



## The scientific principles underpinning inconsistencies in cider quality



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*TIA is a joint venture of the University of Tasmania and the Tasmanian Government*

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Cider Australia	Dr Paul Smith	Lachlan Girschik
Spreyton Cider Co.	Dr Keren Bindon	Megan Dykman
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Published by Tasmanian Institute of Agriculture, 2016

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## Executive Summary

The global cider industry has exhibited steady growth and is forecast to continue on a steep trajectory. Given Tasmania's reputation as The Apple Isle, we have a rich opportunity to further develop and strengthen our cider industry in this growing market. In order to do this, it is important to understand problems associated with cider-making that can lead to potential faults and impact quality.



Although there is limited formal research on cider faults and quality problems, the craft of cider making has been detailed by several prominent and respected authors. It has been acknowledged that many recognised cider faults are caused by inconsistencies in production, and therefore, providing information and guidance for cider-making is of critical importance in improving and maintaining cider quality for Tasmania.

Cider quality can be affected all through the cider-making process from apple selection, to post-fermentation changes during transfer or bottling. The available literature suggests that whilst the use of “true” cider apple cultivars is desirable for a greater phenolic content and higher residual sugar levels, the blending of suitable dessert and culinary varieties does not necessarily lead to bland or unsatisfying ciders, particularly if dessert fruit is picked at an appropriate maturity stage. For instance, early harvested dessert apples appear to yield cider with higher polyphenolic concentration than those harvested at a later maturity stage, and therefore, may be important for producing ciders with greater phenolic consistency. The use of dessert outgrades also reduces apple waste and can be a successful value-adding component for orchardists. However, as sugar content tends to increase with maturity stage, finding a balance between different apple cultivars and selection of maturity stage is an important consideration in crafting desired cider styles. Nevertheless, it seems that apple cultivar may have a bigger impact on cider residual sugar content than maturity stage, although further studies are needed to confirm this.

During the fermentation process, environmental factors including temperature, initial pH, and inoculum all appear to have a significant effect on cider style, and additional research would help determine optimal parameters for each. At present, it has been documented that a temperature of 20°C, a pH of 3.6 and a cultured yeast inoculum of 9% may be reliable for achieving timely, clean cider fermentation outcomes.

It also appears that the addition of sulfite in the form of sodium or potassium metabisulfite to must can be beneficial for avoiding secondary microbial infection and to prevent cider faults post-fermentation, including acetification and *Brettanomyces* contamination (where this is not desired as a part of the cider style). Sulfite additions also help select for *Saccharomyces spp.* by suppressing other yeasts, thereby generating a more consistent flavour profile and avoiding some problems of stuck fermentation. However, it must be noted, sensory quality is subjective in this regard, and some find inoculated beverages to be aromatically bland and lacking in mouthfeel complexity, compared with wild ferments.

The yeast strain is also an important factor influencing cider style as it can affect the flavour profile and aroma of the cider. More recently, yeasts that produce low or little H<sub>2</sub>S are considered beneficial where cider makers want to decrease the risk of sulfur taints. However, additional research is needed to assess alternate strains for reliability in terms of fermentation kinetics, compared with their conventional counterparts, as the rate of fermentation may effect further cider quality factors and production (e.g stuck fermentation, initiation of secondary or malo-lactic fermentation when not desired).



The occurrence of widely recognised cider faults is still apparent in some commercially available ciders, but many can be avoided with closer attention to fermentation management, including pH monitoring, correct levels of sulfur addition, nutrient supplementation, managing air contact and standard hygiene procedures. Methods to adjust fault ciders post-fermentation are available and include filtration and fining.



In conclusion, it is apparent that cider quality can be adjusted by numerous means throughout the whole cider-making process. The available literature summarised in this report provides ample suggestions and methods for juice production and fermentation management to achieve desired, fault-free cider styles but further research, particularly into cultivars that are relevant to the Tasmanian cider industry, application of sulfur and nutrient supplementation, and balancing residual sugar, ethanol level, acid perceptibility, and phenolic impact on mouthfeel (astringency, rounded mouthfeel) could assist the Tasmanian craft cider industry ensuring consistent high quality and distinctive ciders for our consumer base.



## Introduction

The global cider industry has demonstrated staggered, but steady, growth and now faces a forecast steeper positive trajectory. Largely contributing to this is a major increase in boutique cideries in regions that produce large volumes of apples and an increased demand from consumers for a beverage of a lower alcohol content.

Given Tasmania's long standing reputation as The Apple Isle, it is no surprise that Tasmania now has global recognition as a producer of fine ciders.

For continued success and strengthening of the Tasmanian cider brand, it has been identified that producers need to identify weaknesses in their product and identify remedies, to bring all Tasmanian ciders up to a quality baseline. Better understanding of common faults and how to avoid them is one appropriate strategy.



A review of the accessible scientific literature reveals a gap in the knowledge of defined cider faults. This could well be due to the subjective nature of fault identification. It is possible that more detailed information on cider faults is available in the wealth of French literature, and this should be explored. It is also possible to draw on information from other fields, such as the wine industry, where wine faults, taints and flavors have been clearly categorized (Australian Wine Research Institute, 2016).

Jolicoeur (2013) reports that the vast majority of formal cider faults are caused by errors or negligence on the cider maker's part, and he gives several recommendations to avoid such problems, including good sanitation, temperature control, tight control of timing of phases, and reducing contact with air. However, in addition to the defined cider faults, inconsistency in cider quality can also be considered a fault.

In light of this situation, the purpose of this booklet was to consolidate information from accessible scientific literature which summarises the contributing factors to cider inconsistencies. Improved knowledge around the various factors associated with cider flavour will hopefully stimulate thought and direction for further research aimed at ultimately controlling cider quality.

Williams (1974) reported that the use of sulfur dioxide, inoculating with known yeasts and fermenting to dryness solved many of the problems of the early cider industry. This left the challenge of present day cider research to investigate the control of the final cider flavour. The author emphasised that before this can be accomplished, it is essential to have detailed knowledge of the volatile and non-volatile constituents of cider, the contribution these components make to the flavour, the bio-synthetic pathways by which they are formed and the factors which affect the amounts produced. Research has already provided much analytical information and the use of threshold values enables useful data to be obtained on their flavour contribution. The author also promoted the approach of correlating tasting panel data obtained with the analytical data to supplement information about cider quality.

**The following review summarises the contribution of the raw materials, cider making processes, fruit quality characteristics and storage factors in cider quality.**



## Raw materials

### *Cider apples*

Traditionally, and in several places worldwide, ciders are made out of “true cider apples”, or rather, apples that have been grown for the sole purpose of cider-making (Lea & Drilleau, 2003). Although it is extremely rare for cider to be made from one apple cultivar, the blending of true cider apples, as opposed to culinary rejects and dessert apples, generally makes for a higher quality cider. However, taking into account the cost and labour required for growing specialised cider orchards, many modern cider producers, or “New World” cider producers, use apples of the latter group (Pickering, 2008). Factors relating to orchard design, machine harvesting, tree nutrient status, availability and ultimately cost, all influence this decision.

*Although it is extremely rare for cider to be made from one apple cultivar, blending of true cider apples, as opposed to culinary rejects and dessert apples, generally makes for a higher quality cider.*

For instance, modern and large-scale cider makers in the UK tend to enhance ciders that are made from dessert apples and culinary rejects with apple juice concentrate (AJC) and sugar syrup before fermentation (Lea & Drilleau, 2003). This increases the sugar content thereby increasing the alcohol content. This can be of economic value, especially in large-scale cider businesses, as AJC can be bought from the world market at spot prices (Lea & Drilleau, 2003). However, the sole use of dessert apples and rejects affects the overall quality of the cider and does not impart the same flavour and overall mouthfeel as traditional cider cultivars.



In some regions and also with many small-scale boutique cider producers, growing and using cider apple cultivars is still an integral part of cider production. Indeed, cider apple cultivars have many benefits over the aforementioned. For example, true cider apples tend to have higher sugar levels, which aids fermentation and helps to raise the final alcohol content. They also have higher polyphenol levels that provide bitterness and astringency, contributing to the overall mouthfeel of the product. Moreover, the fibrous structure of true cider cultivars has been reported to increase the ease of pressing, which in turn, results in a higher juice yield. However, anecdotal evidence from local industry suggests that this may not always be the case, and that cider varieties can have lower juice yields than dessert varieties. Lea and Drilleau (2003) go on to report that true cider varieties can be stored for several weeks and not lose their texture. This is important in the post-harvest conversion of starch to sugar, and this is also true for dessert and culinary varieties when picked at suitable maturity for storage.



In Asturias, Spain, where cider apple production is an important agricultural business, an apple breeding program has been developed to improve apple cider fruit quality.

The program launched in 1989 by the Regional Institute for Agro-Food Research and Development (SERIDA), has three major aims including:

1. to improve the durable resistance to diseases and pests of local cultivars;
2. to obtain cultivars with no biennial bearing;
3. to improve fruit quality using late maturity apples with high polyphenol contents (Pello-Palma et al., 2016).



In 2008, it was reported at the time that the majority of commercial ciders in Australia are made from a blend of both true apple cider cultivars, such as 'Kingston Black' and 'Sweet Coppin', and dessert apples (Department of Primary Industries New South Wales, 2008). Through blending both types of apples, cider producers can balance the sugar, acid and tannin ratios, whilst making use of what would otherwise be wasted organic material.



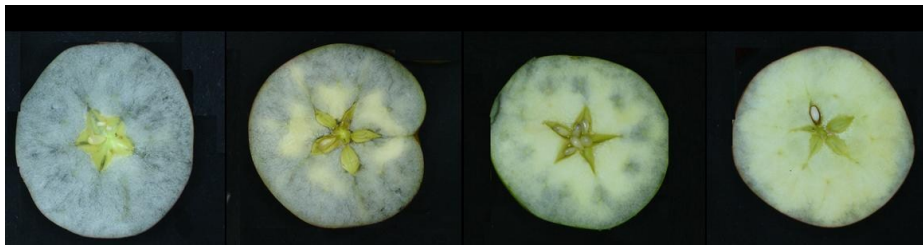
## Apple ripening

Apple ripening involves a series of biochemical transformations that affect the content of several chemical components including sugars, organic acids, phenols and nitrogen-containing compounds (Blanco et al., 1992). These components collectively influence the sensory qualities of apples. The final stage of ripening also has a strong impact on the type of these apple components produced and therefore, organoleptic features, which individuals experience via the senses. As a result, apple ripening is an important aspect of cider quality (Blanco et al., 1992).

In general, ciders are blended from a variety of apples, and therefore the sugar, alcohol content and flavor profile of the final product will vary depending not only on the cultivar used, but also on the maturity at which the apples were pressed (Lea & Drilleau, 2003). This is particularly true for ciders that are produced wholly or partially from culinary or dessert reject fruit, as apples may be rejected at various times during the pre- and post-harvest phase. Dessert apples that are rejected at harvest due to the inability to meet consumer standards for reasons such as size, physical damage or superficial injuries are often destined for juice or cider processing. On the other hand some apples may be rejected at a later date due to storage related disorders (Fidler et al, 1973). Therefore, cider makers produce cider from apples at different maturity stages depending on what is available at the time, which may result in inconsistencies in alcohol content, flavor profile and overall quality of the resulting cider.



Nevertheless, in cider processing it is typical to only press apples between ripeness and senescence as the apple must yield and sugar content is higher. Alberti et al. (2016) measured the impact of several variables to examine and compare the chemical profile of apple juice and cider that was made from unripe, ripe and senescent dessert apple varieties. They examined sixty-five analytical parameters, such as phenolic content and antioxidant capacity, and processed the data via two-way analysis of variance (ANOVA) and principal component analysis (PCA). When the cider was processed, it was found that sucrose concentration increased between unripe and senescent stages which was explained by the conversion of starch to glucose. This, in turn, affected the ethanol content. Conversely phenol content reduced (15 %) during the alcoholic fermentation of unripe apple ciders, whilst the ciders made with senescent apples contained 24-52 % more volatile compounds than the former. Among the analysed classes, phenolic acids and flavanols were most affected by fermentation, showing an average reduction of 28-33 %. Most importantly, the study showed that the apple variety tended to have a higher impact on the variables than ripening stage.



Similarly, Fuleki et al. (1994) examined the sugar composition of varietal juices produced from 11 cultivars comparing fresh and stored apples using High Performance Liquid Chromatography (HPLC). It was found that cultivar, as well as cold storage significantly influenced the content of sugars. In general the sucrose content significantly decreased while both the fructose and glucose concentrations increased.



A substantial decrease in sucrose and in most cases small increases in glucose and fructose contents during apple storage have also been reported (Hansen and Rumpf, 1979). Sugar constituents such as raffinose, sorbitol and total sugars showed no significant differences between fresh and stored apple varieties (Fuleki et al, 1994), yet other studies showed that sorbitol concentration increased upon storage (Hansen & Rumpf 1979, Ackerman et al., 1992). Indeed, from the sugar composition results, Fuleki et al. (1994) concluded that metabolism of sorbitol during storage differs between apple cultivar which may explain the variation seen in sugar content of apple juice between cultivars such as 'Red Delicious' and 'Golden Delicious'.

Adversely, Blanco et al. (1992) performed a biochemical study involving the ripening of cider apple varieties and demonstrated that the processing date can significantly influence the production and quality of the derivatives obtained. They focused on changes in the major sugars and organic acids in 5 Spanish apple varieties in the final stage of ripening using HPLC, but also monitored the total nitrogen, polyphenols, sugars and starch throughout the same period in order to determine the optimum degree of apple ripeness for cider production. In general, all the compounds underwent significant changes close to the optimal degree of ripeness.

*Apple ripeness influences the chemical characteristics of the apple which in turn will affect the sensory properties of cider products.*

In general fructose, sucrose, glucose and total sugars tend to accumulate at the end of the ripening period, with differences in the expansiveness of the ripening period and sugar profile varying according to apple variety (Blanco et al, 1992). However, of all the sugars, fructose was the most extensively conserved and accumulated at the end of the ripening period. On the other hand, the variation in total polyphenol content (Folin index) was similar in all varieties apart from one. In general, the phenolic compound concentration reached a minimum prior to the final accumulation of sugars, which may mainly result from the conversion of phenolic compounds of low molecular mass, mainly flavanols, to flavolans of high molecular mass. Lastly, the starch content decreased in the final stage of ripening, which can be related to a sharp decrease in malic acid and a concomitant increase in sugars.

Indeed, other authors, such as Board and Woods (1983) determine the degree of fruit ripeness from sugar: acid ratios rather than starch content, as these two components tend to have a stronger influence on the sensory properties of apples. Blanco et al. (1992) concluded that the starch-iodine test could also be used as an accurate indicator for ripeness in each variety and therefore could be a useful tool for cider producers to target desired maturity levels for their cider apples.

In general, it can be assumed that apple ripeness influences the chemical characteristics of the apple which in turn will affect the sensory properties of cider products. Whilst it may prove advantageous to use ripe to senescent apples for cider production, it also appears that cider variety has a strong, if not stronger, influence on these factors. Therefore, it is the balance of these two components that is likely to prove more effective in improving cider quality than apple ripeness by itself. However, more research is needed to build a sufficient database of cider apple cultivars and their associated sensory properties during maturation to enable selection and harvest timing.

*It is the balance of variety and ripeness that is likely to prove most effective in improving cider quality.*





## Polyphenols

Polyphenols can be defined as a 'range of oligomeric procyanidins based on a flavonoid (-)epicatechin structure' (Lea & Drilleau, 2003). Polyphenols play a major role in cider quality as they contribute to organoleptic properties. For instance they affect cider flavour by conferring bitterness and astringency whilst contributing to the overall mouthfeel of the product. Polyphenols influence colour characteristics through their association in oxidation reactions and have weak antimicrobial properties. Polyphenols also influence cider aroma acting as precursors for volatile constituents (Lea & Drilleau, 2003; Sanoner et al., 1999).

Four classes of phenolic compounds have been described in apples, including hydroxycinnamic acid derivatives, monomeric and oligomeric flavan-3-ols (procyanidins), flavonols and dihydrochalcones (Guyot et al., 1998).



For the apple cider industry hydroxycinnamic acid derivatives and flavan-3-ols are of particular importance due to their physiochemical properties. Whilst hydroxycinnamic acid derivatives are largely involved in tannin properties from oxidation and condensation processes, the flavan-3-ols such as procyanidins contribute to cider astringency through protein and salivary protein interactions (Guyot et al., 1998). Furthermore, the association between procyanidins and other macromolecules may also affect cider stability during storage resulting in hazes and precipitations (Van Buren, 1989). Therefore, the measurement of phenolic content in apples and ciders is crucial for varietal choice, contributes to organoleptic properties, and is also an indicator of stability in storage (Cliffe et al, 1994).



Although the importance of polyphenols in cider quality has been widely proclaimed, few studies have researched the link between their chemical composition and mouthfeel perception. Previously it has been hard to measure the phenolic content of natural beverages due to the diverse and complex chemical nature of phenolics (Cliffe et al, 1994). However, the development and advance of reverse-phase HPLC over the last two decades has provided significant process in phenolic compound analysis. Nevertheless, whilst research into the effects of chemical compounds on organoleptic characteristics in wine is extensive, there is limited research available on cider. Furthermore, research associated with wine cannot be directly transferred to cider as the composition, acid characteristics and procyanidins between the two tend to differ significantly (Symoneaux et al. 2015).

Studies that have researched polyphenol composition and mouthfeel perception have mainly focused on procyanidins in model solutions, as procyanidins tend to be the dominant phenolic class (Sanoner et al., 1999). Procyanidins are members of the proanthocyanidin class of flavonoids, which are also sometimes referred to as condensed tannins. Previous work has identified that small procyanidins are more bitter than larger ones and that the higher the average degree of polymerization (aDP), the more astringent the solutions are (Lea & Arnold, 1978; Symoneaux et al., 2014). Symoneaux et al. (2014) also demonstrated that it is the concentration of procyanidins, rather than the aDP, that impacts sweetness and sourness.

In an extension of this work, Symoneaux et al. (2015) used 72 cider-like model solutions with a trained sensory panel and cider professionals to evaluate the interaction and impact of apple procyanidins, fructose, acid content and ethanol on each other as well as the sensory attributes of bitterness, astringency, sweetness and sourness.



Symoneaux et al. (2015) found that procyanidins, in terms of both fraction and concentration, greatly impacted bitterness, astringency, sweetness and sourness. The results showed that the fraction of procyanidins decreased bitterness, but increased astringency. Similar to previous work, it was also noted that the effect of procyanidins on bitterness and astringency increased with higher degrees of polymerisation. Increases in procyanidin concentration decreased sweetness, but increased sourness perception (Symoneaux et al. 2015).

The presence of ethanol significantly increased the perception of bitterness in model cider solutions whilst the presence of acid and fructose decreased it. These findings allowed Symoneaux et al. (2015) to build a predictive model focusing on how each component impacts the main sensory attributes and can therefore predict the organoleptic properties of ciders based on their composition. Therefore, predictive models based on cider components, particularly procyanidins, could prove to be advantageous in assessing cider throughout the production phase to ensure sensory attributes are in accordance with the desired product and a high quality product ensolds.

Nevertheless, it should be noted that this study was performed on French ciders, and that the model values used here may fall outside of the range of Australian ciders. Therefore, in order to assess key attributes and develop a similar model, the experiment needs to be replicated with Australian ciders.

*Predictive models based on cider components, particularly procyanidins, may assist the cider maker match sensory properties to the desired end product .*

In assessing polyphenol content for cider quality, apple variety also plays an important role as polyphenols differ between cultivars. In general the polyphenol content is higher in true cider apples, reportedly up to 10 times more than that of dessert apples (Lea & Drilleau, 2003; Van Buren, 1970). Indeed, many dessert apples are only slightly acidic and poorly concentrated in phenolic compounds (Sanoner et al., 1999). For instance, Sanoner et al. (1999) studied the polyphenol profiles of French cider apple varieties (14 French, 1 English), using HPLC following thiolytic and demonstrated that each one had a higher polyphenol concentration than that of the dessert apple 'Golden Delicious'. The polyphenol classes also significantly differed between true cider cultivars, with bitter varieties exhibiting increased concentrations. Although, Sanoner et al. (1999) demonstrated that polyphenol content differs according to variety, only one dessert apple was used for cider apple comparison and therefore, the extent to which these differences may occur with other dessert apples varieties is scarcely reported.



Girschik (2014) explored the effect that apple maturity (pre-commercial, commercial and post commercial harvest maturities) and apple size (over and undersized commercial seconds) had on the resulting key cider quality characteristics of three readily available dessert apple varieties in Tasmania (Pink Lady, Royal Gala and Red Delicious). The results showed that whilst no difference in total phenolics according to fruit size was detected, there was a significant decrease in total phenolics from the pre-commercial to the commercial harvest maturity in the 3 dessert apples observed. This suggests that early maturity dessert apples could be selected to increase the phenolic content, and therefore organoleptic properties, of the resultant cider.



It is clear that polyphenols have a significant impact on the sensory attributes of cider. However, although previous studies have shown promising findings on the interaction between procyanidins and sensory attributes, further research needs to be completed to verify these models and to identify critical limits. Moreover, the assessment of polyphenol concentration based on apple cultivar also needs a stronger data base.



## Fermentation

The fermentation process has a significant impact on cider quality and sensory attributes through a variety of factors including yeast selection, apple juice composition, nutrient load, microbial presence, and the ratio of inoculum to substrate (Peng et al., 2015).



During fermentation, yeast converts sugar into alcohol and carbon dioxide, turning apple juice into apple cider (Ye et al., 2014). Throughout this process, yeast also releases a vast array of flavour and aroma precursors from the sugars to which they are bound. Therefore, the type of yeast involved in the fermentation process can have a direct effect on flavour and aroma characteristics, and quality of the resulting cider.

In traditional or Old World cider making, no external source of yeast is added and therefore, the flavour compounds that develop originate from the mixed yeast microflora found naturally on the apples (Lea & Drilleau, 2003). In general, the first few days of fermentation is dominated by mixed yeast species that multiply rapidly. However, they are eventually taken over by *Saccharomyces spp.* that complete the sugar to alcohol conversion. Although the traditional method of cider-making involves no additives, environmental factors may leave the cider prone to secondary microbial infection, which may adversely affect the ciders flavour profile and overall sensory characteristics. Therefore, the use of sulfites ( $\text{SO}_2$ ) is often encouraged as this immediately kills and suppresses non-*Saccharomyces* species, along with most bacteria, and results in the slower multiplication of *Saccharomyces spp.*, which have a high tolerance of sulfites (Jolicoeur 2013).

This allows the *Saccharomyces spp* to dominate the fermentation and produce a more predictable and benign flavour profile (Lea & Drilleau, 2003). Moreover, SO<sub>2</sub> also reduces the chance of secondary infections. Nevertheless, the antimicrobial activity of sulfites is pH dependent and is only active in the undissociated form. Therefore, the addition of malic acid is encouraged before SO<sub>2</sub> additions to reduce the pH to below 3.8 (Lea & Drilleau, 2003).

*The use of sulfites (SO<sub>2</sub>) is often encouraged as this immediately kills and suppresses non-Saccharomyces species along with most bacteria, that may contribute to undesirable flavours or faults.*

Alternatively, the use of specific cultured yeasts can also be beneficial for the rapid multiplication of particular yeast species that dominate fermentation and result in predictable flavour profiles (Lea & Drilleau, 2003). It also prevents the risk of hydrogen sulfide taints that may result from sulfite additions. However, more recently, active dried wine yeasts have been the addition of choice as the mixed inoculum and commercial technology of preparing and storing these yeasts has been near-perfected. However, without sulfite additions, these methods still run the risk of proliferating spoilage bacteria that may affect the final flavour profile (Lea & Drilleau, 2003).

Apart from the differences in yeast microflora as mentioned above, there are a number of other factors that can affect flavour compounds and ultimately cider quality. Indeed, flavour compounds are mainly derived from raw materials (Peng et al., 2015). However, the concentration and proportion of those that are released can be influenced by a number of fermentation conditions, such as temperature, SO<sub>2</sub> dosage and initial pH value. Indeed, it has been shown that fermentation temperature can significantly alter the rate of fermentation through the assimilation and uptake of nitrogen and sugar (Sablayrolles et al. 1996).



Also, Peng et al. (2015) undertook a study aimed at optimising the process of fermentation through three main fermentation parameters, including fermentation temperature, initial pH value and inoculum volume, in order to ultimately improve cider quality. Through sensory scores and analysis, it was observed that the quality of cider was mainly influenced by fermentation temperature ( $p \leq 0.01$ ), followed by initial pH value ( $p \leq 0.01$ ) and inoculum volume ( $p \leq 0.01$ ).

*The sensory quality of cider was mainly influenced by fermentation temperature, followed by initial pH value, and inoculum volume.*

Through response surface methodology (RSM) coupled with central composite rotatable design method (CCRD), Peng et al. (2015) also produced a predictive model, which enabled them to theoretically produce the best comprehensive quality for apple wine using the optimal parameters of 20 °C fermentation temperature, pH of 3.6 and inoculum volume of 9%.



## Colour

Cider colour (or sometimes referred to as chroma) is an important sensory attribute that is determined by juice oxidation or degradation. In general, the less oxidation that occurs during cider production, the less discolouration that will transpire (Lea & Drilleau, 2003). However, discrepancies in cider colour tend to be unavoidable during processing. Therefore, the knowledge of how and why these alterations occur can aid producers in harnessing their preferred cider colour by either altering their techniques or predicting the need and concentration for colour additives if necessary.

The alteration of cider colour begins as early as pressing when the resultant juice is exposed to oxygen, as the oxidation of phenols results in the formation of coloured quinones. It has been found that the oxidation of juice in the presence of pulp, opposed to that of the juice alone, lowers the total polyphenols and chroma in the solution (Lea & Drilleau, 2003). Cider chroma is then further reduced almost immediately in the cider making process through pH adjustment and sulfite addition. As sulfite binds to quinoidal forms within the cider, the colour is chemically and visually reduced when added immediately after pressing. However, if the sulfite is added at a later time, less colour reduction will take place. This is predicted to be a result of quinones becoming more stable and therefore less susceptible to nucleophilic addition and reduction (Lea & Drilleau, 2003).

*The alteration of cider colour begins as early as pressing. Sulfite addition, pH adjustment and fermentation can all reduce colour to around 50% of the original colour.*



Cider colour is also largely affected by fermentation. Indeed, it is predicted that the initial colour at pressing is diminished by approximately 50 % (Lea & Drilleau, 2003). This can be explained by the strong reductive power of yeasts that readily reduce keto or carbonyl groups to hydroxyls, resulting in a consequential loss of chroma. However, ciders that are supplemented with apple juice concentrate are unlikely to undergo such a dramatic loss in colour as the carbonyl-amino chromophores that result are resistant to the reducing action of yeast (Lea & Drilleau, 2003). However, this does not always translate in to a better cider colour and many poor quality concentrates may therefore yield ciders with excessive natural colour.

In some instances, such as in commercial UK regulations, cider colour has become standardised and often permitted food colours are used to enable uniformity across production. Therefore, alterations in cider colour through standard production practices tend to be neutralised.



## Formal Cider Faults

The most common formal cider faults are film yeasts or flower sickness, acetification, mousiness, *Brettanomyces* infection (Brett), hazy ciders that don't clear, and sulfuric or rotten-egg smells (Jolicoeur, 2013). In earlier cider production eras, framboisé (cider-sickness), oiliness and black or green cider were common, but have now been more or less eradicated due to modern materials and sanitisers (Jolicoeur, 2013).

Storage disorders can have a major impact on cider production, resulting in reduced cider quality. The knowledge of how to avoid and deal with such issues is therefore valuable, not just to ensure a high quality product, but also to ensure that the final product is saleable.

### *Cider Sickness, Film Yeast or Framboisé*

Film yeast proliferation is probably the most common problem in cider making today (Jolicoeur, 2013). It is generally caused by spoilage yeasts, such as from the genera of *Mycoderma*, *Pichia*, *Hansenula* or *Candida mycoderma*. As these yeasts are aerobic microorganisms, they need air to develop and reproduce themselves. Therefore, without air contact, the sickness cannot develop.



Flower sickness appears as a thin whitish or greyish film on the surface of the cider, which breaks easily upon being touched (Jolicoeur, 2013). Jolicoeur (2013) explains that if the flower is left to develop without intervention, some of the alcohol is broken down, the cider becomes lifeless and insipid, and an unpleasant smell can appear.



Although generally not a regular occurrence in cider-making today, cider sickness can also be caused by the bacterium *Zymomonas anaerobia* (Lea & Drilleau, 2003) or *Zymomonas mobilis pomaceae* (Coton and Coton, 2003). These strains of bacteria can ferment sugar in bulk sweet ciders, resulting in a renewed fermentation and peculiar aromas that have been associated with raspberries and banana skins. In addition, the production of acetaldehyde by the bacteria also causes a dense white turbidity. This is caused by the reaction of acetaldehyde with phenolic compounds, resulting in an insoluble aldehyde-phenol complex (Coton and Coton, 2003). As a further complication, acetaldehyde can also not be controlled through sulfiting, as it binds to any available SO<sub>2</sub>.

Nevertheless, cider sickness can be simply avoided by storing ciders below pH 3.7 or by avoiding storing them sweet (Coton and Coton, 2003). It is these two conditions that explain the common occurrence of cider sickness in French ciders, in which sweet and low acidity characteristics are favoured, opposed to

English ciders, in which cider sickness is nearly always absent. Therefore, particularly in sweeter ciders, it is crucial to measure the cider pH before and throughout storage to avoid cider sickness and the resultant loss in quality (Lea & Drilleau, 2003). However, if cider sickness does occur, it is often possible to resurrect a light growth of film yeast by keeping the vessel topped-up to exclude air (Lea, 2015).

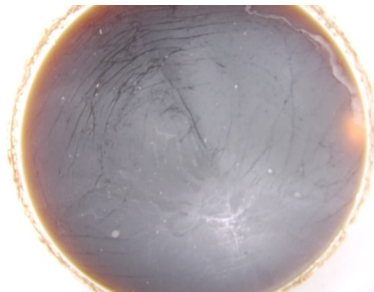
*Cider sickness can be simply avoided by storing ciders below pH 3.7 or by avoiding storing them sweet.*



## Acetification and Volatile Acidity

Acetification is a serious problem that may completely ruin a cider batch. It is caused by bacteria of the genus *Acetobacter*, which are naturally present in the air and on the skin and flesh of the apples (Jolicoeur, 2013). Although these bacteria are resistant to sulfite, they need a lot of air, oxygen and relatively high temperatures to develop into a proliferating colony, and therefore, acetification can be easily avoided. However, if the *Acetobacter* do proliferate, the alcohol is converted to acetic acid, or vinegar.

The first symptom of acetification is the formation of a surface film, which can be distinguished from flower sickness by its moderate robustness and gelatinous consistency. At this stage, if the titratable acidity is assessed, it is likely to have increased due to the formation of acetic acid (Jolicoeur 2013).



Due to the difficulty in remedying cider acetification by this stage, it is often easier to forgo cider making altogether and switch to vinegar production. Nevertheless, for less critical contamination, Lea (2015) suggests the careful addition of potassium carbonate to partly neutralise the cider, although he has also noted that this will reduce total acidity. Other suggestions include storing it until next season, where it can be blended back with fresh apples and re-pressed and re-fermented with a fresh yeast inoculum that many consume some of the acetic acid. Alternatively, the addition of more sugar, no more than 10 g/L, and a fresh culture yeast may also allow its re-fermentation (Lea 2015).

However, sometimes a very slight acetification is not necessarily a catastrophe (Jolicoeur, 2013) and can be considered stylistic. For example, the *sidra de Asturias* from Spain, generally presents a slight acetification that gives the characteristic acidic taste of these ciders.

In order to establish the degree of acetification within a cider sample, it is best to measure the volatile acidity (VA), as volatility is a key property of acetic acid. Although VA can be detected simply through smell, for commercial operations, it is important to have a numerical measurement as there are legal VA limits which may vary from state and country (Jolicoeur 2013).

VA is best measured through steam distillation, although the Garcia-Tena method is still popular in Spain. In general, a VA of under 0.7g/L is considered ideal, as the acetic acid is imperceptible, but may enhance cider flavour. On the other hand, a VA of over 1.3g/L is considered unpleasant, and therefore, problematic. Whilst a VA in between these two values, around 1g/L, does not necessarily affect the drinkability of the cider, the cider should be watched closely and it may not keep long (Jolicoeur 2013).

### *Ropiness*

Ropiness is a microbiological disorder caused by particular strains of lactic acid bacteria (*Lactobacillus* and *Leuconostoc spp.*) that synthesise polysaccharide gels. At low levels, this synthesis increases cider viscosity and alters the characteristics of the cider upon pouring in a way that makes the cider look oily. At higher concentrations, the texture thickens and results in the cider exhibiting a slimy “rope” movement when poured. As the glucan does not severely alter the flavour characteristics of the cider, it can somewhat be cured through agitation and sulfite additions to prevent further growth (Lea & Drilleau, 2003). Fining with bentonite and gelatin may also help to settle out the bacteria and the gel, aiding clarification (Lea & Drilleau, 2003). However, it should also be noted that even if the clarity has somewhat been fixed, sub-acute ropiness can cause membrane or filter blockages.



## *Osmotolerant yeasts*

Osmotolerant yeasts, particularly *Zygosaccharomyces spp.*, are a common microbiological disorder in modern cider production. *Zygosaccharomyces spp.* tend to be associated with the spoilage of high sugar products, such as apple juice concentrate, due to their unique physiological characteristics including the ability to survive at low water activity, resistance to low-acid preservatives, such as sulfites, and the ability to grow at low pH values (Lea & Drilleau, 2003). As apple juice concentrate is often added during the cider making process, the transfer of osmotolerant yeasts is of particular concern in maintaining cider quality.

In cider production, the control of spoilage yeasts is primarily affected by the surrounding environmental conditions, such as temperature and pH, during processing and storage. It is these conditions that can encourage, eradicate, or prevent the growth of certain yeasts. However, the precise physical and chemical limits of these factors is difficult to define as one factor may be influenced by another (Fleet, 2011).

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Wang et al. (2016) attempted to identify some of these limits through the evaluation of the combined effect of sugar content and pH on the growth of *Zygosaccharomyces rouxii* (wild strain, B-WHX-12-54) through inoculation of apple juice concentrate under standard storage conditions (isothermal 25°C).

Wang et al. (2016) demonstrated that pH was the most significant limiting factor to the observed growth parameters (potential maximum growth rate and lag phase duration), with decreases in pH resulting in retarded yeast growth until an eventual extermination.

Sugar content was also found to be a significant determinant. However, although an increase in sugar levels gradually reduced growth, elevating sugar levels to as high as 70 °Brix did not completely inhibit the yeast strain.

In a second experiment, which used both isothermal and non-isothermal conditions in an effort to simulate standard storage and overseas shipping temperature conditions, pH was again found to be the main factor affecting the observed growth parameters. Through mathematical modelling of the tested variables, the authors concluded that a pH value below

*Cider pH was found to be the main factor affecting growth of osmotolerant yeasts when subjected to various simulated shipping and storage temperatures.*

2.0 can achieve complete inhibition of the *Z. rouxii* strain. Alternatively, the decrease of pH to 2.5 was also deemed sufficient to delay the spoilage of apple juice concentrate caused by this strain for more than 60 days under standard storage and overseas shipping conditions. However, these pH values fall outside of the observed Australian commercial cider range.

Alternatively, Rojo et al. (2015) evaluated the use of different chemical preservatives, namely potassium sorbate, sodium benzoate, dimethyldicarbonate, vanillin, ferulic, *p*-coumaric and caffeic acids, to control the growth of five yeast strains of *Z. rouxi* isolated from spoiled concentrated grape juices. It was found that none of the tested preservatives could completely inhibit *Z. rouxii* growth, but the most successful preservative options were obtained from potassium sorbate, sodium benzoate, dimethyldicarbonate and vanillin to a maximum reduction of approximately 40%. Nevertheless, the sole use of these individual preservatives are not feasible against *Z. rouxi* and therefore, there is a need for further research to estimate the combined effect of these inhibitory compounds on *Z. rouxi*, but also on other strains and other *Zygosaccharomyces* species.

## Microbiological Faults:

### *Brettanomyces* and Mousiness

There are many microorganisms that can give taints and off-tastes to a cider. Two common examples of this are mousiness and *Brettanomyces*.

“Mousiness” is a disorder that refers to the generated odour and taste to cider similar to that of a dirty mouse cage. It is presumed that isomers of 2-acetyl or ethyl tetrahydropyridine are the tainting species, and that they are generated by *Lactobacillus* or *Brettanomyces* spp. growth under aerobic conditions in the presence of lysine and ethanol (Lea & Drilleau, 2003).

On the other hand, the proliferation of ‘Brett’, which is short for *Brettanomyces*, is related to horse, barnyard or stable odours. As Brett and Mousiness are both generally attributed to the *Brettanomyces* spoilages yeast, they are often hard to distinguish from one another.



Although the contamination of either of the aforementioned disorders is technically a fault, the “old horse character” conferred to the cider is sometimes sought after, more commonly through malolactic fermentation. Indeed, this characteristic is common in old Europe cideries that ferment their ciders in old wooden barrels that host responsible microorganisms (Jolicoeur 2013). However, as the amount of compounds produced increases, so does the taint, and although individual preferences vary, it can become unbearable. Moreover, once either disorder is contracted, there is no resolution or cure, and heavy sterilization of the equipment is necessary to avoid contraction in following years.

Nevertheless, *Brett* yeast contamination, as well as *Lactobacillus* contamination, is easy to avoid through proper cider-making practices, such as sulfite addition, as both species are SO<sub>2</sub> sensitive (Jolicoeur 2013). Therefore, typically, these disorders are highly preventable.

### *Indole*

Indole is another widespread cider taint that at high levels, can produce an increasingly unpleasant and fecal-like odour (Lea & Drilleau, 2003). Current opinion suggests that it is produced from the beginning through the synthesis of tryptophan by the yeast from inorganic nitrogen. The synthesis of indole appears to be favoured by a low juice content and a low yeast pitching rate, in conjunction with a



fast fermentation, stimulated by high temperatures and the addition of simple inorganic nutrients. Under these conditions, a deficiency in pyridoxine and inadequate vitamin requirements for yeast have been suggested to be the immediate source of indole production. It is therefore feasible that the addition of pyridoxine to the must can eliminate indole production, as suggested by industry sources (Lea & Drilleau, 2003).

## *Sulfur and Rotten-Egg Taints*

Sulfur taints are caused by the release of hydrogen sulfide ( $H_2S$ ), which results in an extremely unpleasant odour that has been described similar to that of rotten eggs.

Hydrogen sulfide is a chemically reactive, volatile, organosulfur compound, and is a fundamental part of yeast metabolism during primary alcoholic fermentation. Briefly, sulfide ions are formed as intermediate molecules in the sulfate-reduction sequence pathway, of which is necessary for the yeasts utilization of sulfur to produce sulfur-containing amino acids (cysteine and methionine) necessary for yeast growth. However, if sulfide production is out of equilibrium with its utilisation, excess sulfide leaks out of the cell into the wine, resulting in  $H_2S$  production, and ultimately spoilage (Dahabieh et al., 2015).

Until recently, all yeast-fermented products contained  $H_2S$  to a varied degree.

However, more recently, a naturally derived wine yeast has been discovered that does not produce  $H_2S$  during fermentation, and is being used to develop various wine and cider yeasts that are rapidly becoming available worldwide (Campbell 2016). However, whilst such strains are beneficial in preventing  $H_2S$

*Whilst low hydrogen sulphide ( $H_2S$ ) yeast strains are now available, they may not have all the desirable traits for fermentation compared to conventional yeast strains.*

production, it is also necessary that they do not underperform on other important fermentation factors. In order to observe such disparities, Dahabieh et al. (2015) compared the performance of low and no- $H_2S$  strains from three distinct core genetic technologies to EC1118 (a popular generalist winemaking strain) and Montrachet 522 (a common strain known to produce high levels of  $H_2S$ ) through Chardonnay grape juice fermentation. Various key functional attributes of winemaking yeast, including fermentation kinetics,  $SO_2$  production, volatile acidity and  $H_2S$  production, were explored and it was found that some of the low and no- $H_2S$  yeast strains did not show equal comparability to several of the key parameters.

For example, the 'Mutagenesis-General 1' and 'Mutagenesis General 2' strains were found to have slower fermentation rates than that of the conventional yeasts and other low and no H<sub>2</sub>S strains. Moreover, the 'Mutagenesis-General 1' strain also produced elevated levels of acetic acid to the order of approximately 1.5-fold more than the other strains. Furthermore, this strain also produced significant amounts of SO<sub>2</sub> during fermentation by approximately four times more than the other observed yeasts. Although this study has been performed on wine fermentation, it nevertheless highlights the variability of low and no-H<sub>2</sub>S strains that are transferrable to cider making and depicts the need to research and test difference strains to provide optimal performance and product quality.

In traditional yeast strains, conventional practices to remove H<sub>2</sub>S post-fermentation include aeration, inert gas stripping, precipitation by copper (II) sulfate, and blending. However, although these methods may be effective, the removal of H<sub>2</sub>S after it has already been formed can result in significant secondary costs, as well as quality and efficiency problems (Dahabieh et al., 2015). For example, during removal, H<sub>2</sub>S may react to form other undesirable sulfur compounds, such as mercaptans and disulfides, which impart an even stronger aroma and cannot be easily removed (Campbell 2016). Furthermore, the strategies to remove H<sub>2</sub>S are non-specific, meaning other compounds that may be desirable, such as esters and thiols, may also be removed in the process (Dahabieh et al., 2015).

Alternatively, nutrient supplementation may be used to aid the prevention of H<sub>2</sub>S formation. Indeed, it is widely acknowledged that nitrogen limitation, especially the amino acids serine, aspartic acid, cysteine and methionine, as well as vitamin limitation, can increase the yeasts ability to form H<sub>2</sub>S. Therefore, the addition of such supplements may aid in its preclusion (Dahabieh et al., 2015).

Other factors that may exuberate H<sub>2</sub>S production include high levels of elemental sulfur in the grape juice or vineyard, high levels of sulfur dioxide during fermentation, and the presence of organic sulfur-containing precursor compounds (Dahabieh et al., 2015). Furthermore, as highlighted previously, the yeast strain can also have a significant effect on the amount of H<sub>2</sub>S produced and therefore, yeasts that produce less H<sub>2</sub>S can be specifically chosen.

## *Discolouration*

The discolouration of ciders, excluding the normal golden-orange colour of partly oxidized tannins, is generally always caused by metals (Lea, 2015). Whilst iron causes blackening, copper produces green hues, both as a result of oxidation reactions between the metal, the tannin in the cider and oxygen in the air.

It is therefore difficult to determine metal discolouration at early cider making stages, due to a lack of air contact. Therefore, it is often upon opening a bottle and pouring that the colour will develop from minutes to hours later.

Although there is little treatment for discolouration, rebottling in the presence of citric acid may provide aid. Alternatively, blue fining can be used on a commercial scale, but Lea (2015) remarks that it should only be performed by a trained chemist.





## *Hazes and deposits*

Cider hazes and deposits are a common problem within the cider industry. Although slight hazes do not tend to affect cider taste, there can be a threshold of acceptable cloudiness, which is particularly important to large-scale commercial operations. In general, the three main types of hazes and deposits are microbial, pectin and tannin related.

### **Microbial hazes**

Microbial hazes can be caused a vast array of spoilage yeasts or by significant bacterial infestations. For example, the slow-growing yeast *Saccharomyces ludwigii* forms clumps at the bottom of sweetened ciders. Although this infection may be considered visually unappealing, it does little to effect the flavour of the product (Lea 2015). Nevertheless, cider clarity can be important to visually perceptive cider quality.

The only reliable way to identify hazes of microbial origin is via a high-powered microscope, which may be impractical in small-cider production operations. It is therefore advised to avoid microbiological infections through standard cleanliness, hygiene and sulfiting procedures (Jolicoeur, 2013).

### **Pectin hazes**

Pectin is one of the most common causes of hazes and can appear as general cloudiness or mobile clots/strings floating within the cider bottle. The best way to prevent pectin haze is through a pectic enzyme (pectinase) treatment before the start of fermentation. These enzymes simply break up the pectin molecules, which then deposit themselves on the lees (Jolicoeur, 2013). Although pectinase can be used after fermentation upon the advent of a pectin haze, it is much less effective in the presence of alcohol, and therefore, prevention is the best strategy (Lea 2015).

### **Tannin hazes**

Tannin hazes are caused by the polymerization of tannin molecules over time to produce larger molecules that become so sizeable that they drop out of solution. This results in a haze or in some cases a compact sediment (Lea 2015).

Tannin hazes are often difficult to predict and tend to develop over time, meaning that a cider that is stored clear may still develop a haze at a later date. Tannin hazes are also often initiated by warming and cooling cycles, such as in a “chill haze”, where a cider that is stable at room temperature may become cloudy after refrigeration (Lea 2015).

As tannin hazes are ultimately caused by ciders with a high amount of tannins, it could be suggested to use less bittersweet fruit in production, as they have particularly high tannin levels. However, as these tannins are also responsible for the characteristic bite of traditional bittersweet ciders, decreasing the quantity of these apples may produce a less authentic taste. Therefore, fining procedures may be considered preferable.



## Methods of control

### *Fining*

There are a number of different fining techniques, although ultimately they all have the same principle. As particles within a cider haze tend to be charged, usually they do not coalesce, as the like charges repel each other, keeping them in suspension. Therefore, by adding a material with an opposite charge, it is possible to neutralize the charges so the particles can adhere to each other and settle out, making removal possible (Lea 2015).



In ciders, as tannin particles and other debris particles tend to be negatively charged, fining is typically performed through the addition of a positively-charged protein and bentonite. Traditionally, egg white and animal blood have been used, but in modern times special gelatins have been developed to take their place. Due to the risk of over-fining, the addition of bentonite, a negatively charged clay, is also common practice as it helps to clear any excess gelatin. Alternatively, kieselsol can be used as a more efficient substitute, as it forms quickly and produces more compact bottoms than bentonite (Lea 2015).

*Most hazes and deposits can be avoided through appropriate hygiene techniques, pectinase treatments and apple selection. However, if contracted, they can often be remedied through fining and filtration techniques.*

Chitosan, a positively charged product produced from crustacean exoskeletons, is also gaining momentum as a gelatin substitute and has recently become available from specialist winemaking suppliers. It is also possible to purchase combination kits which are comprised of both gelatin or chitosan and kieselsol in separate packages. As the amounts are premeasured, the risk of overfining is dramatically reduced (Lea 2015). However, the size of the combination kits is unlikely to make it a feasible option for large-scale operations.

Over the last two decades, the use of fining for clarification has become almost obsolete due to the introduction of cross-flow ultrafiltration, which removes suspended solids to a high degree of clarity without blockage. Nevertheless, this is generally only economical in large scale cider making.

### *Filtration*

Cross-flow ultrafiltration is a common procedure for large commercial cider makers as a highly effective method for clarification. However, due to its costly set-up, smaller craft cider makers tend to rely on sheet filtration methods.

There are a number of good sheet filters available on the market at varying degrees of fineness to remove gross particles, as well as yeasts and most bacteria. However, the process of sheet fining tends to absorb a significant amount of flavour and colour and whilst it may be possible to recycle the sheets back in to the feedstock, the labor in the process may not be worth the slight clarification redeemed. As a further complication, the process of sheet filtration also lends itself to several points of potential microbiological contamination, meaning that if the maker is not careful, they may spoil the entire batch and end up in a worse position than before.

In general, most hazes and deposits can be avoided through appropriate hygiene techniques, pectinase treatments and apple selection. However, if contracted, they can often be remedied through fining and filtration techniques.

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