CHAPTER 16

Shelf Stability, Sensory Analysis, and Volatile Flavor Profile of Raw Apple Juice after Pulsed Electric Field, High Hydrostatic Pressure, or Heat Exchanger Processing

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ABSTRACT

FRESHLY pressed raw apple juice was obtained from a commercial processor. Clarification was performed by ultrafiltration, centrifugation, or plate filtration. Each of the clarified juices was further processed by pulsed electric field (PEF), high hydrostatic pressure (HHP), or heat exchanger (HE) methods. Processed PEF, HHP, and HE apple juice were stored at both 4°C and 23°C for one month. Viability of yeasts and molds, coliforms, aciduric bacteria, *Salmonella* spp., and total plate counts were determined. Microbial spoilage was not detected for heat exchanger and HHP processing, regardless of the temperature or length of storage. A maximum shelf life of one month was observed for PEF processed apple juice stored at 4°C. PEF processed apple juice spoiled during storage at 23°C. Sensory evaluation of attributes for raw apple juice were similar for PEF, HHP, and heat processed apple juice. Generally, apple juice volatile flavor compound concentrations were unchanged or decreased slightly after processing, and during 1 month storage.

INTRODUCTION

Inactivation of microorganisms in food systems by pulsed electric fields (PEF) and high hydrostatic pressure (HHP) was first studied by Sale and Hamilton (1967) and Hite (1899), respectively. Very little research is focused on the shelf life or sensory quality of foods processed by PEF. Matsumoto et al. (1990) reported that no change to the taste or fragrance of sake resulted from PEF processing. Sensory evaluations of milk and orange juice by Grahl et al. (1992) indicated that taste did not deteriorate significantly during PEF treatment. Food processing with HHP is on the verge of becoming a worldwide accepted food process. Japanese researchers have published several articles reporting that HHP treated food retains fresh taste and flavor. By producing the first food products available to consumers in April of 1990 (Rovere, 1995), the Japanese are considered the current world leaders in HHP food processing. Increasing the shelf life with HHP by a few days may be considered successful. By extending the shelf life of a food that spoils within days, greater distribution ranges can be achieved. An example is the processing of mackerel by HHP, which results in a 4-day extension in shelf life as judged by freshness indices and sensory evaluation (Fujii et al., 1994).

To successfully process raw apple juice by either PEF or HHP, the minimum refrigerated shelf life needed for distribution purposes is 1 month (Baranowski, 1996). Microbial load, sensory analysis, and flavor profile analysis may be utilized to define the shelf life of PEF and HHP processed apple juice. The characteristic fruity aroma of apples is a result of volatile flavor compounds, primarily esters, aldehydes, and alcohols (Flath et al., 1967; Willaert et al., 1983). Two of the principal aroma compounds in apples are butyl and hexyl acetate esters (Bartley et al., 1985). To determine the shelf life of PEF and HHP processed apple juice, the microbiological load, volatile flavor compound, and sensory characteristics need to be monitored initially and over time.

Ogawa et al. (1990) stated that HHP processing would be valuable in maintaining the natural flavor and taste of juices. It is the objective of the current research to extend the shelf life of raw apple juice with a pulsed electric field process and a high hydrostatic pressure process, without impacting the sensory quality of the manufactured apple juice.

MATERIALS AND METHODS

CLARIFICATION OF PRESSED APPLE JUICE

Apples were obtained, macerated, and pressed in the pilot plant of a local apple juice processing facility to yield raw apple juice. Raw apple juice was treated for 15 min at room temperature with a commercial pectinase solution, 0.6 mL Clarex 5x (Solvay, Elkhart, IN) per L apple juice, to hydrolyze pectin. Next, 200 Bloom, Type B gelatin (Atlantic, Whiteplains, NY) was added at 0.2 g/L to the apple juice. After an additional 15 min, 0.25 g/L bentonite (KWK American Colloid Company, Arlington Heights, IL) was added to precipitate protein. The apple juice was allowed to settle for 4 hr at 20°C prior to siphoning the upper "racked" portion to be used in the clarification step. The allotted time for each step in the pectin-gelatin-bentonite procedure was shorter than that typically used, because of imposed travel and time restrictions. Less than 60% of the juice portion was recovered because of lack of precipitation of apple particulates.

ULTRAFILTRATION

Clarification of raw apple juice was achieved with an ultrafiltration system (model HF. Lab 5, Romicon, Inc., Woburn, MA) following manufacturer recommendations for use and cleaning. The PM50 (Romicon, Inc., Woburn, MA) hollow fiber cartridge was utilized. Water flux was estimated at 10 L/min. The filtrate was collected in 5 gal food grade pails, and frozen at −40°C until used. As early as 1921, researchers demonstrated storage of apple juice for at least 2 years at −8°C without noticeable loss of flavor, aroma, or color (Cruess et al., 1921). Ultrafiltered apple juice was thawed at 10°C for three days prior to experimental use.

CENTRIFUGATION

Raw apple juice was manipulated in a 4°C cold room. Four aliquots of juice were placed in four 1 L centrifugation buckets. Centrifugation (International Equipment Co., Needham Hts., MA) was performed at 4°C, at a relative centrifugal force of 1300 g for 10 min. Centrifuged apple juice was collected in a 20 L carboy, maintained in a 10°C cold room until used for experimental purposes the next day.

PLATE FILTRATION

Approximately 1% 700 flow Kenite diatomaceous earth (World Minerals, Lompoc, CA) was added to siphoned apple juice to assist in the plate filter process. Filtration was accomplished with a shell-and-leaf pressure filtration system at 15 psi and 20°C. Filtered apple juice was collected in 5 gal food grade pails, and stored overnight at 10°C prior to use in experiments.

PROCESSING OF CLARIFIED APPLE JUICE

Heat Exchanger

The portion of the heat exchanger placed in the heated water bath consisted of coiled stainless steel tubing with an internal diameter of 5 mm, a wall thickness of 0.5 mm, and a length of 7 m. Raw apple juice was pumped through the heat exchanger at a rate of 500 mL/min. A water bath provided the heat necessary to increase the temperature of raw apple juice, with an initial temperature of 12°C, to obtain an exit temperature of 90°C. The processed apple juice was collected into 1 L Scholle bags (type II. MET. W/800R IRR, Scholle Co., Northlake, IL). In addition, one hundred 4 mil polyethylene pouches (Power Plastics Inc., Paterson, NJ) were filled with 25 mL of heated apple juice to monitor microbiological growth over time.

Pulse Electric Field

A pilot plant size pulser (Physics International, San Leandro, CA), in conjunction with an autoclaved sterile recirculating coaxial electrode chamber (Zhang et al., 1995), was utilized for PEF processing. Commercially sterile apple juice supplied by a local processor was used to prime the PEF chamber and tubing in a recirculating manner at a flow rate of 500 ml/min. Gas bubbles were removed from the treatment chamber after addition of commercially sterile apple juice, and prior to application of PEF to reduce the possibility of arcing. Prior to PEF processing, the flow of commercially sterile apple juice was stopped, the inlet tubing was removed from the commercially sterile apple juice source and placed in the raw apple juice, and the direction of flow was operated in the reverse direction for ~2 s to remove any bubbles that may have entered the inlet tubing. Flow of raw apple juice was started at 500 mL/min, and PEF processing was immediately initiated. The PEF operation was run at room temperature (~22°C). An electric field of 65 kV/cm, capacitance of 0.5 μF, and exponential decay pulses of 4 μs were utilized. The PEF processed raw apple juice received 6 pulses per unit volume. The PEF processed apple juice was poured into 1 L Scholle bags (type II. MET. W/800R IRR, Scholle Co., Northlake, IL). In addition, one hundred 4 mil polyethylene pouches (Power Plastics Inc., Paterson, NJ) were filled with 25 mL PEF processed juice to monitor microbiological growth over time.

HIGH HYDROSTATIC PRESSURE PROCESSING

One liter of raw apple juice was poured into each 1 L Scholle bag (type II. MET. W/800R IRR, Scholle Co., Northlake, IL). The Scholle bags were placed in polyethylene pouches (Power Plastics Inc., Paterson, NJ), and 100 mL of sterile distilled water was added to each pouch, followed by removing as much air as possible and heat sealing. One hundred 4 mil polyethylene pouches (Power Plastics Inc., Paterson, NJ) were filled with 25 mL of raw apple juice to monitor microbiological growth over time. A pilot plant scale hydrostatic pressure system (Engineered Pressure Systems Inc., Andover, MA), operated at room temperature ($\sim$22°C), was utilized to process the Scholle bags and polyethylene pouches of apple juice. The pressure come up time was 3.5 min, the holding time at 85 kpsi was 5 min, and the pressure release time was less than 15 s.

VIABILITY OF MICROORGANISMS

Microbial viability was determined for clarified apple juices prior to processing and immediately after processing. At 3 to 4 day intervals, apple juice from two 4 mil polyethylene pouches (Power Plastics Inc., Paterson, NJ) was diluted in 0.1% peptone, and plated in PDA to monitor microbial growth throughout the one month storage period. When researching fruit juice spoilage, Hatcher et al. (1992) suggest aerobic plate count, aciduric bacteria, yeast and molds, *Geotrichum* count, heat resistant molds, and direct microscope counts. Aerobic plate count, aciduric bacteria, and yeast and mold counts were determined for the current study. In addition, *Salmonella typhimurim,* which can survive up to 30 days in pH 3.6 apple juice (Goverd et al., 1979), was monitored. Coliforms were also monitored as a measure of sanitation. Manufacturer recommendations for media preparation were followed. The *Compendium of Methods for the Microbiological Examination of Foods* (Vanderzant and Splittstoesser, 1992) was used as guide for conducting microbial experiments.

The viability of the microorganisms was monitored by counting colony forming units (cfu) in agar plates. Apple juice was serially diluted with 0.1% sterile peptone (DIFCO 01118-01-8) solution and plated in the appropriate media. Agar plates were stored in an inverted position for selected times and temperatures to obtain viable counts. Serial dilutions for the viable counts were performed such that the number of cfu in the agar plates was between 25 and 300. The mean viable count was calculated from four plates.

Yeast and Mold Viability

The serially diluted apple juice was pour plated in DIFCO 0013-17-6 potato dextrose agar (PDA), acidified with 14 mL/L of 10% filter sterilized tartaric acid. PDA plates were incubated at 24°C for 72 hr.

Coliform Viability

The serially diluted apple juice was pour plated in DIFCO 0012-17-7 violet red bile (VRB) agar. After solidification of the VRB agar, additional VRB agar was added to form an overlay. VRB agar plates were incubated at 35°C for 24 hr.

Aciduric Bacteria Viability

The serially diluted apple juice was pour plated in DIFCO 0521-17-1 orange serum agar (OSA). OSA plates were incubated at 30°C for 48 hr.

Salmonella Spp. Detection

The presence of *Salmonella* spp. was detected by adding 25 mL of apple juice to 225 mL sterile tryptic soy broth (DIFCO 0370-17-3), and incubating for 24 hr at 35°C. One milliliter portions of the 250 mL apple juice/tryptic soy broth were added to 10 mL selenite cystine broth (DIFCO 0687-17-1) and tetrathionate broth base (DIFCO 0104-17-6), and incubated at 35°C for 24 hr. The selenite cystine broth culture was streak cultured on bismuth sulfite (DIFCO 0073-17-3), XLD (DIFCO 0788-17-9), and hektoen enteric (DIFCO 0853-17-9) agars. The tetrathionate broth culture was also streak cultured on bismuth sulfite, XLD, and hektoen enteric agars. The agar plates were incubated at 35°C for 24 hr. Colonies with characteristics of *Salmonella* were identified as positive *Salmonella* matches.

Total Plate Count

The serially diluted apple juice was pour plated in DIFCO 0479-17-3 plate count agar (PCA). PCA plates were incubated at 35°C for 48 hr.

STORAGE OF APPLE JUICE

Processed apple juice was stored at 23°C, and in a walk-in cooler at 4°C, for one month. A portion of the unprocessed apple juice was stored at −40°C, and used as the control for the one month sensory evaluation test.

VOLATILE FLAVOR PROFILE ANALYSIS

Purge-and-trap headspace analysis techniques were used for the isolation of volatile flavor compounds, as described by Boylston et al. (1994). Apple juice (200 mL) was placed in a 500 mL round bottom flask. Tetradecane (internal standard, 5 μg) was added to the flasks prior to extraction of volatile flavor compounds. The control, PEF, HHP, and HE apple juice samples were placed in a 40°C water bath, and purged with prepurified nitrogen (25 mL/min). A vacuum was applied to the system through an activated Tenax TA, 60/80 mesh trap (Alltech Associates, Deerfield, IL), 300 mg, packed in 9 mm OD borosilicate glass tubes for the collection of volatiles. The apple juice samples were purged for 5 hr. Tridecane (second internal standard, 1.25 μg) was added to the top of each trap and the volatiles were eluted from the traps with 15 mL hexane (HPLC grade), and concentrated to 200 μL under prepurified nitrogen. The tridecane was used to determine the percent of compound elution through the trap.

The volatile flavor compounds were separated on a 5% phenyl, 95% methylpolysiloxane capillary column (SE-54, 30 m, 0.32 mm ID, Alltech Associates, Deerfield, IL), installed in a gas chromatograph (Model 5880, Hewlett Packard, Avondale, PA) equipped with a flame ionization detector and on-column injection port. The program for the GC oven was 35°C for 15 min, increased to 160°C at 1.5°C/min, then increased to 225°C at 5°C/min and held for 3 min. The temperature was maintained at 250°C for both the injector and detector.

Area counts vs. nanogram quantities (6.25 to 200 ng) were plotted for the internal standard, tetradecane. Peak areas for detected volatile flavor compounds, based on retention time, were converted to nanogram quantities, based on the tetradecane standard curve. Contents of the individual volatile compounds were calculated, based on the recovery of the internal standard and the 200 mL quantity of apple juice used in the isolation. Identification of the volatile compounds in the isolates was based on comparison of GC retention times to pure commercial standards.

SENSORY ANALYSIS

Sensory analysis was performed on apple juice three days after processing to allow time to determine microbiological loads. Apple juice that remained unspoiled at the end of the 1 month storage period was used in sensory evaluation studies. Spoilage was defined as any objectionable flavors, odors, aftertaste, or $\geq 5 \times 10^3$ organisms/mL apple juice.

Panelists evaluated apple juice in individual booths under red lights for difference tests, and under white lights for acceptability tests. The apple juice was placed into 2 ounce clear plastic condiment cups fitted with lids. Low salt crackers and distilled water were provided to clean the palate between apple juice samples. The apple juice treatments were identified with a three digit number. The order of apple juice treatment presentation to the panelists was balanced and randomized.

Difference Test

Difference tests were performed three days and one month after storage of processed apple juice. Thirty-five untrained consumer panelists participated in each difference test. Triangle tests were used to evaluate the apple juice treatments.

Acceptability Test

Ninety-five panelists, 56 females and 39 males, with a mean age of 30, responded to a questionnaire and evaluated apple juice. Each panelist was asked if he/she consumed apple juice and how many servings each of fresh, frozen concentrate, and bottled apple juice were ingested per month. Eighty-seven panelists consumed apple juice at least once per month. The remaining eight panelists did not consume apple juice. Of the total 647 apple juice servings ingested per month by the 95 panelists, the number of fresh, frozen concentrate, and bottled servings consumed were 21%, 28%, and 51%, respectively. The panelists evaluated the processed apple juices for overall acceptability and for sweet, sour and color characteristics, using a nine point hedonic scale, with 9 = like extremely and 1 = dislike extremely. Each panelist evaluated all apple juice treatments. Panelists were presented with two plates with either two or three samples per plate. The order of apple juice presentation to the panelists was randomized.

Trained Panel Test

Eleven trained panelists from a commercial apple juice processing plant rated processed apple juice after one week and one month storage, using a rating scale of 1 (poor quality) to 5 (high quality).

STATISTICAL ANALYSIS

The critical number (minimum) of correct answers table in Meilgaard et al. (1991), was used to determine significance in the triangle difference tests. Significant differences between means for acceptability tests were established at $P \leq 0.05$, and determined using least square means (SAS, 1998).

RESULTS AND DISCUSSION

Sensory panelists participating in the difference analysis were able to detect statistical differences between at least one pair of apple juice treatments for each sensory taste panels performed (Table 16.1). Difference tests were used to determine if processing conditions contributed to significant differences between apple juice treatments that could be perceived by panelists. The nature of observed differences or specific sensory attributes altered by processing conditions is not elucidated by difference tests (Meilgaard et al., 1991). Perceived differences between apple juice processed by different means warranted further research to determine what characteristics might be altered by specific processes.

TABLE 16.1. Results of Sensory Triangle Differences Tests.

Experiment	Process vs.	Process	Significantly Different at
Ultrafiltered (time zero)	Heat exchanger vs.	PEF	$P \leq 0.05$
		HHP	ns
		Control	ns
Centrifuged (time zero)	Heat exchanger vs.	PEF	$P \leq 0.01$
		HHP	$P \leq 0.01$
		Control	$P \leq 0.01$
	Control vs.	PEF	ns
		HHP	ns
	PEF vs.	HHP	ns
Plate filtered (time zero)	Heat exchanger vs.	PEF	ns
		HHP	ns
		Control	$P \leq 0.1$
Plate filtered (1 month)	Control vs.	PEF (4°C)	ns
		HHP (4°C)	ns
		Heat exchanger (4°C)	$P \leq 0.1$
		PEF (23°C)	$P \leq 0.01$
		HHP (23°C)	$P \leq 0.05$
		Heat exchanger (23°C)	ns

ns = Not significantly different.

ULTRAFILTERED APPLE JUICE PROCESSING

Ultrafiltration (UF) of apple juice was adequate to extend the microbiological shelf life of the juice to 30 days (Table 16.2). However, a noticeable "off" flavor, associated with a strong aftertaste, was easily detected in the UF juice by the end of one month storage, regardless of microbiological loads. PEF

TABLE 16.2. Outgrowth of Microorganisms in Processed Ultrafiltered Apple Juice.

Temperature of Storage	Processing Method	Microorganism Outgrowth On	cfu/mL	Number of Days after Processing
4°C	None (control)	APDA	3×10^3	30
		OSA	3×10^3	
	PEF	None	nd	n/a
	HHP	None	nd	n/a
	Heat exchanger	None	nd	n/a
23°C	None (control)	OSA	1×10^6	16
	PEF	OSA	2×10^3	16
	HHP	None	nd	n/a
	Heat exchanger	None	nd	n/a

APDA = acidified potato dextrose agar; OSA = orange serum agar; nd = less than 25 cfu/mL detected; n/a = not applicable.

TABLE 16.3. Sensory Acceptability of Ultrafiltered Apple Juice Three Days after Processing.

Attribute	Heat Exchanger	PEF (4°C)	HHP (4°C)	Control (4°C)
Overall	5.54ab	5.38b	5.83ab	5.92a
Sweetness	5.84a	5.90a	6.22a	6.29a
Sourness	3.57a	3.54a	3.62a	3.53a
Fresh flavor	5.01a	4.91a	5.40a	5.43a
Color	7.30a	7.28a	7.44a	7.37a

Values in the same row with the same letter are not significantly different ($P \leq 0.05$).

processing at 65 kV/cm and 6 pulses resulted in a 4°C microbiological shelf-stable product, but an aciduric bacteria grew slowly during room temperature storage. Processing UF apple juice by HHP, at 85 kpsi for one 5 min cycle, achieved a 4°C and a 23°C microbiologically stable apple juice product. Most of the microorganisms were removed during ultrafiltration, but the enzymes were most likely not removed. Enzyme transmission through the UF membrane normally ranges from 50% to 90%, depending on the extent of membrane fouling (Gutman, 1987). In addition, PEF and HHP processing techniques do not completely inactivate enzymes (Castro, 1994; Vega, 1996).

During ultrafiltration, apple juice was constantly pumped through a filter cartridge system, and exited to a holding tank before being recycled. Oxygen is readily incorporated during the UF process. Fruit juices develop characteristic unpleasant off flavors when improperly pretreated, and when oxygen is not properly excluded (Hard, 1985). The specific chemical mechanisms of such flavor changes are not clear at this time, but can be largely avoided if oxidative enzymes are inactivated. Also, the duration of the filter operation could lead to losses in volatile flavor compounds through adsorption on the ultrafilter membrane surface, as well as to vaporization through recirculation of the retentate (Rao et al., 1987). Panelists found the characteristics of ultrafiltered juice from the different processing methods to be equivalent (Table 16.3), with the exception of "overall" acceptability.

CENTRIFUGED APPLE JUICE PROCESSING

Centrifugation (CF), in itself, was not adequate to reduce the microbial population to acceptable levels (Table 16.4). The refrigerated shelf life of centrifuged apple juice without further processing was less than one week, as noted by the 4°C and 23°C control apple juice in Table 16.4. Additional processing beyond CF by PEF, HHP, or heat exchanger resulted in a microbiologically stable refrigerated apple juice for one month. PEF processed CF apple juice

TABLE 16.4. Outgrowth of Microorganisms in Processed Centrifuged Apple Juice.

Temperature of Storage	Processing Method	Microorganism Outgrowth On	cfu/mL	Number of Days after Processing
4°C	None (control)	PCA	7×10^4	4
		APDA	1×10^7	9
		OSA	1×10^6	9
		VRB	4×10^3	9
	PEF	None	nd	n/a
	HHP	None	nd	n/a
	Heat exchanger	None	nd	n/a
23°C	None (control)	PCA	5×10^3	4
		APDA	3×10^5	4
		OSA	4×10^6	4
	PEF	APDA	3×10^6	9
		OSA	3×10^6	9
	HHP	None	nd	n/a
	Heat exchanger	None	nd	n/a

PCA = plate count agar; APDA = acidified potato dextrose agar; OSA = orange serum agar; VRB = violet red bile agar; nd = less than 25 cfu/mL detected; n/a = not applicable.

stored at room temperature was spoiled by both yeast and bacteria within nine days of processing. HHP and heat exchanger processed CF apple juice resulted in no observable microbiological growth at either 4°C or 23°C for one month.

The sensory scores for the acceptability of centrifuged apple juice (Table 16.5) were approximately one point higher, across the table, as compared to the ratings by panelists for the UF processed apple juice (Table 16.3), indicating that CF apple juice is more acceptable than UF apple juice. Only the "overall" acceptability attribute was determined to be significantly different between two of the processing methods, PEF and heat exchanger.

TABLE 16.5. Sensory Acceptability of Centrifuged Apple Juice Three Days after Processing.

Attribute	Heat Exchanger (23°C)	PEF (4°C)	HHP (4°C)	Control (4°C)
Overall	6.97a	6.27b	6.72ab	6.61ab
Aroma	6.82a	6.61a	6.51a	6.33a
Sweet	6.76a	6.73a	6.71a	6.94a
Sour	3.70a	3.58a	3.54a	3.54a
Fresh flavor	6.77a	6.35a	6.57a	6.53a
Color	5.98a	5.84a	6.25a	5.82a

Values in the same row with the same letter are not significantly different ($P \leq 0.05$).

TABLE 16.6. Outgrowth of Microorganisms in Processed Plate Filtered Apple Juice.

Temperature of Storage	Processing Method	Microorganism Outgrowth On	cfu/mL	Number of Days after Processing
4°C	None (control)	PCA	2×10^4	0
		APDA	2×10^3	0
		OSA	1×10^4	0
	PEF	PCA	8×10^1	29
		APDA	3×10^2	29
		OSA	7×10^1	29
	HHP	None	nd	n/a
	Heat exchanger	None	nd	n/a
23°C	None (control)	PCA	2×10^4	0
		APDA	2×10^3	0
		OSA	1×10^4	0
	PEF	PCA	3×10^6	3
		APDA	3×10^6	3
		OSA	3×10^6	3
	HHP	None	nd	n/a
	Heat exchanger	None	nd	n/a

PCA = plate count agar; APDA = acidified potato dextrose agar; OSA = orange serum agar; VRB = violet red bile agar; nd = less than 25 cfu/mL detected; n/a = not applicable.

PLATE FILTERED APPLE JUICE PROCESSING

The initial microbiological load for the plate filtered (PF) apple juice was much larger than for either the UF (Table 16.2) or CF (Table 16.4) processed juice (Table 16.6). Even with high initial loads, PEF processed, plate filtered juice obtained an extended shelf life at refrigeration temperatures. Whereas, PEF treated apple juice at 23°C spoiled rapidly, and HHP and heat exchanger processed apple juice maintained microbial shelf stability at 4°C and 23°C for the one month study.

The sensory data collected for the plate filtered (PF) acceptability panel (Table 16.7) was quite divergent from the previous ultrafiltered (Table 16.3) and centrifuged (Table 16.5) acceptability panels. Three of the six apple juice attributes were significantly different for the PF apple juice treatments (Table 16.7). Surprisingly, the "overall" acceptability attribute was not significantly different for any pair of apple juice processing methods for the PF apple juice. The three day acceptability sensory scores for the "color" attribute were significantly lower for the heated apple juice than for the apple juice processed by PEF, HHP, or the control apple juice. The heated apple juice was slightly darker, which was considered a negative attribute. The overall mean sensory scores remained high for plate filtered juice, being similar to CF sensory scores (Table 16.4), and about 1 point higher than sensory scores from the UF experiment (Table 16.2).

TABLE 16.7. Sensory Acceptability of Plate Filtered Apple Juice Three Days after Processing.

Attribute	Heat Exchanger (23°C)	PEF (4°C)	HHP (4°C)	Control (4°C)
Overall	6.42a	6.85a	6.85a	6.46a
Aroma	6.59ab	6.95a	6.71ab	6.39b
Sweetness	6.99ab	7.28a	7.09ab	6.74b
Sourness	3.41a	3.17a	3.33a	3.30a
Fresh flavor	6.40a	6.54a	6.58a	6.16a
Color	7.10b	7.66a	7.61a	7.37ab

Values in the same row with the same letter are not significantly different ($P \leq 0.05$).

Plate filtered apple juice from PEF, HHP, or heat exchanger processing methods and storage condition (4°C or 23°C) had low microbial counts, and the apple juice passed an informal tasting session. An exception was the PEF treated apple juice stored at 23°C, which spoiled after just three days at room temperature (Table 16.6) and, therefore, was not tasted in the informal tasting session. The remaining apple juice tasted was palatable. The portion of the control frozen at −40°C, to be used as the control for the one month sensory tests, was thawed for three days in a 10°C cold room prior to the one month sensory tests.

According to Cruess et al. (1921), apple juice can be stored at −8°C for up to two years without changes to flavor, aroma, or color. The apple juice samples processed by PEF and HHP were expected to, score equal to, or better than, the frozen control and the commercially available apple juice. Significant differences were observed for every attribute studied after one month of storage (Table 16.8). The commercial apple juice obtained the lowest sensory scores for each attribute except sourness. The HHP (4°C) sensory scores were equal to the control for every attribute, and greater than the commercial apple juice sensory scores, except for the "sourness" attribute. Sensory scores for PEF (4°C), HHP

TABLE 16.8. Sensory Acceptability of Plate Filtered Apple Juice One Month After Processing.

Attribute	Commercial (23°C)	Heat Exchanger (23°C)	PEF (4°C)	HHP (4°C)	HHP (23°C)	Control (4°C)
Overall	4.14c	6.11ab	5.96ab	6.21a	5.62b	6.35a
Aroma	4.75c	6.22ab	5.69b	6.10ab	6.22ab	6.26a
Sweetness	4.71b	6.72a	6.31a	6.55a	6.72a	6.61a
Sourness	4.63a	2.63b	2.67b	3.05b	2.82b	3.09b
Fresh flavor	4.02c	5.93ab	5.65ab	5.96ab	5.39b	6.05a
Color	6.20b	6.93a	6.97a	7.34a	7.00a	7.14a

Values in the same row with the same letter are not significantly different ($P \leq 0.05$).

TABLE 16.9. Trained Panel Sensory Scores for Plate Filtered Apple Juice One Month After Processing.

Treatment	Sensory Score
Control (4°C)	1.93b
Heat exchanger (4°C)	3.45a
Heat exchanger (23°C)	3.21a
PEF (4°C)	3.38a
HHP (4°C)	3.53a
HHP (23°C)	2.85a

Values with the same letter are not significantly different ($P \leq 0.05$).

(23°C), and heat exchanger (23°C) apple juice were generally higher than the commercial apple juice sensory scores, but lower than the control apple juice sensory scores. The trained panel rated the control apple juice very poorly with the remainder of the apple juice treatments rated as equal (Table 16.9). The control apple juice used for the trained panel was stored at 4°C for one week prior to sensory evaluation, resulting in a partially fermented product as described by the panelists.

The commercial apple juice and apple juice used in the remaining treatments were produced from different lots of apples, and, therefore, are not directly comparable to each other. The commercial apple juice and apple juice used in the remaining treatments were produced from apples stored for the same length of time, but most likely came from two different orchards. Because of the immense scale of the commercial operation, a direct comparison between commercial, PEF, HHP, and heated apple juice was not possible.

It was anticipated that analysis of the volatile flavors in apple juice processed by these innovative methods (PEF and HHP) would yield some insight into the chemical changes taking place that affect sensory scores. The volatile flavor analysis of five selected compounds of importance to apple juice flavor is listed in Table 16.10, with respect to the three experiments involving ultrafiltered, centrifuged, or plate filtered apple juice. Initial butyl and hexyl hexanoate concentrations were greater in the clarified UF and plate filtered control apple juice, and decreased after further processing. The centrifuged control apple juice butyl and hexyl hexanoate concentrations were equal to, or lower than, the apple juice with further processing. Hexyl acetate was markedly lower for both ultrafiltration and centrifugation clarified apple juice as compared to plate filtered apple juice controls. The remainder of the volatile flavor data is otherwise similar, and does not demonstrate striking differences between experiments or within experiments. Boylston et al. (1994), employing a similar volatile flavor extraction method for Gala apples stored for four months, reported hexanal, butyl acetate, hexyl acetate, butyl hexanoate, and hexyl hexanoate concentrations of 22.8, 236.7, 224.0, 39.4, and 39.6 ng/mL,

TABLE 16.10. Contents* of Volatile Flavor Compounds from Apple Juice, as Influenced by Processing and Storage Time.

Experiment	Treatment	Hexanal	Butyl Acetate	Hexyl Acetate	Butyl Hexanoate	Hexyl Hexanoate
Ultrafiltration (time zero)	Control	3.0b	74.4a	5.2bc	0.9a	4.9a
	PEF	9.7a	179.1a	19.0ab	0.3a	0.4b
	HHP	7.7a	89.4a	32.7a	0.1a	0.3b
	HE	6.4ab	81.1a	2.4c	0.7a	0.1b
Centrifugation (time zero)	Control	4.1a	15.7b	14.3ab	0.2b	0.2a
	PEF	1.5a	8.9b	9.6b	0.9b	0.5a
	HHP	3.1a	3.3b	11.6ab	3.6a	0.5a
	HE	0.3a	11.6b	10.3b	0.5b	0.5a
	Commercial	23.4a	66.1a	20.2a	0.9b	0.1a
Plate filtration (time zero)	Control	4.1aX	58.3aX	53.2aX	3.8aX	9.3aX
	PEF	3.0bcX	38.8bY	41.9bY	0.2bX	0.8bX
	HHP	2.5cX	26.5cX	41.0bX	0.0bX	0.0bX
	HE	3.8abX	40.3bX	36.3bX	0.1bX	0.2bX
Plate filtration (one month)	Control	3.3aX	37.8bcY	43.6abY	1.0aY	1.6aY
	PEF 4°C	3.7aX	50.3aX	51.3aX	0.5abX	0.6abX
	HHP 4°C	2.2aX	28.8cX	38.8bcY	0.0bX	0.1bX
	HHP 23°C	2.5aX	25.1cX	36.4bcY	0.0bX	0.1bX
	HE 23°C	3.6aX	35.8bcX	35.1cX	0.1bX	0.1bX
	Commercial	4.1a	39.9ab	19.9d	0.9a	0.7ab

*1 ng/mL apple juice.
Values for each experiment contained in the same column with the same lower case letter are not significantly different ($P \leq 0.05$).
Changes in volatile compound concentrations due to storage time for the plate filtration experiment are indicated by the upper case letters X and Y. If the time zero and one month values are not significantly different, the values will be followed by the same upper case letter.
PEF = pulsed electric field; HHP = high hydrostatic pressure; HE = heat exchanger; control = clarified with no further processing; and commercial = shelf stable commercially processed apple juice.

respectively. The apples utilized by Boylston et al. (1994) were intended for the fresh market, whereas apples in the current study were intended for apple juice production.

CONCLUSIONS

Raw apple juice can be treated by either pulse electric field (PEF) or high hydrostatic pressure (HHP) methods to extend the shelf life of apple juice to one month. In addition to a prolonged shelf life, the acceptability of the PEF and HHP processed apple juice stored at 4°C is maintained equal to that of fresh pressed apple juice, and is more acceptable to consumers than the commercial apple juice tested. Even longer apple juice shelf life extensions may be possible with: (1) PEF, if a combination of more intense electric fields or more pulses are used; or (2) HHP, if a combination of higher pressures and longer times are utilized. Overall, the differences observed with GC suggest that few, if any, changes are occurring to the volatile chemicals in apple juice due to PEF or HHP processing.

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