Journal of the American Pomological Society 60(3):113-128 2006

Characterization of Fermented Cider Apple Cultivars Grown in Upstate New York

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Abstract

Cider apple (*Malus Xdomestica* Borkh.) cultivars were collected from several New York orchards for physiochemical evaluation during 2002-2003, to characterize apples grown specifically for fermented "hard" ciders in upstate New York. Thirty-one cultivars in 2002, and 23 in 2003 (due to biennial bearing and weather events), were analyzed for firmness, pH, titratable acidity, soluble solids, total phenolic content, antioxidant capacity, and yeast assimilable nitrogen. We also categorized them as different cider-making types, based on acidity and tannin (phenolic) content using traditional English cider apple classifications. Physical and chemical characteristics of cider apples were similar to values observed in Europe, although tannin content was often lower in New York. The cultivars analyzed were generally smaller than dessert apples, and juice pH ranged from 2.7 to 4.4, while total acidity ranged from 0.12% to 2.25% (w/w). Soluble solids values ranged from 9 to 18 degrees (Brix scale). Yeast assimilable nitrogen content ranged from 20 to 138 mg N/L, indicating the need to supplement juice with added nitrogen pre-fermentation to achieve recommended levels (for grape wines) of 330 to 470 mg N per L. Total polyphenolic content ranged from 50 to 532 mg Gallic Acid Equivalents (GAE) per 100 g, and antioxidant capacity ranged from 64 to 1282 mg Vitamin C Equivalent Antioxidant Capacity (VCEAC) per L. Most of these cider cultivars had substantially greater polyphenolic and antioxidant content than dessert type apples, which could be advantageous for both cider flavor quality and human dietary benefits. There was substantial variation in fruit yeast assimilable nitrogen content, titratable acidity, and polyphenolics content from year to year.

Introduction

Apple cider—meaning the juice pressed from pulped apples and consumed either fresh or fermented, in un-reconstituted forms—is a popular beverage that is produced and consumed throughout the world. In the U.S. most cider is consumed in its "sweet" or unfermented form, and made from a blend of dessert or processing apples, consisting mostly of drops or grading line culls that are blemished or too small for the fresh market. In Europe, apple cider is usually consumed in its fermented or "hard" form, and often includes a substantial portion of special cider apple cultivars—referred to as bittersweets or bittersharps—that contain substantially more polyphenolic compounds ("tannins") than typical dessert apples (1).

Fermented ciders are an important sector in the food and tourism industries of western Europe. In England, France and Spain there are well-developed regional cider industries producing more than 70 million L of cider that is marketed regionally through ecotourism networks, and exported internationally throughout the world (21). For hundreds of years, fermented cider (generally referred to as cider hereinafter) was a daily staple in farmers' diets throughout the Northeast U.S. (26). With increasing urbanization of the U.S. after the 1860s, and vilification by the Temperance Movement, cider was eclipsed by beer as the popular low-alcohol beverage of choice.

Since 1990, there has been a resurgence of interest and consumption of cider in North America, following on the microbrewery

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[3] This research was supported with funding by USDA/CSREES Hatch project NYG-623401. We would like to thank Dr. Phil Forsline (USDA apple germplasm) for fruit donation.

trend that profoundly altered the beer industry. There are now several hundred small-scale commercial cider-makers ("cideries") located throughout the temperate climate regions of North America, marketing through local restaurants and stores or directly on-farm along with fresh fruit, preserves, and other produce. As this cider industry has developed, the lack of information about fermentation and blending characteristics of indigenous or European cider cultivars grown in the U.S. has become a practical limitation for cider-makers striving to produce consistently high quality ciders.

New York State ranks second after Washington for apple production in the U.S. (35). The world's apple industries have become more highly integrated during recent decades, and market prices for apples have been depressed by excess supply relative to demand, so that apple growers everywhere are seeking new market outlets and value added apple products to increase profitability (27). An extensive network of wineries and "wine trails" has evolved since the 1980s in New York's Finger Lakes, Hudson Valley and Long Island regions—attracting several million agritourists annually. There are many commercial apple orchards located along or nearby these wine trails, providing ample opportunities for diversification and expansion of this high value direct market sector to include farm cideries. Farms that produce cider from apples grown on site would qualify for various tax and marketing advantages under the U.S. Farm Winery Act of 1976, substantially increasing their potential profitability. Despite the economic potential of this cider niche market, there has been very little land-grant university research to support U.S. cider-makers. With the closure of the Long Ashton Station research program in England during the 1980s, the only remaining cider research programs (excepting a few proprietary research efforts within major cider producers such as H.P. Bulmers in the U.K.) are in Le Rheu in France and Villaviciosa in Spain—regions where the cider industries are based upon entirely different apple cultivars than in the U.S. or U.K. We conducted the present study because of the need for basic information about the physical and chemical properties, and fermentation or blending characteristics of traditional North American and imported European cider apple cultivars.

Apples can be classified into three categories based upon their utilization: fresh/dessert, processing/culinary, and juice/cider. Fresh/dessert apples usually have high soluble solids content (primarily sugars and sugar alcohols such as sorbitol), low to moderate total (titratable) acidity, low polyphenolics content, and distinctive aromas or flavor. Processing/culinary apples often have textural properties important for slicing or saucing, and lower sugar : acid ratios than dessert apples, making them taste more tart. Juice/cider apples comprise two distinct types in Europe vs. North America. Most U.S. sweet ciders are blends of several different dessert and processing apples, resulting in well balanced sugar : acid ratios and palatable fresh ciders that are pasteurized, bottled and refrigerated until consumption. Certain dessert apples—for example 'Northern Spy,' 'McIntosh,' 'Liberty,' 'Golden Russet,' 'GoldRush,' and 'Golden Delicious'—are preferred by some sweet cider producers in the U.S. (37). However, as fermented ciders became more important in North America during the past decade, the criteria for cider apples have evolved and expanded to include some old European or American cultivars thought to have relatively high tannin content. These cultivars are often quite astringent or bitter, and can be unpalatable for fresh consumption; but when blended with other types of apples, they impart desirable complexity, clarity, balance, and perceived textures or "mouthfeel" to fermented ciders. There is little factual information about the responses and qualities of traditional European cider apples grown under local climate and soil conditions in the U.S., and this was another rationale for our study. Most of these special cider cultivars contain

high concentrations of polyphenols, but their acidity and sugar contents vary and may overlap with dessert or culinary apples. To help cider-makers obtain the optimal blends and ratios of acidity, polyphenolics, and sugar-derived alcohol or residual sweetness in their products, a quantitative classification system was developed at the Long Ashton cider research station in the U.K. during the early 1900s. Every apple can be classified within one of four categories based on these criteria (18):

- Sweet (< 0.2% polyphenolics w/v, and < 0.45% malic acid w/v)
- Bittersweet (> 0.2% polyphenolics w/v, and < 0.45% malic acid w/v)
- Sharp (< 0.2% polyphenolics w/v, and > 0.45% malic acid w/v)
- Bittersharp (> 0.2% polyphenolics w/v, and > 0.45% malic acid w/v)

Most dessert and culinary apples fall within the Sweet or Sharp categories above, while most of the special cider cultivars are Bittersweets, with relatively few classified as Bittersharps. Some of the Bittersharps can be fermented as a single-cultivar juice to produce "varietal" ciders that are analogous to wines derived from a single grape, such as 'Shiraz' or 'Chardonnay.' However, the best quality European ciders are usually fermented from blends of many different apples, including enough Bittersweets and Bittersharps to ensure clarity, balance, and a pleasant astringency; enough Sharps to keep the cider pH below 3.8 so that spoilage microbes will be suppressed during fermentation and storage or aging; and enough Sweets to provide adequate sugar for fermentation to the desired final ethanol content—usually 4 to 8% (v/v) in ciders. In practice, most premier cider-makers in Europe utilize a mixture of apples containing at least 20% (v/v) Bittersweets or Bittersharps to obtain the optimal sugar/alcohol/acidity/tannin ratios in their finished ciders. As the U.S. cider industry has developed, the lack of domestic sources and reliable information about Bittersweet and Bittersharp apples has become a serious concern.

Many fruit pigments and polyphenolics also have substantial free radical scavenging or antioxidant capacity (21). The recent popular interest in these health-promoting attributes of fruit provides another marketing opportunity for ciders made from high-tannin cultivars. However, because the specific contents and types of polyphenolics may differ among apple cultivars, from region to region, and from year to year even for the same apple cultivar, there is a need for research to quantify these characteristics for cider apples grown in New York (29).

Another important attribute for successful yeast-based fermentation is the amount of nitrogen available for yeast metabolism during fermentation—called yeast assimilable nitrogen (YAN). The sources of nitrogen most readily available to yeast in fruit juices include primary amino acids and ammonium. The YAN content in cider apples is usually less than in wine-grapes, and is influenced by the specific cultivar, soil conditions and climate conditions during the annual growing season (6,17,30). Without enough YAN in the initial juice, yeast can become metabolically stressed, causing problems such as incomplete or "stuck" fermentations, unpleasant odors from reduced sulfur compounds, or other detrimental flavors in the final product (16). Despite the inherent risks of off-flavors with low-N fermentations, there is a tradition of defecation or keeving in French and English ciders that is intended to slow the rate of fermentation in hopes of retaining a higher proportion of fruit aromatics and retaining some residual sugar in the bottled product to produce effervescence in bottle aged ciders (18). Keeving is the process of adding calcium chloride and pectin methyl esterase in the juice or pulp, which over time forms a gelatin like cap, trapping nitrogen and other nutrients (18). Regardless of the cider-makers' desired range

of YAN in the initial juice, it is important to know what YAN values are typical of cider cultivars grown under climatic and soil conditions typical of the northeastern and other regions in the U.S.

The main objective of our study was to evaluate the physical and chemical properties of diverse European and American cider apple cultivars obtained from orchards of the Finger Lakes region in New York during two consecutive growing seasons in 2002 and 2003, in order to provide research-based information about aspects of selected apple cultivars that may be useful to the developing fermented cider industry in North America.

Materials and Methods

Chemicals. Folin-Ciocalteu's phenol reagent, 2,2'-azino-bis(3ethylbenzothiazoline-6-sulfonic acid) (ABTS) as diammonium salt, and gallic acid were obtained from Sigma Chemical Co. (St. Louis, Mo.). The 2,2'-azobis(2-amidinopropane) dihydrochloride (AAPH) was obtained from Wako Chemicals USA Inc. (Richmond, Va.). Ascorbic Acid (Vitamin C) (99+%) was purchased from Fisher Scientific (Pittsburg, Pa.). All chemicals used were of analytical grade.

Fruit. Random samples, each containing at least ten apples representing 31 cultivars (in 2002) or 23 cultivars (in 2003, designated * in the following list) were obtained from the USDA Malus germplasm repository in Geneva N.Y., or from the nearby orchard of one of the authors (Merwin) in Trumansburg, N.Y. Fruit was randomly sampled from plots of 5 eight-year-old trees for each cultivar. The trees were trained to vertical axe form, and grafted onto either M.9 or Bud.9 rootstocks. The following cultivars were sampled: 'Bedan des Partes'*, 'Blahova Oranzova Renetor', 'Brown Snout'*, 'Calville Blanc'*, 'Canavial 14', 'Cap of Liberty', 'Chisel Jersey'*, 'Dabinett', 'Doucet Rouge', 'Edward VII', 'Ellis Bitter', 'Fillbarrel', 'Frequin Tardive de la Sarthe', 'Gold Rush', 'Golden Russet', 'Grosse Lauenette'*, 'King David', 'Kingston Black'*, 'Margil', 'Michelin', 'Muscadet Bernay'*, 'Porter's Perfection', 'Redfield', 'Reinette Clochard', 'Roxbury Russet'*, 'Stembridge Jersey', 'Tremletts Bitter', 'Wamdesa', 'Wetonka', 'Wickson', and 'Zapta.' The selection of cultivars for inclusion was based upon published lists of preferred cider cultivars from England (24), France (4), North America (26), or from characterizations in the USDA-PGRU Malus germplasm repository at Geneva, N.Y. (P. Forsline, personal communication). Each cultivar was harvested at commercial maturity, from early Sept. to early Nov. in both years. Many European bittersweet cultivars are prone to drop a large proportion of their crop during several weeks before all fruit are fully ripened on the trees. These drops are mechanically gathered from beneath trees and used for cider. It is customary to "sweat" or store cider apples for several weeks or months after harvest, until starch hydrolysis is completed, the fruit have softened to improve juice extraction, and fermentable sugars are at the maximum potential for each cultivar (18). This was the procedure followed in our study. The sample weights averaged about 1 kg taken in triplicate. Because of biennial bearing tendencies in some of these cultivars, not all of the apples were available in both years. Weather patterns were quite different during the two growing seasons of our study. In 2002 there was above normal rainfall during April and May, but the rest of that growing season was unusually hot and dry for upstate N.Y.; 2003 was cloudy, cool, and precipitation was above normal throughout that growing season in the two source orchards for fruit in this study. These fortuitous weather patterns provided a useful range of climate patterns for assessing the climate-related variation in physicochemical attributes of the selected cultivars.

Before chemical analysis, the samples were weighed, and firmness and visual color were determined as described below. The apples were diced and a subset of 150 g was taken

and immediately frozen stepwise at –10°C and then –40°C until samples could be lyophilized. The remaining apples were milled and pressed for fresh juice analyses including pH, titratable acidity, soluble solids, and YAN. Freeze dried samples were extracted using 80% methanol and analyzed for total polyphenolics content and antioxidant capacity. In the samples from 2003, total polyphenolic content of fresh juice was also determined for comparison with methanol extracted samples.

Extraction. A subset of 150 g from the original 1 kg sample of apples was diced with skins intact, placed in plastic sealed bags protected from light, frozen and lyophilized using a Virtis SR50C freeze dryer (Virtis Co. Gardiner, N.Y.). Freeze-dried samples were ground to a fine powder using a Waring Blender (New York, N.Y.) held in plastic bags protected from light at 4°C until analyses were performed.

Polyphenolic compounds were extracted using the ultrasound method (14), from 1 g subsamples of lyophilized apple in 10 ml of 80% aqueous methanol. The headspace of sample vials was flushed with nitrogen to prevent degradation of polyphenolics, and samples were sonicated for 20 min with a Branson 2200 (Fischer Scientific; Fair Lawn, N.J.). The samples were then centrifuged at 10,000 rpm for 20 min in a Sorvall RC-5B refrigerated ultra-centrifuge (DuPont Instrument; Wilmington, Del.). They were then decanted and the previous process was repeated with the supernatant. The two decant volumes were combined and diluted to 25 ml with 80% methanol, and samples were stored at -10°C in glass bottles protected from light until total phenolic content and antioxidant assays were performed.

Analysis. Flesh firmness was measured by pressure testing 4-6 fruits with a McCormick penetrometer (Yakima, Wash.). Skin was removed in three places and tests were performed at 120° separations on each apple. All data were averaged and reported as Newtons (N). The pH and titratable acidity were measured using a ThermoOrion PerpHect Log R model 370 pH meter (Waltham, Mass.) equipped with a Ross Sure Flow electrode (Beverly, Mass.). Titratable acidity was determined by a titration of 10 g of cider diluted in 100 ml distilled deionized water, using 0.1 N sodium hydroxide to a pH endpoint of 8.2. Results were expressed in percent malic acid (w/w). Soluble solids were measured by a Leica Auto ABBE digital refractometer (Buffalo, N.Y.) and reported as degrees Brix.

Yeast assimilable nitrogen was determined by two enzymatic assays: Unitab™ Reagents for primary amino nitrogen, and ammonia enzymatic methods (Unitech Scientific, Calif.). The primary amino nitrogen assay is based on spectrophotometric measurement using standard o-phthaldialdehyde and N-acetyl-l-cysteine (OPA/NAC) reagents (9). The ammonia assay is also a colorimetric analysis.

Antioxidant capacity of the fruit was expressed as vitamin C equivalent antioxidant capacity (VCEAC) using the radical scavenging activity method (15). The 2.5 mM 2,2'-azino-bis(3ethylbenzothiazoline-6-sulfonic acid) as diammonium salt (ABTS) radical solution was made by mixing phosphate buffer solution (PBS) solution with 1.0 mM 2,2'-azobis(2-amidinopropane) dihydrochloride (AAPH) and ABTS and heated at 68°C for 13 min. The absorbance of the radical solution was adjusted to 0.650 ± 0.020 at 734 nm. The radical solution (0.98 ml) was added to the sample (0.02 ml) and incubated at 37°C for 10 min. Reduction of the sample and radical solution was calculated based on a control of water and radical solution when the absorbance was read at 734 nm. The standard curve was based on ascorbic acid and results were reported as mg VCEAC per 100 g fruit.

Total polyphenolic concentrations in each cultivar were measured using a colorimetric analysis with the Folin-Ciocalteu's reagent (31). The method is based on a blue color formation from redox reaction between reagent

and polyphenolic compounds. The samples were diluted as necessary and read at 750 nm using an UV/Vis diode-array spectrophotometer (BrandTech Scientific; Essex, Conn.) after the addition of reagents and incubation time of 90 min. The standard curve was based on gallic acid and results were expressed as mg gallic acid equivalents (GAE) per 100 g of fresh fruit or juice.

Statistical Analysis. All data were subjected to analysis of variance (ANOVA) procedures using Minitab version 14 or SAS v6.12 (SAS Institute, Cary, N.C.). Fisher's protected least significant differences were used to separate year and cultivar means when there were significant F tests ($P = 0.05$). Pooled standard deviations were calculated for means, except when the deviation had a large range within cultivars. Statistical analyses indicated that both apple cultivar and year of harvest had significant effects on all attributes analyzed. In this report we concentrate primarily on the cultivar effects, because the main purpose of our study was to characterize cider apple cultivars, not the effects of random annual climate variation. The values reported for each cultivar attribute are the mean of three analytical replicates.

Results and Discussion

The average weight of fruit sampled for all cultivars (102 g) was smaller than average weights reported for most dessert apples (145 g) grown in New York (8). The average weights per individual cultivar ranged from 37 g for 'Wickson' to 206 g for 'Canavial 14' (Table 1). Flesh firmness values ranged from 49 N for 'Ellis Bitter' to 125 N for 'Wetonka' and 'Zapta'. Most of these cider apples were within the range of firmness ratings typical for fresh eating apples (Table 1), which are generally consumed with a firmness rating of 80 to 100 N depending on the cultivar (13). However, some of the English cider apples have a distinctly "mealy" texture when they are fully ripe (data not shown), and this trait would be undesirable if they were grown for dual purpose (dessert and cider) use. On the other hand, some of the other cultivars (e.g. 'Golden Russet', 'GoldRush', 'Roxbury Russet', and 'Margil') have a very crisp texture and are currently popular as "antique" niche cultivars in the eastern U.S.

The juice pH of these apples ranged from 2.7 for 'Zapta' to 4.4 for 'Bedan des Partes' and 'Chisel Jersey' and the titratable acidity ranged from 0.1% for 'Dabinett' to 2.25% for 'Zapta' (Table 2). Since the pH of juice for fermentation should be around 3.3 to 3.8, juice from most of these cultivars would need to be blended with high acid cultivars or adjusted with malic acid in order to achieve the desired pH for cider fermentation (18).

The soluble solids ranged from 8.5 °Brix for 'Wamdesa' to 18.9 °Brix for 'Wickson' (Table 2). Soluble solids are related to the amount of alcohol that yeast can produce from a starting juice. For every two °Brix, the typical yeast strain can potentially produce about 1% of alcohol plus one atmosphere (a standard unit of measurement for bottled beverages) of dissolved CO_2. The legal limit for hard cider produced in the United States specifies an alcohol content between 1.5% and 7%, and if the finished cider is higher than 7%, then it must be labeled as apple wine and is subject to a different taxation rate. Cultivars with Brix levels above 14° would therefore need to be blended with less sweet apples to produce ciders within legal limits.

An important factor in the success of fermentation is the amount of YAN in the juice. Nitrogen is essential for yeast growth and a deficit could lead to excessively slow or stuck fermentations or off-flavors produced by metabolically stressed yeast (10, 11, 16, 18). Historically, cider-makers have sometimes promoted a low YAN in juice through a cultural practice known as defecation or keeving, adding calcium chloride and pectin methyl esterase to form a gelatin like cap which traps nitrogen and other nutrients to achieve a slow

Table 1. Average fruit weight and description of visual skin color for selected cider apple cultivars in 2002 and 2003.

	Weight (g)		Firmness (N)		
Cultivars	**2002**	**2003**	**2002**	**2003**	**Skin color**
Bedan des Partes	82 jkl	---	116 cd	---	Green-yellow with red
Blahova Oranzova Renetor	103 gh	103 g	104 ef	83 ef	Red-yellow striped
Brown Snout	51 pq	---	75 ijk	---	Green with brown end
Calville Blanc	130 de	---	71 jkl	---	Green with red
Canavial 14	200 a	213 a	98 fgh	81 fg	Green with brown flecks
Cap of Liberty	34 r	50 jk	91 h	75 ghi	Red-yellow striped
Chisel Jersey	73 klmn	---	112 d	---	Red-green
Dabinette	70 lmno	110 fg	78 ij	80 fgh	Red-green striped
Doucet Rouge	111 efg	106 g	100 efg	96 c	Red and green-yellow
Edward VII	179 b	213 a	98 fgh	83 ef	Green
Ellis Bitter	103 gh	157 b	54 n	44 l	Red-yellow striped
Fillbarrel	101 ghi	130 cde	70 klm	85 ef	Red-yellow striped
Frequin Tardive de la Sarthe	59 nop	56 ij	118 abcd	105 b	Yellow-red striped
Gold Rush	122 def	134 cd	101 efg	96 c	Yellow-green with russet
Golden Russet	60 mnop	124 def	121 abc	94 cd	Green-yellow with russet
Grosse Launette	140 d	---	65 lm	---	Green-red with russet
King David	130 de	140 bc	95 gh	81 fg	Dark red with some yellow
Kingston Black	72 klmn	---	64 m	---	Dark red with green top
Margil	125 def	104 g	103 ef	69 ij	Red-orange with russet
Michelin	91 hij	73 h	54 n	73 hi	Yellow-green
Muscadet Bernay	86 ijk	---	100 efg	---	Green-brown with red
Porter's Perfection	72 klmn	70 hi	105 e	104 b	Red spotted with green top
Redfield	153 c	134 cd	81 i	63 jk	Red skin and flesh
Reinette Clochard	154 c	134 cd	118 bcd	88 de	Green
Roxbury Russet	180 b	---	100 efg	---	Green with russet
Stembridge	75 klm	116 fge	67 lm	72 i	Red-yellow
Tremlett's Bitter	110 fg	117 fge	81 i	57 k	Red-yellow striped
Wamdesa	61 mnop	70 hi	105 e	92 cd	Green-red
Wetonka	55 op	35 k	125 a	125 a	Green-red
Wickson	39 qr	36 k	123 ab	125 a	Red-yellow
Zapta	59 nop	74 h	125 a	125 a	Green
	Pooled SD= 42	Pooled SD= 48	Pooled SD= 21	Pooled SD= 21	

[z] Means within a column followed by a letter in common were not significantly different (a=0.05)

fermentation in the juice remaining beneath the cap that will eventually stop fermenting with some residual sugars. This practice of keeving increases the chances of quality problems and off-flavors. Research has shown that nitrogen supplementation enhances the quality or consistency of wines during grape fermentation (10), and the same principle may be applicable to cider fermentation, because the same or similar yeast strains are used for

Table 2. Average pH and titratable acidity values (percent (w/w) malic acid) for selected cider apple cultivars.

Cultivars	pH		Titratable acidity (g malic acid/100 g juice)		Soluble solids (°Brix)	
	2002	2003	2002	2003	2002	2003
Bedan des Partes	4.40 a	---	0.24 no	---	14.39 fg	---
Blahova Oranzova Renetor	3.41 klm	3.37 i	0.79 h	0.67 ef	15.28 e	12.56 efg
Brown Snout	3.95 f	---	0.47 m	---	18.06 b	---
Calville Blanc	3.28 no	---	0.73 hi	---	13.85 ghij	---
Canavial 14	3.41 klm	3.24 lm	0.93 efg	0.88 d	13.57 hij	12.91 efg
Cap of Liberty	3.14 p	3.16 no	1.33 b	1.06 c	18.88 a	13.63 bcd
Chisel Jersey	4.39 a	---	0.16 pq	---	13.53 ij	---
Dabinette	4.39 a	4.32 b	0.10 q	0.16 j	13.83 ghij	13.22 def
Doucet Rouge	4.09 de	4.01 e	0.22 op	0.23 hi	15.51 de	12.33 gh
Edward VII	3.09 pq	3.04 p	1.00 de	1.03 c	10.60 lm	10.87 ij
Ellis Bitter	4.16 cd	4.54 a	0.21 op	0.15 j	11.74 k	12.92 def
Fillbarrel	4.01 ef	3.95 f	0.27 no	0.28 h	16.39 c	15.92 a
Frequin Tardive de la Sarthe	3.84 g	4.12 d	0.31 n	0.14 j	16.57 c	12.96 def
Gold Rush	3.19 op	3.22 lm	0.78 h	0.61 f	14.30 fgh	11.52 hi
Golden Russett	3.65 h	3.61 g	0.54 lm	0.46 g	18.05 b	15.14 a
Grosse Launette	4.30 ab	---	0.21 op	---	13.22 j	---
King David	3.43 kl	3.21 mn	0.89 fg	1.01 c	13.33 ij	13.73 bcd
Kingston Black	3.47 jk	---	0.67 ij	---	16.16 cd	---
Margil	3.63 hi	3.53 h	0.57 kl	0.41 g	16.44 c	14.06 bc
Michelin	4.08 de	4.04 e	0.27 no	0.24 hi	13.45 ij	11.74 gh
Muscadet Bernay	4.14 cd	---	0.25 no	---	14.93 ef	---
Porter's Perfection	3.31 mn	3.36 ij	0.88 g	0.70 e	14.97 ef	13.87 bc
Redfield	3.35 lmn	3.27 kl	0.91 fg	0.66 ef	15.37 e	12.46 fgh
Reinette Clochard	3.43 kl	3.31 jk	0.64 jk	0.68 e	14.06 ghi	15.55 a
Roxbury Russet	3.33 lmn	---	0.96 def	---	14.82 ef	---
Stembridge	4.24 bc	4.26 c	0.23 op	0.20 ij	15.02 ef	14.16 b
Tremlett's Bitter	3.25 no	3.12 o	1.02 d	1.01 c	11.01 kl	10.59 j
Wamdesa	3.02 q	2.93 q	1.25 b	1.42 b	9.99 mn	8.47 l
Wetonka	3.33 lmn	3.33 ij	0.65 ijk	0.42 g	9.38 n	10.08 jk
Wickson	3.55 ij	3.31 jk	1.16 c	0.88 d	18.89 a	14.00 bc
Zapta	2.75 r	2.64 r	2.00 a	2.50 a	10.77 l	9.50 k
	Pooled SD=0.46	Pooled SD=0.49	Pooled SD =0.43	Pooled SD=0.53	Pooled SD=2.47	Pooled SD=1.91

[z] Means within a column followed by a letter in common were not significantly different (a=0.05)

both. Yeast assimilable nitrogen includes all amino acids except proline and ammonium ions. The YAN levels vary by year, location and cultivar and are lower in apples than grapes or beer worts. European apple varieties nitrogen content may range from 40-350 mg/L and higher values are obtained in fruit that is harvested from orchards which are heavily fertilized (23). Enological recommendations for a clean, controlled and complete wine fermentation range from 330 to 470 mg of YAN per L of initial must (12). Cidermaking specialists

Table 3. Average yeast assimilable nitrogen (YAN) for juice from selected cider apple cultivars.

Cultivars	Yeast assimilable nitrogen (mg N/L)	
	2002	2003
Bedan des Partes	82 ± 14 fghi	---
Blahova Oranzova Renetor	75 ± 17 hij	69 ± 26 bcde
Brown Snout	94 ± 19 defgh	---
Calville Blanc	45.2 ± 8.5 mno	---
Canavial 14	190 ± 29 a	49 ± 12 efgh
Cap of Liberty	28.3 ± 4.2 opq	12.6 ± 3.8 j
Chisel Jersey	90 ± 14 efgh	---
Dabinette	13.3 ± 1.9 q	45 ± 20 efgh
Doucet Rouge	62 ± 17 ijklm	85 ± 30 b
Edward VII	110 ± 12 cd	39 ± 10 fghi
Ellis Bitter	30.5 ± 3.4 opq	27 ± 12 hij
Fillbarrel	77.4 ± 2.6 ghij	52.6 ± 5.5 cdefg
Frequin Tardive de la Sarthe	30.0 ± 6.5 opq	12.2 ± 2.2 j
Gold Rush	36.3 ± 2.5 nop	13.8 ± 2.7 j
Golden Russett	66 ± 11 ijkl	76.1 ± 9.5 bc
Grosse Launette	110 ± 18 cd	---
King David	94 ± 12 defgh	56 ± 32 cdef
Kingston Black	24.4 ± 5.6 pq	---
Margil	93.0 ± 7.9 defgh	18.2 ± 9.5 ij
Michelin	58.2 ± 9.0 jklm	20.3 ± 1.9 ij
Muscadet Bernay	130 ± 22 bc	---
Porter's Perfection	110 ± 12 cd	50 ± 23 defgh
Redfield	53.3 ± 8.3 klmn	86.0 ± 9.7 b
Reinette Clochard	98 ± 13 def	46.8 ± 5.0 efgh
Roxbury Russet	137.8 ± 9.8 b	---
Stembridge	79 ± 13 fghi	19.0 ± 6.3 ij
Tremlett's Bitter	95.6 ± 1.8 defg	75 ± 18 bcd
Wamdesa	33 ± 10 nopq	136.3 ± 1.2 a
Wetonka	93.5 ± 6.0 defgh	126 ± 17 a
Wickson	73.6 ± 5.7 hijk	28 ± 15 ghij
Zapta	46 ± 18 lmno	148.6 ± 8.7 a

recommend supplementing nitrogen content up to 200 mg/L (18, 23).

The observed range of YAN content in our apples ranged from 12 mg N/L for 'Frequin Tardive de la Sarthe' and 'Cap of Liberty' to 190 mg N/L for 'Canavial 14' (Table 3). The average YAN content in most of these apples was substantially lower than typical levels (200 mg N/L) reported in grapes. It may therefore be important for cider-makers to adjust the nitrogen content of juice in order to obtain a complete fermentation and a good quality cider without off-flavors due to yeast nitrogen deficiency. Fertilizer nitrogen applications were minimal in the two source orchards for this study, where the soils were relatively high

in organic matter and typically provide about 80 to 100 kg N per ha annually from natural nitrogen mineralization processes. Based on these contributing factors and the YAN values that we observed, it may be advisable to supplement juice from low nitrogen cultivars with available nitrogen sources for consistent fermentation, unless the cider-maker intends to make a bottle conditioned naturally effervescent cider with 4 to 5% alcohol and 1-2% residual sugar content. In the latter case it may be desirable to maintain the low-nitrogen status of the juice, despite the concomitant risks during fermentation.

Polyphenolic compounds or tannins are important in apples and finished cider, because they may enhance the perceived clarity, body and "mouthfeel" of the product. Without sufficient tannins, ciders may be perceived as flat and insipid by some consumers. There are two assay methods commonly used to determine tannin content on the juice or finished cider, the Lowenthal permanganate titration and the Folin-Ciocalteu colorimetric assay. Previous research has shown that these assays produce similar results, so that data reported from either method can be compared (17). Total phenolics were assayed using a methanol extraction of the lyophilized apple to determine the total amount of polyphenolics in whole fruit, and to compare that to the amount obtained in juice. The phenolics values for apples ranged from 46 mg GAE/ 100 g for 'King David' to 587 mg GAE/ 100 g for 'Zapta' (Table 4). Dessert apples typically have total phenolic contents of 50 to 230 mg GAE/ 100 g fresh weight as measured by the Folin-Ciocalteu assay (19, 21, 36). Previous research with European grown cider cultivars has shown that cider fruit is higher in phenolic compounds than dessert fruit and our findings with North American grown cider cultivars agree with this conclusion (18, 28).

In addition to total polyphenolic content from methanol extracts, pressed juices were tested for total polyphenolic content immediately after pressing. The percentage of polyphenolic compounds that were retained in the juice, representing those compounds extracted through normal pressing as well as those not easily oxidized, varied substantially among the different cultivars (Fig. 1). The percentage of retained polyphenolics ranged from 14% to 70% for 'Canavial 14' and 'Zapta', respectively, and this may be a useful attribute for cider-makers to know, because almost all U.S. ciders are produced from juice fermentations, as opposed to the mash fermentations that are preferred for certain distilled cider products such as *eau de vie*.

Antioxidant capacity of the apples ranged from 56 mg VCEAC per 100 g for 'King David' to 1706 mg VCEAC per 100 g for 'Wamdesa' (Table 4). These cider apple cultivars had a wide range of antioxidant capacity, with the low end of their range similar to dessert apples in antioxidant capacity (3, 20, 33). Approximately half of the cider apples we tested had greater antioxidant capacity than the average dessert apple. There was a strong positive correlation (r=0.85) between total polyphenolic content and antioxidant capacity of apple extracts, which has been previously reported for dessert apples (32, 34).

The total polyphenolics content of these cider cultivars in N.Y. was lower than values reported for western Europe (2, 7, 33), but similar to values reported for these same cultivars in the same and other regions of the U.S. (8, 25). In the combined ANOVA across both years, the effect of year in our study was significant. Comparing the analyzed fruit attributes across two very different growing seasons—hot/dry 2002 and cool/wet 2003—the trends were mixed from 2002 to 2003. For most but not all of the 23 cultivars that were sampled in both years, juice pH was relatively unchanged, titratable acidity decreased, soluble solids decreased, YAN and polyphenolics content decreased, but antioxidant activity (VCEAC) increased from 2002 to 2003 Tables 1-4). These trends

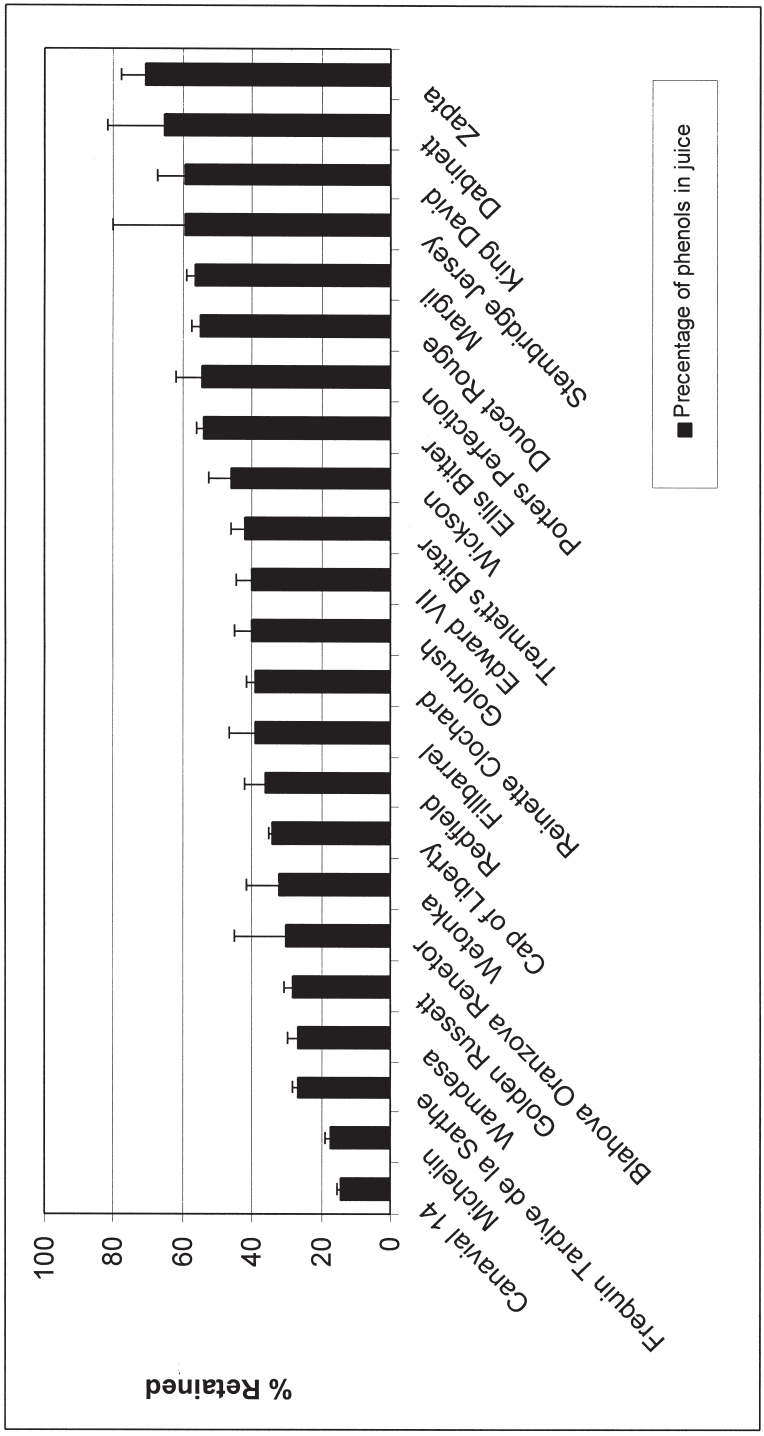

Figure 1. Percentage of retained phenolic compounds from whole apples into freshly pressed juice measured by total polyphenolic content assay of apple extract and juice. Values are pooled means for fruit sampled in 2002 and 2003, except as noted.

Table 4. Average total polyphenolics content (as gallic acid equivalents or GAE) and antioxidant capacity (vitamin C equivalent antioxidant capacity or VCEAC) of selected cider apple cultivar extracts.

	Total phenolics in extract (mg GAE/100g)		Antioxidant capacity (mg VCEAC/100g)	
Cultivars	**2002**	**2003**	**2002**	**2003**
Bedan des Partes	220 ± 17 ghi	---	285 ± 32 hijk	---
Blahova Oranzova Renetor	115 ± 22 klm	115 ± 24 klm	306 ± 43 ghij	131 ± 16 lm
Brown Snout	310 ± 58 def	---	388 ± 130 fgh	---
Calville Blan	210 ± 16 ghij	---	224.6 ± 4.0 ijkl	---
Canavial 14	129 ± 16 jklm	452 ± 31 bcd	268 ± 32 hijkl	343 ± 13 jk
Cap of Liberty	450 ± 25 b	376.0 ± 7.1 ed	825 ± 125 b	674 ± 17 ef
Chisel Jersey	340 ± 57 de	---	551 ± 55 d	---
Dabinette	346 ± 42 d	297 ± 63 fg	592 ± 160 cd	661 ± 14 fg
Doucet Rouge	312 ± 11 def	194.3 ± 2.0 hij	279.1 ± 8.2 hijk	358 ± 43 ijk
Edward VII	98.0 ± 9.5 lm	121.8 ± 5.7 jklm	178.8 ± 6.5 jklmn	228 ± 35 kl
Ellis Bitter	279 ± 35 defg	276 ± 51 fg	491 ± 49 def	537 ± 76 gh
Fillbarrel	581 ± 89 a	451 ± 59 cd	237 ± 70 ijkl	1023 ± 102 c
Frequin Tardive de la Sarthe	284 ± 17 defg	228 ± 14 ghi	145 ± 27 lmn	490 ± 91 hi
Gold Rush	150 ± 31 ijkl	324 ± 32 ef	209 ± 49 ijklm	324 ± 48 jk
Golden Russett	236 ± 30 fgh	148 ± 17 jk	285 ± 120 hijk	250 ± 35 jkl
Grosse Launette	188 ± 22 hijk	---	265 ± 81 hijkl	---
King David	53.5 ± 3.8 m	46.9 ± 4.3 m	56 ± 21 n	72 ± 10 m
Kingston Black	308 ± 37 def	---	415 ± 150 efg	---
Margil	148 ± 17 ijkl	123.2 ± 2.1 jkl	237 ± 53 ijkl	336 ± 27 jk
Michelin	253 ± 35 fgh	641 ± 68 a	309 ± 53 ghi	609.4 ± 4.9 fgh
Muscadet Bernay	498 ± 133 bc	---	1019 ± 82 a	---
Porter's Perfection	246 ± 16 fgh	328 ± 12 ef	219 ± 13 ijkl	960 ± 51 c
Redfield	351 ± 45 d	414 ± 77 cd	540 ± 73 de	809 ± 24 de
Reinette Clochard	182 ± 32 hijk	182.1 ± 8.1 ijk	167 ± 55 klmn	369 ± 23 ij
Roxbury Russet	123 ± 27 klm	---	267 ± 40 hijkl	---
Stembridge	489 ± 112 bc	496 ± 77 b	870 ± 81 b	939 ± 42 cd
Tremlett's Bitter	262 ± 48 efgh	259 ± 24 fgh	577 ± 39 cd	573 ± 32 fgh
Wamdesa	551 ± 60 ab	415.0 ± 7.5 cd	852 ± 71 b	1706 ± 295 a
Wetonka	464 ± 57 b	377 ± 130 ed	686.0 ± 7.3 c	531 ± 78 gh
Wickson	74 ± 18 lm	56.2 ± 6.5 lm	85 ± 21 mn	81 ± 11 m
Zapta	587 ± 98 a	477 ± 17 bc	845 ± 200 b	1304 ± 157 b

were not consistent enough to support meaningful inferences about the physicochemical responses of individual cultivars to warm vs. cool growing conditions, but they did indicate that these responses were not consistent across this entire group of cultivars.

Cider apple cultivars are divided into useful blending categories based on tannin or total polyphenolics content and acidity in freshly pressed juice. Based on the total polyphenolics content and titratable acidity of juice from these cider cultivars in 2003, we categorized 23 of these apples into the four Long Ashton cider apple classifications (Table 5). Most of them would be categorized as Sharps, because their acidity was > 0.45% and their tannins

Table 5. Categorization of cider apples grown in upstate New York using the English classification of apples by % tannin (w/v measured by Folin-Ciocalteu assay) and % acid (titratable acidity expressed as w/w malic acid) of freshly pressed juice from 2003.

Cultivar	% tannin	% acid
Sweet		
Ellis Bitter	0.15	0.18
Frequin Tardive de la Sarthe	0.06	0.19
Doucet Rouge	0.11	0.23
Michelin	0.11	0.24
Bittersweet		
Dabinette	0.20	0.12
Stembridge	0.29	0.20
Fillbarrel	0.20	0.29
Sharp		
Golden Russett	0.09	0.47
Margil	0.07	0.48
Wetonka	0.11	0.50
Reinette Clochard	0.07	0.66
Gold Rush	0.06	0.66
Blahova Oranzova Renetor	0.03	0.73
Redfield	0.15	0.76
Canavial 14	0.06	0.86
King David	0.03	0.93
Wickson	0.03	0.98
Edward VII	0.05	0.99
Tremlett's Bitter	0.11	1.04
Cap of Liberty	0.13	1.15
Wamdesa	0.11	1.29
Bittersharp		
Porter's Perfection	0.18	0.79
Zapta	0.34	2.17

content was <0.2%. Several cultivars were categorized differently from previous reports for these apples in Europe. For example, 'Tremlett's Bitter' grown in England, reportedly had titratable acidity of 0.27%, much less than the 1%-1.3% observed in our study and reported by LaBelle in 1980 (5, 8). This difference may be due to a misidentification of this cultivar when it was originally imported from England for the USDA Malus germplasm collection at Geneva, N.Y. Most U.S. nurseries have obtained their grafting material of 'Tremlett's Bitter' from the Geneva collection; therefore the true identification of this apple is unknown and could best be determined by DNA fingerprinting methods (Dr. P. Forsline, USDA, personal communication).

Cider is not typically made from a single apple cultivar except for those few cultivars—such as 'Kingston Black' or 'Foxwhelp'—that have the optimal balance of acidity, sugar and tannins (18). Cider (or fruit) should be blended to obtain a final product with a pH < 3.8, a titratable acidity around 0.5%, and tannins content approaching 0.2% (2). Since total tannins vary more than titratable acidity from year to year, cider-makers should consider that the optimal blending of ciders based on tannin content could also vary each year. The data shown in Table 5 are based on data from a single year—2003, and the variation between years was evident in our study, perhaps because the growing seasons in 2002 and 2003 were substantially different.

Conclusion

This research was conducted to provide objective characterizations of a number of cider cultivar apples grown in the U.S. because very little previous research has been reported for most of these cultivars. The results were generally consistent with reports for cider apples grown in western European countries. As a group, the cider cultivars have very different physiochemical profiles compared to dessert apples. The size, color and firmness of these apples remained relatively consistent during 2002 and 2003—two very different growing seasons. The acidity of juice varied substantially, from 2.75 to 4.40 for pH, and 0.1 to 2.0% for titratable acidity. These observations suggest that blending of apples or juice is necessary to obtain the optimum acidity and balance for cider fermentation, and the desirable sensory characteristics and stability in finished ciders. Blending also provides a method to achieve a final sensory profile that characterizes regional ciders, or distinguishes the ciders from a particular cider maker from others, which promotes market differentiation and consumer recognition of cider as a high value product.

Yeast available nitrogen content of apples from N.Y. is evidently lower than levels typical of wine-grapes, suggesting that nitrogen supplementation may be useful in cider fermentations, contrary to some historical or regional cider-making traditions. The nitrogen content of our cultivars was inconsistent from year to year, indicating that nitrogen content in apples is influenced by factors such as weather, location and orchard management practices. Polyphenolics content of most apple cultivars in our study was similar to or higher than those typical of dessert cultivars, supporting the traditional inclusion of these apples in cider blends. The close correlation between polyphenolics and antioxidant activity in our study suggests that consumption of cider made with Bittersweet and Bittersharp apples may have beneficial dietary effects.

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