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Effects of Processing Treatment and Sorbate Addition on the Flavor Characteristics of Apple Cider

TERRI D. BOYLSTON,* HUI WANG, CHERYLL A. REITMEIER, AND BONITA A. GLATZ

Department of Food Science and Human Nutrition, 2312 Food Sciences Building, Iowa State University, Ames, Iowa 50011-1061

Processing treatments used to produce a microbiologically "safe" apple cider were evaluated to determine the impact of these treatments on the overall flavor characteristics. Apple cider with (0.1%) and without (0%) potassium sorbate was subjected to four processing treatments: untreated, irradiated at 2 kGy, irradiated at 4 kGy, and pasteurized. Volatile flavor compounds were isolated from the cider using solid-phase microextraction methods with gas chromatographic analysis. A trained descriptive analysis panel evaluated sensory attributes. The effects of the processing treatment were dependent on the presence of sorbate in the apple cider. Irradiation treatments resulted in a decrease in the content of esters characteristic of apple flavor and an increase in the content of alcohols and aldehydes formed through lipid oxidation reactions. The presence of sorbate reduced the effects of the irradiation treatments on these volatile flavor compounds. Sensory panelists, however, detected higher intensities of undesirable flavor attributes, including "cardboard flavor", and lower intensities of the desirable "apple flavor" in irradiated cider with added sorbate.

KEYWORDS: Apple cider; irradiation; pasteurization; volatile flavor compounds; sensory evaluation; sorbate

INTRODUCTION

Concerns regarding the safety of fresh apple cider and other juices, stemming from contamination of apple cider by *Escherichia coli* O157:H7, have led to more stringent regulation of the juice industry and the investigation of processing methods to provide consumers with a safer product. Cider and juice producers are now required to implement hazard analysis and critical control point (HACCP) programs to attain a 5-log reduction in the most resistant pathogen present (*1*). The challenge to producers is to develop cider-processing techniques that will provide the required reduction in microbial load without adversely affecting flavor and other sensory characteristics (*2*).

Esters, aldehydes, and alcohols in a complex mixture are among the volatile flavor compounds that contribute to the characteristic fruity, apple-like aroma of apples, apple juice, and apple cider. Specifically, butyl, 2-methylbutyl, and hexyl acetates; ethyl 2-methyl, ethyl, propyl, and hexyl butanoates; butyl, isopentyl, and hexyl hexanoates; and butanol, hexanol, hexanal, and *trans*-2-hexenal have been identified as important contributors to apple flavor (*3*−*8*). Synthesis of these flavor compounds occurs in the maturing and ripening fruit, with cultivar differences accounting for differences in the relative composition of volatile flavor compounds and overall flavor characteristics (*5*). During the processing of the apples into apple cider, oxidation of unsaturated fatty acids to C-6 aldehydes and reduction of these aldehydes to alcohols further contribute to the development of flavor (*9*). Differences in apple variety, maturity, and quality, cider processing parameters, and storage conditions contribute to variability in the flavor characteristics and quality of apple juice and cider (*10*).

Sorbates are frequently used in ciders and juices to decrease spoilage and increase shelf life without contributing undesirable taste characteristics. These preservatives are most effective against the growth of yeasts and molds, with their activity against bacteria more limited (*11*, *12*). Sorbates are most effective as microbial inhibitors in low-acid foods, in which a greater percentage of the sorbate is present in the undissociated form (*13*). The hydrophobic form of the acid is better able to permeate the cytoplasmic membrane of microorganisms to inhibit their enzyme systems (*12*). Apple cider treated with sorbates and receiving mild heat treatment was acceptable to consumers (*14*). The combination of sorbates or other preservatives with nonthermal or low-temperature preservation may provide alternatives to conventional heat treatments to achieve the necessary 5-log reduction (*15*).

Currently many cider processors use pasteurization as a means to achieve the necessary 5-log reduction in pathogenic microorganisms. However, pasteurization has an adverse effect on the color, flavor, and viscosity of the cider (*16*). Irradiation is currently being explored as an alternative processing method to pasteurization. Electron beam irradiation at 2.17 kGy effectively achieved the necessary 5-log reduction in *E. coli* O157:H7 (*17*). Research on the effects of irradiation on the sensory

* Author to whom correspondence should be addressed [telephone (515) 294-0077; fax (515) 294-8181; e-mail tboylsto@iastate.edu].

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and flavor characteristics of juices has been limited. Slight differences in odor and flavor quality were observed in apple juice irradiated at 0.5−1.5 kGy, whereas juice irradiated at 2.0 kGy had a dried apple flavor with an uncharacteristic aftertaste (*18*). However, in orange juice and mango pulp, the addition of sorbate effectively inhibited off-flavor formation during irradiation at 10 kGy (*19*). Further analysis of the volatile flavor compounds that contribute to these flavor characteristics is necessary to understand the effects of irradiation on the flavor quality of apple cider and other juices.

Processing methods used to obtain a safe apple cider product must not adversely affect the flavor quality and overall consumer acceptability. The objective of this study was to evaluate the effects of processing treatments and sorbate addition on the flavor quality of apple cider, as evaluated using objective and sensory techniques. Apple cider, with (0.1%) and without (0%) added potassium sorbate, was irradiated at 2 and 4 kGy and compared to untreated (control) and pasteurized apple ciders to determine the effects of processing treatment and sorbate addition on the flavor and sensory characteristics.

MATERIALS AND METHODS

Cider Sample Preparation. Fresh apple cider with (0.1%) and without (0%) added potassium sorbate was purchased from a local producer on the pressing date in the fall of 2000. The ciders with and without potassium sorbate were from the same raw material blend during the same production run. Each sample of cider was divided into 12 batches, with 3 batches randomly assigned to 4 treatments: untreated (control), irradiated at 2 kGy, irradiated at 4 kGy, and pasteurized. All samples were stored at 4 °C prior to processing on the following day. The three batches assigned to each treatment were processed individually to attain three replicates for each treatment.

Pasteurization of the cider was by long-time, low-temperature (LTLT) heating (60 °C for 30 min) in a stainless steel container. The LTLT pasteurization process was used because it could be well controlled in the laboratory for consistent product quality. The cider (150 mL) to be irradiated was packaged in transparent polyethylene bags (532 mL capacity, 2.5 mil thick, Nasco, Fort Atkinson, WI) and irradiated at the Iowa State University Linear Accelerator Facility (Ames, IA). The samples were subjected to electron beam irradiation at target doses of 2.0 and 4.0 kGy at an energy level of 10 MeV and a power level of 10 kW. Irradiation was conducted at room temperature without temperature control. Following all treatments, the cider was transferred to glass bottles, stored at 4 °C, and analyzed within 3 days by sensory and objective methods.

Volatile Flavor Analysis. Solid-phase microextraction (SPME; Supelco, Inc., Bellefonte, PA) techniques were used for the isolation of volatile flavor compounds. Apple cider (40 g) was transferred to a 100-mL headspace bottle and sealed with a Teflon septum. Following a 15-min equilibration of the sample, the volatiles were absorbed onto the SPME fiber [100 μm poly(dimethylsiloxane)] for 30 min. Samples were held in a 40 °C water bath, with stirring, during equilibration and absorption. A gas chromatograph equipped with a splitless injection port and flame ionization detector was used for the analysis of volatile flavor compounds (model 6890, Hewlett-Packard, Inc., Wilmington, DE). The volatiles were thermally desorbed (225 °C) for 1 min via the GC injection port onto a fused-silica capillary column (SPB-5, 30 m × 0.25 mm × 0.25 μm film thickness, Supelco, Inc.). The column pressure was set at 124.0 kPa with a helium flow rate of 1.9 mL/min (linear flow rate = 39 cm/s). The oven was initially held at 30 °C for 3 min and increased at a rate of 5 °C/min to a final temperature of 200 °C. The detector temperature was 220 °C. Flow rates of detector gases were air, 400 mL/min; hydrogen, 30 mL/min; and nitrogen makeup gas, 23 mL/min. Volatile flavor compounds were identified using authentic standards (Sigma-Aldrich, Milwaukee, WI; AccuStandard, Inc., New Haven, CT) and confirmed with GC-MS analyses. Kovats retention indices, based on hydrocarbon standards, were calculated for compounds tentatively identified.

A gas chromatograph−mass spectrometer (Trio 1000, Fisons Instruments, Danvers, MA) with a quadrupole mass analyzer was used for the confirmation of the identity of the volatile compounds. The GC conditions were as for the chromatographic analysis. The conditions for the mass spectrometer were set as follow: source electron energy, 70 eV; source electron current, 150 μA; ion source temperature, 220 °C; interface temperature, 220 °C; source ion repeller, 3.4 V; electron multiplier voltage, 600 V; and scan range, m/z 41−250. Mass spectra of the volatile flavor compounds were compared to the reference spectra in the NBS Library and a flavor and fragrance database (FlavorWorks, Flavometrics, version 2.0, Anaheim Hills, CA) for identification.

Soluble Solids Content and Titratable Acidity. Soluble solids content, pH, and titratable acidity of the apple cider were determined as objective measures of sweetness and acidity. Soluble solids content was measured using a 0−32 °Brix refractometer. pH was recorded using a digital pH-meter (model 420A, Orion Research, Inc., Beverly, MA). Titratable acidity was determined by titrating the cider (20 mL) with 0.1 N NaOH to an endpoint of pH 8.2. Titratable acidity was expressed as grams of malic acid per 100 mL of cider.

Sensory Evaluation. A trained descriptive analysis panel evaluated the flavor attributes of the cider. The panel consisted of eight panelists recruited from faculty and students at Iowa State University. The sensory evaluation research was approved by the Human Subjects Review Committee of the Institutional Review Board at Iowa State University. Panelists were informed that they would be evaluating irradiated, pasteurized, and raw apple cider samples and completed informed consent forms prior to participation in the study. Following 10 1-h training sessions, panelists selected six descriptors, with reference standards, for analysis of the samples. These attributes were sweetness, sourness, astringency, apple flavor, cooked apple flavor, and cardboard-like flavor (*20*).

Due to limitations in the number of samples the panelists could evaluate in one session without errors of fatigue, the ciders with and without sorbate were evaluated by the sensory evaluation panel on separate weeks. A complete design was applied so that each panelist evaluated cider samples from all treatments within a sorbate treatment once at each session. Cider samples were served at room temperature in waxed paper cups (100 mL). Samples were coded with random three-digit numbers and presented to panelists in a random order for evaluation. Panelists evaluated the samples in individual booths under red light to mask color differences among the treatments. An unstructured 15-cm line with anchor points of "none" at 0 cm and "intense" at 15 cm for each attribute was used for the evaluation of the samples. Sensory evaluation data were collected using Compusense 5 data collection and analysis software (Compusense Inc., Guelph, ON, Canada). Panelists were allowed to retaste samples and change ratings. Reference standards, water, and unsalted crackers were provided during evaluation sessions.

Statistical Analysis. The analysis of the instrumental analysis of flavor components was designed as a two-way factorial with processing treatment (untreated, irradiated at 2 kGy, irradiated at 4 kGy, and pasteurized) and sorbate addition (0 and 0.1%) as the main factors. For the instrumental analyses, all samples were analyzed concurrently. Because the ciders with and without added sorbate were evaluated by the sensory evaluation panel on separate weeks, the statistical analysis of the sensory data did not compare the effects of the sorbate addition but focused on the processing treatment effects. Analysis of variance and Fisher's least-squares difference tests ($P < 0.05$) were conducted to determine the effects of the main factors and interactions between the main factors on the content of volatile flavor compounds, intensity of sensory attributes, and soluble solids content, pH, and titratable acidity using the SYSTAT statistical analysis package (version 9.01, SPSS Inc., Chicago, IL). All objective and sensory analyses of the apple cider samples were replicated three times, with all objective analyses conducted in duplicate.

Principal component analysis (PCA) was conducted to examine relationships between taste and flavor components of the apple cider, as determined by objective and sensory analyses. A correlation matrix was used for the extraction of the principal components, with Varimax orthogonal rotation. A minimum eigenvalue of 1.0 was used in the PCA. Perceptual mapping using the biplot method was conducted to develop a model that fits the objective and sensory attributes analyzed (vector coordinates) and the samples evaluated (object coordinates) in a common space to identify relationships between the variables contributing to the flavor characteristics and treatment effects (SYSTAT, version 9.01, SPSS Inc.).

RESULTS AND DISCUSSION

Principal Component Analysis. PCA identifies patterns of interactions between variables to reduce a large data set containing intercorrelated variables to a smaller set of uncorrelated factors. Because of the complexity of the flavor chemistry of apple cider, with several volatile flavor compounds contributing to a sensory attribute, PCA is more effective than correlation and other statistical analysis techniques to demonstrate relationships between variables. In this study, all data from the objective and sensory analyses were included in the PCA. The variables loaded onto nine principal components (PC), with the first four factors accounting for 51.9% of the variability. In general, the volatile flavor compounds tended to associate together within the principal components. However, the PCs were not grouped completely on the basis of classes of flavor compounds, that is, esters or aldehydes. In addition, not all classes of flavor compounds responded similarly to the effects of processing treatments or sorbate addition or interaction between processing treatment and sorbate addition, as shown in **Figure 1** for selected volatile flavor compounds from PC-1, PC-2, and PC-4. Therefore, the effects of these treatments on the content of the volatile flavor compounds will be discussed in the context of each principal component rather than individual volatile flavor compounds. Interactions between processing and sorbate treatments were significant for a majority of the volatile flavor compounds that associated with PC-1, PC-4, PC-6, and PC-7 (**Table 1**). **Tables 2** and **3** focus on the effects of processing treatment and sorbate treatment, respectively, on the volatile flavor compounds contents in apple cider that associated with PC-2, PC-3, PC-8, and PC-9. For these compounds, interactions between processing and sorbate treatments were not significant.

The first principal component (PC-1) included esters, alcohols, and aldehydes. However, the esters that loaded onto this component were not among the esters commonly identified as being important contributors to characteristic apple flavor. However, the processing and sorbate treatments and the interactions between these treatments had a significant effect on the content of many of these volatile flavor compounds. Therefore, the alcohols and aldehydes within this PC may potentially have a greater impact on the flavor of the cider. The second principal component (PC-2) primarily consisted of esters, including compounds such as hexyl acetate, hexyl butanoate, and hexyl hexanoate, which have been identified as key contributors to apple flavor (*3*−*8*). Several terpenoid compounds, including α-farnesene, loaded onto principal component 3 (PC-3). Principal component 4 (PC-4) included hexanal and several esters that are also important contributors to apple flavor (*3*−*8*).

The sensory attributes loaded onto principal components 5, 8, and 9 tended to group onto the principal components with other sensory attributes rather than with the objective measurements of flavor. Apple, cooked apple, and cardboard flavor loaded onto PC-5, with the loading for the desirable flavor attribute, apple flavor, inversely related to the loadings for the undesirable flavor attributes, cooked apple and cardboard. No volatile flavor compounds loaded onto PC-5. Sour loaded onto PC-8, whereas astringent and sweet were inversely related to each other in their loadings onto PC-9.

Volatile Flavor Analysis. Flavor compounds on PC-1 and PC-2, were, in general, affected by processing treatment to the greatest degree (**Tables 1** and **2**). For these compounds, the volatile profile of the 4 kGy irradiated cider was significantly different from those of the pasteurized, untreated (control), and 2 kGy irradiated ciders. The 4 kGy irradiation treatment contributed to an increase in the content of hexanol, other alcohols, and esters that composed PC-1. Hexanol and other oxidation products on PC-1 are formed through free radical oxidation of unsaturated fatty acids; irradiation can generate the free radicals needed for this oxidation reaction. Irradiation has been shown to increase lipid oxidation in orange juice (*21*), oils (*22*, *23*), and meat products (*24*) as well as ascorbic acid oxidation in orange juice and mango pulp (*25*). In addition, for the flavor compounds associated with this principal component,

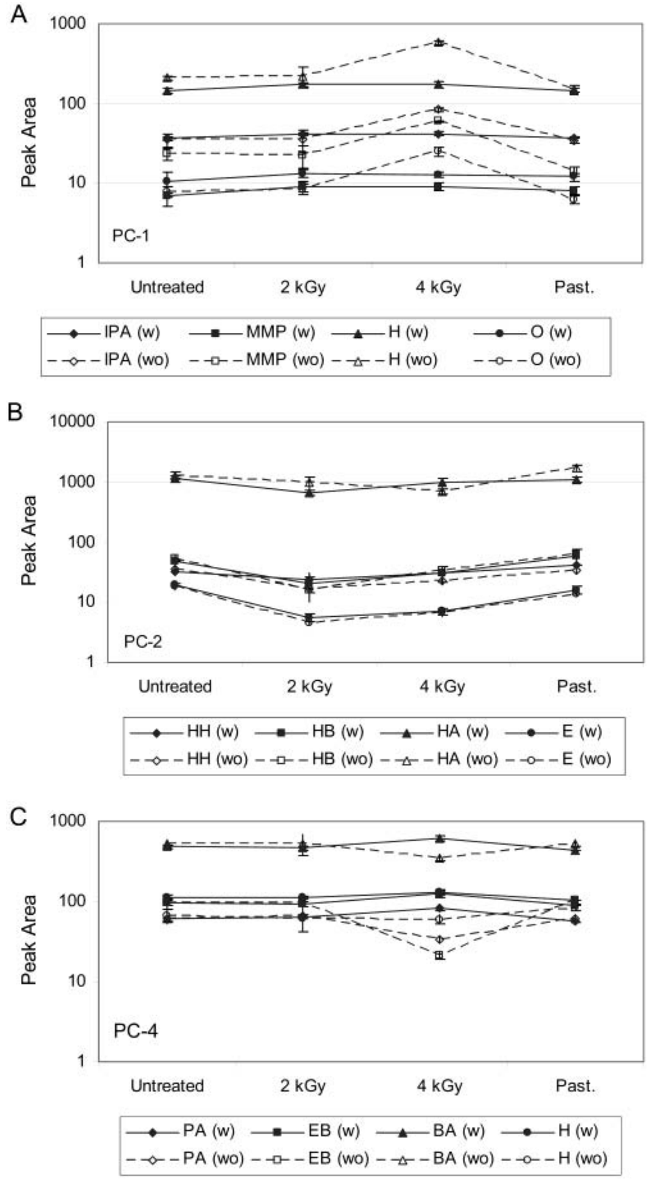

Figure 1. Effect of processing treatment and sorbate addition on content of selected volatile flavor compounds: (A) flavor compounds from PC-1 (IPA, isopropyl acetate; MMP, methyl 2-methylpentanoate; H, hexanol; and O, octanol); (B) flavor compounds from PC-2 (HH, hexyl hexanoate; HB, hexyl butanoate; HA, hexyl acetate; and E, estragole); (C) flavor compounds from PC-4 (PA, propyl acetate; EB, ethyl butanoate; BA, butyl acetate; and H, hexanal). For all flavor compounds, the processing treatments are compared with (w) and without (wo) added sorbate. Data points represent mean ± standard error of duplicate analyses of three replications, basd on peak area of FID response for a 40-g sample.

Table 1. Effect of Processing and Sorbate Treatments on Content[a] of Volatile Flavor Compounds Associated with PC-1, PC-4, PC-6, and PC-7 in Apple Cider[b]

	treatment							
	0% sorbate				0.1% sorbate			
compound	untreated	2 k Gy	4 kGy	pasteurized	untreated	2 k Gy	4 kGy	pasteurized
PC-1								
isopropyl acetate	34.8cx	46.2bx	83.9ax	34.6cx	36.5ax	41.7ax	41.7ay	37.1ax
tert-butyl acetate (RI 723)[c]	21.2cx	28.9bx	38.3ax	20.4cx	23.1bx	29.9ax	29.9ay	23.4bx
octyl acetate	0.8bx	0.0bx	2.2ax	0.8bx	1.4ax	0.4ax	0.5ay	1.1ax
3-hepten-1-yl acetate (RI 1110)	3.0ax	1.9bx	0.0cy	3.1ax	2.7ax	1.5bx	1.9abx	2.6ax
2-phenylethyl acetate	1.9bx	1.4cx	3.7ax	2.0bx	2.0ax	1.6ax	1.7ay	2.0ax
3-methylbutyl propionate	2.4cx	3.3bx	7.0ax	2.9bcx	2.2ax	2.3ay	2.8ay	2.7ax
methyl butanoate	2.6b	2.7b	3.8a	2.5b	2.1b	2.1b	2.8a	2.2b
methyl 2-methylpentanoate	23.2bx	29.0bx	59.2ax	14.0cx	7.0ay	9.2ay	9.0ay	8.2ay
methyl hexanoate	1.3b	1.4b	3.5a	1.7b	1.6a	1.1b	1.5ab	1.4ab
ethyl hexanoate	53.1bx	37.3bx	0.9cy	95.3ax	62.5abx	34.8bx	55.1abx	68.8ax
t-2-octenal	1.9cy	2.6bx	6.5ax	2.6bx	4.3ax	2.9bx	4.1ay	2.4bx
2-decenal (RI 1249)	0.8cx	4.3bx	12.9ax	0.0cy	0.9bx	2.9ay	3.3ay	1.4bx
hexanol	207.6bx	249.7bx	579.6ax	152.0cx	146.1ay	171.2ax	171.2ay	146.3ax
1-octanol	7.9bx	8.5by	22.1ax	6.3by	10.7ax	13.1ax	12.7ay	12.0ax
1-octen-3-ol	0.0bx	0.0bx	1.7ax	0.0bx	0.0ax	0.0ax	0.0ay	0.4ax
t-2-nonenol (RI 1168)	12.9bx	11.7bx	36.3ax	11.8bx	12.6ax	12.2ax	12.2ay	13.3ax
benzaldehyde	0.0	0.0	1.3	0.0	0.3	0.7	0.8	0.4
PC-4								
propyl acetate	62.3bx	81.9ax	33.4cy	62.0bx	60.3bx	62.9by	81.4ax	56.5bx
1-methylpropyl acetate	27.4ay	37.1ax	7.8by	30.1a	38.8bx	36.7bx	49.7ax	35.7bx
2-methylpropyl acetate	7.6	10.4	8.1	8.6	7.4	7.1	9.7	6.7
butyl acetate	520.8bx	684.6ax	350.7cy	533.2bx	480.0bx	466.8by	608.58ax	440.2bx
2-methylbutyl acetate	466.9	558.6	402.0	542.4	413.1	354.4	512.2	390.2
pentyl acetate	54.7ax	63.5ax	30.9by	59.6ax	48.1abx	39.8by	54.7ax	45.0aby
3-hexen-1-yl acetate (RI 1004)	23.1ax	24.2ax	13.8by	22.3ax	22.3ax	19.5by	21.6abx	21.3abx
ethyl propionate	66.9bx	86.5ax	1.8cy	66.0bx	81.4bx	83.3bx	106.0ax	74.3bx
butyl propionate	18.9	20.8	21.0	21.2	17.5	15.7	20.9	16.8
ethyl butanoate	95.5ax	125.1ax	21.1by	104.2ax	97.3bx	92.8by	126.5ax	90.5bx
propyl butanoate	19.2	17.5	14.4	23.4	24.1	18.9	27.9	23.0
hexanal	65.4aby	77.8aby	59.8by	82.5ay	113.8abx	111.9abx	129.8ax	104.2bx
PC-6								
benzyl acetate	1.4ay	1.1ay	1.3ax	1.3ay	7.1ax	4.8bx	1.7cx	4.2bx
octyl butanoate (RI 1434)	2.0abx	2.7ax	1.0bcx	0.0cy	2.8ax	3.2ax	2.0ax	3.3ax
propyl hexanoate	17.7ay	7.9ay	5.9ax	26.9ay	355.2ax	330.1ax	16.9bx	324.7ax
nonanal	7.4	7.2	8.0	7.7	8.9	12.4	7.7	12.0
terpene alcohol (RI 1551)	3.1a	2.4a	0.0b	2.1a	4.4a	3.6A	1.9b	5.0a
terpene ester (RI 1448)	7.6a	6.5a	3.2b	5.3a	10.2a	10.5A	7.1b	15.3a
terpene ester (RI 1532)	2.4a	1.9a	0.0b	1.5a	3.4a	3.1A	2.6b	4.3a
PC-7								
ethyl 2-methylbutanoate	563.5ax	419.7by	227.9cy	581.5ax	529.4ax	466.0bx	393.0cx	517.0abx

[a] Peak area/40 g of apple cider. [b] Means are duplicate analyses of three replications. Means followed by different letters (a–c) within the same row and the same sorbate treatment are significantly different from each other ($P < 0.05$). Means followed by x or y are significantly different from the same processing treatment with different sorbate treatment. [c] Kovats retention indices (RI) are presented for tentatively identified volatile flavor compounds.

the interactions between processing treatment and sorbate addition were significant.

The 4 kGy irradiation treatment contributed to a decrease in the content of several esters that loaded onto PC-2, including hexyl acetate, hexyl butanoate, and ethyl hexanoate. The free radicals generated through irradiation could contribute to the degradation of these flavor compounds. Because many of these esters do contribute to the characteristic apple flavor, the decreased content of these esters in the cider irradiated at 4 kGy could account for the decrease in apple flavor characteristics, as evaluated by the descriptive sensory panel. In apple juice stored for up to a year, decreases in the content of esters and aldehydes were associated with a reduced fruit aroma score (*3*). For the volatile flavor compounds associated with PC-3−PC-9, processing treatment had only a minor impact on the content of the volatile flavor compounds.

The presence of potassium sorbate in the apple cider had mixed effects on the content of the volatile flavor compounds. Contents of the several volatile flavor compounds that loaded onto PC-1 (**Table 1**) and PC-2 (**Table 3**), including hexanol, methyl 2-methylpentanoate, and hexyl acetate, were higher for the cider without added potassium sorbate. On the other hand, the contents of 1-methylpropyl acetate, propyl hexanoate, hexanal, and α-farnesene, as well as other compounds that loaded onto the remaining PCs, were higher in the cider with added potassium sorbate. For many of these compounds, the interactions between processing treatment and sorbate addition were significant, and these interactions will be discussed further.

Interactions between processing treatment and sorbate addition were significant for compounds that loaded predominantly onto PC-1 and PC-4. **Figure 1** illustrates this interaction for selected flavor compounds from each PC. Irradiation increased the content of the compounds within PC-1 (**Figure 1A**); 4 kGy irradiated cider without sorbate had a higher content of these compounds than cider with sorbate. In contrast, the flavor compounds on PC-4 were higher in 4 kGy irradiated cider with sorbate than in cider without sorbate (**Figure 1C**). The compounds within this PC include several esters identified as important contributors to apple flavor and would thus contribute to a more apple-like flavor in irradiated cider containing sorbate.

Table 2. Effect of Processing Treatment on Content[a] of Volatile Flavor Compounds Associated with PC-2, PC-3, PC-8, and PC-9 in Apple Cider[b]

compound	treatment: untreated	2 kGy	4 kGy	pasteurized
PC-2				
hexyl acetate				
0% sorbate	1287.6ab	1158.3bc	703.9c	1696.2a
0.1% sorbate	1143.7a	657.2b	972.3ab	1119.3a
heptyl acetate	2.0a	0.5b	1.2b	2.4a
3-octen-1-yl acetate (RI 1206)[c]	1.6a	0.0b	0.2b	1.7a
hexyl propionate	13.0ab	6.3c	9.0bc	16.0a
butyl butanoate	26.7a	19.7b	29.6a	31.3a
hexyl butanoate	51.1b	18.2c	32.4c	68.5a
butyl 2-methylbutanoate	5.9ab	3.8b	7.5a	8.8a
isopropyl 2-methylbutanoate	9.0	6.4	8.3	12.6
hexyl 2-methylbutanoate	25.4ab	11.6c	19.3bc	33.4a
pentyl hexanoate (RI 1285)	1.7	0.6	1.3	2.0
hexyl hexanoate	34.1a	20.6b	26.2ab	37.6a
undecanone (RI 1288)	0.0b	0.0b	0.0b	0.8a
estragole	18.2a	5.0d	6.9c	13.5b
PC-3				
pentyl heptanoate (RI 1476)	1.6	1.1	1.0	1.4
pentyl octanoate	3.5	3.4	3.3	3.7
β-farnesene	10.2	8.2	7.6	9.5
α-farnesene	211.1	187.5	194.4	209.5
β-caryophyllene (RI 1517)	2.4	2.1	2.4	2.2
PC-8				
pentyl 4-methylpentanoate (RI 1307)	2.8a	2.9a	1.2b	2.1ab
decanal	2.2	2.4	2.4	2.5
PC-9				
isopentyl acetate (RI 864)	0.3b	0.6ab	1.2a	0.0b

[a] Peak area/40 g of apple cider. [b] Means are duplicate analyses of three replications, with data for sorbate treatment (0 and 0.1%) pooled, unless interactions between processing treatment and sorbate treatment were significant ($P < 0.05$). Means followed by different letters (a–d) within the same row are significantly different from each other ($P < 0.05$). [c] Kovats retention indices (RI) are presented for tentatively identified volatile flavor compounds.

The seemingly opposing effect of sorbate on the formation and degradation of volatile flavor compounds during irradiation can be explained by the ability of the neutral, undissociated sorbic acid to function as a scavenger of the hydrogen and hydroxyl radicals formed during irradiation (*25*). The degradation of sorbate during the irradiation of orange juice and mango pulp has been attributed to the reaction of the radicals with sorbic acid (*19*). In the apple cider, the presence of sorbate can quench the radicals that initiate oxidation reactions and contribute to the formation of hexanol and other oxidation compounds (PC-1). In the absence of sorbate, these oxidation reactions would occur and contribute to increased contents of oxidation products. On the other hand, esters and other flavor compounds can be degraded by free radicals. Therefore, the presence of sorbate would slow these degradative reactions and preserve the flavor compounds that contribute to desirable apple-like flavor.

Objective Measurements of Tartness and Sweetness. The effect of processing treatment on the objective measurements of tartness and sweetness is shown in **Table 4**. Processing treatment had only a minor, yet statistically significant, effect on the objective measurements of tartness, pH, and titratable acidity. Similarly, irradiation did not alter the acidity and pH of apple juice concentrate (*18*) or orange juice and mango pulp (*19*). The interaction between processing treatment and sorbate addition had a significant effect on the soluble solids content, which reflects the content of soluble sugars in the cider. In the cider without added sorbate, processing treatment did not have a significant effect on soluble solids content. Zegota (*18*) also reported no significant change in soluble solids content of irradiated apple concentrate. However, in this study, in the presence of sorbate, the pasteurized treatment had significantly higher soluble solids content than the untreated or irradiated ciders.

The addition of potassium sorbate to the cider resulted in a significant increase in pH, from a pH of 3.86 with 0% sorbate to 4.04 with 0.1% sorbate. However, there was no appreciable change in the titratable acidity of the cider. The increase in pH with the addition of sorbate to apple cider is comparable to that observed by Steenstrup and Floros (*15*). Potassium sorbate, which is a weak acid, decreased the degree of ionization of the organic acids but did not affect the total content of organic acids present in the cider. The soluble solids content of the ciders was significantly higher in the cider samples containing sorbate that received pasteurization or irradiation treatment (**Table 4**). For the untreated sample, the addition of sorbate did not have a significant effect on the soluble solids content.

Sensory Evaluation of Flavor Attributes. Table 5 presents the results of the sensory evaluation of the ciders with 0 and 0.1% sorbate. Because the apple cider samples with 0 and 0.1% sorbate were evaluated by panelists in different sessions, the emphasis is placed on the effect of the processing treatment rather than sorbate addition on the sensory attributes. Panelists were able to detect more significant differences between treatments in the ciders with sorbate than in ciders without sorbate.

The effect of processing treatment on the sensory attributes was dependent on the presence of sorbate. For the ciders without sorbate, only the cooked apple flavor attribute was significantly affected by processing treatment, with the intensity of this flavor attribute lowest in the irradiated ciders. However, the similar rating for the cooked apple flavor attribute for the untreated and pasteurized treatments indicates the panelists may have had some confusion with this attribute. In the ciders containing sorbates, irradiation resulted in higher intensities of cardboard flavor and lower intensities of apple flavor in comparison to the untreated and pasteurized treatments. In addition, the

Table 3. Effect of Sorbate Treatment on Content[a] of Volatile Flavor Compounds Associated with PC-2, PC-3, PC-8, and PC-9 in Apple Cider[b]

compound	preservatives without (0%)	preservatives with (0.1%)
PC-2		
hexyl acetate		
untreated	1287.6a	1143.7b
2 kGy	1158.3a	657.2b
4 kGy	703.9b	972.3a
pasteurized	1696.2a	1119.3b
heptyl acetate	1.7	1.4
3-octen-1-yl acetate (RI 1206)[c]	0.9	0.90
hexyl propionate	11.4	10.8
butyl butanoate	29.3	24.3
hexyl butanoate	41.8	41.0
butyl 2-methylbutanoate	8.5a	4.5b
isopropyl 2-methylbutanoate	9.3	8.9
hexyl 2-methylbutanoate	23.5	20.2
pentyl hexanoate (RI 1285)	1.5	1.4
hexyl hexanoate	27.0	32.2
undecanone (RI 1288)	0.2	0.1
estragole	9.6b	11.3a
PC-3		
pentyl heptanoate (RI 1476)	0.9b	1.6a
pentyl octanoate	2.7b	4.1a
β-farnesene	8.2	9.6
α-farnesene	141.9b	265.0a
β-caryophyllene (RI 1517)	2.0b	2.5a
PC-8		
pentyl 4-methylpentanoate (RI 1307)	1.3b	3.2a
decanal	2.3	2.4
PC-9		
isopentyl acetate (RI 864)	0.6	0.4

[a] Peak area/40 g of apple cider. [b] Means are duplicate analyses of three replications, with data for processing treatment (untreated, 2 kGy, 4 kGy, and pasteurized) pooled, unless interactions between processing treatment and sorbate treatment were significant ($P < 0.05$). Means followed by different letters (a–b) within the same row are significantly different from each other ($P < 0.05$). [c] Kovats retention indices (RI) are presented for tentatively identified volatile flavor compounds.

Table 4. Effect of Processing Treatments on Objective Measurements of Sweetness and Tartness[a]

	untreated	2 kGy	4 kGy	pasteurized
pH	3.95ab	3.95bc	3.94c	3.96a
titratable acidity[b]	0.46b	0.47a	0.48a	0.46b
soluble solids[c]				
0% sorbate	14.23ax	14.03ay	14.10ay	14.20ay
0.1% sorbate	14.20bx	14.40bx	14.37bx	14.70ax

[a] Means are duplicate analyses of three replications, with data for sorbate treatment (0% and 0.1%) pooled, unless interactions between processing treatment and sorbate treatment were significant ($P < 0.05$). Means followed by different letters (a–c) within the same row are significantly different from each other ($P < 0.05$). For the effects of sorbate addition on the soluble solids content, means with different letters (x–y) within the same column are significantly different from each other ($P < 0.05$). All variables loaded onto PC-6. [b] Grams of malic acid/100 mL of cider. [c] °Brix.

pasteurized cider had a lower intensity of astringency in comparison to the untreated and irradiated ciders. The reduced intensity of apple flavor in the irradiated apple cider may be associated with the decreased content of hexyl acetate, hexyl butanoate, and ethyl hexanoate and other flavor compounds that loaded onto PC-2. In many lipid-containing foods, the "cardboard flavor" is typically associated with hexanal and other lipid oxidation products (*26*, *27*). However, in the apple cider, the effect of irradiation on the cardboard flavor and the content of lipid oxidation compounds did not show the same trend. Further study is necessary to define the undesirable flavors in apple cider through sensory evaluation and to identify the specific volatile flavor compounds responsible for these undesirable flavor attributes.

Table 5. Effect of Processing on Sensory Attributes[a] of Cider

PC[b]		untreated	2 kGy	4 kGy	pasteurized
		0% Sorbate			
5	apple flavor	7.47	8.16	7.65	6.67
5	cardboard	3.94	3.96	3.52	4.99
5	cooked apple	7.23ab	5.65bc	5.34c	7.48a
8	sour	6.10	5.98	6.81	5.94
9	sweet	8.71	8.35	7.74	7.65
9	astringent	3.59	4.33	4.94	4.80
		0.1% Sorbate			
5	apple flavor	8.65a	6.12b	6.40b	7.52ab
5	cardboard	3.39b	6.94a	7.41a	3.81b
5	cooked apple	6.10	7.05	6.03	6.89
8	sour	5.76	5.73	5.57	5.61
9	sweet	8.80	7.81	7.70	8.93
9	astringent	5.64a	4.94ab	5.92a	4.17b

[a] Attributes were evaluated using a 15-cm scale, with 1 = none and 14 = intense. Results are means of three replications and responses of eight panelists. For each attribute, means followed by different letters (a–c) are significantly different ($P < 0.05$). [b] Principal component.

Relationship between Flavor Attributes and Treatments Effects. Figure 2 represents a biplot of the objective and sensory attributes of cider flavor with calculated values for the individual cider treatments. Two well-defined regions were identified in the biplot. Region 1 is composed of compounds that loaded onto PC-1, including aldehydes, alcohols. and minor esters, and the sensory attribute sour (PC-8). Loadings of ethyl propionate and 3-hepten-1-yl acetate were inversely related to the other compounds of PC-1; thus, in the biplot, these two compounds are associated with region 2. Compounds that loaded onto PC-2, PC-3, and PC-4 clustered onto region 2, which included several esters and terpenoid compounds that have been identified as important contributors to fruity, apple-like flavor. The cooked apple, cardboard, and sweet sensory attributes were associated with region 2.

Integration of the cider samples onto the biplot demonstrated the effect of processing treatment and sorbate on the flavor characteristics of the apple cider (**Figure 2**). The cider samples with 0.1% sorbate tended to cluster into region 2, which was characterized as containing ester terpenoid compounds typical of apple flavor. For the cider samples containing 0.1% sorbate, there was no clear trend with respect to the effect of processing. The ability of sorbate to scavenge radicals formed during irradiation (*24*) may account for the absence of an irradiation effect within the biplot. On the contrary, the cider samples with 0% sorbate demonstrated a definitive processing effect. Cider without sorbate and irradiated at 4 kGy clustered within region 1 and had higher contents of the compounds associated with region 1. The untreated cider without sorbate clustered within region 2, whereas the cider without sorbate and irradiated at 2 kGy clustered in the area between regions 1 and 2. For the cider samples without sorbate, a definitive shift away from the characteristic apple and fruit flavors of the cider samples with increasing intensity of irradiation was observed.

In conclusion, irradiation and pasteurization treatments and the addition of sorbate affected the flavor characteristics of apple cider, as evaluated using objective and sensory methods. Irradiation contributed to decreases in the content of several esters that contribute to characteristic apple cider flavor, with

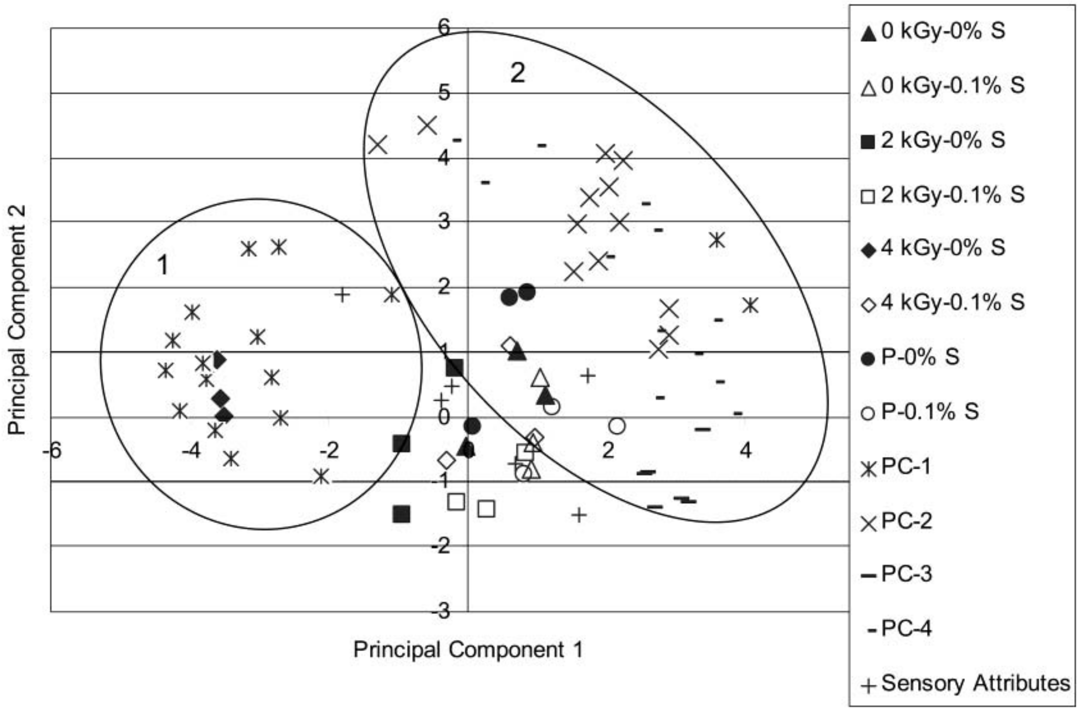

Figure 2. Biplot of the PCA of apple ciders showing the associations between volatile flavor components (PC-1–PC-4) and sensory attributes and the relationships of the ciders from different processing (untreated, 2 kGy irradiation, 4 kGy irradiation, and pasteurized) and sorbate (S) treatments. Vector coordinates representing individual volatile flavor compounds and sensory attributes represent pooled responses for all processing and sorbate treatments and three replications. Object coordinates represent the three replications of each processing and sorbate treatment.

an increase in the content of products of lipid oxidation. The presence of sorbate reduced the effect of irradiation on the breakdown of esters and the formation of lipid oxidation products. Sensory evaluation indicated that undesirable flavors were more predominant in irradiated cider with sorbate than without sorbate. Further research is necessary to understand the role of processing treatment and sorbate addition on the overall flavor characteristics of apple cider to ensure these processing treatments provide consumers with a safe, high-quality apple cider.

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