The Effect of Pasteurization Temperature on Consumer Acceptability, Sensory Characteristics, Volatile Compound Composition, and Shelf-Life of Fluid Milk

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ABSTRACT

The relationship among consumer acceptability, descriptive sensory attributes, and shelf-life was determined for 2% milk pasteurized at 77, 79, 82, and 85°C. Sensory descriptive attributes and volatile compound composition were monitored over the shelf-life of the products to determine if treatments could be differentiated at various times through out the shelf-life of the product. Consumers preferred 79°C milk over other treatments on d 0; however, at d 6 postpasteurization, 79 and 82°C milks were preferred over the 77°C treatment. Consumers were grouped into 8 clusters based on product liking for both d 0 and d 6 evaluations. The largest cluster liked all pasteurization treatments, and 79°C milk was highly acceptable to all consumers who liked milk. Similar sensory descriptors indicated the end of shelf-life for all pasteurization treatments even though treatments could be differentiated by descriptors on d 0. This research reveals that altering the pasteurization temperature from 79°C may cause a decrease in consumer acceptability to some consumers. Also, altering pasteurization temperature did not affect shelf-life or sensory descriptors and volatile compound composition at the end of shelf-life.

Key words: pasteurization temperature, consumer acceptability, sensory analysis, fluid milk shelf-life

INTRODUCTION

There has been increased interest in recent years in raising the minimum standard temperatures for fluid milk pasteurization. This is partly due to microbiological concerns such as reports that the current pasteurization temperatures may not completely inactivate *Mycobacterium paratuberculosis*. *Mycobacterium paratuberculosis* has been linked to Crohn's disease in humans, although there have been conflicting reports

and research efforts are ongoing (Stabel et al., 1997; McDonald et al., 2005). The interest in higher pasteurization temperatures also comes from a desire in the industry to increase the shelf-life of fluid milk so that the product may be more competitive in the beverage industry (Chapman et al., 2001).

Although it has been reported that many processing plants already operate at temperatures well above the minimum standards (Erba et al., 1997; C. H. White, unpublished data, 2005), little work has been published describing the changes in sensory attributes or consumer acceptance of fluid milk that is pasteurized at higher temperatures. The shelf-life of the bottled fluid milk in the United States is reported to average between 10 and 21 d when stored at 4 to 8°C (Allen and Joseph, 1985; Chapman et al., 2001). The shelf-life varies depending on raw milk quality, processing conditions, microbial growth, packaging materials, temperature abuse, and exposure to light (TetraPak Processing Systems, 2000; Simon and Hansen, 2001). The dairy industry is able to achieve a 45-d shelf-life through the use of ultrapasteurization processes; however, this method of heat treatment imparts a strong cooked flavor in the milk that consumers, especially children, may find undesirable (Chapman and Boor, 2001). Because of milk's naturally mild, slightly sweet flavor, the development of any off-flavors is particularly noticeable in the product. There are many causes of off-flavors including feed sources, postpasteurization contamination, artificial or natural light exposure, storage temperature, and packaging materials. Researchers have concluded that the development of objectionable flavors in pasteurized milk is generally a result of bacterial growth (Simon and Hansen, 2001), and unpleasant aromas in fluid milk are characteristic of milk spoilage (Hayes et al., 2002). Minimal research was encountered in the literature that describes the effect that changing HTST pasteurization temperature has on sensory attributes of the product as perceived by consumers. There is an apparent need in the industry for studies on HTST pasteurized fluid milk similar to the work performed by Chapman et al.

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(2001). These researchers characterized the sensory attributes of ultrapasteurized milk through quantitative descriptive analysis and principal components analysis (PCA).

Researchers have utilized multiple extraction techniques (Bendall, 2001; Simon and Hansen, 2001; Toso et al., 2002) in pursuit of identification and quantitative measurement of volatile compounds responsible for off-flavors in bovine milk. Christensen and Reineccius (1992) reported that heated milk off-flavor is due to an increase in the concentration of sulfur compounds. However, these researchers also found that sulfur volatile compounds reached maximum levels after moderate heat treatments and then remained the same or decreased following more severe heat treatments. Contarini and Povolo (2002) studied the effect of heat treatments on volatile compounds in commercially processed milk samples using headspace-solid-phase microextraction (HS-SPME) and GC. These researchers identified 11 compounds, most of which belonged to the ketone family. Ketones with a higher molecular weight such as 2-heptanone, 2-pentanone, and 2-undecanone increased in direct correlation with the more severe heat treatments.

The primary objective of this research was to determine the effect of pasteurization temperature on the consumer acceptability and shelf-life of fluid milk. The secondary objective was to use descriptive analysis to characterize differences in fluid milk due to increased pasteurization temperatures over storage time. The final objective of this research was to use PCA to relate consumer acceptability data to sensory descriptors, volatile compounds, and shelf-life.

MATERIALS AND METHODS

Fluid Milk Processing

Fluid milk used in this study was reduced fat (2% fat), homogenized, pasteurized milk (Mueller Accu-Therm Plate Exchanger, Model A120BF, Springfield, MO) from the Mississippi State University dairy processing plant (Starkville, MS). To minimize variation in milk quality among samples, one filler head was used to fill the plastic half-gallon containers. Four pasteurization temperatures were used in this study (77, 79, 82, and 85°C) and each treatment temperature was held for 15 s. For each replication, 200 L of milk was pasteurized for each treatment and there was 15 min between pasteurization treatments. Six replications were performed for consumer acceptability and shelf-life testing. Approximately 1 replication was performed per month in the fall, winter, and spring. For 3 of these 6 replications, volatile compound composition and sensory attributes were determined over the shelf-

life of the product. The microbial quality of the raw material was acceptable to the dairy with standard plate counts <50,000 cfu/mL. All processed samples were also below the acceptable counts of 20,000 cfu/mL (US Food and Drug Administration, 2001). Milk samples were stored in a 7°C ± 1°C cooler. The storage temperature was monitored and recorded daily.

Shelf-Life/Expert Judges

Four expert judges skilled in the use of the American Dairy Science Association (ADSA) milk scorecard conducted shelf-life determinations throughout the course of this study. The judges began evaluations of the milk 7 d after pasteurization and continued tasting each sample daily until the end of shelf-life was reached for all samples. The shelf-life of each sample was considered to be 1 d before the day that judges scored it unacceptable from a sensory standpoint. Unacceptable samples were ones that would ordinarily be given a value of 5 or lower on the ADSA scorecard. Therefore, if a sample were judged unacceptable at 15 d, the shelf-life for that sample was recorded as 14 d. For the first 3 replications, expert judges tasted 3 samples for each treatment from previously unopened jugs. For replications 4 through 6, judges tasted 2 samples for each treatment (77, 79, 82, and 85°C) from previously unopened jugs. A third plastic jug was opened in the event that one sample of a treatment temperature was scored as objectionable (a score of 5 or below) while the other sample of the treatment temperature was still acceptable, which is a practice commonly used in the dairy industry (C. H. White, unpublished data, 2005). Once 2 or more samples of each treatment were scored at 5 or below, the treatment was considered to have passed its shelf-life.

Consumer Acceptability

Consumer panels were conducted on d 0 (day of pasteurization) and d 6 for all 6 replications in this study. All consumer evaluations were performed at Garrison Sensory Evaluation Laboratory, Mississippi State University. Participants were recruited from the department, university, and surrounding community. Panelists evaluated the 4 temperature treatments and a control (79°C) from the dairy plant's daily production for a total of 5 milk samples. The control samples were used to verify that the 79°C treatment in the study was similar in consumer acceptability to treatments that are produced daily in the plant. All samples for consumer tests, as well as descriptive and instrumental analysis, were poured in dim lighting. Consumers received 28.4 mL of milk sample in hot/cold insulated

Table 1. Food and chemical standards used for descriptive analysis

Attribute	Description	Reference
Aroma		
Cooked ¹	Aromatic associated with cooked milk ¹	Evaporated milk (Nestlé Carnation)
Free fatty acid ¹	Aromatic associated with short-chain FFA	Crumbled Feta cheese (Athenos)
		Butyric acid ¹
Fruity ¹	Aromas associated with fruits such as pineapple ¹	Dole pineapple chunks in 100% pineapple juice (Dole Packaged Foods Corp.) ¹
Sulfur/eggy ¹	Aromatics associated with sulfurous compounds ¹	Boiled mashed egg ¹
Flavor		
Cooked ¹	Taste associated with cooked milk	Evaporated milk (Nestlé Carnation)
Free fatty acid ¹	Taste associated with short-chain FFA	Dannon lowfat plain yogurt (The Dannon Company, Inc.)
		Crumbled Feta cheese (Athenos)
Fruity ¹	Taste associated with fruits such as pineapple ¹	Dole pineapple chunks in 100% pineapple juice (Dole Packaged Foods Corp.) ¹
Lactone ¹	Taste associated with milkfat ¹	Coconut milk (A Taste of Thai)
Rancid ¹	Taste associated with oxidized oils ¹	Old coconut milk (A Taste of Thai)
Oxidized ²	Taste associated with cardboard/papery ²	Milk exposed to ultraviolet light
Basic tastes		
Sour ^{1,3}	Taste stimulated by acids ³	Citric acid solution (0.08%) ^{1,3}

¹Drake et al., 2001.²Shipe et al., 1978.³Meilgaard et al., 1991.

cups with snap on lids (Dart Container Corporation, Mason, MI). Samples were labeled with random 3-digit numbers and the order of samples was randomized on the score sheets. Panelists were asked to expectorate and rinse their mouths with water (Mountain Spring Water, Blue Ridge, GA) between each sample. The score sheets directed panelists to evaluate the milk samples on the attributes of “flavor” and “overall liking” using a 9-point hedonic scale (Meilgaard et al., 1991). A minimum of 50 panelists performed the evaluations on each test day.

Descriptive Sensory Analysis

Eight panelists were trained in descriptive evaluation of fluid milk attributes over a 2-mo period (approximately 35 h). The panelists ranged in age from mid 20s to early 40s, and the sex ratio was balanced. All panelists were recruited from the Department of Food Science, Nutrition and Health Promotion, Mississippi State University, and were selected based on availability, willingness to participate, and prior experience on trained panels.

Evaluations were performed via round table in a temperature-controlled descriptive analysis room separated from the preparation area. Commercially available fluid milk as well as food and chemical references were used for panelists’ training. Each training session lasted approximately 1 h. Panelists evaluated samples and discussed their sensory descriptors. During training sessions, panelists generated 4 aroma and 7 flavor attributes (Table 1) that were included on the score sheet. The attributes were scored on a 15-point numer-

ical intensity scale (Meilgaard et al., 1991) where 0 = none and 15 = extreme. In addition to the established attributes, unlabeled intensity scales allowed assessors to write in other perceived aromas or flavors as detected.

To minimize variance, samples for descriptive analysis, consumer tests, and instrumental analysis were poured from the sample container for each treatment temperature. Fluid milk for descriptive analysis was served in insulated cups with snap-on lids (Dart Container Corporation) as were used for consumer tests. The samples were coded with random 3-digit numbers and were served in randomized order. Panelists tasted 1 sample from each treatment (within each replication) twice to evaluate the sensory descriptors. Panelists were provided unsalted crackers (Unsalted Tops Premium Saltine Crackers, Nabisco, Parsippany, NJ) and spring water (Mountain Spring Water) as well as expectorant cups (Dart Container Corporation) for rinsing their palates between each sample. Evaluations were performed on d 0 and 6 for all 3 replications, as well as days throughout the shelf-life of each replication (d 10, 13, 19).

Volatile Flavor Compounds

Sample Preparation. Solid-phase microextraction was utilized to extract the volatile flavor compounds from the milk samples. An aliquot (10 mL) of each treatment was placed in a precleaned 40-mL amber vial (40 mL; outside diameter: 28 mm × height: 98 mm; Supelco, St. Louis, MO) with a screw cap, a Teflon silica septum (tan polytetrafluoroethylene/white silicone;

outside diameter: 22 mm $\times$ thickness: 31.75 mm; Supelco), and a magnetic stirring bar (diameter: 8 mm $\times$ length 13 mm, magnetic octagonal bar; Fisher, Pittsburgh, PA) for agitation of samples, and tightly closed. The internal standard solution (1,3-dichlorobenzene; Sigma-Aldrich Chemical Co., Milwaukee, WI), which was prepared (1 mg/kg, vol/vol) using high-resolution GC-grade methanol (EMD Chemicals Inc., Gibbstown, NJ), was added (1 μ L) into the vial for quantification of the relative abundance (mg/kg) of detected volatile odor chemicals. The sample was stored at room temperature (21°C) for 30 min to allow for equilibration between the sample and the headspace within the vial. Volatile compounds were extracted from the headspace of the sample using a StableFlex 1-cm 50/30- μ m 3-phase (divinylbenzene/carboxen/polydimethylsiloxane) SPME fiber that was stabilized at 50°C along with the sample using a heating block (Reacti-Therm, Pierce Biotechnology Inc., Rockford IL) for 30 min. The SPME fiber was injected into a Varian 3900 gas chromatograph equipped with a CP-1177 split/splitless injector (Varian Inc., Walnut Creek, CA). Volatile compounds were analyzed in triplicate for each sample.

GC-Mass Selective Detector. Samples were screened using a GC-mass selective detector (GC-MSD) to obtain a general understanding of the volatile flavor compounds that were present in the milk pasteurization treatments at different days during their shelf-life. The GC-MSD consisted of a Varian 3900 gas chromatograph and a Saturn 2100T ion-trap mass selective detector (MSD, Varian Inc.) equipped with an Rtx-5 (Crossbond 5% diphenyl-95% dimethyl polysiloxane) capillary column (Restek, Bellefonte, PA) with the following dimensions: 30 m length $\times$ 0.25 mm i.d. $\times$ 0.25 μ m film thickness. The GC conditions were as follows: injection port, 225°C; oven temperature program: 40°C for 1 min, increased at 13°C/min to 250°C, and held for 1 min (total running time of 18.15 min). The conditions of the MSD were as follows: interface temperature, 250°C; ionization energy, 70 eV; mass range, 33 to 350 amu; scan rate, 2.2 scans/s. Ultra-high-purity helium was used as the carrier gas at a constant flow rate of 0.96 mL/min. Volatile compounds were identified using the NIST 02 library (National Institute of Standards and Technology, Gaithersburg, MD). The following chemical standards were injected into the GC-MSD to verify a subset of the compounds that were tentatively identified using the mass spectral data associated with the compounds and the NIST 02 library: 2-butanone and 2-heptanone (Acros Organics, Pittsburgh, PA), 1-butanol (Fisher Scientific), and butanoic acid, limonene, hexanoic acid, hexenol, propi-

onic acid, phenol, methyl isobutyl ketone, and ethanol (Sigma-Aldrich Chemical Co.).

Statistical Analysis

A randomized complete block design with 6 replications was used to analyze the effects ($P < 0.05$) of fluid milk pasteurization treatment on shelf-life and consumer acceptability. The least significant difference (LSD) test was used to separate means when differences occurred. Agglomerative hierarchical clustering (XLStat, 2006, Addinsoft USA, New York, NY) was performed to cluster consumers together based on their liking and preference of milk pasteurization treatments. Dendrograms and dissimilarity plots were utilized to determine the appropriate number of clusters that should be used to group consumers. Descriptive sensory attributes and volatile composition data were analyzed using PCA (SAS Institute, 2002) to differentiate between milk pasteurization treatments.

RESULTS AND DISCUSSION

Shelf-Life

There was no difference ($P > 0.05$) in shelf-life as determined by expert judges among the 4 pasteurization treatments. The shelf-life for the 4 fluid milk samples ranged from 13.2 to 14.9 d (Table 2). From these results, it appears that shelf-life at these pasteurization temperatures was more dependent on other factors such as bacterial load, postpasteurization contamination, and storage conditions. The shelf-life of bottled fluid milk in the United States was reported to average between 10 and 21 d when stored at 4 to 8°C (Allen and Joseph, 1985; Chapman et al., 2001). The milk samples in the present study were held at 7°C $\pm$ 1°C throughout the study, and Barnard (1972) stated that for every 3°C increase in holding temperature, the shelf-life of milk was shortened by one half. The temperature used in this study was chosen because it is more customary in dairy research, reflecting typical temperatures of dairy cases in the supermarket and home refrigerators (White, 1993).

Consumer Acceptability

On d 0 (day of pasteurization), consumers ($n = 298$) preferred ($P < 0.05$) milk that was pasteurized at 79°C over all other treatments with a mean score of 6.7, which was categorized between “like slightly” and “like moderately” on the 9-point hedonic scale (Table 2). The other 3 treatment temperatures (77, 82, and 85°C) received mean ratings corresponding to “like slightly” on the hedonic scale. Similar results were noted for

Table 2. Mean overall consumer acceptability¹ and flavor acceptability evaluated on d 0 and 6, and shelf-life of 2% fluid milk pasteurized at varying temperatures

Treatment ²	Day 0		Day 6		Shelf-life, d
	Overall acceptability	Flavor acceptability	Overall acceptability	Flavor acceptability	
77°C	6.1 ^b	6.2 ^b	6.1 ^b	6.2 ^b	13.2 ^a
79°C	6.7 ^a	6.6 ^a	6.5 ^a	6.6 ^a	14.9 ^a
82°C	6.1 ^b	6.2 ^b	6.6 ^a	6.2 ^b	14.7 ^a
85°C	5.9 ^b	6.0 ^b	6.4 ^{ab}	6.0 ^b	13.7 ^a
SE	0.09	0.11	0.11	0.13	1.1

^{a,b}Means within each column with unlike superscripts are different ($P < 0.05$).

¹Consumer overall acceptability and flavor scores were evaluated using a 9-point hedonic scale where 1 represents dislike extremely, 5 represents neither like nor dislike, and 9 represents like extremely.

²All treatment temperatures were held for 15 s.

consumer scores of the “flavor” attribute (Table 2). Differences ($P < 0.05$) were also observed for consumer panels conducted 6 d postpasteurization. The panelists ($n = 298$) preferred ($P < 0.05$) samples pasteurized at 79 and 82°C over those pasteurized at 77°C, based on the attribute of “overall acceptability.” However, all 6-d milk samples received mean scores categorized between “like slightly” and “like moderately” on the 9-point hedonic scale. Based on the attribute of “flavor,” consumers preferred the 79°C sample over the other 3 treatments. Results demonstrate that overall consumer acceptability differences between the 79°C treatment and other pasteurization treatments were more distinctive at d 0 than d 6.

Cluster Analysis

Cluster analysis was used to further understand the consumer acceptability of fluid milk. Consumers were grouped into 8 clusters (Tables 3 and 4) based on treatment preference at d 0 and d 6 postpasteurization.

Each cluster represented consumers with similar milk preferences. The analysis of acceptability by consumer segments served as a functional indicator for the dairy industry of potential implications for changes to the pasteurization process upon purchaser preference.

Day 0 Cluster Analysis. Consumers in clusters 4 through 8 liked milk in general, and all of these clusters found milk pasteurized at 79°C to be highly acceptable. This may be positive for the industry because the majority of processing plants pasteurize their fluid milk products at 79 to 81°C for ≥ 20 s (C. H. White, unpublished data, 2007). In cluster 4, panelists preferred ($P < 0.05$) milks processed at 79 and 82°C, which they “liked moderately,” whereas they “liked slightly” 85°C and “disliked slightly” 77°C treatments. Consumers in cluster 5 preferred ($P < 0.05$) 79 and 85°C treatments. The sixth cluster, which contained 8% of consumers, “neither liked nor disliked” 85°C milk, whereas other samples were in the “like moderately” to “like very much” range. Perhaps this cluster did not like the cooked flavor associated with the higher

Table 3. Consumer acceptability¹ based on cluster analysis of 2% fluid milk pasteurized at varying temperatures immediately postpasteurization (d 0)

Cluster	Consumers		Pasteurization temperature, °C			
	n	%	77	79	82	85
1	45	15.1	5.6 ^a	4.5 ^b	5.8 ^a	5.4 ^a
2	33	11.1	5.4 ^b	6.1 ^a	3.5 ^c	3.0 ^c
3	11	3.7	4.6 ^{ab}	5.2 ^a	3.0 ^b	4.3 ^{ab}
4	49	16.4	4.3 ^c	7.4 ^a	7.2 ^a	6.2 ^b
5	24	8.1	5.1 ^b	7.2 ^a	4.1 ^b	7.6 ^a
6	17	5.7	7.7 ^a	7.1 ^a	7.4 ^a	5.1 ^b
7	68	22.8	7.5 ^{ab}	7.5 ^{ab}	7.8 ^a	7.3 ^b
8	51	17.1	7.2 ^a	7.2 ^a	6.1 ^b	5.5 ^c

^{a-c}Means within each cluster with unlike superscripts are different ($P < 0.05$).

¹Consumer acceptability was evaluated using a 9-point hedonic scale where 1 represents dislike extremely, 5 represents neither like nor dislike, and 9 represents like extremely.

Table 4. Consumer acceptability¹ based on cluster analysis of 2% fluid milk pasteurized at varying temperatures 6 d following pasteurization

Cluster	Consumers		Pasteurization temperature, °C			
	n	%	77	79	82	85
1	28	9.3	4.2 ^b	6.0 ^a	6.7 ^a	4.4 ^b
2	18	6.0	5.2 ^b	3.9 ^c	5.7 ^b	6.8 ^a
3	17	5.7	6.1 ^a	3.6 ^c	5.9 ^a	4.6 ^b
4	16	5.3	6.2 ^a	6.4 ^a	3.9 ^b	3.4 ^b
5	25	8.3	4.4 ^b	7.0 ^a	7.3 ^a	7.5 ^a
6	59	19.7	5.4 ^c	6.2 ^b	5.3 ^c	7.1 ^a
7	46	15.3	6.8 ^b	6.7 ^b	7.5 ^a	5.2 ^c
8	91	30.3	7.3 ^a	7.6 ^a	7.6 ^a	7.6 ^a

^{a-c}Means within each cluster with unlike superscripts are different ($P < 0.05$).

¹Consumer acceptability was evaluated using a 9-point hedonic scale where 1 represents dislike extremely, 5 represents neither like nor dislike, and 9 represents like extremely.

pasteurization temperature. The largest number of consumers was in cluster 7. These consumers "liked moderately" to "liked very much" all samples of milk. The final group of consumers on d 0 preferred ($P < 0.05$) 77 and 79°C milks over the other samples, followed by 82°C and then 85°C milks.

Day 6 Cluster Analysis. Consumers from the d 6 taste panel were also grouped into 8 clusters based on milk preferences. In cluster 2, 85°C was the most preferred treatment with a mean overall acceptability score corresponding to "like moderately" on the hedonic scale. This group (15% of consumers) must have liked the cooked flavor of this sample, whereas in general they do not find milk very acceptable. This is an interesting consideration, because perhaps there are small segments of consumers who do not typically consume fluid milk but might if the product had a more cooked flavor brought on by higher pasteurization temperatures. On the other hand, consumers in cluster 4 "disliked slightly" to "disliked moderately" the higher treatment temperatures (82 and 85°C), likely due to the cooked flavor. Cluster 5 preferred ($P < 0.05$) 79, 82, and 85°C treatments over the lowest pasteurization temperature (77°C). Cluster 6 contained the second-largest segment of consumers, and this group preferred treatment 85°C, followed by 79°C, and then 77°C and 82°C. Cluster 7 demonstrated an interesting contrast in milk preferences. Although cluster 6 preferred 85°C, cluster 7 rated that treatment the lowest. Furthermore, whereas cluster 6 rated the 82°C treatment a mean score of 5.3, cluster 7 preferred this treatment temperature above the others and rated it 7.5, which is between "like moderately" and "like very much" on the hedonic scale. Cluster 8 had the largest number of consumers (30%), and this group found all treatment temperatures to be very acceptable.

Descriptive Analysis

Milks that were pasteurized at 4 different temperatures were differentiated by aroma and flavor attributes using PCA (Figure 1). The PCA biplot is useful for understanding the differences observed. According to the eigenvalues, the majority (65.2%) of variation was explained by dimension 1, the attributes that are closer to the horizontal axis. Dimension 2 explained 14.2% of variation in milk samples. Thus, samples spaced further apart on the biplot were perceptually more different than samples found closer together (Dijksterhuis, 1997).

As would be expected, the 2 higher treatment temperatures (82 and 85°C) were highly characterized by a cooked aroma and flavor at 0 d (day of pasteurization; Figure 1). Meanwhile, the 77 and 79°C treatments had

a milder taste on 0 d. The 85°C treatment was still distinguishable by the cooked flavor and aroma on 6 d. When the descriptive analysis results were applied to the cluster analysis results, the idea was reinforced that some consumers objected to a strong cooked flavor such as can be seen in d 6, cluster 4, whereas others seemed to prefer a cooked flavor (d 6, cluster 6). By d 13 of product shelf-life, treatments 77, 79, and 85°C were more closely associated with the flavor term "oxidized." The sensory defect of oxidation may be the result of more than one factor, yet it is often characterized as cardboardy, oily, or painty. Light exposure may result in flavors described as light-activated flavors, burnt, or sunlight flavor (Shipe et al., 1978; Marsili, 2007). Throughout the course of milk shelf-life, the product changes as off-flavors develop. The descriptive panelists were able to discern those changes, and by d 17 and 19 the product was characterized by the flavor terms "acid," "sour," "butyric," and "rancid." Results reveal that milk at d 0 can be differentiated by cooked aroma, cooked flavor, and oxidized descriptors, but different temperature treatments cannot be differentiated at d 10 or more postpasteurization, and rancid, acid, sour, and butyric descriptors defined the end of shelf-life for all treatments. Rancid flavor in milk is a result of the hydrolysis of short-chain triglycerides to FFA by lipases, which naturally occur in milk and are also produced by psychrotrophic bacteria (Bodyfelt et al., 1988). "Microbial flavors" is a term used to describe off-flavors and aromas in milk that result from undesirable organisms and enzymes such as the sour odor characterized by acetic and propionic acids (Shipe et al., 1978).

Volatile Flavor Compounds

When results from the GC-MSD analysis are plotted on the PCA biplot (Figure 2), it is again clear that there were changes in the product over its shelf-life. In the present study, component 1 (horizontal) accounted for 37.5% of the variation, whereas component 2 explained 18.2% of the variation. Starting on d 0 (day of pasteurization), the 77°C treatment was highly correlated with the volatile compound hydroxylamine, as well as phenol and butanoic acid. The 79°C treatment was associated with greater concentrations of hydroxylamine, phenol, butanoic acid, hexanoic acid, and hexanol. Yet, the 79°C treatment was also associated with the compounds benzoic acid, *p*-xylene, nonanone, and eugenol to a lesser extent. The 82°C treatment was characterized by compounds such as benzoic acid, *p*-xylene, nonanone, and eugenol. Vazquez-Landaverde et al. (2005) determined that 2-nonanone was not an

Figure 1. Principal component biplot of descriptive analysis for milk pasteurized at varying temperatures 0 to 19 d postpasteurization. Individual samples are identified by pasteurization temperature (77, 79, 82, and 85°C) and day of evaluation (d 0, 6, 13, 17, and 19).

important aroma contributor in raw and pasteurized milk samples. At d 0, the 85°C treatment is perceptually the most different from the other treatments. This treatment is plotted in the lower right quadrant, alongside compounds such as hexenol, decane methyl, tetrahydrofuran, butanone, and hydroperoxide.

By d 7, the 82 and 85°C treatments were more similar in terms of distinguishing the volatile compounds present, which included butanol, methyl isobutyl ketone, pentane, butanediol, and guanidine. Milk pasteurized at 77°C was more closely characterized by the volatile compounds limonene, heptanol, and nonane. Contarini et al. (1997) detected limonene in their research, but were not able to identify its contribution to milk taste and odor, nor were they able to find relevant information on this compound in their review of litera-

ture. By d 10 and 13, considerable changes occurred in the product and all treatment temperatures became more closely defined by the volatile compounds acetic acid, heptanone, and hexanone. Sour or acid flavors perceived by the descriptive sensory panel at the end of samples' shelf-life may have been the result of enzymatic activity characterized by acetic acid (Shipe et al., 1978). It is important to note from these results that (similarly to the descriptive results) milk samples could be differentiated based on volatile compound composition on d 0 and 6 but not on d 10 and 13. This suggests that each milk treatment followed a similar pattern of degradation and may be spoiling in similar ways. This is likely because all milk treatments were processed at the same facility and were from the same source (Fromm and Boor, 2004).

Figure 2. Principal component biplot of volatile compound profiles of milk pasteurized at varying temperatures 0 to 13 d postpasteurization. Individual samples are identified by pasteurization temperature (77, 79, 82, and 85°C) and day of evaluation (d 0, 6, 13, 17, and 19).

CONCLUSIONS

Varying pasteurization temperature had no effect on shelf-life. Consumers preferred milk that was pasteurized at 79°C over all other treatments on the day of pasteurization, yet at 6 d postpasteurization, the 79 and 82°C treatments were preferred over the 77°C treatment. This reveals that altering the pasteurization temperature between 77 and 85°C had a greater effect on consumer acceptability early on in the shelf-life of the products. On both d 0 and 6, all consumers that liked milk found the 79°C treatment to be highly acceptable, and the largest cluster on each day (23 and 30% of consumers) liked all treatment temperatures. Some clusters also liked milk with a cooked flavor (82 and 85°C treatments), and other clusters did not like milk with a cooked flavor. Therefore, altering pasteurization temperatures above 79°C may result in decreased acceptance in some, but not all, consumer groups on d 0 and d 6 postpasteurization. This research also revealed that milk could not be differentiated based on pasteurization temperature by a trained sensory descriptive panel or volatile compound composition toward the end of shelf-life.

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