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Original article

Quality of applesauces processed by pulsed electric fields and HTST pasteurisation†

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Summary A pilot plant scale continuous flow pulsed electric field (PEF) and high temperature short time (HTST) processing system was integrated with an aseptic packaging machine. Fuji applesauce and blueberry applesauce were processed with PEF followed by HTST pasteurisation (PEF + HTST). PEF + HTST processed Fuji applesauce from fresh Fuji apples demonstrated high and stable sensory scores during 9 months storage at 27 °C, and had comparative sensory quality with Meal Read-to-Eat (MRE) and commercial applesauce products stored at 4 °C. PEF + HTST processed blueberry applesauce from pre-pasteurised materials had lower sensory scores than PEF + HTST processed Fuji applesauce and was significantly less stable during the storage at 27 °C. PEF + HTST processed applesauces had aerobic count and mould and yeast count of < 10 cfu mL^{-1} during storage. Electrical conductivity, pH and °Brix, were not significantly changed throughout storage time ($P > 0.05$).

Keywords Applesauce, aseptic packaging, HTST, PEF, sensory quality, shelf stability.

Introduction

Apples are perceived as a healthy food (Lee & Mattick, 1989) because of their levels of phytochemicals, such as phenolics. Twenty-two percent of the fruit phenolics consumed in the United States are from apples, making them the largest source of phenolics (Vinson *et al.*, 2001).

The United States processes about 500 000 tons of apples into applesauce resulting in about 325 000 tons of applesauce per year. A common method of making applesauce is to use a specially designed machine to peel and core the apple, leaving the white flesh. The flesh is chopped into small chunks, cooked by steam (85–99 °C for 20–30 min), and pressed through a screen to finish the process. Jars, single serving plastic cups, or other containers are filled with hot applesauce, sealed, cooled, labeled and packaged. Bulk-packaged applesauce is often used as a raw ingredient with other fruits or vegetables to make different flavoured products. Thus, applesauce may undergo a second thermal process when used as an ingredient. Such a double process is used in the retort processed flexible single-serve pouches for the Army Meals, Ready-to-Eat (MRE). The double thermal process could have a significant negative impact on the colour, flavour, texture and nutrient content of final applesauce products. Therefore, shelf stable minimally processed applesauce products are in demand in the military food system. The market demand for minimally processed fruits and vegetables has undergone rapid expansion in recent years because of busy lifestyles, increasing purchase power, and health conscious consumers (Baldwin *et al.*, 1995).

Pulsed electric field is a non-thermal processing method used to maximise quality, enhance shelf stability and maintain food safety by inactivating spoilage and pathogenic microorganisms. This processing method is advantageous because it meets safety requirements and minimises the negative impact to colour, flavour, and nutrient content typically seen with thermal processing (Zhang *et al.*, 1995; Evrendilek *et al.*, 1999, 2000, 2001, 2004; Jin & Zhang, 1999; Yeom *et al.*, 2000, 2004). Fresh orange juice and tomato juice treated by a

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†Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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commercial scale PEF system have been reported for achieving 196 days and 112 days shelf-life at 4 °C respectively (Min *et al.*, 2003a, 2003b). High temperature short time (HTST) pasteurisation is currently performed for fruit juices or milk to extend shelf-life of foods at refrigerated temperature. However, neither PEF process nor HTST pasteurisation produce shelf stable foods (Evrendilek *et al.*, 2000; Hermawan *et al.*, 2004; Jin *et al.*, 2004). Therefore, a combinational process is needed. Our previous research showed that combining PEF and HTST processes (PEF + HTST) could produce shelf stable yogurt products (Jin *et al.*, 2004). The objective of this research was to investigate the sensory quality and microbial stability of PEF + HTST processed applesauces in comparison with MRE and commercial applesauce products.

Materials and methods

Preparation of samples

Two types of applesauce were prepared for this study. One was plain applesauce including commercial brand plain applesauce, MRE plain applesauce and PEF + HTST processed Fuji applesauce, and the other was berry applesauce including commercial brand berry applesauce with low sugar content, MRE berry applesauce and PEF + HTST processed blueberry applesauce. Commercial applesauce products were purchased from a local grocery store (Natick, MA, USA) and MRE applesauce was supplied by the ration processor Ameriqual Inc. of Evansville, IN, USA in 4.5 oz (128 g net weight) foil laminated high barrier pouches with know pack dates. The commercial and MRE applesauce samples were used as reference samples for the PEF + HTST treatment samples. In house Fuji applesauce and blueberry applesauce were formulated and prepared for PEF + HTST processing in the PEF Pilot Plant at the Ohio State University (OSU, Columbus, OH, USA). Fuji applesauce was made freshly from Fuji apples. Fuji apples were used because of their firm texture and sweet taste. Fresh Fuji apples were purchased from a local farm. They were picked from trees and delivered to the PEF pilot plant the next day. The apples were stored in a walk-in refrigerator (4–6 °C) and used within 2 weeks. A special method of making applesauce was developed to avoid thermal processing during sauce making. Figure 1 shows the processing steps in the manufacture of Fuji applesauce from fresh apples. Hand-operated home style apple peelers (GAPC-240; Progressive International Corp., Kent, WA, USA) were used to peel and de-core the apples. A Stephan Sauce Machine (VCM 44-S; Stephan Machinery Corp., Columbus, OH, USA) was used to chop, press and screen applesauce. Ascorbic acid test strips (EM Scientific, Gibbstown, NJ, USA) were used

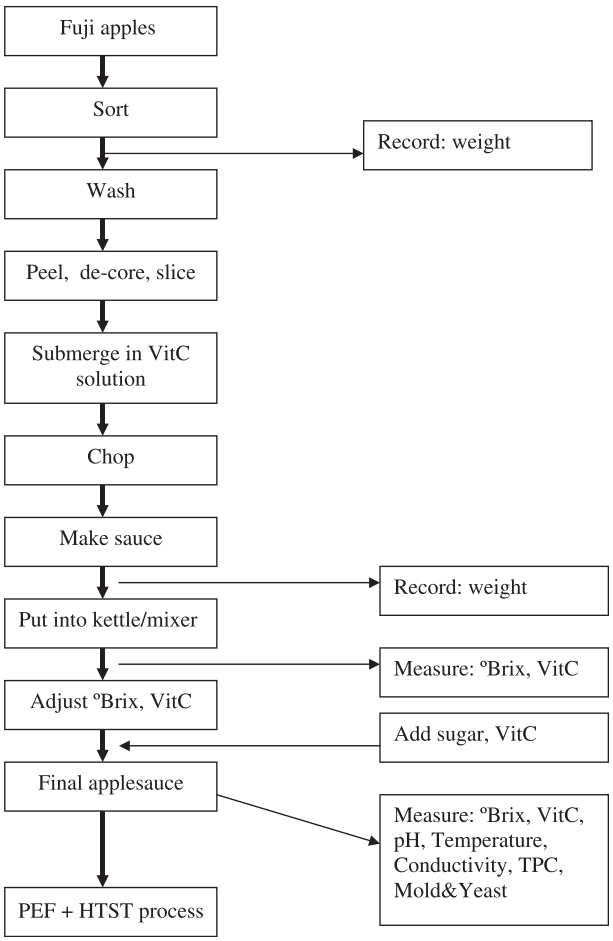

Figure 1 Flow chart of making applesauce from fresh Fuji apples.

to test vitamin C content of applesauce. The fresh made Fuji applesauce was used for PEF + HTST processing. A small amount of this product was hot-filled into sanitised glass jars for a benchmark comparison of initial quality. Blueberry applesauce was formulated by mixing pre-pasteurised applesauce with pre-pasteurised and frozen blueberry puree obtained from Maine Wild Blueberry Co. (Machias, ME, USA). Table 1 provides formulation information of these applesauces. The average density of the applesauces was 1100 kg m^{-3} (20 °C) to 1070 kg m^{-3} (60 °C), and the average viscosity was 460 cP (20 °C) to 414 cP (60 °C).

Integrated pilot plant scale PEF processing system

An integrated OSU pilot plant scale PEF processing system as illustrated in Fig. 2 was used to process PEF + HTST applesauces. The PEF system consisted of OSU-2 co-field continuous flow tubular PEF treatment chambers (OSU), OSU-2 fluid handling system (OSU), OSU-6 high voltage pulse generator (Diversified

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Table 1 Formulation of applesauces

Product name	Applesauce (%)	Blueberry puree (%)	Sugar (%)	Vitamin C*
Fuji Applesauce	92†	0	8‡	1000 ppm
Blueberry Applesauce	89§	11¶	0	0%

*Vitamin C (Natural Foods Inc., Toledo, OH, USA).
†Made from fresh Fuji apples (Lynd Fruit Farm, Pataskala, OH, USA).
‡Pure sugar (Domino, Baltimore, MD, USA).
§Pasteurised applesauce (Musselman's, Spartanburg, South Carolina, USA).
¶Pasteurised and frozen blueberry puree (Maine Wild Blueberrry Company).

Technology Inc., Bedford, MA, USA) and an aseptic packaging machine (Benco Asepack/2, Placenza, Italy).

Pulsed electric field treatment chambers
Each PEF treatment chamber, through which the food passes during processing, consisted of two boron carbide electrodes and a ceramic insulator. The inner diameter of the chambers was 0.635 cm, and the gap distance between the electrodes was 1.27 cm. Four chambers were connected in series (electrically in parallel), thus enabling the products to flow sequentially through all the four chambers.

Fluid handling system
A sanitary fluid handling system provided the processing and transfer of the product to a packaging machine. A deaerator (D-16 Versator; Cornell Machine Corp, Springfield, NJ, USA) was operated at 740–750 mmHg vacuum to eliminate the air entrapped in product during ingredients mixing prior to PEF treatment. A Moyno progressive cavity pump (Model CFB 2C SSV3SAA; Moyno Industrial Products, Springfield, OH, USA) provided a constant pulseless flow to facilitate a uniform treatment of the product. Tubular heat exchangers were used for heating, holding and cooling of the product (Streaker, 1999).

High voltage pulse generator
The high voltage pulse generator provides bipolar square waveform pulses with a maximum peak voltage of ±60 kV and maximum peak current of 750 A into multiple PEF chambers during PEF processing. The 60 kV power supplies charge storage capacitors that are periodically discharged by a series of solid-state switches to give the square wave bipolar pulses. The high voltage pulse generator may operate at a maximum repetition rate of 2000 pulses per second (PPS) and pulse width of 2–10 μs. Pulses were monitored with a high voltage probe (VD-60; Northstar, Albuquerque, NM, USA), current monitors (Model 110; Pearson, Palo Alto, CA, USA) and oscilloscopes (TDS-210; Tektronix, Beaverton, OR, USA).

System monitoring
A magnetic flow meter (Model AM202AG; Johnson-Yokogawa, Newman, GA, USA) was used to measure the treatment flow rate. The backpressure of fluid was controlled at 200–275 kPa (30–40 psi) by a downstream Moyno pump (Model CFB 2C SSV3SAA; Moyno

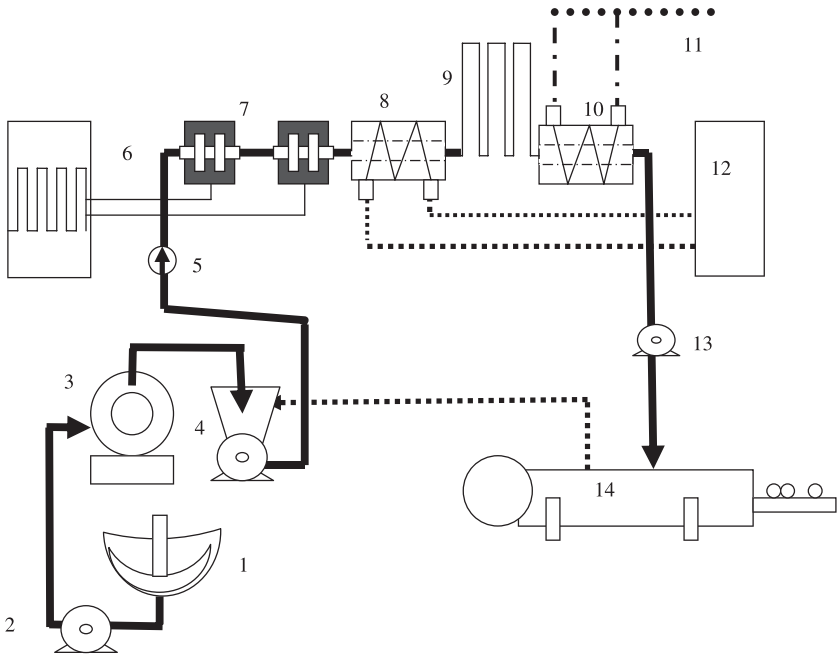

Figure 2 Schematic diagram of OSU-2 integrated pilot scale pulsed electric fields + high temperature short time (PEF + HTST) process system. (1) mixer/product tank; (2) transfer pump; (3) deaerator; (4) product feed pump; (5) flow meter; (6) pulse generator; (7) treatment chambers; (8) heat exchanger (heating); (9) holding tube; (10) heat exchanger (cooling); (11) city water supplier; (12) hot water heater; (13) back-pressure control pump; (14) aseptic packaging machine.

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Industrial Products, Springfield, OH, USA). A series of sanitary resistance temperature devices (RTD, Model R1T285L4801; Inotek, Bensenville, IL, USA) were placed in short t-pieces at the inlet and outlet of PEF treatment chambers and at the inlet and outlet of the heating and cooling heat-exchangers. The sanitary RTD probes were connected to a FP-RTD-122 Field Points™ data log system (National Instruments Co., Austin, TX, USA) and the temperature data were captured by the network module and saved in a computer.

Packaging machine

An aseptic packaging machine (Benco Asepak/2) was integrated with the pilot plant PEF system and equipped with steam and hydrogen peroxide sterilisation. After the PEF and HTST treatment, the applesauces were aseptically packaged in 113-mL tri-laminate plastic cups thermoformed by the packaging machine. The base material (Allista Plastic Packaging Co., Muncie, IN, USA) consisted of K-resin/crystal polystyrene blend (HIPS), ethylene vinyl alcohol (EVOH) and low-density polyethylene (LDPE) from outside to inside respectively. Cup-lidding material was aluminium foil laminated with polyamide and LDPE.

Pulsed electric field + HTST processing

A combination of PEF followed by HTST pasteurisation (PEF + HTST; Fig. 3) was used as this combination produced shelf stable yogurt products previously (Jin *et al.*, 2004), while products processed by PEF or HTST alone pasteurisation had <3 month shelf-life at room temperature (data not shown). As illustrated in Fig. 3, applesauce was mixed with other ingredients in a mixer, passed through deaerator and pumped into the system by feed pump. The prepared applesauces were PEF treated in PEF treatment chambers followed by being heated, held, cooled and aseptically filled in 113-mL cups that were thermally formed inline by the packaging machine. The PEF + HTST process conditions were summarised in Table 2. These conditions were selected based on many preliminary pilot scale tests on applesauce products. The PEF residence time was 0.019 s. The total PEF effective treatment time was 109 μs for Fuji applesauce and 82 μs for blueberry applesauce respectively. For HTST processing, the hold time was 24 s for all samples as determined by fixed flow rate and length of hold tube. Bipolar square pulses with a pulse width of 2.2 μs were used for both Fuji and blueberry applesauce products. Other PEF process parameters (field strength, pulse repetition rate and total treatment time) were adjusted so that the equivalent temperature difference between chamber inlet and outlet was reached for both Fuji and blueberry applesauces, i.e. both applesauce products had a similar temperature profile during PEF processing. The estimated energy input for both products were 200 J mL^{-1} during PEF processing. The estimated energy input for Fuji applesauce was 80 and 45 J mL^{-1} for blueberry applesauce during HTST processing. The holding temperature for blueberry applesauce was 70 °C and for Fuji applesauce was increased to 80 °C to inactivate enzymes from fresh apples. The flow rate was 125 L h^{-1}, which provided the minimum but constant pulseless flow. Figure 4 shows the temperature profile for Fuji applesauce during PEF + HTST processing. Blueberry applesauce had similar temperature profile to Fuji applesauce except that blueberry applesauce had lower holding temperature (70 °C). Prior to the processing, the entire system was sterilised in place (SIP) by recirculating pressurised hot water at 121 °C for 30 min.

Sample storage

Approximately 250 cups were collected randomly from the aseptic packaging machine, among which 100 cups were stored at 22 °C for microbial stability evaluation and physical property analysis at OSU. A total of 150 cups were shipped to the US Army Natick Soldier System Center (Natick, MA, USA) for sensory evaluations after tests for *Salmonella* spp., *Listeria monocytogenes* and *Escherichia coli* O157:H7 by Silliker Laboratories Inc. (Columbus, OH, USA), to confirm the absence of the pathogenic microorganisms. In US Army Natick Soldier System Center, samples were stored at 27 °C in storage boxes prior to withdrawals for sensory and analytical evaluations. This temperature has been the standard for military ration shelf-life.

Sensory evaluation

Two commercial reference samples (pain applesauce and berry applesauce) were purchased as needed. They came in single-serve plastic cups; further samples had to be purchased as time progressed. Commercial samples were stored at 4 °C and drawn just prior to each panel. Consumer panelists generally consisted of 34–41 judges. These consumers only rated how much they liked the samples on a 9-point Hedonic scale. Technical panels consisted of an average of fourteen trained judges. Trained descriptive panelists rated attributes for intensity and quality. Areas of evaluation included: appearance, colour, odour, overall flavour, natural fruit flavour, texture and overall quality. Technical panelists used two scales: a 9-point quality scale for overall appearance, colour, odour, overall flavour, fruit flavour, texture, overall quality and a 0–15+ intensity scale for tartness/sourness, sweetness and chroma. Because of availability of panels and the need to assess microbial stability of the PEF products, the initial sensory evaluation was conducted after PEF samples had been held at 4 °C (Fuji for 91 days and blueberry for

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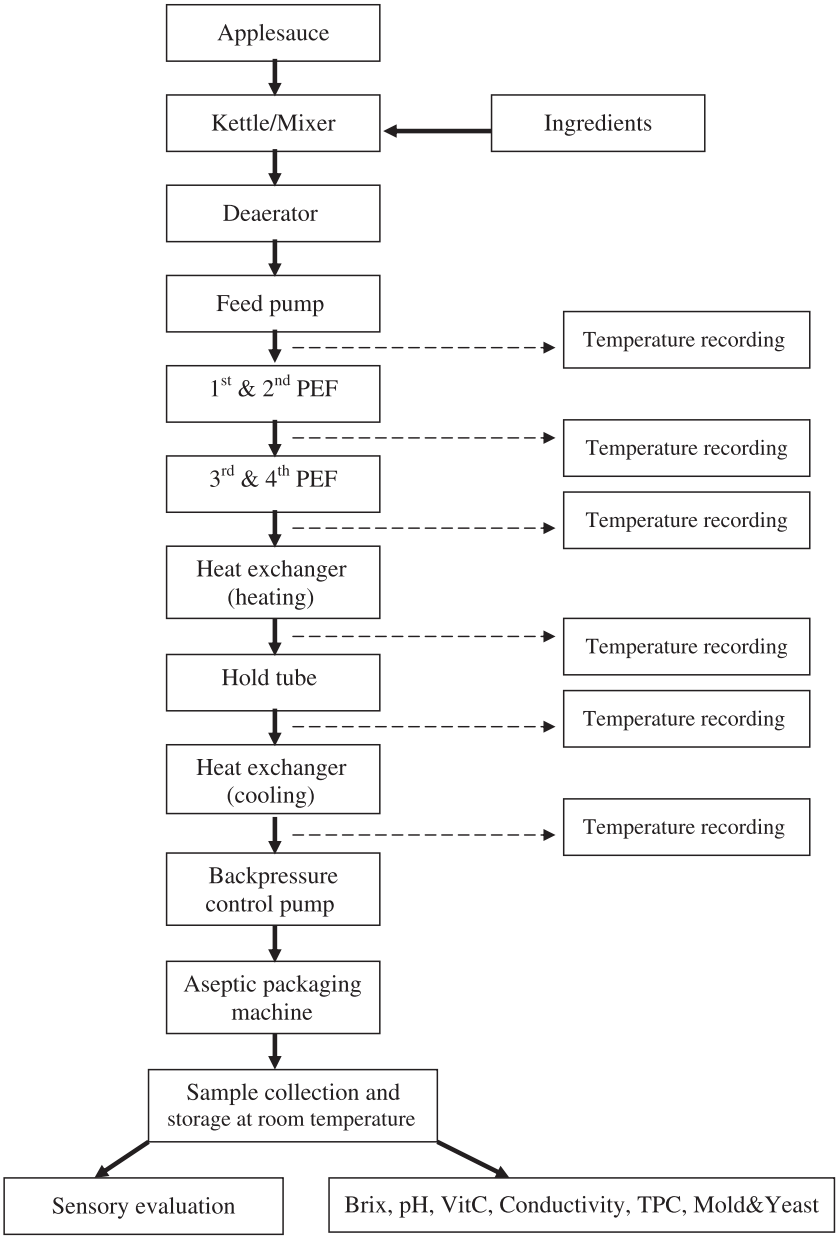

Figure 3 Procedure of pulsed electric fields + high temperature short time processing.

Table 2 Process conditions of applesauces

PEF and HTST treatment condition	Fuji applesauce	Blueberry applesauce
Field strength (kV cm^{-1})	32	39
Pulse width (μs)	2.2	2.2
Pulse repetition rate (PPS)	666	500
Total treatment time (μs)	109	82
Holding temperature (°C)	80	70
Holding time (s)	24	24

PPS, pulses per second.

203 days, post-production). Thereafter, treatment samples stored at 27 °C were sensory tested at 0, 3, 6 and 9 month intervals. Treatment samples stored at 4 °C were sensory tested at 0 and 12 months. All the sensory evaluations were performed at the US Army Natick Soldier System Center.

Microbiological analysis

Microbial shelf-life stability of the PEF processed applesauce products held at 22 °C was determined using total

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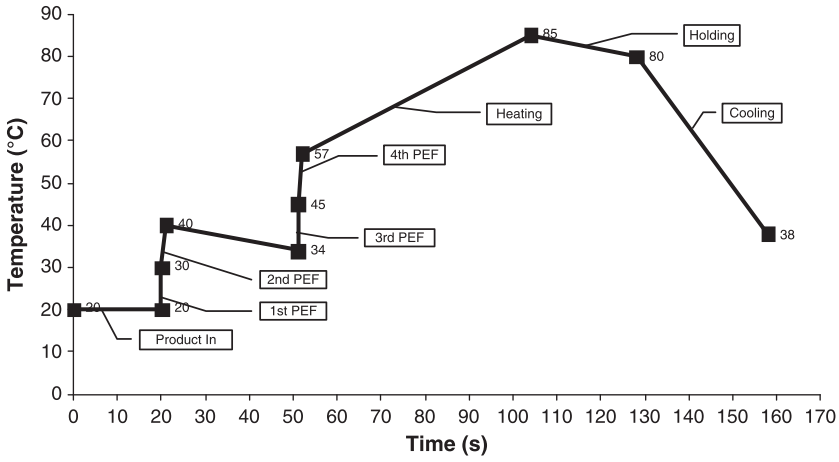

Figure 4 Temperature profile of Fuji applesauce during pulsed electric fields + high temperature short time pasteurisation.

aerobic plate count, and total yeast and mould counts prior to conducting sensory studies. Plate count agar (PCA) was used for aerobic plate count, and potato dextrose agar (PDA) acidified with 10% tartaric acid for yeast and mould counts. PCA, PDA and peptone were purchased from Difco/BBL Laboratories (Sparks, MD, USA) and tartaric acid from Sigma (St Louis, MO, USA). The applesauce samples were diluted with 0.1% sterile peptone water and surface plated on PCA agar and acidified PDA agar for total aerobic plate count and yeast and mould count respectively. To determine the microbial load in 1 mL of the non-diluted sample, ten dishes of 1:10 diluted samples were plated and the counts were added together. PCA plates were incubated at 37 °C for 2 days, and PDA plates at 25 ° C for 5 days. All microbiological tests were triplicated and conducted at the OSU.

Measurement of physical properties

Physical properties including electrical conductivity, pH and total soluble solids °Brix, were measured at room temperature. Electrical conductivity was measured using YSI model thirty conductivity meter (YSI Incorporated, Yellow Spring, OH, USA). An Orion pH meter (Model 370; Beverly, MA, USA) was used to measure pH. A hand-held refractometer by Fisher Scientific (Pittsburg, PA, USA) was used to determine °Brix. Three sample cups were taken from storage and each cup was measured in triplicate. Colour analyses were conducted at the Natick Soldier Center on duplicate samples taken at each storage interval using a Hunter Lab colourimeter (MiniScan model MS-S-4500L; Hunter Associate Laboratory, Reston, VA, USA) with the version 4.0 software to calculate Hunter *L*, *a*, *b* colour values.

Statistical analysis

The experiments were conducted in duplicate. All data were analysed by analysis of variance using SAS version 9.1 software (SAS Institute, Cary, NC, USA). Duncan's multiple range tests were used to determine the significant difference of mean values. Unless stated otherwise, significance is expressed at 5% level.

Results and discussion

Sensory quality

From consumer sensory evaluation, all initial treatment and reference samples were liked similarly by consumers except the MRE sample which was rated slightly lower (Table 3) than some of the samples. At that time (zero time for sensory evaluation), PEF Fuji plain applesauce had been stored in 4 °C for 91 days, and PEF blueberry applesauce had been stored at 4 °C for 203 days. After continuous storage at 27 °C for 9 month or 4 °C for 12 month, the PEF Fuji plain applesauce was still

Table 3 Consumer overall acceptability of plain applesuaces*,†,‡

Storage (months)	PEF Fuji plain (4 °C)	PEF Fuji plain (27 °C)	MRE plain reference (27 °C)	Commercial plain reference (4 °C)
0§	5.89[ab]	5.89[ab]	5.46[b]	6.51[a]
3		6.66[a]	6.42[a]	6.63[a]
6		6.82[a]	6.28[a]	7.10[a]
9		6.29[a]	6.66[a]	6.77[a]
12	6.56[a]		6.51[a]	7.05[a]

*This test was performed on thirty-four consumer panelists.
†Treatment samples stored at 27 °C were sensory tested at 0, 3, 6, and 9 month intervals, and treatment samples stored at 4 °C were sensory tested at 0 and 12 months.
‡Scale: 1, 'dislike extremely'; 9, 'like extremely'; scores in the same row with different superscript letters are significantly different ($P < 0.05$).
§Pulsed electric field (PEF) Fuji applesauce samples had been stored in 4 °C for 91 days.
MRE, Meal Read-to-Eat.

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Table 4 Consumer overall acceptability of berry applesuaces*,†,‡

Storage (months	PEF blueberry (4 °C)	PEF blueberry (27 °C)	MRE raspberry reference (27 °C)	Commercial berry reference (4 °C)
0§	6.22[a]	6.22[a]	6.56[a]	5.92[b]
3		4.66[b]	6.16[a]	5.21[ab]
6		5.41[b]	6.51[a]	5.69[ab]
9		4.86[c]	6.66[a]	5.83[b]
12	5.51[b]		6.51[a]	4.95[b]

*This test was performed on thirty-four consumer panelists.
†Treatment samples stored at 27 °C were sensory tested at 0, 3, 6 and 9 month intervals, and treatment samples stored at 4 °C were sensory tested at 0 and 12 months.
‡Scale: 1, 'dislike extremely'; 9, 'like extremely'; scores in the same row with different superscript letters are significantly different ($P < 0.05$).
§Pulsed electric field (PEF) blueberry applesauce samples had been stored in 4 °C for 203 days.
MRE, Meal Read-to-Eat.

comparable with or better than references that were stored at a reference temperature (4 °C). PEF blueberry applesauce had degraded significantly in terms of preference by consumers when stored at higher storage temperature (27 °C) for another 9 months. However, PEF blueberry applesauce had higher score than the commercial reference at lower storage temperature (4 °C) at 12 month sensory evaluation time when the PEF blueberry applesauce samples had been stored for 580 day (Table 4). In other word, PEF blueberry applesauce stored over 19 months was still comparable with the commercial reference stored for12 months in terms of consumer preference.

Tables 5 and 6 show sensory quality attributes determined by trained panelists at zero time sensory evaluation. The PEF Fuji applesauce demonstrated high quality, six of ten attributes had highest scores as commercial process had four of ten highest scores (Table 5). Only one attribute 'Tartness/Sourness' level is significant lower than references, which may be related to formula or variety of apples but not to processing. In contrast to consumer sensory evaluation, technical sensory evaluation revealed that overall the PEF blueberry had lower scores than MRE and commercial references (Table 6). Four attributes are not significantly different from others; overall quality is similar to commercial reference but lower than MRE; Tartness/Sourness is similar to MRE but lower than commercial reference. The scores for overall appearance, colour and texture are significant lower than other references.

To further investigate the sensory quality of PEF applesauces as affected by storage time and temperature, 'Overall Flavour Quality' and 'Overall Quality', the two main attributes that have been the most revealing regarding the different effect of PEF on the products are presented. Figures 5 and 6 illustrate overall quality and overall flavour of PEF applesauces evaluated by fourteen trained panelists. Treatment samples stored at 27 °C were sensory tested at 0, 3, 6 and 9 month intervals. Treatment samples stored at 4 °C were

Table 5 Technical sensory evaluation of plain applesauces*,† (initial time = 0)

Sensory attributes	MRE plain applesauce reference	Commercial plain Applesauce reference	PEF Fuji applesauce
Overall appearance	6.57[a]	6.86[a]	6.79[a]
Colour (non-enzymatic browning)	5.93[c]	6.93[b]	7.29[a]
Chroma intensity‡	6.69[b]	7.26[b]	9.92[a]
Odour	6.14[b]	6.79[a]	7.07[a]
Overall flavour	5.43[b]	6.64[a]	6.93[a]
Sweetness intensity‡	7.82[a]	7.94[a]	9.23[a]
Tartness/sourness intensity‡	7.72[a]	8.34[a]	5.10[b]
Natural fruit flavour	5.43[b]	6.43[a]	6.64[a]
Texture	6.71[a]	6.71[a]	6.36[a]
Overall quality	5.50[b]	6.64[a]	6.57[a]

*This test was performed on fourteen technical panelists.
†PEF Fuji applesauce samples had been stored in 4 °C for 91 days.
‡0–15+ scale used (0, lowest; 15, highest intensity), other values from 1 to 9 quality scale; scores in the same row with different superscript letters are significantly different ($P < 0.05$).

Table 6 Technical sensory evaluation of berry applesauces*,† (initial time = 0)

Sensory attributes	MRE raspberry applesauce reference	Commercial berry applesauce reference	PEF blueberry applesauce
Overall appearance	6.92[a]	6.42[a]	5.58[b]
Colour (non-enzymatic browning)	7.33[a]	6.92[a]	6.17[b]
Chroma intensity‡	10.76[a]	8.53[b]	6.52[c]
Odour	6.50[a]	6.92[a]	6.33[a]
Overall flavour	6.67[a]	5.67[a]	5.92[a]
Sweetness intensity‡	8.43[a]	6.43[a]	7.67[a]
Tartness/sourness intensity‡	7.11[b]	9.53[a]	6.21[b]
Natural fruit flavour	5.67[a]	5.08[a]	5.58[a]
Texture	6.67[a]	6.67[a]	5.50[b]
Overall quality	6.67[a]	6.00[ab]	5.67[b]

*This test was performed on fourteen technical panelists.
†Pulsed electric field (PEF) blueberry applesauce samples had been stored in 4 °C for 203 days.
‡0–15+ scale used (0, lowest; 15, highest intensity), other values from 1 to 9 quality scale; scores in the same row with different superscript letters are significantly different ($P < 0.05$).
MRE, Meal Read-to-Eat.

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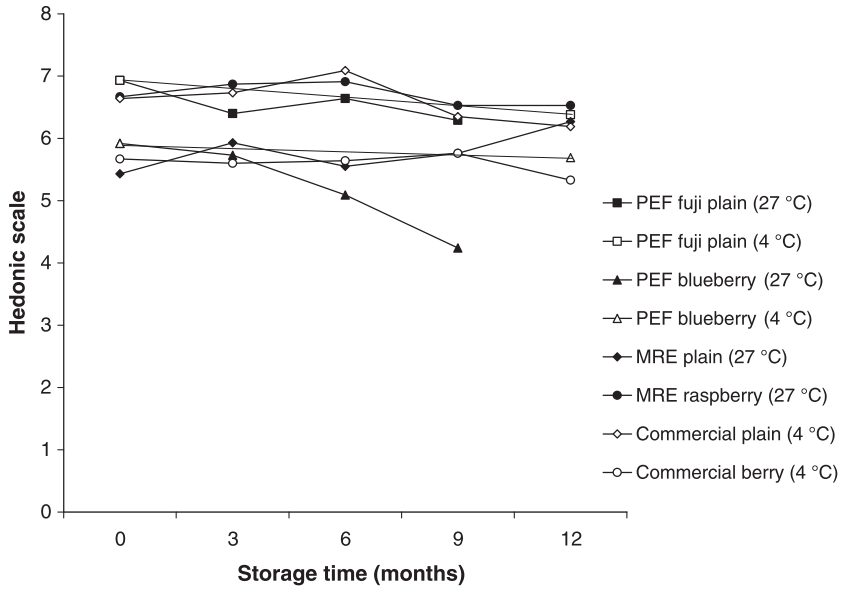

Figure 5 Overall flavour of applesauce evaluated by fourteen trained panelists. Scale: 1, 'dislike extremely'; 9, 'like extremely'. Treatment samples stored at 27 °C were sensory tested at 0, 3, 6 and 9 month intervals, and treatment samples stored at 4 °C were sensory tested at 0 and 12 months.

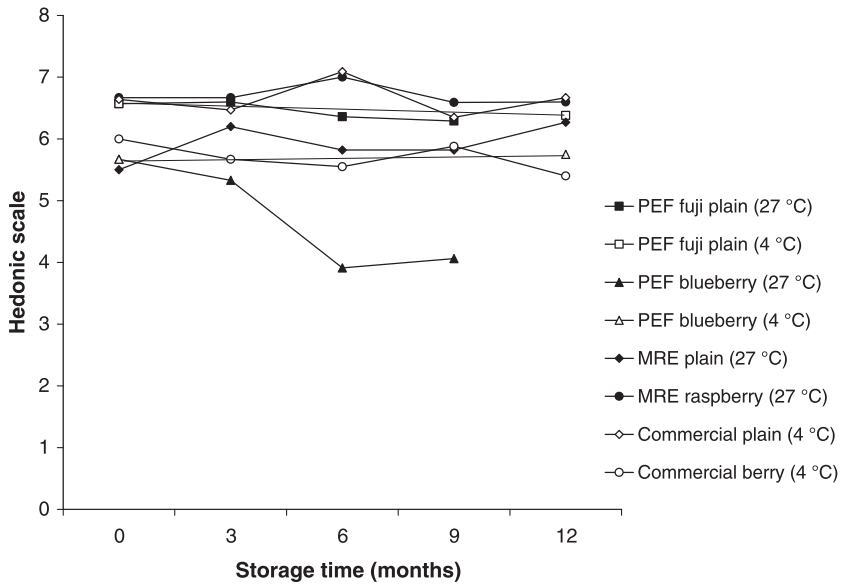

Figure 6 Overall quality of applesauce evaluated by fourteen trained panelists. Scale: 1, 'dislike extremely'; 9, 'like extremely'. Treatment samples stored at 27 °C were sensory tested at 0, 3, 6 and 9 month intervals, and treatment samples stored at 4 °C were sensory tested at 0 and 12 months.

sensory tested at 0 and 12 months and then lines were fitted to each of the two points. References were also included to illustrate both the variation and quality seen in both the commercial sector and the military (MRE) environment as compared with the PEF treated and stored samples. PEF Fuji plain applesauce shows the sensory quality stability throughout the storage period at both 4 and 27 °C (Figs 5 and 6), which agrees with the consumer evaluation (Table 3). PEF blueberry applesauce kept stable in terms of overall flavour and overall quality over additional 12 months at 4 °C when the total shelf-life was over 580 days at 4 °C. However, PEF blueberry applesauce decreased sensory scores after 3 months at 27 °C, which suggests that storage time and temperature had more impact on the sensory quality of PEF blueberry applesauce than other products.

In general, PEF blueberry applesauce had lower sensory scores than PEF Fuji plain applesauce and had significant differences after initial evaluations when stored at 27 °C. Known factors that contributed to this phenomena include: (i) PEF blueberry applesauce had 3 months longer holding time at 4 °C than PEF Fuji

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applesauce; (ii) the ingredients used for PEF blueberry applesauce (applesauce and blueberry puree) had already been thermally pasteurised once before PEF + HTST processing; and (iii) blueberry pigments in PEF blueberry applesauce are subject to oxidative degradation and the Benco cups were not made of high barrier materials.

Sensory analyses revealed that the applesauce processing method used for PEF Fuji applesauces in this experiment was comparative to traditional commercial processing methods. PEF process did not negatively affect the sensory quality of applesauce.

Compared with traditional sauce-making methods (cooking for 20–30 min), PEF + HTST process (PEF plus 70–80 °C for 24 s) has much less thermal impact on product quality. PEF + HTST process still effectively inactivates most enzymatic activity that can result in rapid product deterioration and sensory quality losses during storage. The results from this study demonstrated that PEF + HTST process can be used to produce applesauce products with sensory quality stability for at least 9 months at 27 °C. Further investigation using fresh blueberries and apples is warranted.

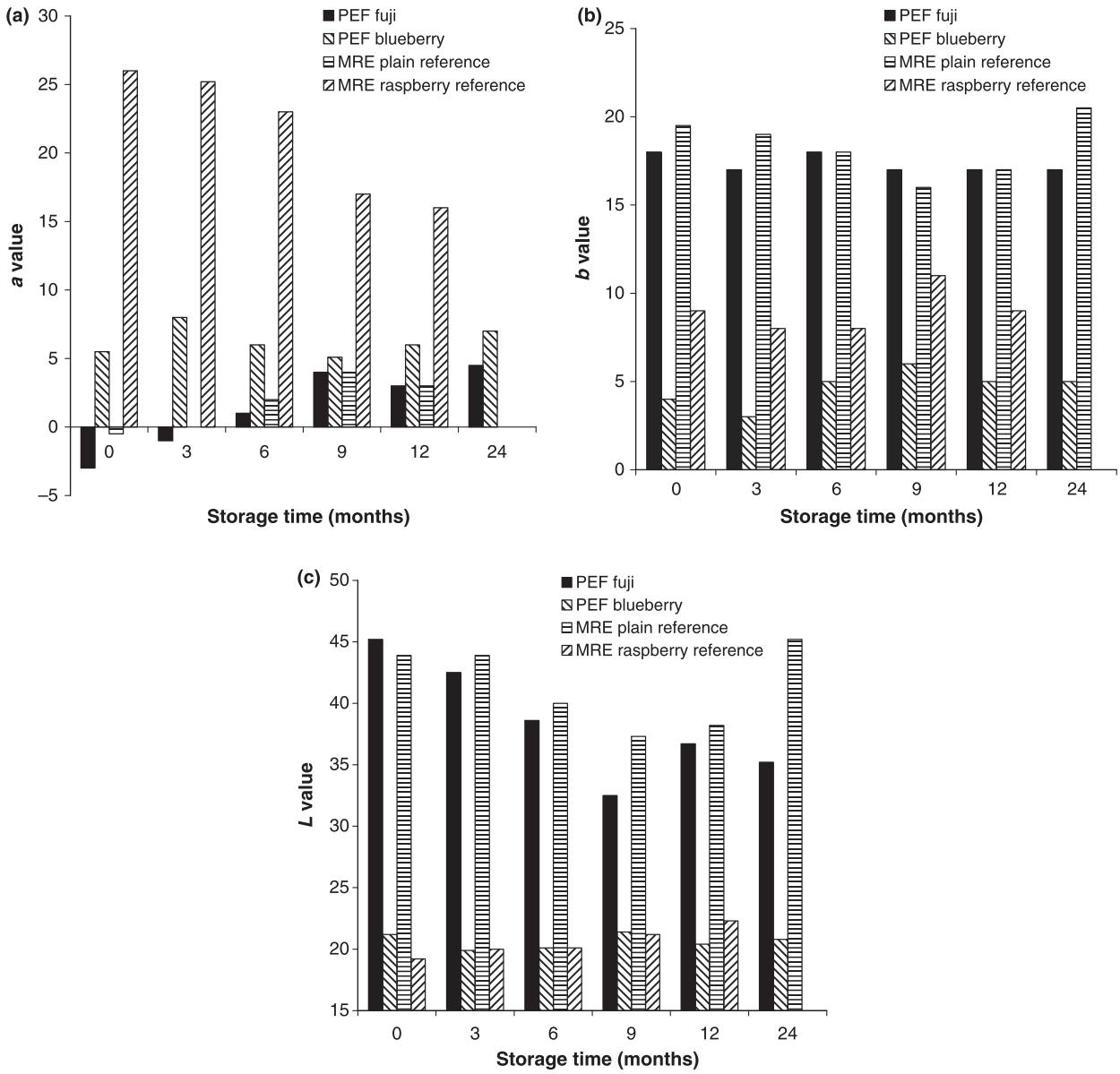

Figure 7 Hunter colour parameters of applesauce stored at 27 °C. a, redness (*a* value); b, yellowness (*b* value); c, whiteness (*L* value).

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Microbial shelf-life stability

The PEF applesauces had microbial shelf-life stability during storage periods. The pre-PEF + HTST processed Fuji applesauce had aerobic and yeast and mould counts of 4.0 and 4.2 logs cfu mL^{-1} respectively. The pre-PEF + HTST processed blueberry applesauce had aerobic and yeast and mould counts of 3.4 and 2.3 logs cfu mL^{-1} respectively. After PEF + HTST processing, no visible colonies were found on the plates and the total aerobic plate counts and the yeast and mould counts were all <10 cfu mL^{-1}. PEF Fuji applesauce and blueberry applesauce maintained the microbial counts at <10 cfu mL^{-1} at 22 °C throughout storage of 308 days and 385 days respectively (data not shown). Microbial evaluations of treated samples were stopped at days of 308 and 385 because of consistent results below the detection limit. Effectiveness of PEF + HTST process inactivation of microorganisms in applesauce was demonstrated. The process of PEF + HTST can be used to produce shelf-stable applesauce. Preference and quality data from panelists has not been collected to validate quality beyond 9 months at 27 °C even though microbial/safety data implies stability beyond a year at 22 °C. With the temperature differential and judging the slope of the degradation seen up to 9 months, it stands to reason that the plain applesauce has a good chance of being sensory acceptable at 22 °C after 1 year.

Evrendilek *et al.* (2000) studied shelf-life of apple juice and cider processed by mild heat + PEF. They found that the apple cider samples processed by mild heat followed by PEF (HTST + PEF) had a longer shelf-life than those processed by PEF alone, 68 days at room temperature. Hermawan *et al.* (2004) found that inactivation of *Salmonella enteritidis* in liquid egg by PEF followed by 50 °C for 3.5 min (PEF + 55 °C) was significantly higher than that of PEF alone, 55 °C for 3.5 min, or 55 °C for 3.5 min followed by PEF (55 °C + PEF. Sequential applications of PEF followed by heat and heat followed by PEF were not equivalent in lethality (Hermawan *et al.*, 2004).

Colour, electrical conductivity, pH and °Brix

Figure 7 shows changes in colour parameters for the samples stored at 27 °C. The Hunter *L* value was higher for the lighter coloured products, MRE plain and Fuji applesauce, and did drop with time in storage at 27 °C as products darkened somewhat. The raspberry was bright rose in colour and had the highest a value, which it maintained well during storage. The *b* values seem less sensitive to storage at 27 °C.

The initial pH, electrical conductivity (S/m) and °Brix of PEF Fuji applesauce were 3.65, 0.16 and 17.8 respectively. The initial pH, electrical conductivity (S/m) and °Brix of PEF blueberry applesauce were 3.33, 0.17 and 16.2 respectively. There were no significant changes in pH, electric conductivity and °Brix of PEF Fiji applesauce at 22 °C for 305 days or PEF blueberry applesauce at 22 °C for 395 days when analysis was stopped (data not shown). This insignificant change in the pH, electrical conductivity and °Brix during storage may be as a result of the effective inactivation of spoilage microorganisms by PEF + HTST processing (Min *et al.*, 2003a).

Conclusions

This is the first report for PEF + HTST processing of applesauce products. The combinational process of PEF + HTST significantly improved microbial shelf-life stability of applesauce products without significant loss of physical attributes during storage at room temperature. PEF Fuji applesauce from fresh Fuji apples demonstrated high and stable sensory scores during a 9-month storage period at 27 °C, and had comparative sensory quality with MRE and commercial applesauce products stored at 4 °C. PEF blueberry applesauce from pre-pasteurised materials had lower sensory scores than PEF Fuji applesauce and was significantly less stable during the storage at 27 °C. This study indicates that a continuous pilot scale PEF + HTST processing system in combination with aseptic packaging can produce shelf-stable applesauce with high sensory quality and stability when fresh raw materials are used. Further study is recommended to investigate the nutritional quality as impacted by processes and during storage.

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