles can be observed based on their positions relative to the volatile compound vectors. For example, Ciders 2 and 3 are close together and near the vectors for compounds like 1-hexanol and hexyl acetate, suggesting fruity, floral and apple/pear aromas characterise their aroma profiles.

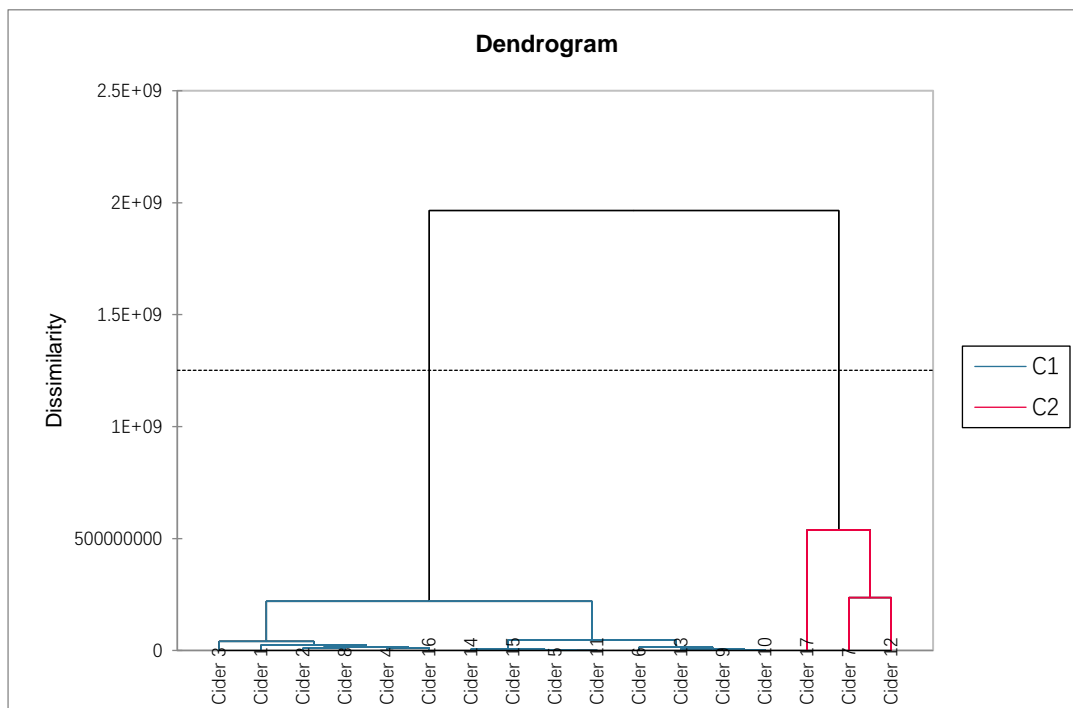


Figure 5: Dendrogram for New Zealand craft ciders based on volatile components and Euclidean distance with Ward linkage.

Figure 5 is a dendrogram resulting from agglomerative hierarchical cluster analysis of the volatile compound data. It shows how the ciders group together based on similarities in their aromatic profiles composed of the measured volatile compounds.

The y-axis represents the distance or degree of dissimilarity between the clusters. The ciders grouped under shorter branches are more similar in their overall volatile composition than those grouped in longer branches higher up the tree.

Two main clusters are labelled in blue (C1) and red (C2). Ciders within each colour cluster are more similar to each other in aromatic profile than they are to ciders in the other central cluster.

The profile plot (Appendix B, Figure B1) shows higher concentrations of various volatile compounds in cluster 2 compared to cluster 1. The ethanol content was similar in both clusters, indicating comparable alcohol content. However, cluster 2 had higher concentrations of 1-pentanol, 1-hexanol and 1-octanol, which produced herbal and citrus aromas, for example. Cluster 2 also had higher levels of acetic acid, which produced vinegar-like aromas. In particular, cluster 2 contained significantly higher levels of esters such as isoamyl acetate, hexyl acetate and ethyl octanoate, which contributed to the fruit and banana aromas. Other compounds such as decanal, caprylic acid and ethyl octanoate were also present in high levels in cluster 2, adding to the complexity and richness of its aroma profile.

For example, ciders 9 and 10 are closely grouped in the blue C1 cluster, likely due to higher levels of similar volatile compounds resulting in similarity in aromas between them compared to other samples.

By integrating the hierarchical clustering results with the principal component biplot of the volatile data, a richer multi-dimensional perspective on the relationships between cider aroma profiles can be gleaned. This combination of dimension reduction and clustering techniques enables the mapping of the volatile compounds and samples to reveal samples with similar and different chemical components.

Table 2 provides a list of the volatile chemical compounds detected in the cider samples, along with their corresponding odour descriptors from the literature.

Table 2: Odour descriptions for volatile compounds in New Zealand craft ciders (n=17).

<b>Components</b>	<b>Odour Description</b>
Ethanol	Fruity <sup>a</sup>
1-Pentanol	Fusel <sup>b</sup>
1-Hexanol	Herbaceous, grassy, floral <sup>c</sup>
1-Octanol	Citrus, green <sup>d</sup>
2,3-Butanediol	Sweet <sup>e</sup>
Acetic acid	Vinegar <sup>h</sup>
Isoamyl acetate	Fruity, banana <sup>i</sup>
Hexyl acetate	Apple, pear, banana <sup>g</sup>
2,4-Hexadienoic acid, ethyl ester	Floral <sup>j</sup>
Phenylethyl Alcohol	Rose, honey <sup>f</sup>
Ethyl Octanoate	Fruity, candy, pineapple <sup>k</sup>
Decanal	Citrus <sup>l</sup>
Octanoic Acid	Cheese, milk, ripe fruit <sup>m</sup>
Ethyl nonanoate	Fatty, fruity, nutty, oily <sup>c</sup>
Ethyl 9-decenoate	Roses, banana <sup>f</sup>
Ethyl Decanoate	Fruity, grape <sup>c</sup>
n-Decanoic acid	Fatty, soapy <sup>f</sup>
Isoamyl octanoate	Sweet, waxy, green, soapy, pineapple, coconut <sup>n</sup>
Hexyl octanoate	Fresh, vegetable, fruity <sup>o</sup>
Ethyl Dodecanoate	Candy, floral, waxy, soapy <sup>c</sup>

<sup>a</sup> (Eade et al., 2009), <sup>b</sup> (National Center for Biotechnology, 2024), <sup>c</sup> (Genovese et al., 2009), <sup>d</sup> (Czerny et al., 2008), <sup>e</sup> (Richter et al., 2016), <sup>f</sup> (Arcari et al., 2017), <sup>g</sup> (Pino et al., 2012), <sup>h</sup> (Health, 2023), <sup>i</sup> (Burdock, 2019), <sup>j</sup> (Collin et al., 2008), <sup>k</sup> (Englezos et al.,

2016), <sup>l</sup> (Kim et al., 2019), <sup>m</sup> (García-Carpintero et al., 2011), <sup>n</sup> (Vázquez-Pateiro et al., 2020), <sup>o</sup> (Li et al., 2023)

There are overlapping or related odour profiles for many of the compounds, mainly fruity, floral, and sweet. For example, ethanol, isoamyl acetate, hexyl acetate and ethyl caprylate are all associated with fruity flavours. Phenylethyl Alcohol and Ethyl 9-decanoate are linked to rose and floral notes, while 2,3-butanediol contributes a sweet sensation.

However, some compounds introduce more nuanced or distinct aromatic qualities. 1-octanol and decanal impart citrus notes, while cheesy, milky, and ripe fruit odours characterise octanoic acid. Ethyl nonanoate, on the other hand, introduces nutty and oily nuances to the aroma profile.

The information from Table 2 helps explain some of the differences and similarities among the samples as in Figures 4 and 5. For example, Cider 12 and 17. Firstly, both ciders exhibit prominent fruity and floral characteristics, as evidenced by their proximity to vectors representing these chemical compounds (Figure 4). Secondly, ciders 17 and 12 were classified in the same cluster generated by hierarchical cluster analysis. This clustering suggests that these two ciders possess more similar olfactory characteristics to each other than ciders assigned to different clusters. The short branch lengths connecting ciders 17 and 12 in the dendrogram reinforced their aromatic similarity.

### **4.3 Focus Group and Consumer Sensory Evaluation**

Focus group discussions revealed participants' opinions on the nuances of the sensory attributes of different ciders. The descriptions used in the focus groups included appearance, aroma, flavour, mouthfeel and aftertaste.

Figure 6 provides a visual representation of the sensory characteristics that focus group participants perceived to be associated with ciders.



Figure 6: Wordcloud showing words used to describe the cider samples tasted during the focus group session.

The results showed that the participants used different words to describe the ciders, Prominent among these words were carbonated/fizzy, golden, fruity, smooth, smooth, sour and colourless. On the other hand, words such as floral, candied, amber and oaky were the least frequently used words to describe the ciders as seen indicated in the literature (Alderson et al., 2021).

As shown from the word cloud, sensory attributes like 'Carbonated/Fizzy,' 'Golden', and 'Sour' were the most frequently mentioned attributes. These attributes could also be prescriptive instead of mere descriptors because they may include the impact of regional apple types, the type of fermentation involved, or the ageing process related to appellation.

For example, the " Carbonated/Fizzy " represented may be linked to the method of producing cider in some regions, where the cider is fermented in bottles, as in méthode champenoise, which is used to produce sparkling wines.(Abid et al., 2013)

Similarly, the attribute 'Golden' could refer to the colour of the cider as impacted by the apple variety used. References to 'Sour' flavours may go on to describe the existence of certain wild yeast strains or the impact of certain specific fermentation methods.

Researchers can understand the relationship between sensory and chemical quality and character by combining these consumer-driven sensory perceptions with chemical composition analysis and volatile components.

Plotting the results from the CATA data analysis shows the relationship between samples and the sensory attributes which can reveal the characteristics of the samples. The results are presented for each of the three sensory evaluation sessions before combining the data for all sessions. Figure 7 shows the correspondence analysis plot for session 1.

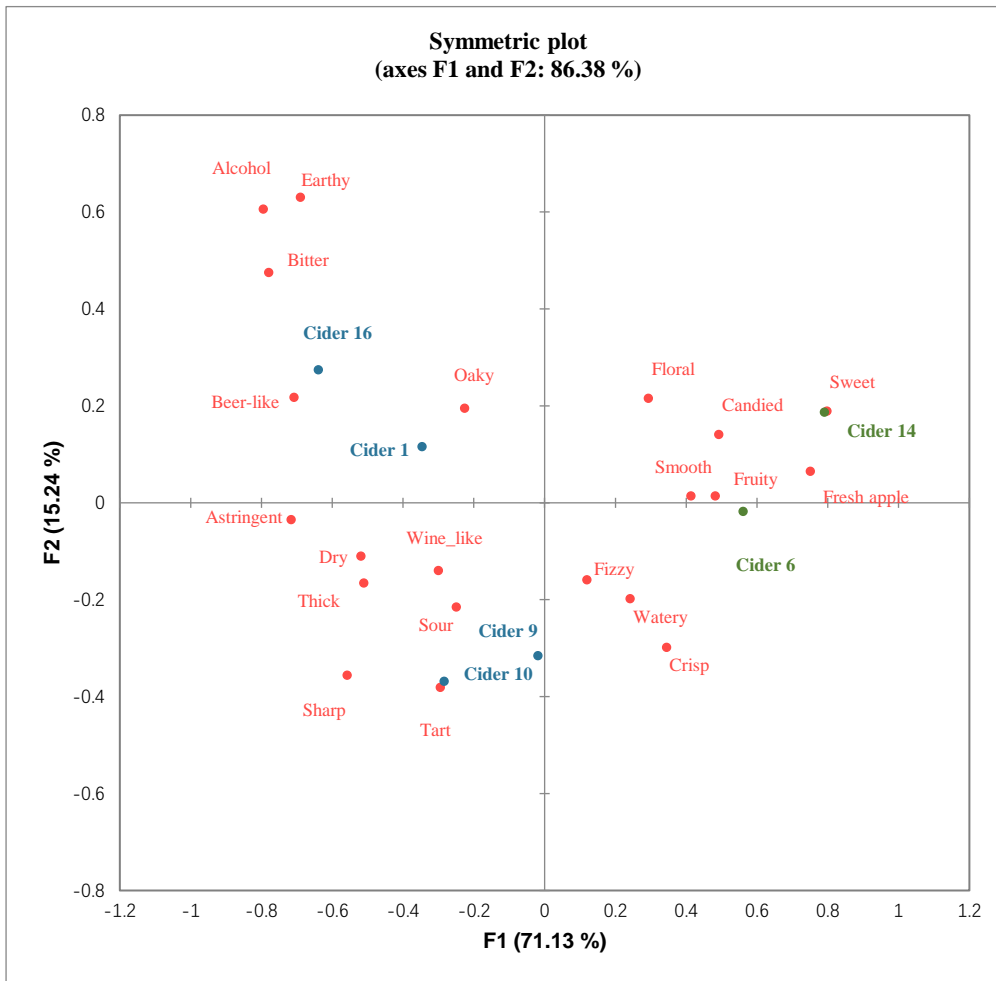


Figure 7: Correspondence analysis symmetric plot of sensory attributes and cider samples for session 1 from the North Island (blue) and those from the South (green) (Axes F1 and F2: 86.38 %).

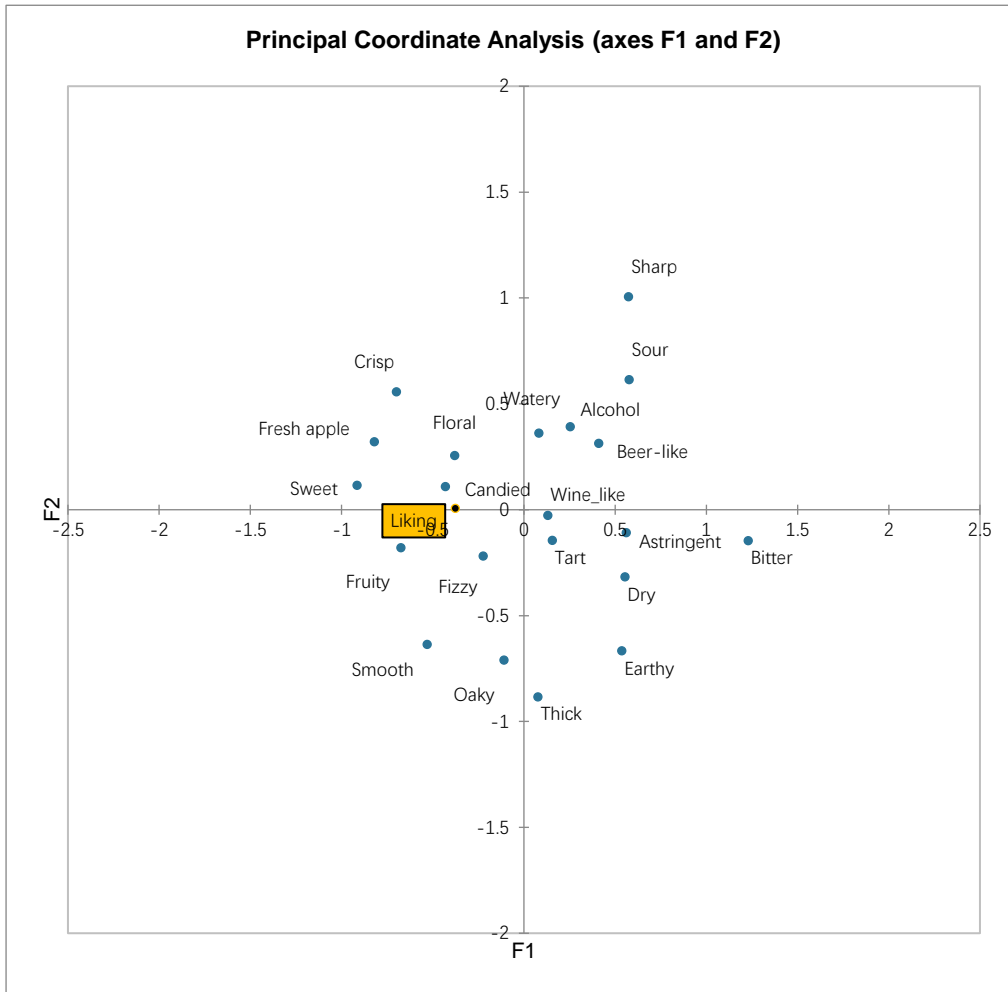


Figure 8: Principal coordinate analysis (PCoA) plot for liking and sensory attributes used for samples in Session 1.

The first dimension (F1, 71.13%) contrasted sweet, fruity, fresh apple sensory attributes against bitter, oaky, and beer-like characteristics. Ciders like Cider 6 and 14 were closely associated with heightened perceptions of sweetness and fruitiness. In contrast, Cider 16 was associated with attributes such as bitterness and oaky flavours. The second dimension (F2, 15.24%) further discriminated the products based on perceived levels of fizziness/carbonation and alcohol intensity.

The PCoA biplot (Figure 8) elucidates the underlying sensory dimensions and liking correlations. By analysing the PCA results alongside the Symmetric Plot (Figure 7), it

can be inferred that Cider 6 and 14 are associated with high liking scores, sweetness, fruity flavours, and fresh apple attributes at the positive end of F1. In contrast, Cider 16 occupied the opposing end of F1 with bitter, oaky, beer-like, and astringent flavours alongside a lower liking score.

Subsequent pairwise comparisons utilising the critical difference procedure revealed significant variations in attribute strength across different products.

Table 3: Frequency table for sensory attributes from Cochran Q test for session 1:

<b>Attributes</b>	<b>Cider 10</b>	<b>Cider 6</b>	<b>Cider 9</b>	<b>Cider 14</b>	<b>Cider 1</b>	<b>Cider 16</b>
Sweet	0.167 (a)	0.600 (bc)	0.133 (a)	0.867 (c)	0.233 (ab)	0.067 (a)
Sour	0.300 (a)	0.167 (a)	0.333 (a)	0.133 (a)	0.233 (a)	0.333 (a)
Bitter	0.067 (a)	0 (a)	0.067 (a)	0.033 (a)	0.200 (ab)	0.367 (b)
Fruity	0.267 (a)	0.400 (ab)	0.300 (a)	0.733 (b)	0.233 (a)	0.167 (a)
Floral	0.100 (a)	0.267 (a)	0.133 (a)	0.367 (a)	0.167 (a)	0.233 (a)
Candied	0.100 (a)	0.167 (a)	0.033 (a)	0.233 (a)	0.167 (a)	0.033 (a)
Wine-like	0.233 (a)	0.200 (a)	0.333 (a)	0.100 (a)	0.267 (a)	0.367 (a)
Tart	0.300 (a)	0.100 (a)	0.367 (a)	0.100 (a)	0.233 (a)	0.233 (a)
Earthy	0 (a)	0.033 (ab)	0.033 (ab)	0 (a)	0.233 (b)	0.233 (b)
Fresh apple	0.167 (ab)	0.400 (bc)	0.100 (a)	0.500 (c)	0.133 (ab)	0.033 (a)
Oaky	0.100 (a)	0.067 (a)	0.067 (a)	0.100 (a)	0.133 (a)	0.200 (a)
Beer-like	0.100 (ab)	0 (a)	0.133 (ab)	0.033 (a)	0.233 (ab)	0.333 (b)
Watery	0.333 (b)	0.267 (ab)	0.133 (ab)	0.233 (ab)	0.033 (a)	0.200 (ab)
Thick	0.033 (a)	0.067 (a)	0.167 (a)	0 (a)	0.133 (a)	0.133 (a)
Crisp	0.200 (a)	0.233 (a)	0.067 (a)	0.100 (a)	0.100 (a)	0.033 (a)
Sharp	0.167 (a)	0 (a)	0.133 (a)	0 (a)	0.200 (a)	0.100 (a)
Smooth	0.233 (a)	0.300 (a)	0.067 (a)	0.300 (a)	0.133 (a)	0.133 (a)

Table 3 (continued)

<b>Attributes</b>	<b>Cider 10</b>	<b>Cider 6</b>	<b>Cider 9</b>	<b>Cider 14</b>	<b>Cider 1</b>	<b>Cider 16</b>
Fizzy	0.233 (a)	0.267 (a)	0.267 (a)	0.267 (a)	0.300 (a)	0.133 (a)
Astringent	0.167 (ab)	0 (a)	0.233 (ab)	0 (a)	0.333 (b)	0.333 (b)
Alcohol	0.067 (a)	0.033 (a)	0 (a)	0.033 (a)	0.133 (ab)	0.333 (b)
Dry	0.233 (abc)	0.200 (ab)	0.400 (bc)	0 (a)	0.300 (abc)	0.533 ©

(a), (b), (c)...Frequencies with different letters in a row indicate significant differences based on the Sheskin test at  $p < 0.05$ .

The Symmetric Plot, depicted in Figure 7, visually represents these sensory dimensions by plotting cider samples and sensory attributes in a biplot configuration. The proximity between sample and attribute vectors within this plot signifies the strength of association, facilitating the identification of critical sensory characteristics for each product. Table 3 shows the multiple pairwise comparisons which indicate whether or not a given attribute significantly characterises a sample.

In the analysis of Session 2, Principal Component Analysis (PcoA) and Multiple Pairwise Comparisons were conducted too. The Symmetric Plot (Figure 9) illustrates the underlying sensory dimensions, with the first two principal components (F1 and F2) accounting for 83.19% of the total variance.

Cider 5 and 11 are located at the positive end of F1 (Figure 10), associated with sweetness, fruity flavour, and fresh apple attributes, leading to higher liking scores. In contrast, Cider 2 and 15 were at the opposing end of the F1 scale, associated with bitter, sour, fizzy, and astringent flavours, resulting in lower liking scores.

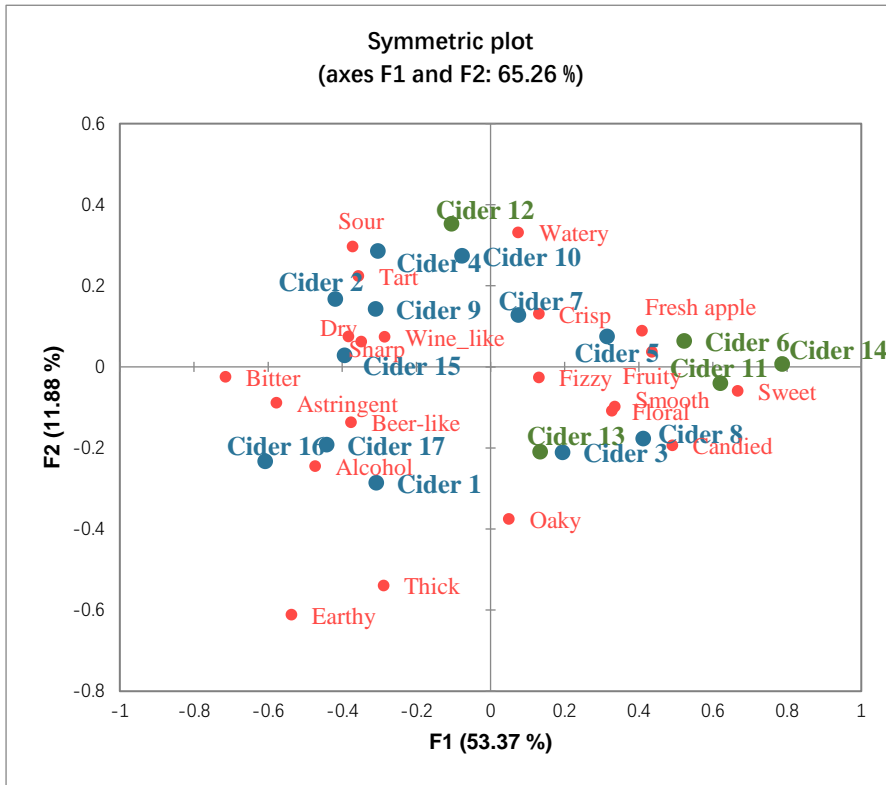


Figure 9: Correspondence analysis symmetric plot of sensory attributes and cider samples for session 1 from the North Island (blue) and those from the South (green) (Axes F1 and F2: 83.19 %).

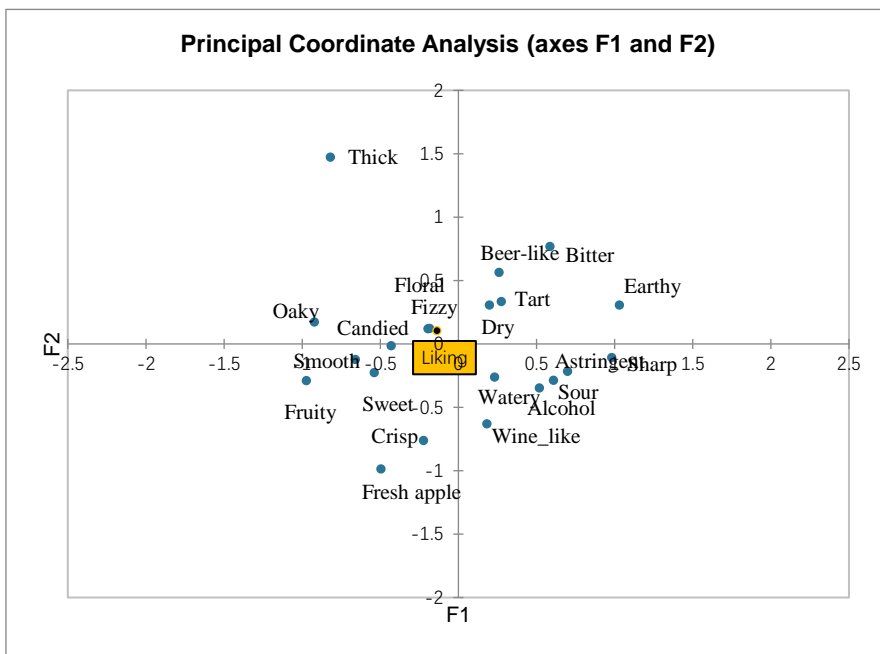


Figure 10: Principal coordinate analysis (PcoA) plot for liking and sensory attributes used for samples in Session 2.

Multiple pairwise comparisons identified significant differences in attribute intensity across products (Table 4).

Table 4: Frequency table for sensory attributes from Cochran Q test for session 2:

Attributes	Cider 5	Cider 11	Cider 12	Cider 15	Cider 2	Cider 4
Sweet	0.467 (ab)	0.700 (b)	0.167 (a)	0.233 (a)	0.133 (a)	0.133 (a)
Sour	0.200 (ab)	0.067 (a)	0.433 (b)	0.333 (ab)	0.400 (b)	0.433 (b)
Bitter	0.067 (a)	0 (a)	0.133 (ab)	0.367 (b)	0.367 (b)	0.233 (ab)
Fruity	0.567 (b)	0.600 (b)	0.267 (ab)	0.200 (a)	0.200 (a)	0.200 (a)
Floral	0.167 (ab)	0.367 (b)	0.133 (ab)	0.200 (ab)	0.133 (ab)	0.067 (a)
Candied	0 (a)	0.067 (a)	0.033 (a)	0.033 (a)	0.033 (a)	0.033 (a)
Wine-like	0.133 (a)	0.100 (a)	0.267 (a)	0.367 (a)	0.300 (a)	0.233 (a)
Tart	0.133 (a)	0.067 (a)	0.167 (a)	0.333 (a)	0.300 (a)	0.267 (a)
Earthy	0 (a)	0.067 (a)	0 (a)	0.167 (a)	0.100 (a)	0.033 (a)
Fresh apple	0.533 (b)	0.433 (ab)	0.300 (ab)	0.200 (a)	0.167 (a)	0.333 (ab)
Oaky	0.133 (a)	0.100 (a)	0.033 (a)	0.067 (a)	0.067 (a)	0.033 (a)
Beer-like	0.167 (a)	0.067 (a)	0.100 (a)	0.133 (a)	0.133 (a)	0.167 (a)
Watery	0.100 (a)	0.300 (a)	0.333 (a)	0.167 (a)	0.167 (a)	0.133 (a)
Thick	0.033 (a)	0.033 (a)	0.033 (a)	0 (a)	0 (a)	0 (a)
Crisp	0.200 (a)	0.167 (a)	0.267 (a)	0.133 (a)	0.100 (a)	0.233 (a)
Sharp	0.133 (ab)	0 (a)	0.067 (ab)	0.167 (ab)	0.133 (ab)	0.233 (b)
Smooth	0.267 (ab)	0.467 (b)	0.167 (ab)	0.133 (a)	0.200 (ab)	0.200 (ab)
Fizzy	0.267 (a)	0.167 (a)	0.167 (a)	0.200 (a)	0.100 (a)	0.200 (a)
Astringent	0.067 (a)	0.133 (ab)	0.067 (a)	0.333 (b)	0.167 (ab)	0.233 (ab)
Alcohol	0.067 (ab)	0 (a)	0.167 (ab)	0.233 (b)	0.133 (ab)	0.067 (ab)
Dry	0.233 (a)	0.100 (a)	0.333 (a)	0.233 (a)	0.367 (a)	0.400 (a)

(a), (b), (c)...Frequencies with different letters in a row indicate significant differences based on the Sheskin test at  $p < 0.05$

The sensory characteristics of each cider sample were revealed by the sensory assessment. Cider 11 stood out with the highest sweetness (0.700) and fruity flavour (0.600) as well as significant floral (0.367) and smoothness (0.467). This suggested a well-balanced, fruity and smooth cider. In contrast, Ciders 4 and 12 had the highest acidity (0.433), suggesting heavier acidity, while Ciders 15 and 2 had higher bitterness (0.367) and astringency (0.333 for Cider 15), suggesting a more complex flavour, possibly with tannins.

Figure 11 shows the correspondence analysis plot for session 3.

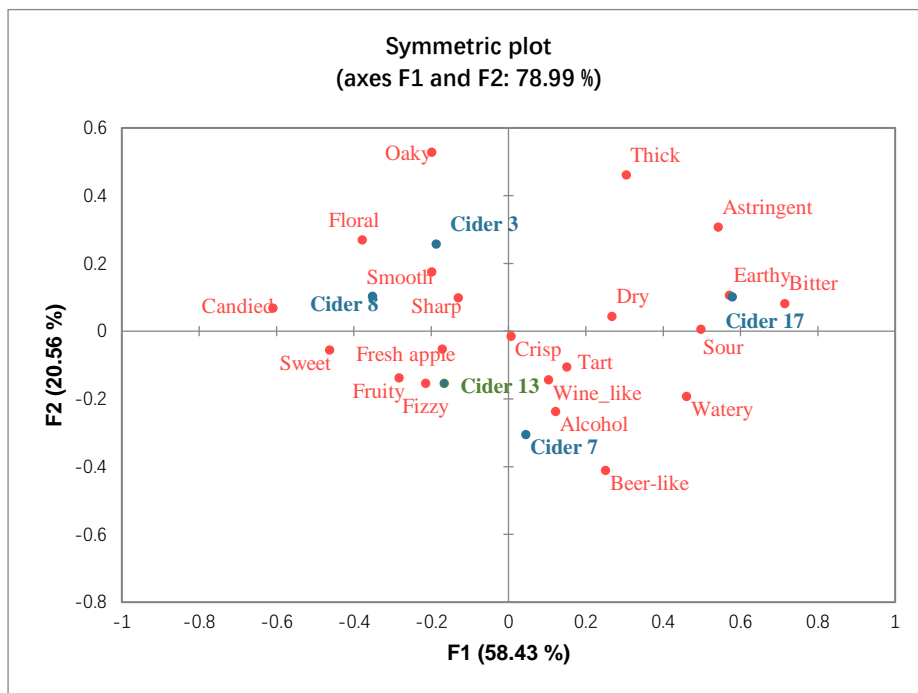


Figure 11: Correspondence analysis symmetric plot of sensory attributes and cider samples for session 3 from the North Island (blue) and those from the South (green) (Axes F1 and F2: 78.99 %).

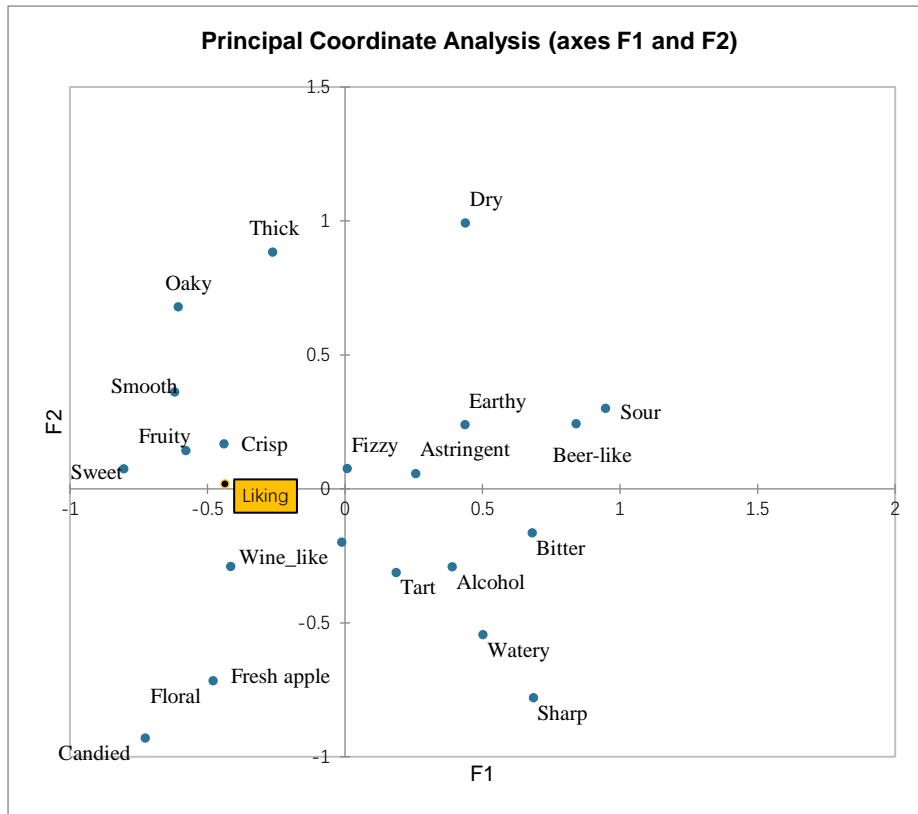


Figure 12: Principal coordinate analysis (PcoA) plot for liking and sensory attributes used for samples in Session 3.

Pairwise comparisons of session 3 were again performed using the critical difference procedure to verify significant differences in the strength of attributes across products.

Table 5: Frequency table for sensory attributes from Cochran Q test for session 3:

Attributes	Cider 17	Cider 7	Cider 8	Cider 13	Cider 3
Sweet	0.067 (a)	0.367 (ab)	0.533 (b)	0.400 (b)	0.367 (ab)
Sour	0.367 (b)	0.167 (ab)	0.100 (a)	0.133 (a)	0.100 (a)
Bitter	0.300 (b)	0.100 (ab)	0 (a)	0.100 (ab)	0.100 (ab)
Fruity	0.167 (a)	0.400 (a)	0.433 (a)	0.400 (a)	0.300 (a)
Floral	0.067 (a)	0.067 (a)	0.167 (a)	0.167 (a)	0.233 (a)
Candied	0 (a)	0.033 (a)	0.100 (a)	0.133 (a)	0.100 (a)

Table 5 (continued)

<b>Attributes</b>	<b>Cider 17</b>	<b>Cider 7</b>	<b>Cider 8</b>	<b>Cider 13</b>	<b>Cider 3</b>
Wine-like	0.267 (a)	0.267 (a)	0.167 (a)	0.233 (a)	0.167 (a)
Tart	0.167 (a)	0.167 (a)	0.067 (a)	0.133 (a)	0.133 (a)
Earthy	0.333 (b)	0.100 (ab)	0.100 (ab)	0.100 (ab)	0.067 (a)
Fresh apple	0.233 (a)	0.367 (a)	0.333 (a)	0.367 (a)	0.367 (a)
Oaky	0.133 (a)	0.033 (a)	0.167 (a)	0.100 (a)	0.267 (a)
Beer-like	0.233 (a)	0.267 (a)	0.067 (a)	0.233 (a)	0.067 (a)
Watery	0.233 (a)	0.200 (a)	0.067 (a)	0.067 (a)	0.067 (a)
Thick	0.200 (b)	0 (a)	0.067 (ab)	0.100 (ab)	0.133 (ab)
Crisp	0.267 (a)	0.300 (a)	0.233 (a)	0.200 (a)	0.267 (a)
Sharp	0.100 (a)	0.100 (a)	0.100 (a)	0.133 (a)	0.167 (a)
Smooth	0.300 (ab)	0.167 (a)	0.500 (b)	0.333 (ab)	0.300 (ab)
Fizzy	0.167 (a)	0.200 (a)	0.267 (a)	0.400 (a)	0.167 (a)
Astringent	0.233 (b)	0.067 (ab)	0.067 (ab)	0.033 (a)	0.100 (ab)
Alcohol	0.167 (ab)	0.067 (a)	0.033 (a)	0.300 (b)	0.067 (a)
Dry	0.433 (a)	0.267 (a)	0.233 (a)	0.167 (a)	0.200 (a)

(a), (b), (c)...Frequencies with different letters in a row indicate significant differences based on the Sheskin test at  $p < 0.05$

Based on session 3 (Figure 11, Table 6) with 5 dry cider styles, it can be interpreted that F1 accounts for 58.43% of the variance and is mainly a comparison between Cider 8 and Cider 17. Cider 8 is characterised by higher attribute scores for smoothness and sweetness, which lie on the positive side of F1. On the other hand, Cider 17 scored higher for the attributes “Earthy”, “Thick”, “Astringent”, and “Bitter”, while scoring lower for “Sweet”, all of which were located on the negative side of the F1. This suggests that F1 represents overall taste palatability or consumer preference and that smoother, sweeter attributes may be preferred. F2 explained 20.56% of the variance and

appeared to be the difference between full-bodied and lighter-tasting characteristics. Taste characteristics such as “Thick”, “Crisp”, and “Smooth” were associated with positive F2 values, as shown by the score for Cider 17 in Table 5 (“Thick” at 0.200). Lighter-bodied characteristics such as “Watery”, by contrast, are associated with negative F2 values, as the score for Cider 7 shows as an example (“Watery” at 0.200).

Figure 13 shows the combined correspondence analysis plot when the data from the three sessions were combined.

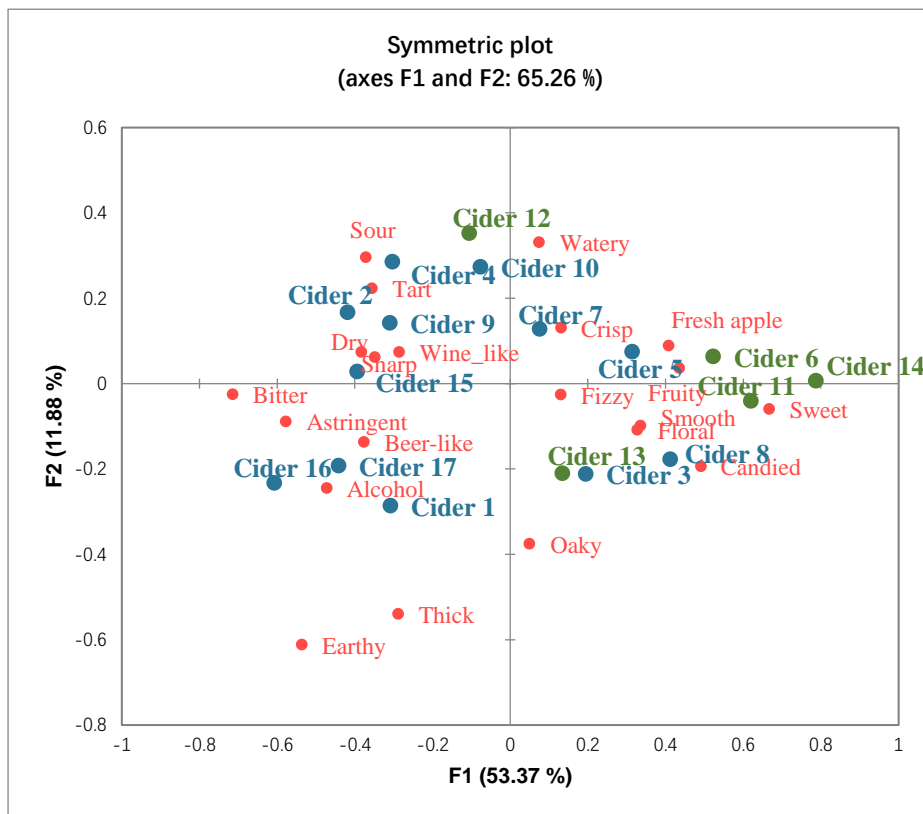


Figure 13: Correspondence analysis symmetric plot of sensory attributes and cider samples for all three sessions showing distinction between samples from the North Island (blue) and those from the South (green).

Combining the data from all three sessions shows that cider samples from the South Island were mostly associated with fresh apple, fruity, sweet and floral flavours as well

as fizzy and smooth. Only a few samples from the north island were observed to be associated with these attributes. Most of the samples from the North Island were associated with attributes that were opposite to those from the South Island.

In summary, the analyses of the three PCA biplots revealed different sensory characteristics and liking of the cider samples. Ciders 5, 6, 8, 11 and 14 consistently scored high in sweetness, fruitiness, fresh apple flavour and overall preference across the different analyses. These ciders are characterised by positive sensory attributes, showing an excellent sensory profile characterised by pleasant sweetness, fruitiness, and freshness. On the other hand, ciders 2, 15, 16, and 17 scored the highest on the PCA biplot for bitterness, acidity, oak/beer flavour and astringency. Although these ciders were strong in these less favoured sensory attributes, they received lower liking scores, suggesting that their sensory characteristics were less appealing to the panellists.

#### 4.4 Classification of Ciders

Partial least square discriminant analysis (PLS-DA) was used to classify and predict samples based on the island of origin of the ciders using the chemical and volatile components data. The confusion matrix and predictions are shown in Table 6 and Figure 14 respectively.

Table 6: Confusion matrix for the classification of New Zealand craft ciders based on North and South Islands.

	North	South	None
North	12	0	0
South	4	1	0

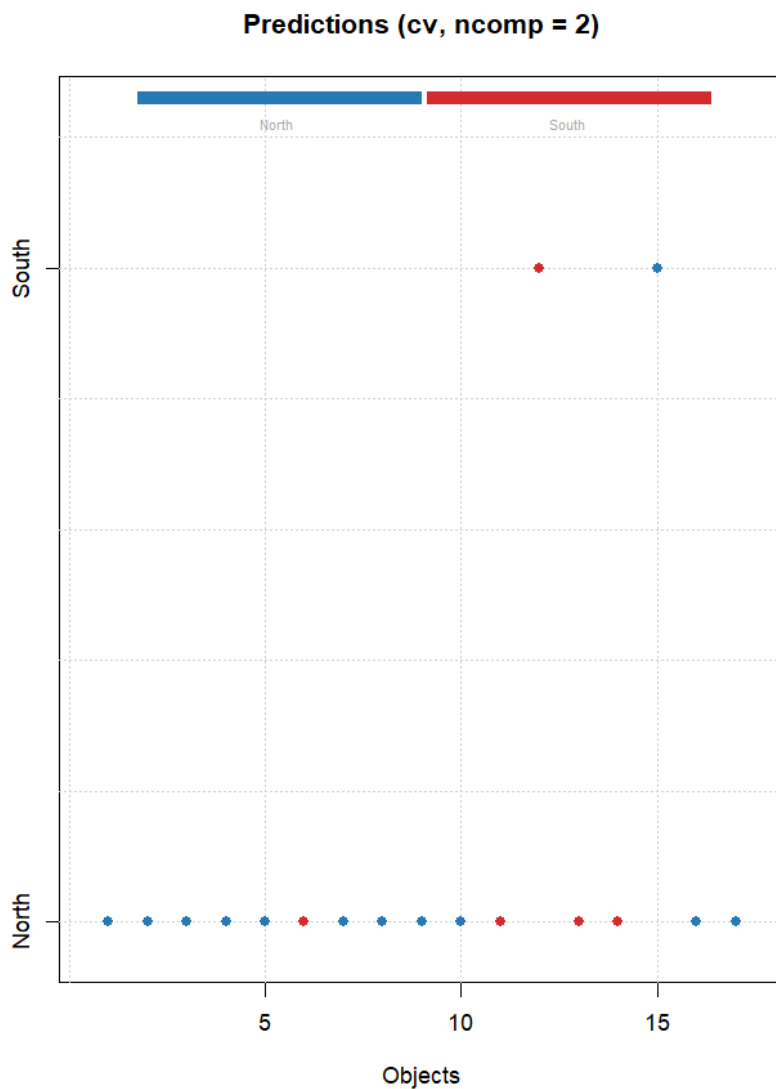


Figure 14: Prediction of class membership of New Zealand craft ciders based on North and South islands. Cider origin is shown as: blue – North Island, red – South Island.

The confusion matrix shows that all the ciders from the north island were correctly classified, but only one was correctly classified from the south. The predictions also show a similar trend as the confusion matrix – misclassifying four from the South Island as originating from the North Island. However, one of the ciders from the north island was also misclassified upon prediction. This indicates that the ciders from the north island have similar volatile and chemical composition data compared to those from the

South Island. However, since there was a comparatively low representation of South Island ciders in this study, more samples need to be assessed to better represent the characteristics of ciders from the South Island for robust classification.

## Chapter 5 Discussion

Based on chemical composition and volatile profiles, the analysis' primary findings identified unique patterns and groupings among the selected craft cider samples from New Zealand. The application of additional multivariate statistical methodologies such as PCA and hierarchical clustering was possible in the present study to distinguish the patterns and clusters of the cider samples. These patterns and classifications were very much influenced by production factors like the type of apples used, geographical location, method of fermentation and ageing process.

The results of the cluster analysis were that the cider samples had differences in the chemical compositions in terms of the sugar concentration, titratable acidity, tannin content and colour characteristics and these differences could be because of the use of the different apple varieties and methods of production. This study aligns with Nešpor et al. (2019) who observed that the level of the chemical compounds in apple juice differed with fruit type and the process used in making cider.

The titratable acidity and pH ranges observed (Appendix A, Table A1) in the New Zealand samples were also within the typical ranges reported by Lea (2003) for traditional English cider, who found a range of 3.0 – 7.0 g/L for the titratable acidity and 3.0 – 3.8 for pH. A negative correlation between TA and pH in the PCA biplot was observed, which agrees with the general pattern of cider acidity characteristics. Peng et al. (2009) reported an inverse relationship between titratable acidity and pH for cider made from Fuji apples, supporting the general pattern of cider acidity profiles in this study.

The AHC analyses provided additional evidence for the distinction between different ciders that could be linked to certain types of apples such as Kingston apples or production techniques like oak ageing. These findings are also in line with the observations of Antón-Daz et al. (2016) about processing cider in different ways who stated that exposure to lees during cider production impacts the volatile profile and other sensory properties of cider.

In this study, the results of volatile components of the ciders revealed some interesting patterns which showed some similarities and differences with the findings of previous studies on ciders from other regions. The results of principal component analysis (PCA) showed that the first (F1) and second (F2) principal components explained a total of 44.39% of the total variance (Figure 4), suggesting that the chemical composition of the ciders is of considerable complexity and more physicochemical variables need to be assessed to account for a higher total variance among the samples.

According to the PCA biplot of volatile components (Figure 4), Cider 3 and Cider 6 were located in the same quadrant of the plot. This position suggests that the two ciders are similar in terms of certain volatile compounds; in particular, they are closer to the vectors of 2,4-hexadienoic acid, ethyl ester, ethanol, and acetic acid. Specifically, the positions of Cider 3 and Cider 6 suggest that they have higher concentrations of 2,4-hexadienoic acid, ethyl ester (with a high squared cosine value of 0.600 on F2) and ethanol (with a squared cosine value of 0.476 on F2) (Appendix B, Table B3). This chemical compositional profile may give both ciders unique aroma and flavour profiles that may include some floral or fruity notes (Table 2).

According to Antón et al. (2014) ethyl esters (including ethyl 2,4-hexadienoate) contribute significantly to the aromatic profile of cider, usually bringing out fruity flavours. Ethanol plays an essential role in perceiving other volatile compounds in cider, according to Lorenzini et al. (2019). It also affects the body and flavour. Their findings suggest that higher levels of certain ethyl esters, combined with increased ethanol levels, tend to produce more distinctive aromas and flavours in cider. These usually manifest themselves as fruity and floral aromas that are easy to detect. This is consistent with the data shown in the Cider 3 and Cider 6 PCA biplot. Judging from their position in the graph, their flavours may be more subtle and intense than those of some of the other samples.

In contrast, Cider 17 is located on the right side of the graph and is closer to the vectors for isoamyl octanoate (which has the highest squared cosine value of 0.916 on F1) and ethyl octanoate (which has a high squared cosine value of 0.763 on F1). This suggests that Cider 17 may have a more intense fruity character, as these compounds are

commonly associated with fruit aromas (Antón et al., 2014). However, the results of the sensory evaluation (Table 5) showed that Cider 17 had a relatively low score (0.167) for fruit characteristics. Also, Cider 17 had a high score on “Sour” (0.367) and “Bitter” (0.300) attributes, which were not significant in the PCA biplot. Besides, Cider 17 had the highest score on the attribute "Dry" (0.433), which may explain why it had a lower perceived sweetness (0.067). The discrepancy between what is observed in sensory experiments and what people taste shows how complex the determination of cider flavour can be. It has been found in previous research that if a particular compound is high in experimental data, it may not come through in the glass (Peng et al., 2009). For example, Lea (2003) highlights the importance of acidity and tannins to the overall flavour balance of cider. This may explain why Cider 17, despite being high in certain fruit aroma compounds, does not stand out in actual perceived fruit characteristics. Moreover, research by Wei et al. (2020) suggests that chemical interactions in cider may lead to unexpected sensory effects, such as the high acidity and bitterness observed in this study.

Moreover, Table B3 (Appendix B) shows that phenyl ethanol (phenylethyl alcohol) has a squared cosine value of 0.484 on F1, indicating that it is one of the essential compounds for differentiating between different cider samples. This is similar to the findings of Alonso-Salces et al. (2004) for French cider, highlighting the potential for New Zealand-grown apples to produce ciders with complex flavour profiles comparable to traditional cider regions.

The study of volatile compounds revealed the diversity of cider aroma compounds, and some ciders were fruity, floral ester phenolic, oaky, and beery. Such a variety of aroma profiles can be explained by the nature amount and composition of esters, higher alcohols and phenolic compounds because these significantly affect the sensory properties of cider. This finding agrees with other studies that have identified phenolic compounds, esters and higher alcohol content as critical factors that explain the distinctive smell aroma of cider (Villière et al., 2012; Wu et al., 2023).

The volatile composition found in this study reaffirms the diversity in the volatile composition of New Zealand craft ciders, suggesting that different production methods,

apple varieties, or fermentation conditions may lead to significant differences in the chemical components and, hence, the sensory characteristics of the final product.

The cluster analysis of the volatile compounds showed significant similarities or dissimilarities between the aroma profiles of various ciders. Most cider samples were clustered into one big group, with only three clustering in a small group. This implies that many of the samples were similar in their volatile composition. This approach is identical to that employed by Perestrelo et al. (2019), which involved analysis of HS-SPME/GC-MS coupled with chemometrics used to distinguish the ciders in terms of volatile profile.

Using focus group discussions and CATA, the sensory analysis found out that consumers perceive many attributes in cider, for example, colour, odour, taste, mouthfeel, and flavour. This is similar to other research which also found that cider has a complex sensorial character (Cole et al., 2023; Picchi et al., 2023).

Based on sensory data analysis, this research identified consumer liking and acceptance factors based on chemical composition and volatile constituents. The research found that higher concentrations of certain esters were associated with fruity aromas that consumers preferred. This aligns with previous research indicating that ethyl esters contribute significantly to the aromatic profile of cider (Antón et al., 2014).

Sensory data was then related to chemical content and volatile attributes using techniques such as PCA and preference mapping to determine the attributes that influenced consumers' preference and acceptance. Liking ratings for ciders with high perceived sweetness, fruitiness, and fresh apples were positively correlated, as stated by Moss et al. (2021) and Tozer et al. (2015) using two different sensory evaluation methods, TCATA, and category scale to show that consumers' preference is for sweeter and fruitier cider.

From the concentration values interpreted in Table B1 (Appendix B), it could be seen that the concentration of various volatile components in cider samples produced from other production areas or regions is quite different. The differences in taste regarding

each region's ciders can be credited to these differing terroirs as well as the manufacturing process of each cider, which explains this variation in chemical characteristics.

Cider 1 from the Hawke's Bay region, for example, has significant amounts of chemicals that are known to produce fruity scents evocative of candy and pineapple, such as ethyl octanoate (11,567.87 µg/L) and ethyl decanoate (6,801.39 µg/L). The region's rich soil and moderate climate could cause this chemical signature (Way et al., 2022). But, as Figure 7 illustrates, sensory evaluation did not confirm the fruitiness of Cider 1 despite its high proportion of compounds associated with fruity aroma and flavour. Even though these compounds are frequently linked and related to fruity flavours, individual variations in sensory thresholds, matrix effects, and olfactory sensitivity may affect how these compounds are perceived (Guth, 1997; Plutowska & Wardencki, 2008).

Different aromas are perceived differently because of the overall matrix of the cider (including sugars, acids and other flavour compounds). This is because the overall matrix can mask or alter the effects of individual flavour compounds (Plutowska & Wardencki, 2008). Under-reported fruit tastes might be caused by inadequate descriptors in identifying the diverse fruit tastes or the insensitiveness of the used scale (Lawless & Heymann, 2010). Furthermore, the combination of different volatile compounds may lead to the formation of new flavours that cannot be obtained when analysing the components separately, which is why sensory perception may become more complex (Polášková et al., 2008).

Finally, the differences in the techniques employed for quantifying volatile compounds may also produce variations in the reported concentrations, and the true sensory impact of the volatile compounds may not be reflected. Comparing the content of these compounds in Cider 1 to the content of the same ciders from Hawke's Bay (Cider 2, Cider 3, Cider 4, Cider 5), it is possible to notice that all these ciders are similar and contain more fruity esters, including ethyl octanoate and ethyl decanoate. This observation, therefore, implies that the specific conditions of Hawke's Bay and the varieties of apples used to make these ciders give these specific ciders a flavour different from the ones made in other regions.

However, Cider 6 from the West Coast region had higher concentrations of some compounds like 1-pentanol (2513.76  $\mu\text{g/L}$ ) which has a solvent-like smell like fuel alcohol. Possible reasons for this disparity could be due to the regional characteristics of the West Coast's climate with steep terrain and high rainfall affecting the levels of chemicals in the apples and the cider-making process.

Likewise, Otagi's ciders (Cider 15, Cider 16, and Cider 17) had different chemical profiles and even higher levels of certain compounds like octanoic acid that provided Otago these ciders with their particular aroma and flavours. These differences may be attributed to the fact that Otagi is located by the coastline and, therefore, experiences a slightly different climate from the rest of the country, as well as the kind of apples that are grown in the region.

By comparing the chemical compositions of cider samples from different producing areas, it can be concluded that the effect of terroir (weather conditions, type of soil and altitude) is crucial in defining the taste of craft cider. Furthermore, the choice of apple varieties used in cider production, the type of fermentation process, and the ageing process used by cider producers in each region also influence the chemical composition of the cider reflected in the data.

## Chapter 6 Conclusion and Recommendations

The key chemical components contributing to the differences among the cider samples were pH, tannins,  $a^*$  and  $b^*$ . The volatile compounds detected in the headspace of the ciders were mainly alcohols, acids and esters. The main volatiles contributing to the explaining most of the variations among the samples were ethyl octanoate, isoamyl octanoate, 1-octanol, acetic acid and ethanol. The diversity and complexity of volatile components in New Zealand craft cider have been shown by the results of this study.

In the focus group discussions, sensory terms were successfully generated for the craft ciders and span both negative and positive drivers of consumer liking. Analysis of CATA showed that cider samples differed in sweetness, acidity and fruitiness (significant difference). The taste varied greatly between ciders in the studies. Fruity and sweet ciders tend to be liked by consumers; but not as much for samples characterised by bitter and astringent notes.

The PCA biplots showed that while there was some regional clustering, there was also significant overlap between cider samples from the North and South Islands. North Island ciders tended to contain higher levels of esters such as ethyl octanoate, while South Island ciders showed greater diversity in chemical composition. This suggests that while regional factors have some influence on cider characteristics, other variables, such as production methods and apple varieties, may be more important. Production approaches such as the use of single or multiple fermentation techniques and the use of different barrels during the aging process produce specific aroma characteristics. The complexity of the flavor and the aftertaste can also be influenced by other factors such as apple selection, fermentation technology, aging process, etc.

The study explored the chemistry, aroma and taste of New Zealand craft cider. Using New Zealand craft cider as a case study, all elements were investigated from the chemical components, aroma and true flavour. One of the other interesting aspects is that neither chemical analysis nor tasting in isolation provides a complete picture, and it probably requires both to appreciate what makes cider definitive about its taste profile.

Considering the limitations of this study, the following recommendations will be made for future related research:

Firstly, region-to-region comparisons need to be conducted more thoroughly. Samples from various regions across New Zealand should be gathered on average and tested regularly to facilitate meaningful assessments based on geographic impact.

Secondly, statistical analyses require reinforcement through expanded samples. Since harvest amounts fluctuate annually, a multi-year examination is advised. Furthermore, distinguishing traditional and modern techniques may reveal how each affects attributes like odour.

Thirdly, analysing how distinct apple varieties impact sensory and chemical properties is paramount. For instance, this study mentioned investigating the effect of traditional and table apple varieties on final flavour. Also, focus groups of cider experts could be used to provide more accurate descriptive terms for improved surveys. Larger consumer studies may uncover the linkage between composition, flavour profiles, and public attitudes.

Fourthly, it would be useful to explore how timing influences composition, such as how ageing duration and barrel type influence cider. A comprehensive microbiological analysis may uncover new insights into the role of yeasts and microbes in developing character. The use of approaches like gas chromatography with mass spectrometry and olfactometry could provide odour-impact aroma compounds in ciders.

Lastly, widening the scope, for instance, to include international ciders and consumers from different countries could enable cross-cultural assessment of ciders. These recommendations would contribute to a complete understanding of New Zealand craft cider qualities and shaping aspects.

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## Appendices

### Appendix A Chemical Parameters

TA calculation:

Let: V = Volume of sodium hydroxide (ml)

C = Concentration of sodium hydroxide (M)

Then, for a 10 ml sample:

$$\text{Titrateable acidity} = V * C * 7.50 \text{ g/L}$$

or

$$\text{Titrateable acidity} = \text{Vol } 0.1 \text{ mol/L NaOH (ml)} * 0.75 \text{ g/L}$$

Delta E calculation:

The standard  $L_0^*$ ,  $a_0^*$ ,  $b_0^*$  were:

$$L_0^* = 35.01$$

$$a_0^* = 0.85$$

$$b_0^* = -0.92$$

\*The subscript s means cider sample.

$$\text{Delta E} = \sqrt{(L_s^* - L_0^*)^2 + (a_s^* - a_0^*)^2 + (b_s^* - b_0^*)^2}$$

Table A1: Raw data for chemical parameters of New Zealand craft ciders.

Sample No.	°Brix %	pH	TA (g/L)	Tannin (mg/100ml)	L*	a*	b*	▲ E
Cider 1	7.40	3.72	6.98	1.01	33.92	-0.33	3.62	4.82
Cider 1	7.30	3.73	6.98	1.02	33.45	-0.29	3.51	4.83
Cider 1	7.30	3.73	6.90	1.02	33.61	-0.44	3.55	4.86
Cider 2	5.70	3.65	6.83	0.31	33.79	0.20	1.47	2.76
Cider 2	5.70	3.68	6.75	0.31	33.74	0.29	1.41	2.71
Cider 2	5.60	3.66	6.83	0.31	33.61	0.25	1.44	2.80
Cider 3	6.30	3.64	6.75	0.50	33.90	0.14	1.86	3.17
Cider 3	6.20	3.66	6.75	0.50	33.57	0.13	1.86	3.21
Cider 3	6.20	3.66	6.75	0.50	33.67	0.15	1.87	3.17
Cider 4	5.60	3.64	6.15	2.74	32.96	0.04	2.94	4.45
Cider 4	5.60	3.66	6.08	2.77	33.10	0.06	2.98	4.41

Table A1 (continued)

<b>Sample No.</b>	<b>°Brix %</b>	<b>pH</b>	<b>TA (g/L)</b>	<b>Tannin (mg/100ml)</b>	<b>L*</b>	<b>a*</b>	<b>b*</b>	<b>▲ E</b>
Cider 4	5.50	3.65	6.15	2.80	32.97	-0.04	2.89	4.41
Cider 5	7.20	3.47	5.93	0.45	31.42	0.29	1.91	4.61
Cider 5	7.20	3.46	5.93	0.45	31.51	0.28	1.90	4.53
Cider 5	7.20	3.46	5.85	0.45	31.59	0.27	2.03	4.55
Cider 6	6.90	3.52	5.33	0.23	33.81	0.88	-0.70	1.22
Cider 6	6.90	3.49	5.25	0.23	33.83	0.77	-0.65	1.21
Cider 6	6.90	3.48	5.33	0.23	33.80	0.69	-0.76	1.23
Cider 7	6.50	3.56	7.50	0.91	33.49	0.48	0.35	2.01
Cider 7	6.50	3.55	7.58	0.91	33.52	0.53	0.34	1.98
Cider 7	6.30	3.56	7.43	0.92	33.51	0.50	0.35	2.00
Cider 8	6.40	3.70	5.85	0.39	33.20	0.34	1.72	3.24
Cider 8	6.30	3.71	5.85	0.40	33.21	0.36	1.70	3.22
Cider 8	6.30	3.73	5.78	0.40	33.23	0.34	1.71	3.22
Cider 9	7.30	3.69	7.05	0.46	32.95	0.15	3.45	4.88
Cider 9	7.20	3.72	7.05	0.46	32.94	0.16	3.45	4.88
Cider 9	7.30	3.71	7.13	0.46	32.98	0.17	3.55	4.95
Cider 10	4.40	3.61	6.30	0.28	32.31	0.82	0.04	2.87
Cider 10	4.40	3.63	6.23	0.28	32.30	0.79	0.05	2.88
Cider 10	4.40	3.61	6.30	0.28	32.32	0.77	0.07	2.87
Cider 11	6.10	3.64	3.60	0.29	31.31	3.38	0.86	4.82
Cider 11	6.00	3.63	3.68	0.29	31.38	3.42	0.87	4.79
Cider 11	6.00	3.63	3.60	0.29	31.38	3.39	0.89	4.79
Cider 12	5.90	3.63	6.53	0.46	32.46	0.95	-0.27	2.63
Cider 12	5.90	3.62	6.45	0.46	32.36	0.91	-0.28	2.72
Cider 12	5.90	3.62	6.53	0.46	32.45	0.96	-0.29	2.64
Cider 13	6.70	3.73	6.75	0.61	33.36	0.72	0.30	2.06
Cider 13	6.70	3.74	6.75	0.61	33.35	0.69	0.26	2.04
Cider 13	6.70	3.74	6.68	0.61	33.37	0.68	0.29	2.05
Cider 14	9.00	3.39	5.18	0.19	32.96	1.12	-0.33	2.15

Table A1 (continued)

Sample No.	°Brix %	pH	TA (g/L)	Tannin (mg/100ml)	L*	a*	b*	▲ E
Cider 14	8.90	3.41	5.18	0.19	32.87	1.13	-0.32	2.24
Cider 14	8.90	3.40	5.10	0.19	32.89	1.10	-0.34	2.21
Cider 15	5.40	3.84	4.80	0.48	34.47	0.45	0.010	1.21
Cider 15	5.40	3.84	4.88	0.48	34.55	0.47	0.08	1.16
Cider 15	5.40	3.85	4.80	0.48	34.54	0.46	0.09	1.18
Cider 16	5.60	3.83	5.78	0.59	34.08	0.02	1.39	2.62
Cider 16	5.60	3.83	5.78	0.59	33.90	0.00	1.38	2.69
Cider 16	5.50	3.84	5.78	0.59	33.84	0.03	1.36	2.69
Cider 17	5.50	3.83	5.18	0.69	34.23	-0.10	2.26	3.41
Cider 17	5.50	3.83	5.25	0.69	34.17	-0.09	2.29	3.45
Cider 17	5.50	3.82	5.25	0.69	34.25	-0.12	2.25	3.40

Table A2: The mean of chemical parameters derived in Minitab for craft cider from New Zealand.

Sample	°Brix %	pH	TA (g/L)	Tannin (mg/100mL)	L*	a*	b*	Delta
Cider 1	7.3333	3.72667	6.95	1.01567	33.66	-0.353	3.56	4.8367
Cider 10	4.4	3.61667	6.275	0.281333	32.31	0.7933	0.0533	2.87333
Cider 11	6.0333	3.63333	3.625	0.292667	31.3567	3.3967	0.8733	4.8
Cider 12	5.9	3.62333	6.5	0.459333	32.4233	0.94	-0.28	2.6633
Cider 13	6.7	3.73667	6.725	0.610667	33.36	0.6967	0.2833	2.05
Cider 14	8.9333	3.4	5.15	0.187	32.9067	1.1167	-0.33	2.2
Cider 15	5.4	3.84333	4.825	0.482667	34.52	0.46	0.09	1.1833
Cider 16	5.5667	3.83333	5.775	0.588333	33.94	0.0167	1.3767	2.6667
Cider 17	5.5	3.82667	5.225	0.689333	34.2167	-0.103	2.2667	3.42
Cider 2	5.6667	3.66333	6.8	0.312667	33.7133	0.2467	1.44	2.7567
Cider 3	6.2333	3.65333	6.75	0.499333	33.7133	0.14	1.8633	3.1833
Cider 4	5.5667	3.65	6.125	2.7677	33.01	0.02	2.9367	4.4233
Cider 5	7.2	3.46333	5.9	0.453667	31.5067	0.28	1.9467	4.5633

Table A2 (continued)

Sample	°Brix %	pH	TA (g/L)	Tannin (mg/100mL)	L*	a*	b*	Delta
Cider 6	6.9	3.4967	5.3	0.227667	33.8133	0.78	-0.703	1.22
Cider 7	6.4333	3.55667	7.5	0.91267	33.5067	0.5033	0.3467	1.99667
Cider 8	6.3333	3.71333	5.825	0.394667	33.2133	0.3467	1.71	3.22667
Cider 9	7.2667	3.70667	7.075	0.46	32.9567	0.16	3.4833	4.9033

Table A3: Squared cosines for PCA variables: chemical parameters for craft ciders from New Zealand.

	F1	F2	F3	F4	F5	F6	F7	F8
°Brix %	0.060	0.117	<b>0.522</b>	0.181	0.086	0.025	0.008	0.000
pH	<b>0.364</b>	0.133	0.337	0.089	0.010	0.044	0.023	0.000
TA	0.322	0.000	<b>0.340</b>	0.091	0.197	0.049	0.001	0.000
Tannin	<b>0.358</b>	0.078	0.013	0.262	0.278	0.010	0.001	0.000
L	0.266	<b>0.562</b>	0.015	0.061	0.062	0.002	0.033	0.001
a	<b>0.673</b>	0.052	0.160	0.000	0.000	0.097	0.017	0.000
b	<b>0.587</b>	0.318	0.006	0.075	0.000	0.002	0.009	0.003
Delta	0.099	<b>0.811</b>	0.048	0.024	0.013	0.001	0.002	0.004

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest.*

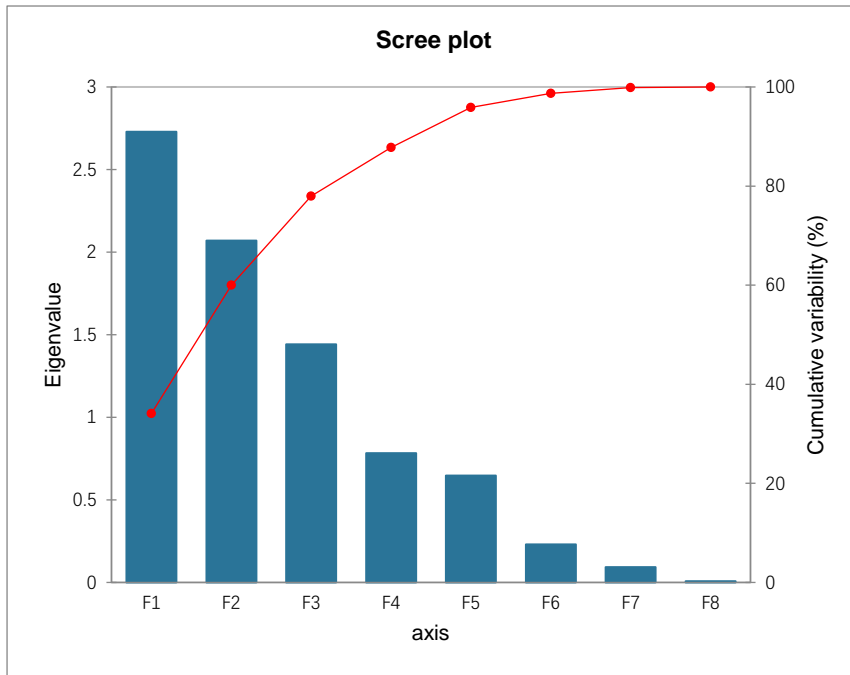


Figure A1: PCA scree plot of chemical components for craft ciders from New Zealand.

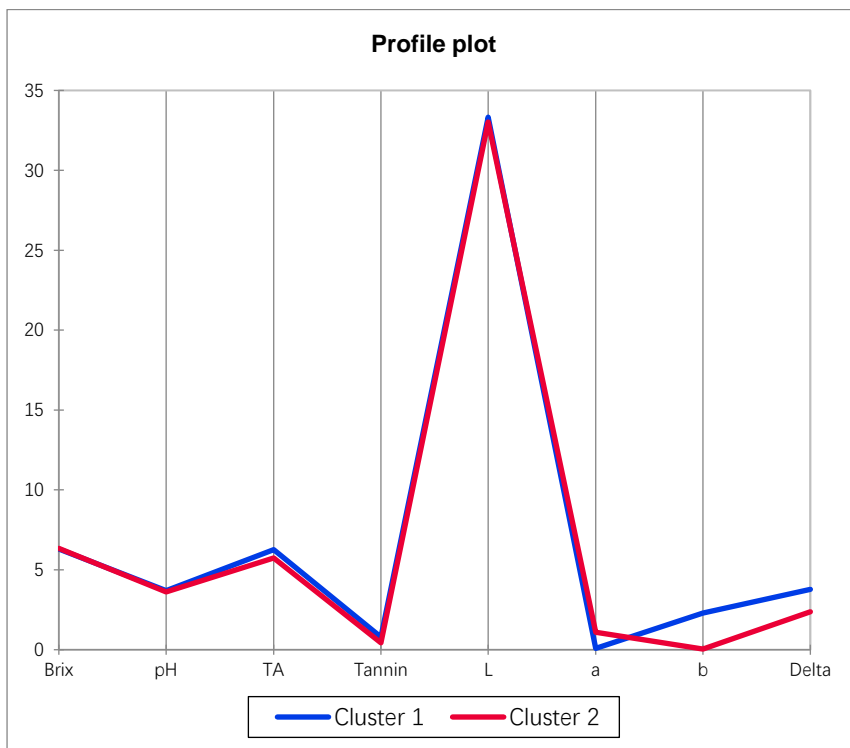


Figure A2: Profile plot for chemical parameters in New Zealand craft ciders.

## Appendix B Volatile Compounds

Table B1: Concentrations of volatile components in the New Zealand craft ciders analysed (n=17).

Sample	Ethnaol	1-Pentanol	1-Hexanol	1-Octanol	2,3- Butanediol	Acetic acid	2,4-		Hexadienoic acid, ethyl ester	Phenylethyl Alcohol	Ethyl Octanoate	Decanal	Octanoic Acid	Ethyl nonanoate	Ethyl 9- decenoate	Ethyl Decanoate	n- Decanoic acid	Isoamyl octanoate	Hexyl octanoate	Ethyl Dodecanoate
							Isoamyl acetate	Hexyl acetate												
Cider 1	6916.67 <sup>a</sup>	1077.58 <sup>cds</sup>	407.53 <sup>b</sup>	—	—	341.53 <sup>a</sup>	—	—	2487.34 <sup>b</sup>	—	11567.87 <sup>bc</sup>	—	—	—	—	6801.39 <sup>cd</sup>	—	—	—	577.52 <sup>ab</sup>
Cider 2	2473.41 <sup>defg</sup>	558.15 <sup>de</sup>	381.81 <sup>b</sup>	—	—	278.60 <sup>ab</sup>	—	—	3664.95 <sup>a</sup>	—	10076.56 <sup>bc</sup>	365.66 <sup>abc</sup>	1170.76 <sup>bc</sup>	—	234.80 <sup>cd</sup>	5287.97 <sup>cd</sup>	—	106.36 <sup>c</sup>	186.55 <sup>ab</sup>	212.62 <sup>b</sup>
Cider 3	4424.64 <sup>bc</sup>	698.81 <sup>cde</sup>	269.68 <sup>bc</sup>	—	—	—	—	—	2816.25 <sup>b</sup>	—	10432.14 <sup>bc</sup>	548.44 <sup>a</sup>	738.06 <sup>cd</sup>	261.51 <sup>a</sup>	370.14 <sup>cd</sup>	4869.10 <sup>cd</sup>	—	159.12 <sup>c</sup>	261.96 <sup>ab</sup>	229.44 <sup>b</sup>
Cider 4	2192.89 <sup>efgh</sup>	448.80 <sup>c</sup>	—	122.36 <sup>b</sup>	—	—	290.26 <sup>bcd</sup>	1022.16 <sup>a</sup>	101.46 <sup>c</sup>	—	8537.98 <sup>c</sup>	—	2561.97 <sup>a</sup>	—	—	7595.39 <sup>cd</sup>	1993.39 <sup>b</sup>	193.82 <sup>bc</sup>	275.39 <sup>ab</sup>	414.89 <sup>b</sup>
Cider 5	1858.22 <sup>efgh</sup>	296.67 <sup>c</sup>	—	142.68 <sup>b</sup>	56.52 <sup>c</sup>	—	168.81 <sup>bcde</sup>	170.86 <sup>cd</sup>	389.32 <sup>c</sup>	451.68 <sup>a</sup>	2263.38 <sup>c</sup>	151.10 <sup>bcd</sup>	—	—	—	1865.41 <sup>cd</sup>	313.19 <sup>b</sup>	—	124.40 <sup>b</sup>	—
Cider 6	5461.47 <sup>ab</sup>	2513.76 <sup>ab</sup>	238.63 <sup>bc</sup>	—	—	—	—	542.39 <sup>cd</sup>	431.83 <sup>c</sup>	—	3360.98 <sup>c</sup>	162.02 <sup>bcd</sup>	—	—	—	641.87 <sup>cd</sup>	218.18 <sup>b</sup>	—	418.17 <sup>a</sup>	—
Cider 7	2664.52 <sup>defg</sup>	695.46 <sup>cde</sup>	—	—	—	—	279.89 <sup>bcd</sup>	—	513.02 <sup>c</sup>	204.01 <sup>a</sup>	22706.70 <sup>ab</sup>	—	—	—	—	34854.71 <sup>a</sup>	7748.73 <sup>a</sup>	1022.21 <sup>ab</sup>	—	3974.75 <sup>a</sup>
Cider 8	2230.30 <sup>defgh</sup>	950.36 <sup>cde</sup>	119.34 <sup>bc</sup>	—	144.27 <sup>c</sup>	—	782.05 <sup>a</sup>	745.18 <sup>ab</sup>	449.41 <sup>c</sup>	1061.42 <sup>a</sup>	7559.27 <sup>c</sup>	237.35 <sup>bcd</sup>	—	—	247.22 <sup>d</sup>	4548.73 <sup>cd</sup>	145.44 <sup>b</sup>	333.40 <sup>bc</sup>	194.39 <sup>ab</sup>	430.45 <sup>b</sup>
Cider 9	2948.69 <sup>cdef</sup>	507.82 <sup>de</sup>	31.90 <sup>c</sup>	—	—	—	300.97 <sup>bcd</sup>	483.39 <sup>bc</sup>	—	722.30 <sup>a</sup>	5037.61 <sup>c</sup>	299.15 <sup>abc</sup>	—	—	233.76 <sup>d</sup>	492.49 <sup>cd</sup>	164.33 <sup>b</sup>	438.33 <sup>bc</sup>	—	492.49 <sup>b</sup>
Cider 10	2118.36 <sup>cdef</sup>	1884.65 <sup>bc</sup>	—	—	100.50 <sup>d</sup>	104.85 <sup>c</sup>	294.04 <sup>bcd</sup>	—	—	329.37 <sup>a</sup>	6154.00 <sup>c</sup>	314.54 <sup>abc</sup>	—	—	—	—	—	—	—	—
Cider 11	910.62 <sup>gh</sup>	—	—	—	34.16 <sup>ef</sup>	—	51.57 <sup>de</sup>	—	—	—	2722.66 <sup>c</sup>	168.47 <sup>bcd</sup>	—	—	—	2469.59 <sup>cd</sup>	—	—	—	137.03 <sup>b</sup>

Table B1(continued)

Sample	Ethnaol	1-Pentanol	1-Hexanol	1-Octanol	2,3-		2,4-		Hexadienoic acid, ethyl ester	Phenylethyl Alcohol	Ethyl Octanoate	Decanal	Octanoic Acid	Ethyl nonanoate	Ethyl 9-decenoate	Ethyl Decanoate	n-Decanoic acid	Isoamyl octanoate	Hexyl octanoate	Ethyl Dodecanoate		
					Butanediol	Acetic acid acetate	Isoamyl acetate	Hexyl acetate														
Cider 12	3553.16 <sup>cdef</sup>	3270.41 <sup>a</sup>	304.62 <sup>bc</sup>	555.01 <sup>b</sup>	212.76 <sup>b</sup>	227.66 <sup>b</sup>	—	—	—	469.93 <sup>a</sup>	3140.28 <sup>bc</sup>	113.97 <sup>bcd</sup>	—	—	687.98 <sup>cd</sup>	32511.09 <sup>a</sup>	—	—	—	—		
Cider 13	2938.89 <sup>bcde</sup>	2303.16 <sup>ab</sup>	158.86 <sup>bc</sup>	74.51 <sup>b</sup>	267.76 <sup>a</sup>	—	—	—	279.99 <sup>c</sup>	—	7921.93 <sup>c</sup>	96.55 <sup>cd</sup>	1847.32 <sup>ab</sup>	—	—	—	—	—	—	—		
Cider 14	459.00 <sup>b</sup>	86.19 <sup>c</sup>	—	27.05 <sup>b</sup>	20.74 <sup>fg</sup>	—	—	—	39.41 <sup>de</sup>	—	—	181.88 <sup>bcd</sup>	—	—	—	338.10 <sup>cd</sup>	76.44 <sup>b</sup>	—	88.08 <sup>b</sup>	—		
Cider 15	2236.62 <sup>defgh</sup>	306.48 <sup>c</sup>	141.56 <sup>bc</sup>	128.51 <sup>b</sup>	—	—	—	—	138.01 <sup>ede</sup>	163.80 <sup>ed</sup>	—	502.53 <sup>a</sup>	1961.45 <sup>c</sup>	115.65 <sup>bcd</sup>	—	—	1607.84 <sup>bc</sup>	2593.07 <sup>cd</sup>	—	110.85 <sup>c</sup>	—	350.20 <sup>b</sup>
Cider 16	4033.60 <sup>bcd</sup>	934.17 <sup>dc</sup>	345.13 <sup>bc</sup>	—	122.61 <sup>ed</sup>	—	—	—	339.42 <sup>bc</sup>	328.14 <sup>cd</sup>	—	1251.20 <sup>a</sup>	8353.18 <sup>c</sup>	394.20 <sup>ab</sup>	322.47 <sup>d</sup>	211.59 <sup>a</sup>	2753.58 <sup>b</sup>	7853.42 <sup>c</sup>	—	399.48 <sup>bc</sup>	—	1102.68 <sup>b</sup>
Cider 17	3831.03 <sup>bcde</sup>	1805.40 <sup>bcd</sup>	896.08 <sup>a</sup>	16339.21 <sup>a</sup>	—	—	—	—	427.79 <sup>b</sup>	—	—	1487.51 <sup>a</sup>	26654.98 <sup>a</sup>	—	1932.51 <sup>ab</sup>	—	7925.50 <sup>a</sup>	16954.09 <sup>b</sup>	—	1515.88 <sup>a</sup>	—	2088.78 <sup>ab</sup>

\* The (—) means “Not detected”.

a,b,c...h Means with the different letters in a column indicate significant differences based on Tukey’s test (p < 0.05).

Unit of chemical components: ug/L

Table B2: Squared cosines for PCA variables: volatile compounds for craft ciders from New Zealand.

	<b>F1</b>	<b>F2</b>	<b>F3</b>	<b>F4</b>	<b>F5</b>
Ethnaol	0.044	<b>0.476</b>	0.001	0.000	0.071
1-Pentanol	0.034	0.095	0.196	<b>0.207</b>	0.109
1-Hexanol	<b>0.470</b>	0.370	0.111	0.001	0.003
1-Octanol	<b>0.713</b>	0.015	0.094	0.009	0.000
2,3-Butanediol	0.011	0.010	<b>0.255</b>	0.195	0.003
Acetic acid	0.016	<b>0.374</b>	0.001	0.287	0.042
Isoamyl acetate	0.226	<b>0.323</b>	0.025	0.089	0.006
Hexyl acetate	0.012	0.190	0.019	0.272	<b>0.358</b>
2,4-Hexadienoic acid, ethyl ester	0.025	<b>0.600</b>	0.133	0.023	0.005
Phenylethyl Alcohol	<b>0.484</b>	0.063	0.210	0.020	0.046
Ethyl Octanoate	<b>0.763</b>	0.038	0.112	0.001	0.015
Decanal	0.017	0.271	0.049	<b>0.292</b>	0.138
Octanoic Acid	0.106	0.023	0.018	0.094	<b>0.184</b>
Ethyl nonanoate	0.001	0.166	0.006	<b>0.273</b>	0.229
Ethyl 9-decenoate	<b>0.738</b>	0.013	0.139	0.022	0.020
Ethyl Decanoate	<b>0.312</b>	0.001	0.152	0.218	0.009
n-Decanoic acid	0.102	0.107	<b>0.678</b>	0.029	0.026
Isoamyl octanoate	<b>0.916</b>	0.014	0.028	0.012	0.002
Hexyl octanoate	0.100	0.034	0.006	<b>0.369</b>	0.303
Ethyl Dodecanoate	<b>0.573</b>	0.030	0.349	0.010	0.000

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest.*

Profile plot

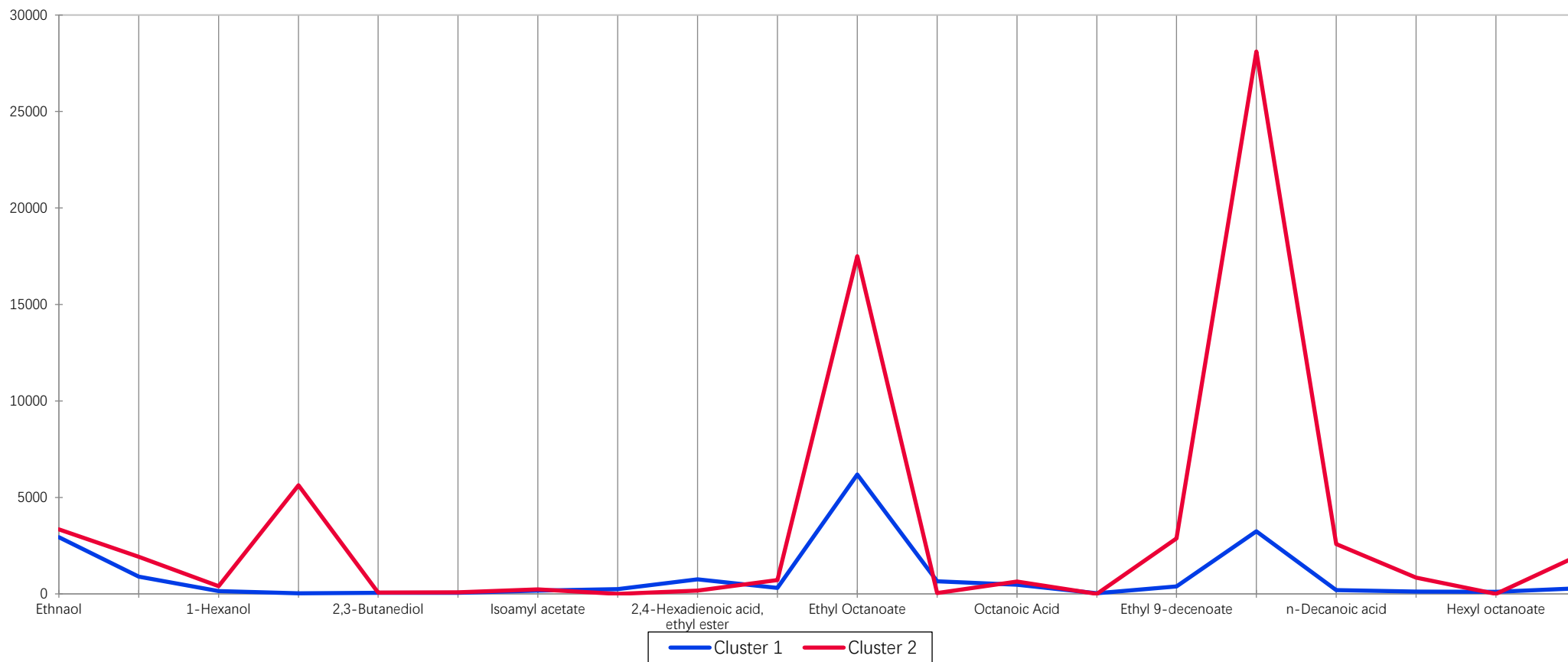


Figure B1: Profile plot for volatile components in New Zealand craft ciders.

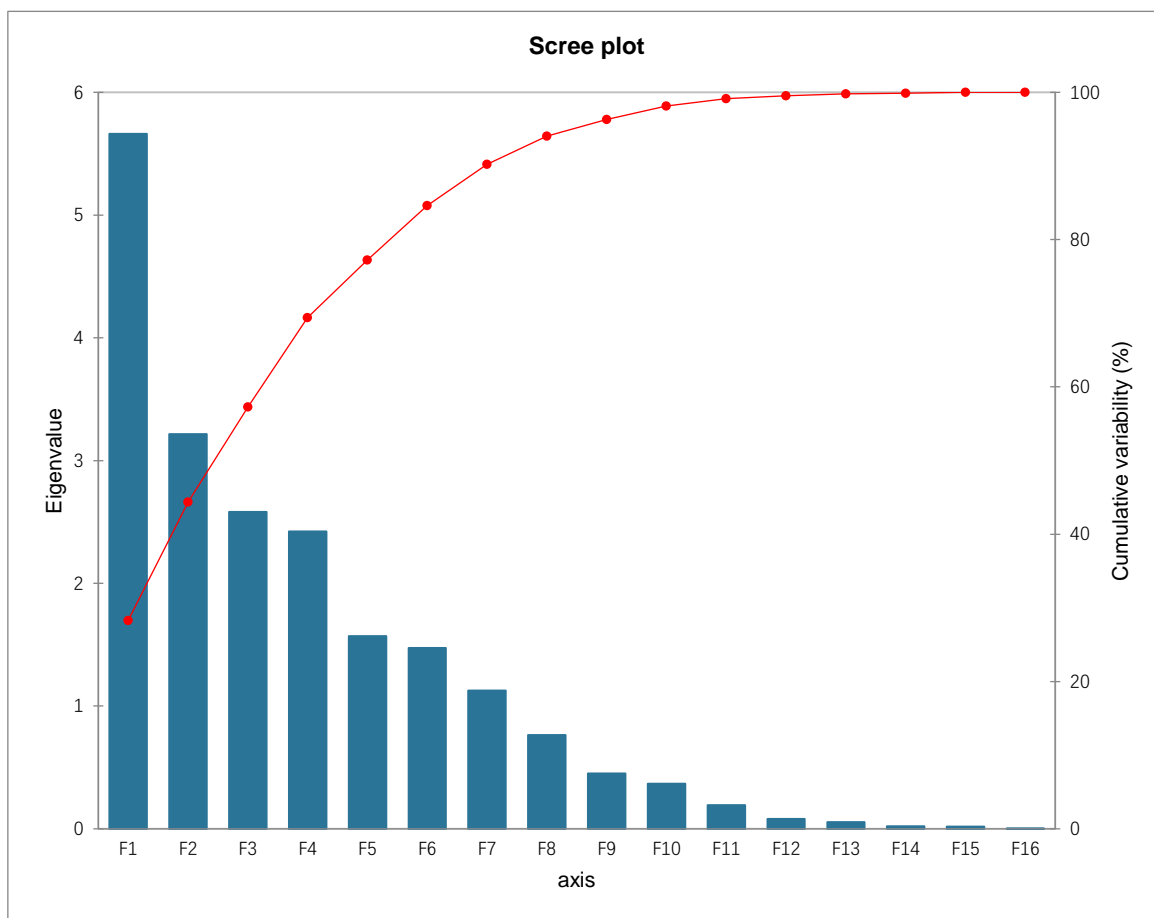


Figure B2: PCA scree plot of volatile components for craft ciders from New Zealand.

## Appendix C Focus Group and Consumer Panel Discussion

Table C1: Sensory attribute frequencies in cider tasting in Focus Group.

Vocabulary to Describe Cider	Frequencies
Carbonated/Fizzy	19
Golden	14
Sour	12
Smooth	11
Fruity	9
Sweet	9
Dry	7
Colourless	6
Watery	5
Yellow	4
Alcohol/Burning	4
Tart	4
Beer-like	3
Earthy/Musty	3
Wine-like	2
Thick	2
Oaky	1
Crisp	1
Floral	1
Sharp	1
Candied	1
Amber	1

Table C2: For Consumer Panel Discussion cider samples grouping.

---

<b>Session Number</b>	<b>Cider Number</b>
Session 1	Cider 1
	Cider 6
	Cider 9
	Cider 10
	Cider 14
	Cider 16
Session 2	Cider 2
	Cider 4
	Cider 5
	Cider 11
	Cider 12
	Cider 15
Session 3	Cider 3
	Cider 7
	Cider 8
	Cider 13
	Cider 17

---

## Default Question Block

### Apple Cider Focus Group

Hello! I am a Masters student in Food Technology at Massey University. As part of my thesis, I will be exploring consumer opinions about craft ciders from different regions in New Zealand. I am looking for volunteers to participate in a **Focus Group on apple cider**.

*This project has been reviewed and approved by the Massey University Human Ethics Ohu Matatika 1, Application OMI 23/37. If you have any concerns about the conduct of this research, please contact the Chairperson, Massey University Human Ethics Ohu Matatika 1, email [humanethics1@massey.ac.nz](mailto:humanethics1@massey.ac.nz)*

Please read the Invitation Letter on the next page for more information about this study.

Please click and read this Invitation Letter

### INVITATION LETTER

I have read the Invitation Letter.

- I would like to participate
- I am not interested

Please answer the following questions:

What is your age group?

- 20 to 55 years
- More than 55 years

Are you allergic or intolerant to alcohol, apples, pear, rhubarb, or sulphites?

- Yes
- No

Figure C1: Focus Group intention questionnaire.

Are you pregnant or lactating?

- Yes
  - No
- 

Do you have a history of alcohol abuse/alcoholism?

- Yes
  - No
- 

Will you be in Auckland between 22nd January and 2nd February 2024?

- Yes
  - No
- 

Please enter your email address. [This will be used for sign-up confirmation only.](#)

Or you can email the researcher at [Wei.Gong.6@uni.massey.ac.nz](mailto:Wei.Gong.6@uni.massey.ac.nz) [to express your interest in the study](#)

Powered by Qualtrics

Figure C1 (continued)



## Cider Focus Group

**Do you want to take part in consumer research?**

**Do you meet the following criteria:**

- Aged 20 - 55 years
- Not allergic or intolerant to alcohol, apples, pear, rhubarb, or sulphites
- Willing to drink apple cider or regular apple cider drinker
- Not pregnant or lactating
- No issues or history of alcohol abuse/alcoholism

**If you meet the above criteria and are interested in participating, please register your interest to attend a 2-hour focus group session where you will taste samples of apple cider and share your opinions.**

**When:** 5<sup>th</sup> February 2024

**Where:** Innovation Complex Building (IC 2.37), Massey University Albany campus.

**You will receive assorted snacks as a thank-you for participating.**

**To register your interest please scan this QR cod**



For more information, contact: [Wei.Gong.6@uni.massey.ac.nz](mailto:Wei.Gong.6@uni.massey.ac.nz)

*This project has been reviewed and approved by the Massey University Human Ethics Ohu Matatika 1, Application OM1 23/37. If you have any concerns about the conduct of this research, please contact the Chairperson, Massey University Human Ethics Ohu Matatika 1, email [humanethics1@massey.ac.nz](mailto:humanethics1@massey.ac.nz).*

Figure C2: Cider Focus Group flyer.



## Cider Consumer Panel

**Do you want to take part in consumer research?**

**Do you meet the following criteria:**

- Aged 20 - 55 years
- Not allergic or intolerant to alcohol, apples, pear, rhubarb, or sulphites
- Willing to drink apple cider or regular apple cider drinker
- Not pregnant or lactating
- No issues or history of alcohol abuse/alcoholism

If you meet the above criteria and are interested in participating, please register your interest to attend three 20-minute consumer panel sessions where you will taste samples of apple cider.

**When:** 20<sup>th</sup>, 22<sup>nd</sup> and 23<sup>rd</sup> February 2024

**Where:** Innovation Complex Building (IC 2.22), Massey University Albany campus.

You will receive assorted snacks as a thank-you for participating.

To register your interest please use the QR code.



For more information, contact: [Wei.Gong.6@uni.massey.ac.nz](mailto:Wei.Gong.6@uni.massey.ac.nz)

*This project has been reviewed and approved by the Massey University Human Ethics Ohu Matatika 1, Application OM1 23/37. If you have any concerns about the conduct of this research, please contact the Chairperson, Massey University Human Ethics Ohu Matatika 1, email [humanethics1@massey.ac.nz](mailto:humanethics1@massey.ac.nz).*

Figure C3: Cider consumer panel flyer.



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## Consumer Sensory Evaluation of New Zealand Apple Ciders

### INFORMATION SHEET

#### FOCUS GROUP

##### Who am I?

My name is Wei Gong, a student studying for the Master of Food Technology degree at Massey University. My research is focused on regional differences in the sensory and chemical properties of New Zealand craft ciders. I want to explore the consumer opinions and liking of apple ciders as well as the words they use to describe the sensory properties of apple ciders. My project supervisors are Dr. Charles Diako and Dr. Tony Mutukumira.

The purpose of this letter is to invite you to participate in my project.

##### What is this research about?

Production of cider/perry in New Zealand is increasing. Given the growing number of craft cidemakers in the country, individual ciders from cideries may differ significantly in their sensory properties. Research (Phetxumphou, et al., 2020) and initiatives such as the Cider Lexicon Project have been undertaken in the United States to improve and unify the cider language in the United States. However, consumers in different parts of the world may differ in their choice of words for cider description. Thus, the aim of this project is to identify the key aroma, flavour, taste, and mouthfeel attributes that New Zealand apple cider consumers use to describe commercially brewed ciders.

##### What benefits will the research bring?

This study will provide insights into how New Zealand cider consumers describe commercially brewed ciders. This information will be beneficial to the New Zealand cider industry and provide a useful reference for comparing cider languages from different countries.

##### Why are you being asked to participate?

I am seeking your consent to participate in a focus group discussion if you meet the following criteria, viz. you are (i) 20 – 55 years old, (ii) not allergic or intolerant to alcohol, apples, pear, rhubarb, or sulphites, (iii) willing to drink apple cider or a regular apple cider drinker (iv) not pregnant or lactating, (v) No issues or history of alcohol abuse/alcoholism.

##### What will you be asked to do?

The focus group is expected to take approximately 2 hours. The discussion will follow a semi-structured approach where you share your opinion about selected New Zealand craft ciders. You will also sniff and taste the ciders and discuss descriptions for each of the ciders. As a safety precaution, you will not consume more than 1 standard drink during the session, and you will be required to undergo a breath test at the end of the discussion to ensure that your blood alcohol concentration is

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Figure C4: Comprehensive information sheet for the Focus Group.



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zero before leaving the session. For safety reasons, the researcher will not allow you to leave the venue until your blood alcohol concentration is zero.

As part of your consent to take part in the focus group, you will be asked to maintain confidentiality about what is discussed. This will be explained at the beginning of the focus group.

**What will happen to the data?**

The focus group discussion will be audio recorded using a Massey laptop computer. This audio recording is the data we are collecting for this research. The recorded discussion will be transcribed by Wei Gong to ensure confidentiality. While the project is being completed, the recording will be stored on Massey University servers accessible through the researchers' password-protected computers. The recording will remain stored on Massey University servers for five years, after which it will be destroyed. Signed consent forms will be securely archived by the supervisors of this research.

No names or other identifying information of participants will be used in my thesis. Results may also be used in presentations and publications.

**What are your rights?**

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time during the session;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded. Email the researcher if you need a summary of the findings.

To ensure that you are happy overall with the content and context of what has been discussed during the session, I will summarise the discussion at the end of the session to provide an opportunity for correction if necessary.

If you agree to participate in the research, please provide your email address at the end survey and I will reach out to you with participation confirmation.

Please contact me or my supervisors if you have any questions about the project. The contact details are as follows:

Student Researcher	Supervisors	
Wei Gong <a href="mailto:Wei.Gong.6@uni.massey.ac.nz">Wei.Gong.6@uni.massey.ac.nz</a>	Dr. Charles Diako <a href="mailto:C.Diako@massey.ac.nz">C.Diako@massey.ac.nz</a>	Dr. Tony Mutukumira <a href="mailto:A.N.Mutukumira@massey.ac.nz">A.N.Mutukumira@massey.ac.nz</a>

Thank you for considering this invitation.

Sincerely,

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Figure C4 (continued)



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Wei Gong

Student ID: [REDACTED]

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**Compensation for Injury**

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

1. Phetxumphou, K., Cox, A.N. and Lahne, J. (2020). Development and characterization of a Check-All-That-Apply (CATA) Lexicon for Virginia Hard (Alcoholic) Ciders. *Journal of the American Society of Brewing Chemists*, 78:4, 299-307, <https://doi.org/10.1080/03610470.2020.1768784>

2. [Cider Lexicon Project - American Cider Association](#)

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Figure C4 (continued)



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**Consumer Sensory Evaluation of New Zealand Apple Ciders**

**FOCUS GROUP PARTICIPANT CONSENT FORM**

I have read and understand the Information Sheet attached as Appendix I. I have had the details of the study explained to me, my questions have been answered to my satisfaction, and I understand that I may ask further questions at any time during the session. I have been given sufficient time to consider whether to participate in this study and I understand participation is voluntary and that I may withdraw from the study at any time.

1. I understand that I have an obligation to respect the privacy of the other members of the group by not disclosing any personal information that they share during our discussion.
2. I understand that all the information I provide will be kept confidential to the extent permitted by law, and the names of all people in the study will be kept confidential by the researcher.

*Note: There are limits on confidentiality as there are no formal sanctions on other group participants from disclosing your involvement, identity or what you say to others in the focus group. There are risks in taking part in focus group research and taking part assumes that you are willing to assume those risks.*

3. I agree to participate in the focus group under the conditions set out in the Information Sheet attached as Appendix I.

**Declaration by Participant:**

I \_\_\_\_\_ [print full name]\_\_\_\_\_ hereby consent to take part in this study.

**Signature:** \_\_\_\_\_

**Date:** \_\_\_\_\_

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ki Pūrehuroa

Figure C5: Focus Group participant consent form.

Table C1: Specific information used for Focus Group cider samples.

<i>Sample No.</i>	<i>Code</i>	<i>Island</i>	<i>Details</i>
Cider 5	372	North	This cider is a traditional England flavour with no obvious regional style. It can be used as a blank group for easy comparison with following ciders.
Cider 6	519	South	The brewing style of this cider is French, and in comparison, to the first cider, one can appreciate the impact of the different brewing styles on the cider during the tasting process, which is a comparison between an Old-World cider and a New World cider.
Cider 17	693	North	Compared with Cider 6, they are both tart and fresh. But Cider 6 is from the west coast of the South Island and Cider 17 is from the North Island's west coast, and it's easy to compare these two ciders in a group to see if terroir influences the cider.
Cider 11	835	South	Cider 11 was fermented in French oak. Its colour was difference. Its moderate sweetness and unique flavour profile make it a compelling option for the focus group's tasting session. These attributes can lead to an engaging and enjoyable discussion within the focus group.

Table C1 (continued)

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<i>Sample No.</i>	<i>Code</i>	<i>Island</i>	<i>Details</i>
Cider 10	204	North	The apples for this cider are locally sourced and not from Hawkes Bay, so it makes for a different terroir experience.
Cider 13	471	South	Traditional style cider, originally produced in the countryside of the West of England, is renowned for its rich and distinctive character. It has a cloudy appearance and a strong, pure apple flavour. A comparison of Cider 6 with Cider 13, also a traditional cider, sparks a discussion about the different methods of making Old World (English) cider, followed by a comparison between ciders made using Old World methods in New Zealand's South Island and North Island, and a discussion of the effects of geography and terroir on cider flavour.

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## Appendix D Consumer Panel Discussion Vocabulary Explanation for tricky terms

### Exploring Cider Sensory Vocabulary

#### **Astringent**

In the context of apple cider, “**astringency**” refers to a drying sensation in the mouth, often caused by apple or pear tannins. Tannins are non-volatile phenolic substances that contribute to the body and texture of cider, and they can also lengthen the finish and aftertaste.

#### **Dry**

In the context of cider, "**dry**" refers to the taste profile that results from the fermentation process, where most of the sugars in the apple juice are converted into alcohol by the yeast. A dry cider typically has little to no residual sugars, leading to a less sweet.

#### **Tart**

In cider, "**tart**" refers to a sharp, pungent, acidic flavour. It is often used to describe the taste of certain ciders with pronounced acidity or sourness. The tartness in cider can be compared to the sourness you get when eating sour candies.

#### **Floral**

"**Floral**" refers to any aroma or flavour reminiscent of a flower. These range from apple blossom aroma to floral flavours such as rose, lavender or honeysuckle. These characteristics usually come from the specific type of apple, fermentation process and yeast strain used.

#### **Fruity**

"**Fruity**" includes a wide range of flavours derived from the natural characteristics of the apple or other cider-production fruits, depending on the apple variety and other fruits added

during fermentation. "Fruity" is a multi-dimensional characteristic that includes taste and aroma.

## Appendix E Cider Sample Specific Information

Table E: The specific information for sensory evaluation of New Zealand craft ciders (n=17).

Sample	Region	Island	Style	Apple Varieties	Production Method
Cider 1	Hawkes' Bay	North	Modern Sweet/Medium Ciders	Kingston Black, Stoke Red, Tremlett's Bitter, Chisel Jersey + Small Value of Fuero Rous	Made by modern processes, possibly using controlled fermentations
Cider 2	Hawkes' Bay	North	Modern Sweet/Medium Ciders	Kingston Black, Stoke Red, Tremlett's Bitter, Chisel Jersey and others.	Made by modern processes, possibly using controlled fermentations
Cider 3	Hawkes' Bay	North	Modern Sweet/Medium Ciders	French Cider Apples	Made by modern processes, possibly using controlled fermentations
Cider 4	Hawkes' Bay	North	Modern Sweet/Medium Ciders	Blend of Green Apple Varieties	Made by modern processes, possibly using controlled fermentations
Cider 5	Hawkes' Bay	North	Modern Sweet/Medium Ciders	Kingston Black	Made by modern processes, possibly using controlled fermentations

Table E (continued)

<b>Sample</b>	<b>Region</b>	<b>Island</b>	<b>Style</b>	<b>Apple Varieties</b>	<b>Production Method</b>
Cider 6	West Coast	South	Light and experimental Ciders	100% New Zealand Apples, Granny Smith	Modern production methods
Cider 7	Hamilton	North	Light and experimental Ciders	Mixed Apple	Crafted, extra dry style
Cider 8	Hamilton	North	Traditional Dry Ciders	Kingston Black	Small-scale traditional methods
Cider 9	Hamilton	North	Traditional Dry Ciders	Sweet Alford	Small-scale traditional methods
Cider 10	Gisborne	North	Light and experimental Ciders	Mixed Apple	Modernization and large-scale production
Cider 11	Marlborough	South	Light and experimental Ciders	Mixed Apple	Modern production methods
Cider 12	Marlborough	South	Modern Sweet/Medium Ciders	Mixed Apple	Modern production methods
Cider 13	Nelson	South	Light and experimental Ciders	Mixed Apple	Traditional methods (e.g. scrumpy), rubbing of mixed apples.

Table E (continued)

<b>Sample</b>	<b>Region</b>	<b>Island</b>	<b>Style</b>	<b>Apple Varieties</b>	<b>Production Method</b>
Cider 14	Nelson	South	Light and experimental Ciders	Mixed Apple	Modern production methods
Cider 15	Otaki	North	Traditional Dry Ciders	Kingston Black + Slack Ma Girdle	Traditional methods, including dry and oak ageing
Cider 16	Otaki	North	Traditional Dry Ciders	Sweet Alford + Slack Ma Girdle	Traditional methods, including dry and oak ageing
Cider 17	Otaki	North	Traditional Dry Ciders	Heritage apples and cider apple varieties	Traditional methods, including dry and oak ageing

\*Traditional Apple Cider Varieties include Dabinett Harry, Masters Jersey, Yarlinton Mill, Kingston Black, Stoke Red, Foxwhelp, Brown Snout, Tremlett's Bitter

## Appendix F The Sensory Questionnaire for Consumer Panel Discussion

### Welcome to the Apple Cider Study



Click the *next* button to begin

Please enter your **Sample Set Number** attached to the Information Sheet.

Please click *next* to confirm your sample set number is correct.

123

Figure F: The Sensory Questionnaire for Consumer Panel Discussion.

Please **look, sniff, taste**, and indicate your overall liking for this sample.

**Sample: BC111**

How much do you like/dislike this sample?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure F (continued)

Here is a list of words to describe the **colour, taste, aroma/flavour, and texture/mouthfeel** of different apple ciders.

Please select the words that you think describe this sample.

There are no right or wrong answers. You can select as many or as few as you wish.

**Sample: BC111**

<input type="checkbox"/> Sweet	<input type="checkbox"/> Sour	<input type="checkbox"/> Bitter
<input type="checkbox"/> Colourless	<input type="checkbox"/> Green tinge	<input type="checkbox"/> Golden
<input type="checkbox"/> Amber	<input type="checkbox"/> Yellow	<input type="checkbox"/> Fruity
<input type="checkbox"/> Floral	<input type="checkbox"/> Candied	<input type="checkbox"/> Wine-like
<input type="checkbox"/> Tart	<input type="checkbox"/> Earthy/Musty	<input type="checkbox"/> Fresh apple
<input type="checkbox"/> Oaky	<input type="checkbox"/> Beer-like	<input type="checkbox"/> Watery
<input type="checkbox"/> Thick	<input type="checkbox"/> Crisp	<input type="checkbox"/> Sharp
<input type="checkbox"/> Smooth	<input type="checkbox"/> Fizzy/Carbonated	<input type="checkbox"/> Astringent

Figure F (continued)

<input type="checkbox"/> Alcohol/Burning	<input type="checkbox"/> Dry	<input type="checkbox"/> Other (please specify, you can specify more than one) <input type="text"/>
--	------------------------------	--

Please leave any comments you may have about this sample

**Sample: BC111**

Please cleanse your palate with a piece of cracker, followed by a few sips of water.

Once ready, please click **next** and press the button in the booth for your next sample.

 **4:22**

Please cleanse your palate with a piece of cracker, followed by a few sips of water.

Once ready, click **next** and press the button in the booth for your next sample.



Figure F (continued)

Please cleanse your palate with a piece of cracker, followed by a few sips of water.  
Once ready, click **next** and press the button in the booth for your next sample.

Next

Please cleanse your palate with a piece of cracker, followed by a few sips of water.  
Once ready, click **next** and press the button in the booth for your next sample.

Next

Please cleanse your palate with a piece of cracker, followed by a few sips of water.  
Once ready, click **next** and press the button in the booth for your next sample.

Next

### **Please complete the following short survey**

These questions provide additional information on demographics for the study.

Next

Figure F (continued)

How do you describe your gender?

Male

Female

Non-binary

Prefer not to say

Other (Please state)

Next

Which of the following age ranges do you belong to?

20 - 29

30 - 39

40 - 49

50 - 55

Next

Figure F (continued)

How frequently do you drink cider?

Once a day

More than once per week

Once per week

Once per fortnight

Once per month

Other (Please state)

Figure F (continued)

**Thank you for completing this study!**



**Please press the button and wait for the test administrator**



Figure F (continued)