Cider (Cyder; Hard Cider)

B Jarvis, Daubies Farm, Upton Bishop, Ross-on-Wye, UK

Introduction

Cider (cyder, United States: hard cider) is an alcoholic beverage produced by the fermentation of apple juice; a related product, perry (also known as pear cider) is produced by the fermentation of pear juice. Cider and perry have been produced for more than 2000 years in temperate areas of the world. Traditional cidermaking in England, France (Normandy and Brittany), northern Spain, Ireland, and Germany is based largely on farmhouse production; in the eighteenth and nineteenth centuries, farm laborers in England received up to 2 l cider day^{-1} as part of their wages.

In England, commercial cidermaking started during the late nineteenth century, although some farmhouse cider had been sold commercially since the eighteenth century. Total cider production in England in 1900 was estimated at 0.25×10^6 hl, of which about 0.025×10^6 hl was produced commercially. In 2010, total European production of cider and perry was 14.3×10^6 hl, of which the United Kingdom produced about 9×10^6 hl, mostly as commercial products. Commercial ciders are now produced also in Argentina, Austria, Australia, Belgium, Canada, China, Finland, New Zealand, South Africa, Sweden, Switzerland, and the United States.

Cider Production

Ciders are made by fermenting the juice of apples, often with some added pear juice. The juice may be either fresh or reconstituted from concentrate. In England, France, and Spain, most cider is produced from the juice of special cultivars of cider apples, referred to as bittersweet, bitter-sharp, sweet, or sharp, depending on the relative levels of tannins and acids. Such ciders have a higher degree of astringency than those made from the juice of culinary or dessert apples. The alcohol content of cider made only from juice ranges up to about 6.5% alcohol by volume (abv), depending on the sugar content of the apple juice. In many countries, chaptalization (i.e., the addition of fermentation sugars) is practiced widely, especially in years when juice sugars are low. In some cases, the total fermentable sugar may be increased so that the fermented product contains up to 12% abv. Such strong ciders are blended and/or diluted to produce commercial ciders within the range 1.2–8.5% abv. Products with a higher alcohol content are generally sold as apple wine.

Preparation of Cider Juice

The fruit is transported from the orchards to the cider mill, where it is washed and milled using equipment such as a knife mill. The milled fruit is pressed using either batch or continuous presses, and the solid residue (pomace) from the first pressing may be extracted with water to maximize the yield of sugar and tannins. In some processes, the milled fruit may be liquefied by treatment with pectolytic and amylolytic enzymes, before centrifugation to separate the juice from residual solids. The spent apple pomace is used for the extraction of pectin (if enzyme treatment has not been used), as cattle feed or as a soil conditioner.

The juice is normally treated with SO_2 gas or sodium metabisulfite to a level of 100–200 $\mu g\ l^{-1}$ and is allowed to stand for 24 h before use. If a clear juice is required, the cloudy pressed juice may be treated with pectinases and amylases; enzyme treatment is normal if the juice is to be concentrated for storage purposes.

Concentrated juices are generally prepared in a multistage evaporator and may have volatile aromas added back. The concentrate, at about 72°Bx, can be stored for 2 or 3 years at refrigeration temperatures without serious loss of quality. The concentrate is diluted with an appropriate volume of water to reconstitute it for fermentation.

Cider Fermentation

The juice is transferred to fermentation vats, where yeast nutrients such as ammonium phosphate, ammonium carbonate, and pantothenic acid are added, together with any chaptalizing sugars and an appropriate yeast culture. Fermentation is allowed to proceed at 15–25 °C until all the fermentable sugars have been used, which usually takes about 3–8 weeks, depending on the temperature. The raw cider is sometimes chilled, to facilitate flocculation of the yeast, before being racked off from the lees and transferred to other vats for maturation. The maturation process can take up to 2 months, but the cider is often matured for more than a year before further processing.

Final Preparation

The strong cider base (up to 12% abv) is centrifuged and/or fined to remove solids; increasingly, microfiltration processes are being used commercially to produce a bright cider that is blended with apple juice or water to give an appropriate level of alcohol (usually 3.5–8.5% abv). At this stage, sweetener and other ingredients may be added to adjust the acid–sweetness balance, according to the organoleptic style of cider required. Increasingly, flavoring with fruit juices such as cranberry or raspberry also gains popularity. The blended cider may be carbonated and packaged into bottles, cans, kegs, or barrels for distribution and sale, or it may be packaged as a still product without carbonization. Processes involved in the preparation of certain special ciders are discussed later in this chapter.

The Microbiology of Apple Juice and Cider

The fermentation of apple juice to cider occurs naturally through the metabolic activity of the yeasts and bacteria present

Table 1 Typical microbial contaminants of freshly pressed apple juice

Typical species	*SO_2 sensitivity*	*Growth in juice*
Yeasts		
Saccharomyces cerevisiae var. *cerevisiae*	± or –[a]	++++[b]
Saccharomyces cerevisiae var. *uvarum*	± or –	++++
Saccharomyces cerevisiae var. *carlsbergensis*	± or –	++++
Saccharomycodes ludwigii	–	++++
Kloeckera apiculata	+++	++++
Candida pulcherrima	++++	++++
Pichia spp.	++++	++++
Torulopsis famata	++	++++
Rhodotorula spp.	++++	++++
Filamentous fungi		
Penicillium spp.	++	++++
Aspergillus spp.	++++	++++
Paecilomyces varioti	+	++++
Byssochlamys fulva	–	++++
Cladosporium spp.	++++	++
Botrytis spp.	+	++++
Bacteria		
Acetobacter xylinum	++	++++
Pseudomonas spp.	++++	–
Escherichia coli	++++	– (some strains ±)
Salmonella spp.	++++	–
Micrococcus spp.	++++	–
Bacillus spp.	– (spores)	–
Clostridium spp.	– (spores)	–

[a]– (resistant), ±, +, ++, +++, ++++ (increasing sensitivity).
[b]– (unable to grow), ±, +, ++, +++, ++++ (increasing ability to grow).

on the fruit at harvest, which are transferred into the apple juice on pressing. Other microorganisms, from the milling and pressing equipment and the general environment, can also contaminate the juice at this stage. Examples of typical juice-associated organisms are shown in Table 1, together with an indication of their susceptibility to SO_2 and their ability to grow in apple juice. Unless such organisms are inhibited, for example, by the use of SO_2, a mixed fermentation occurs. This causes significant variations in organoleptic characteristics between batches, even if the composition of the apple juice remains constant.

The preferred approach for the production of commercial cider is by inoculation with a selected strain of a *Saccharomyces* spp., following control of the indigenous and adventitious microorganisms using sulfite and/or pasteurization. However, the transfer of fermented juice into different maturation and storage vessels may result in a secondary fermentation by microorganisms that occur naturally in the traditional oak vats which are frequently used. These organisms may produce beneficial or detrimental changes in the chemical and organoleptic properties of the final cider.

The Role of SO_2 in Apple Juice and Cider

The use of SO_2 as a preservative in cidermaking is controlled by legislation in most countries. The maximum level permitted in the final product in Europe is 200 mg l^{-1} but different limits may apply elsewhere. The addition of SO_2 to apple juice results in the formation of so-called sulfite addition compounds, through binding to carbonyls. When dissolved in water, SO_2 or its salts produce a mixture of molecular SO_2, bisulfite, and sulfite ions, the equilibrium of which is pH dependent (Figure 1). The antimicrobial activity of SO_2 is due to the molecular SO_2 that remains unbound (the so-called free SO_2). Less SO_2 is needed in juices of high acidity: for instance, 15 mg l^{-1} of free SO_2 at pH 3 has the same antimicrobial effect as 150 mg l^{-1} at pH 4.

The binding of SO_2 is dependent on the nature of the carbonyl compounds present in the juice. Naturally occurring compounds that bind SO_2 include glucose, xylose, and xylosone. If the fruit has undergone any degree of rotting, other binding compounds are formed, including 2,5-dioxogluconic acid and 5-oxofructose (2,5-D-threo-hexodiulose). Such juices require increased additions of SO_2 if wild yeasts and other microorganisms are to be controlled effectively. The addition of SO_2 to fermenting juice results in rapid combination with acetaldehyde, pyruvate, and α-oxoglutarate produced by the fermenting yeasts. Consequently, all additions of SO_2 must be completed immediately after pressing the juice although, provided initial fermentation is inhibited, further additions to give the desired level of free SO_2 can be made during the following 24 h. Studies have shown that the presence of sulfite-binding compounds in fermented cider depends on the quality of the original fruit, the type of apple juice (i.e., cider, dessert,

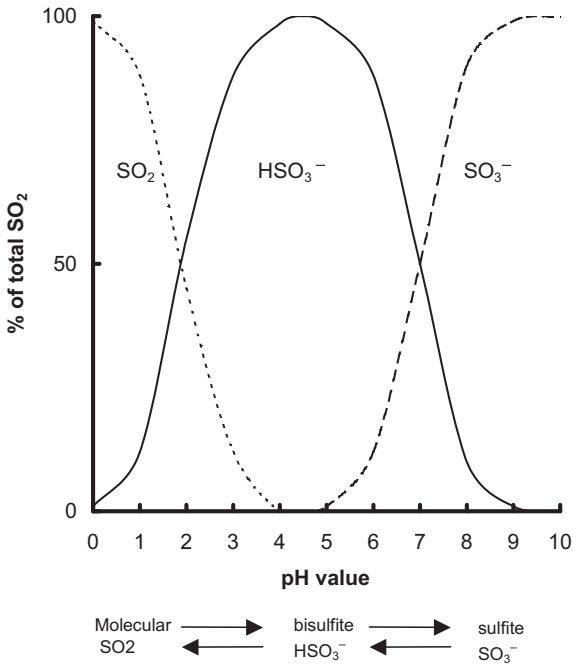

Figure 1 Distribution of sulfite, bisulfite, and molecular SO_2 as a function of pH in aqueous solution. Reproduced with permission from Hammond, S.M., Carr, J.G., 1976. The antimicrobial activity of SO_2 – with particular reference to fermented and non-fermented fruit juices. In: Skinner, F.A., Hugo, W.B. (Eds.), Inhibition and Inactivation of Vegetative Microbes. Academic Press, London. pp. 89–110 (S.A.B. Symposium Series No. 5).

or culinary juice) and whether pectinases were used for clarification, the strain of yeast and its ability to produce sulfite compounds, the fermentation conditions, and the extent to which yeast nutrients have been added.

Fermentation Yeasts

In traditional farmhouse cidermaking, especially when the juice is not sulfite treated, the indigenous yeasts that are important in fermentation include *Candida* spp., *Kloeckera apiculata*, and *Saccharomyces* spp. Generally, the *Candida* and *Kloeckera* die out within the first few days, but they may be important in the initial fermentation. When the juice has been treated with sulfite, the fermentation process is carried out primarily by strains of *Saccharomyces* spp., especially *S. cerevisiae* vars. *cerevisiae*, *bayanus*, *capensis*, *carlsbergensis*, and *uvarum*.

In commercial practice, specific strains are added to the sulfite-treated juice as a pure culture. The starter culture is prepared in the laboratory from freeze-dried or liquid-nitrogen-frozen cultures, which are resuscitated and then cultivated by increasing volumes of a suitable culture medium, to give an inoculum for use in a starter propagation plant. The nature of the cultivation medium varies, but it is often based on sterile apple juice supplemented with appropriate nitrogenous substrates and vitamins, such as pantothenate and thiamin. Increasingly, commercially produced dried or frozen yeast cell preparations are used, either for direct vat inoculation or as inocula for the yeast propagation plant. The condition of the yeast at pitching is critically important – the culture must have both high viability and high vitality if cider fermentation at high original gravity is to be effective. The ideal attributes of a cider fermentation yeast are summarized in Table 2.

Table 2 Desirable characteristics of yeasts for cidermaking

Attribute	*Objective*
Produces polygalacturonase	Hydrolyzes soluble pectin
High vitality and viability, producing consistently high fermentation rate	Strong fermentation characteristics
Resistant to SO_2 and low pH	Competes well with wild yeasts
Resistant to high original gravity and ethanol	Good commercial characteristics
Ferments to dryness	Efficient utilization of sugars
Does not produce excessive foam	Avoids product loss from frothing
Strongly flocculant	Ensures good racking off
Minimal production of SO_2	Avoids excessive levels of SO_2
Minimal production of SO_2^- binding compounds	Minimizes binding of SO_2
Nonproducer of H_2S and acetic acid	Avoids undesirable metabolites
Compatible with malolactic bacteria	Important for malolactic fermentation
Good production of aroma compounds, organic acids, and glycerol	Important for flavor production

Modified from Jarvis, B., Forster, M.J., Kinsella, W.P., 1995. Factors affecting the development of cider flavour. In: Board, R.G., Jones, D., Jarvis, B. (Eds.), Microbial Fermentations: Beverages, Foods and Feeds. J. Appl. Bacteriol. Symp. Suppl., 79, pp. 5s–18s (S.A.B. Symposium Series No. 24).

After inoculation, the starter yeasts, together with SO_2–resistant wild yeasts selected from the juice, increase in number from an initial level of about 10^5 cfu ml^{-1} to 5×10^6 – 5×10^7 cfu ml^{-1}. Following an initial aerobic growth phase, the resulting O_2 limitation and high carbohydrate levels in the media trigger the onset of the anaerobic fermentation process. Fermentation typically takes some 3–8 weeks to proceed to dryness (S.G. 0.990–1.000) at which time all fermentable sugars have been converted to alcohol, CO_2, and other metabolites.

In controlled fermentations, a maximum temperature of 25 °C will generally be permitted, although slow fermentation at or below 16 °C is common in some countries, especially in France. Because of the exothermic nature of the fermentation process, temperatures of 30 °C or above can be attained during periods of high ambient temperature. In Australia, it is not uncommon for temperatures as high as 35–40 °C to occur in the vat, in the absence of a cooling facility. Generally, temperatures >25 °C are considered undesirable, because during rapid fermentation many desirable flavor compounds are not produced, some undesirable flavors are produced, and alcohols and other metabolites may be lost by evaporation. In addition, the activity of the desirable yeast strain may be inhibited, leading to stuck fermentations and the growth of undesirable thermoduric yeasts and spoilage bacteria. Stuck fermentations can sometimes be restarted by the addition of nitrogen (10–50 mg l^{-1}), usually as ammonium sulfate or di-ammonium phosphate, together with thiamine (0.1–0.2 mg l^{-1}) and/or a yeast cell wall (ghost cell) preparation.

At the end of fermentation, the yeast cells flocculate and settle to the bottom of the vat – this process may be aided by chilling the cider in the vat. A certain amount of cell autolysis occurs, liberating cell constituents into the cider. The raw cider is racked off the lees (i.e., the settled yeast cells) as a cloudy product and is transferred to storage vats for maturation. In some plants, the cider may be centrifuged or rough-filtered at this time. If the cider is left too long on the lees, autolysis may become excessive, leading to an increase in nitrogenous materials, which act as substrates for subsequent undesirable microbial growth and the development of off flavors in the product.

Maturation and Secondary Fermentation

Traditionally, cider vats are made of wood (usually oak). The wood acts as a reservoir of microorganisms, such as yeasts and lactic acid bacteria which are important in the secondary fermentation of cider (Figure 2); undesirable organisms, such as acetic acid bacteria, may also occur. Modern processes using sterilizable stainless steel vats for fermentation and maturation lack the native microflora. If secondary fermentation is required, it is necessary either to inoculate the vats with a culture of malolactic organisms suitable for cider (N.B. malolactic cultures sold for wine are generally unsuitable for cider making) or to use a process of backslopping, in which part of an earlier batch of matured cider is used as an inoculum (with all the inherent risks of such action). The maturation vats are filled with racked-off cider and provided with an over-blanket of CO_2 or otherwise sealed to prevent the ingress of air, which would stimulate the growth of undesirable film-forming

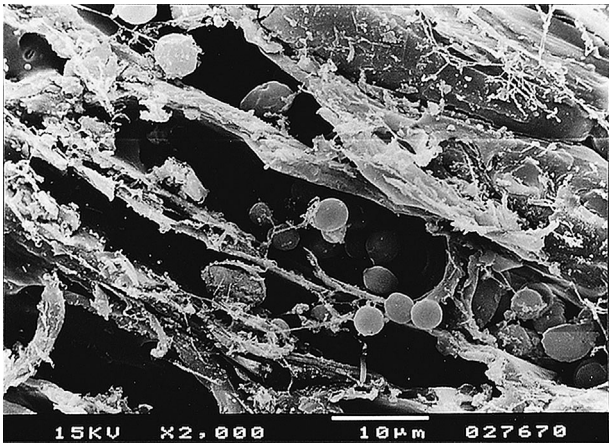

Figure 2 Electron micrograph of a section 1.2 cm below the surface of an oak wood block suspended in fermented cider for 10 weeks, showing individual yeast and bacterial cells within the structure of the wood. Reproduced with permission from Swaffield, C.H., Scott, J.A., Jarvis, B., 1997. Observations on the microbial ecology of traditional alcoholic cider storage vats. Food Microbiol. 14, 353–361.

yeasts (e.g., *Brettanomyces* spp., *Pichia membranaefaciens, Candida mycoderma*) and aerobic bacteria (e.g., *Acetobacter xylinum*).

During the maturation process, the growth of malolactic acid bacteria (e.g., *Lactobacillus pastorianus* var. *quinicus*, *L. mali*, *L. plantarum*, *Leuconostoc mesenteroides* and other species, and *Pediococcus* spp.) can occur extensively, especially if wooden vats are used. The malolactic fermentation (MLF) results in the conversion of malic acid to lactic acid and also produces secondary metabolites. The MLF reduces the acidity of the cider and imparts subtle changes that improve the flavor of the product. However, in certain circumstances, metabolites of the lactic acid bacteria may damage the flavor and result in spoilage – for instance, excessive production of diacetyl (and its vicinal-diketone precursors), the butterscotch-like taste of which can be detected in cider at a threshold level of about 0.6 mg l^{-1}.

In ciders made without SO_2, such as the farmhouse ciders of the Basque region of Spain, it is common for the MLF to occur concurrently with the yeast fermentation. This leads to complex flavor development and, because the lactic acid bacteria also metabolize some of the sugar, to reduced alcohol levels.

Pathogenic and Spoilage Microorganisms in Cider

Bacterial pathogens such as *Salmonella* spp., *Escherichia coli*, and *Staphylococcus aureus* may occasionally occur in apple juice, being derived from the orchard soil, farm and processing equipment, or human sources. Outbreaks of food poisoning have occurred because of *E. coli* O157: H7 strains in freshly pressed nonpasteurized apple juice (usually known in the United States simply as cider). Normally, the acidity of both apple juice and fermented cider prevents the growth of pathogens, which survive for only a few hours. However, the specific strains of *E. coli* involved in food poisoning have a greater tolerance to acid and can survive for up to 30 days at 20 °C in apple juice. These strains are destroyed by normal pasteurization conditions and do not survive in fermenting cider for more than 2–3 days because of the interaction of alcohol and acidity. The presence of bacterial endospores from species of *Bacillus* and *Clostridium* may be indicative of poor plant hygiene. They can survive for long periods and are frequently found in cider; however, because of its low pH value, they do not create a spoilage or health threat.

The juice from unsound fruits and juice contaminated within the pressing plant may show extensive contamination by microfungi, such as *Penicillium expansum*, *P. crustosum*, *Aspergillus niger*, *A. nidulans*, *A. fumigatus*, *Paecilomyces varioti*, *Byssochlamys fulva*, *Monascus ruber*, *Phialophora mustea*, and species of *Alternaria*, *Cladosporium*, *Botrytis*, *Oosporidium*, and *Fusarium*. None of these are of particular concern in cidermaking, except that spores of heat-resistant species, such as *Byssochlamys* spp., can survive pasteurization and grow in cider if it is not adequately carbonated.

The growth of *P. expansum* on apples leads to the occurrence of the mycotoxin patulin in the apple juice. Most countries have imposed a guideline limit of 50 µg l^{-1} for patulin. At high levels, patulin inhibits the yeasts used as starter cultures, but they metabolize the patulin under anaerobic fermentation conditions within a few days, to form a number of compounds, including ascladiol. Patulin, therefore, would not be expected to occur in cider unless patulin-contaminated juice were added to sweeten the fermented cider.

The role of organisms, such as *Brettanomyces* spp. and *Acetobacter xylinum*, in the spoilage of ciders during the latter stages of fermentation and maturation was mentioned previously. Of equal concern is the yeast *Saccharomycodes ludwigii*, which is often resistant to SO_2 levels as high as 1000–1500 mg l^{-1}. *S. ludwigii* is an indigenous contaminant of cidermaking facilities and can grow slowly during all the stages of fermentation and maturation. Its presence in bulk stocks of cider does not cause an overt problem. However, if it is able to contaminate 'bright' cider at bottling, its growth will result in a butyric flavor and the presence of flaky particles that spoil the appearance of the product. Although the organism is sensitive to pasteurization, it is not unknown for it to contaminate products at the packaging stage, either as a low-level contaminant of clean but nonsterile containers or directly from the packaging plant and its environment. Clumps of the organisms may also survive if it is present in unfiltered cider at the time of pasteurization.

Environmental contamination of final products with yeasts, such as *Saccharomyces cerevisiae* vars. *cerevisiae*, *bailii*, and *uvarum* can also occur. These will metabolize residual or added sugar to generate further alcohol and, more importantly, to increase the concentration of CO_2. Strains of these organisms are frequently resistant to SO_2. In bottles of bright cider inoculated with such fermentative organisms, carbonation pressures up to 900 kPa have been recorded. To avoid any risk of burst bottles, it is essential to maintain an adequate level of free SO_2 in the final product, particularly in multiserve containers that may be opened and then stored with a reduced volume of cider. Alternatively, a second preservative such as benzoic or sorbic acid can be used, where permitted by legislation. This precaution is not necessary for products packaged in single-serve cans and bottles, which receive a terminal pasteurization process after filling.

Some Special Fermentation and Other Processes

Keeving and Cidre Bouché

In France and parts of southwest England, the process of keeving is used to prepare traditional cider. Apple pulp is packed into barrels immediately after milling and held for 24 h at $\leq$5 °C; the thick juice is run into sulfite-treated barrels where pectin esterases produce pectic acid. This reacts with calcium to form an insoluble complex that rises slowly to the surface as the wild-yeast fermentation proceeds, to produce a thick brown cap. Pectin reacts also with tannins and proteins to form a sediment and, at the end of the fermentation, a clear liquor is drawn off between the brown cap and the sediment. The product is a naturally sweet, relatively low-alcohol cider (ca. 4% abv) that is matured in bottles closed with wired mushroom stoppers. A typical French product of this process is cidre bouché.

Traditional Conditioned Draught Cider

This product receives a secondary fermentation process. After filling barrels with a bright cider, a small quantity of fermentable carbohydrate is added, followed by an inoculum of active alcohol-resistant yeasts. The subsequent growth is accompanied by a low-level fermentation that generates sufficient CO_2 to produce a pétillant cider, together with a haze of yeast cells. Such products have a shelf life in the barrel of about 4–6 weeks.

Double Fermented Cider

Double fermented products are initially fermented to an alcohol content of about 5% abv and then chilled to stop the fermentation process. The liquor is racked off immediately and is either sterile-filtered or pasteurized before transfer to a second fermentation vat. Additional sugar and/or apple juice is added and a secondary fermentation is induced following inoculation with a selected alcohol-tolerant strain of *Saccharomyces* spp. Such a process permits the development of complex flavors in the cider.

Frankfürter Apfelwein mit Speierling

In Germany, most cider (apfelwein) production occurs in the area around Frankfurt. One local specialty uses berries from the Speierling tree (*Sorbus domestica*) to add astringency to the cider that is made from culinary apples. The speierling berries are placed into a muslin bag that is suspended in the fermenting apple juice to permit extraction of the bitter flavor constituents. The product is extremely astringent.

Sparkling Ciders

Traditionally, sparkling ciders were prepared according to the Méthode Champenoise. After bright filtration, the fully fermented dry cider is filled into bottles containing a small amount of sugar and an appropriate Champagne yeast culture. The bottles are corked, wired, and laid on their sides for the secondary fermentation process, which will take 1–2 months at 5–18 °C. Following this stage, the bottles are placed in special racks with the neck in a downward position. The bottles are gently shaken each day to move the deposit down onto the cork, a process that can take up to 2 months. The disgorging process involves careful removal of the cork and yeast floc without loss of any liquid; sometimes the neck of the bottle is frozen to aid this process. The disgorged product is then topped up using a syrup of alcohol, cider, and sugar before final corking, wiring, and labeling. It is not difficult to understand why this process is rarely used nowadays. Most commercial sparkling ciders are normally prepared by artificial carbonation to a level of 3.5–4 vol. CO_2.

Cider Vinegar

Fermented cider is refermented under aerobic conditions at 15–25 °C using selected strains of *Acetobacter* spp. to produce cider vinegar. The product typically contains up to 5% acetic acid and is used for culinary purposes and for its reputed health properties.

Further Processes

Fermented cider and perry may be distilled to produce spirit liquors such as Eau-de-vie-de-cidre, cider brandy, and calvados. Blends of cider and distilled cider liquor may be sold as intermediate products: for instance, Cider Royale is a blend of cider and cider brandy containing about 15–20% abv. Note that the addition of distilled liquor to a cider is permitted only if excise duty is levied as a spirit drink.

Biochemical Changes during Cidermaking

The chemical composition of cider is dependent on the composition of the apple juice, the nature of the fermentation yeasts, microbial contaminants and their metabolites, and any additives used in the final product.

Composition of Cider Apple Juice

Apple juice is a mixture of sugars (primarily fructose, glucose, and sucrose), oligosaccharides, and polysaccharides (e.g., starch), together with malic, quinic, and citromalic acids; tannins (i.e., polyphenols), amides, and other nitrogenous compounds; soluble pectin; vitamin C; minerals; and a diverse range of esters, in particular ethyl- and methyl-*iso*-valerate, which give the typical apple-like aroma. The relative proportions are dependent on the variety of apple; the environmental and cultural conditions under which it was grown; the state of maturity of the fruit at the time of pressing; the extent of physical and biological damage (e.g., rotting because of mold); and, to a lesser extent, the efficiency with which the juice was pressed from the fruit.

The treatment of fresh juice with SO_2 is important in the prevention of enzymic and nonenzymic browning reactions of the polyphenols; SO_2 also complexes carbonyl compounds to form stable hydroxysulfonic acids. If the apples contain a high proportion of mold rots, appreciable amounts of carbonyls such as 2,5-dioxogluconic acid and 2,5-D-threo-hexodiulose will occur.

Products of the Fermentation Process

The primary objective of fermentation is the production of ethyl alcohol, and the biochemical pathways that govern this process are well recognized. Various intermediate metabolites can be converted to form a diverse range of other end products, including glycerol (up to 0.5%). Diacetyl and acetaldehyde may also occur, particularly if the process is inhibited by excess sulfite and/or uncontrolled lactic fermentation occurs. Other metabolic pathways will operate simultaneously, with the formation of long- and short-chain fatty acids, esters, lactones, and so on. Methanol is produced in small quantities ($10–100\,mg\,l^{-1}$) as a result of demethylation of pectin in the juice.

The tannins in cider change significantly during fermentation; for instance, chlorogenic, caffeic, and *p*-coumaryl quinic acids are reduced with the formation of dihydroshikimic acid and ethyl catechol. The most important nitrogenous compounds in apple juice are the amino acids asparagine, aspartic acid, glutamine, and glutamic acid; smaller amounts of proline and 4-hydroxymethylproline also occur. Aromatic amino acids are virtually absent from apple juice. With the exception of proline and 4-hydroxymethylproline, the amino acids are largely assimilated by the yeasts during fermentation. However, leaving the cider on the lees significantly increases the amino nitrogen content as a consequence of the release of cell constituents during yeast autolysis.

Inorganic compounds in cider are mostly derived from the fruit and depend on the conditions prevailing in the orchard. Their levels do not change significantly during fermentation. Trace quantities of iron and copper occur naturally, but the presence of larger quantities derived from process equipment, results in significant black or green discoloration because of the formation of iron and copper tannates, with flavor deterioration.

Changes during Cider Maturation

Maturation results in further changes in the composition of the cider, but these changes are not fully understood. The primary effect of the MLF is the conversion of malic acid into lactic acid, which, being a weak acid, results in a reduction in the apparent acidity. Much of the lactic acid is esterified, with the formation of ethyl, butyl, and propyl lactates. This removes harshness and gives a more balanced, smoother flavor. Other desirable flavor changes arising from the MLF include production of small quantities of diacetyl, which gives a butterscotch flavor to the cider, although as noted, excessive levels of diacetyl are undesirable.

Some strains of lactic acid bacteria also produce excessive quantities of acetic acid if residual sugar is present in the maturing cider. Sulfur aromas and flavors resulting from yeast autolysis are generally lost during maturation, although unpleasant sulfur compounds, such as mercaptans, may be produced if the cider is infected by film yeasts. Acetic acid may be formed either from the uncontrolled growth of heterofermentative lactic acid bacteria or, more commonly, from the growth of strains of *Acetobacter* spp. Butyric flavors are generally caused by the growth of *S. ludwigii* and mousy flavors (believed to be the result of 1,4,5,6-tetrahydro-2-acetopyridine and related compounds) are generally ascribed to the growth of film yeasts, such as *Brettanomyces* spp. Table 3 illustrates some of the key flavor compounds found in cider.

Table 3 Some key flavor compounds in cider

Group of compounds	*Examples of important flavor metabolites* [a]
Alcohols	**Ethanol; propan-1-ol; butanol-1-ol; isopentan-1-ol; heptan-1-ol; hexan-1-ol; 2- and 3-methylbutan-1-ol; 2-phenylethanol**
Organic acids	**Malic; lactic**; *butyric; acetic*; **hexanoic**; nonanoic; octanoic; succinic
Aldehydes	**Acetaldehyde; benzaldehyde**; butylaldehyde; **hexanal**; nonanal
Carbonyls	Pyruvate; decalactone; decan-2-one
Esters	*Amyl, butyl, and ethyl acetates*; **ethyl and butyl lactate**; diethyl succinate; **ethyl benzoate; ethyl hexanoate; ethyl guiacol; ethyl-2- and ethyl-3-methylbutyrate; ethyl octanoate; ethyl octenoate; ethyl decanoate; ethyl dodecanoate**
Sulfur compounds	*Methanediol*; *ethanthiol*; *methyl thioacetate*; *dimethyl-disulfide*; *ethyl-methyl-disulfide*; *diethyl-disulfide*
Others	*Diacetyl*; *1,4,5,6-tetrahydro-2-acetopyridine*

[a]Compounds in italics are generally considered undesirable when more than traces are present; compounds in bold are essential flavor constituents.

Modified from Jarvis, B., Forster, M.J., Kinsella, W.P., 1995. Factors affecting the development of cider flavour. In: Board, R.G., Jones, D., Jarvis, B. (Eds.), Microbial Fermentations: Beverages, Foods and Feeds. J. Appl. Bacteriol. Symp. Supplement., 79, pp. 5s–18s (S.A.B. Symposium Series No. 24).

See also: Acetobacter; *Candida*; **Ecology of Bacteria and Fungi in Foods:** Influence of Redox Potential; ***Escherichia coli* O157:** *E. coli* O157:H7; **Fermentation (Industrial):** Basic Considerations; **Fermentation (Industrial):** Control of Fermentation Conditions; **Fermented Foods:** Origins and Applications; Natural Occurrence of Mycotoxins in Food; **Preservatives:** Classification and Properties; **Preservatives:** Traditional Preservatives – Organic Acids; **Permitted Preservatives:** Sulfur Dioxide; ***Saccharomyces*:** *Saccharomyces cerevisiae*; **Starter Cultures:** Importance of Selected Genera; Starter Cultures Employed in Cheesemaking; **Wines:** Microbiology of Winemaking; **Wines:** Malolactic Fermentation; **Yeasts:** Production and Commercial Uses.

Further Reading

Beech, F.W., 1972. English cider making: technology, microbiology and biochemistry. In: Hockenhull, D.J.D. (Ed.), Progress in Industrial Microbiology, vol. 11. Churchill Livingstone, Edinburgh, pp. 133–213.

Beech, F.W., Davenport, R.R., 1983. New prospects and problems in the beverage industry. In: Roberts, T.A., Skinner, F.A. (Eds.), Food Microbiology: Advances and Prospects. Academic Press, London, pp. 241–256 (S.A.B. Symposium Series No. 11).

Charley, V.L.S., 1949. The Principles and Practice of Cider-Making. Leonard Hill Ltd, London.

Dinsdale, M.W., Lloyd, D., Jarvis, B., 1995. Yeast vitality during cider fermentation: two approaches to the measurement of membrane potential. J Inst. Brew. 101, 453–458.

Hammond, S.M., Carr, J.G., 1976. The antimicrobial activity of SO_2 – with particular reference to fermented and non-fermented fruit juices. In: Skinner, F.A., Hugo, W.B. (Eds.), Inhibition and Inactivation of Vegetative Microbes. Academic Press, London, pp. 89–110 (S.A.B. Symposium Series No. 5).

Jarvis, B., 2001. Cider, perry, fruit wines and other alcoholic fruit beverages. In: Arthey, D., Ashurst, P.R. (Eds.), Fruit Processing, second ed. Blackie Academic and Professional, London, pp. 111–114.

Jarvis, B., Lea, A.G.H., 2000. Sulphite binding in ciders. Int. J. Food Sci. Technol. 35, 113–127.

Jarvis, B., Forster, M.J., Kinsella, W.P., 1995. Factors affecting the development of cider flavour. In: Board, R.G., Jones, D., Jarvis, B. (Eds.), Microbial Fermentations: Beverages, Foods and Feeds. J. Appl. Bacteriol. Symp. Suppl., 79, pp. 5s–18s (S.A.B. Symposium Series No. 24).

Lea, A.G.H., 2003. Cidermaking. In: Lea, A.G.H., Piggott, J.R. (Eds.), Fermented Beverage Production, second ed. Blackie Academic and Professional, London, pp. 59–88.

Lea, A.G.H., 2009. Keeving. www.cider.org.uk/keeving.html last visited on 17 August 2011.

Lea, A.G.H., 2011. Small-Scale Cidermaking. www.cider.org.uk last visited on 17 August 2011.

Moss, M.O., Long, M.T., 2002. The fate of patulin in the presence of the yeast *Saccharomyces cerevisiae*. Food Addit. Contam. 19, 387–399.

Swaffield, C.H., Scott, J.A., Jarvis, B., 1997. Observations on the microbial ecology of traditional alcoholic cider storage vats. Food Microbiol. 14, 353–361.

Williams, R.R. (Ed.), 1991. Cider and Juice Apples: Growing and Processing. University of Bristol, Bristol.