Effects of Ultraviolet Irradiation on Chemical and Sensory Properties of Goat Milk

K. E. Matak,^{*1} S. S. Sumner,[†] S. E. Duncan,[‡] E. Hovingh,[‡] R. W. Worobo,[§] C. R. Hackney,^{*} and M. D. Pierson[†]

^{*}Human Nutrition and Foods Program, West Virginia University, Morgantown 26506

[†]Department of Food Science and Technology, Virginia Tech, Blacksburg 24061

[‡]Department of Veterinary and Biomedical Sciences, The Pennsylvania State University, University Park 16802

[§]Department of Food Science & Technology, Cornell University, New York State Agricultural Experiment Station, Geneva 14456

ABSTRACT

Sensory and chemical consequences of treating goat milk using an UV fluid processor were assessed. Milk was exposed to UV for a cumulative exposure time of 18 s and targeted UV dose of 15.8 ± 1.6 mJ/cm². A triangle test revealed differences between the odor of raw milk and UV irradiated milk. Oxidation and hydrolytic rancidity was measured by thiobarbituric acid reactive substances and acid degree values (ADV). As UV dose increased, there was an increase in thiobarbituric acid reactive substance values and ADV of the milk samples. A separate set of samples were processed using the fluid processor but with no UV exposure to see if lipase activity and agitation from pumping contributed to the differences in odor. The ADV increased at the same rate as samples exposed to UV; however, sensory studies indicated that the increase of free fatty acids was not enough to cause detectable differences in the odor of milk. Solid phase microextraction and gas chromatography were utilized for the analysis of volatile compounds as a result of UV exposure. There was an increase in the concentration of pentanal, hexanal, and heptanal (relative to raw goat milk) after as little as 1.3 mJ/cm² UV dose. Ultraviolet irradiation at the wavelength 254 nm produced changes in the sensory and chemical properties of fluid goat milk.

Key words: goat milk, ultraviolet, solid phase microextraction and gas chromatography, acid degree value

INTRODUCTION

The market for goat milk products is expanding, and the consumer trend toward fresher and more natural food choices has created a niche market for minimally processed and raw dairy foods (Reed and Grivetti,

2000). Consumer preference for raw dairy products is driven, in part, by perceived superior sensory characteristics that cannot be obtained when the milk is heat-treated (Buchin et al., 1998). Although thermal pasteurization of milk has proven to be effective at reducing pathogenic bacteria and controlling lipase activity, UV irradiation may be an alternative method that would be less costly than traditional pasteurization methods for producers working with smaller volumes of milk.

Ultraviolet irradiation, a process that does not involve heat to kill microorganisms (Sastry et al., 2000), is effective against numerous microorganisms found in drinking water (Parrotta and Bekdash, 1998) and apple cider (Wright et al., 2000; Hanes et al., 2002; Basaran et al., 2004). Recently, Matak et al. (2005) demonstrated the effectiveness of UV processing for the reduction of the bacterial pathogen *Listeria monocytogenes* in goat milk. Microbial inactivation from UV light is associated with photochemical changes that take place in proteins and nucleic acids within the cell membrane when UV light is absorbed (Sastry et al., 2000). Mutations occur that disrupt DNA transcription and replication, which ultimately cause death of the microorganism (Miller et al., 1999).

It has been well reported that UV and visible light, with wavelengths between 280 nm and 700 nm, are key factors in the creation of flavor defects and malodors in milk (Bradley, 1980; Cadwallader and Howard, 1998; Borle et al., 2001; Min and Boff, 2002). Historical studies that looked at the potential of UV irradiation for vitamin D enrichment at the specific germicidal wavelength of 254 nm did not report negative sensory data (Capstick et al., 1946; Burton, 1951; Caseiro et al., 1975). Matak and others (2005) demonstrated UV processing as an effective, nonthermal process to attain a greater than 5-log reduction ($P < 0.0001$) of *L. monocytogenes* in goat milk. This was accomplished when the flow rate of the milk through the UV processing unit was increased to the point where the milk was exposed to the UV source in a state of turbulent flow. At this

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¹Corresponding author: Kristen.matak@mail.wvu.edu

flow rate, the milk received a cumulative UV dose of 15.8 ± 1.6 mJ/cm² (Matak et al., 2005); this current study was conducted to determine if chemical and sensory properties of goat milk were affected by UV processing.

MATERIALS AND METHODS

Goat Milk

Fresh, raw goat milk was purchased in 18-L quantities from a commercial dairy. Milk was collected from the bulk tank, transported, and stored at $\leq 4^{\circ}\text{C}$ in an insulated covered 18.9-L (5-gal) cooler (Igloo Products Corp., Houston, TX) that had been sanitized with 200 ppm of hypochlorite solution. Samples were processed within 12 h of collection, and all analyses, except fatty acid profile, were concluded within 8 h of processing. Samples for fatty acid profiles were frozen and maintained at -80°C until analyses were conducted. Separate batches of milk were purchased within a 2-mo period for each of the 3 study replications, and gross composition (total fat, protein, total solids) was evaluated. An infrared analyzer (Infrared Analyzer 115 Vac, Denver Instrument Company, Arvado, CO) was used to measure moisture content and total solids. The modified Babcock procedure was used to measure milkfat (Marshall, 1993). A dye-binding method and commercial assay kit (BioRad protein assay, BioRad, Hercules, CA) was used to measure protein content spectrophotometrically (Spectronic 20 Colorimeter, Bausch & Lomb Inc., Rochester, NY; Bradford, 1976).

Fresh, raw goat milk served as the control for all chemical and sensory analyses.

UV Irradiation

Milk samples were exposed to UV irradiation using a commercial UV fluid processor (CiderSure 3500A, FPE Inc., Rochester, NY), the details of which are described elsewhere (Matak, et al., 2005). The UV dose was calculated using equation [1],

$$\text{UV dose (mJ/cm}^2\text{)} = \text{irradiance} \times \text{exposure time, [1]}$$

where irradiance was measured as described by Quintero-Ramos et al. (2004), and exposure time was a factor of the flow rate.

Milk (3 L) was passed through the processor 12 consecutive times for the targeted exposure time of 18 s and targeted UV dose of 15.8 ± 1.6 mJ/cm² (**12 pass UV**). This UV dose was in the range that is effective at achieving a 5-log reduction in *L. monocytogenes* in fresh goat milk (Matak et al., 2005). The processor was operated at 75% capacity (a turbulent flow rate of 567

L/h) so that comparisons could be made with findings from previous studies. At this flow rate, the lamps generate approximately 1.3 mJ/cm² UV dose at exposure times between 1 and 2 s as measured by 2 UVX-25 sensors (UVP Inc., Upland, CA). A separate batch of milk (1.5 L) was passed through the UV apparatus 12 times with the UV lights turned off (**12 pass no UV**). This was to determine if agitation caused by the act of pumping the milk through the UV apparatus 12 times had an effect on milk properties due to shear and lipase activity.

Multiple passes through the processor were necessary to achieve the desired UV exposure; therefore, after each pass the unit was cleaned and sanitized according to Basaran and others (2004). Total cleaning time was less than 2 min, and total processing time (including cleaning) was less than 30 min.

An aliquot (100 mL) was sampled for chemical analyses after 4, 6, 8 and 12 passes through the processor for subsequent chemical analyses. Samples were collected in 100-mL borosilicate milk dilution bottles (Corning Inc., Corning, NY) and 500-mL HDPE containers (Nalge Nunc Int., Rochester, NY), fitted with lids, and covered with aluminum foil to prevent further light exposure. The calculated UV dose for each of these samples was 5.2, 7.8, 10.4, and 15.6 mJ/cm², respectively. Sample temperature was maintained ($\leq 4^{\circ}\text{C}$) by holding samples in an ice bath during sample preparation, between processing passes, and during analytical and sensory preparation.

Sensory Testing

Virginia Tech Institutional Review Board approval was received for the sensory study. Because unpasteurized milk samples were used and UV processing is not yet an approved process for milk, samples were assessed for differences in odor, not taste. Comparisons included fresh, raw goat milk (control) vs. 12 pass UV; 12 pass UV vs. 12 pass no UV; control vs. 12 pass no UV. Each comparison was evaluated using a triangle test, which was conducted once and not replicated. Immediately after processing, samples (~15 mL) were poured into 20-mL semiopaque plastic cups, fitted with plastic lids, assigned a random 3-digit code, and stored and maintained at $\leq 4^{\circ}\text{C}$ until sensory testing was concluded. Sensory tests occurred within 6 h of treatment. All combinations of the 2 samples were presented within each sensory session an equal number of times. Two sets of 3 samples were presented to each panelist, representing a balanced order of presentation. Panelists were instructed to identify the sample that smelled different in each group of 3. There was additional space

for comments with instructions to describe any odors associated with the unique sample.

Twenty-four volunteers (≥ 18 yr) were recruited from the Food Science and Technology Department (Virginia Tech) to serve on each panel session. Each panelist contributed 2 observations per testing session for a total of 48 observations per triangle test. Testing was conducted in individual booths in the Food Science and Technology sensory laboratory. Panelists were required to complete a consent form, approved by the Institutional Review Board at Virginia Tech, prior to testing. Each panelist was verbally reminded not to drink the samples but to smell them only.

Chemical Analyses

The extent of oxidation as a result of processing with and without UV irradiation was assessed chemically using 3 different methods: thiobarbituric acid reactive substances (TBARS) test, acid degree values (ADV), and volatile analysis by solid-phase microextraction with gas chromatography. All samples were tested concurrently within 6 h following UV exposure.

The TBARS test measures malondialdehyde and other reactive substances in the sample, and the results are reported as milligrams of sample per liter. Results of this test are based on the color reaction of lipid peroxidation products and thiobarbituric acid; color absorbance was read spectrophotometrically at 532 nm (Spectronic 20 Colorimeter, Bausch & Lomb Inc., Rochester, NY). Samples (control, 4 pass UV, 6 pass UV, 8 pass UV, 12 pass UV, and 12 pass no UV) were tested in duplicate using a modified version of the TBARS test described by van Aardt and others (2005b).

The ADV are classified as a standard method for indication of hydrolytic rancidity resulting from enzymatic activity and used as a measurement of free fatty acids in milkfat recovered from an extraction method and titration. These values, coupled with sensory evaluation, can be used as an indicator of rancid off-flavors in milk. The procedure for measuring ADV is described by Marshall (1993). Samples (control, 4 pass UV, 6 pass UV, 8 pass UV, 12 pass UV, and 12 pass no UV) were tested in duplicate.

Solid-phase microextraction with gas chromatography is an extraction and analytical technique used to detect concentrations of volatile flavor compounds in foods and beverages. The solid-phase microextraction fibers (75- μ m carboxen-polydimethyl siloxane), manual holder assemblies, Viton septum, caps, micro stirring bars, and 40-mL glass bottles were purchased from Supelco Inc. (Bellefonte, PA). Prior to use, fibers were conditioned in a gas chromatography injection port at 280°C for 1 h. Volatile compounds associated with light

oxidation (hexanal, heptanal, pentanal, and methyl sulfide) were purchased from Sigma Chemical (St. Louis, MO). Identification was made for each day of analysis by comparing gas chromatography retention times (RT) of stock solutions containing each compound at concentrations of 100 and 500 μ g/mL (Marsili, 1999; van Aardt et al., 2001, 2005a). Concentrations of volatile compounds were not quantified; therefore, peak areas of identified compounds were compared relative to fresh, raw goat milk (control).

Volatile compounds were assessed in the control, 12 pass UV, and 12 pass no UV samples to consider differences as related to sensory evaluation outcomes. Milk (25 mL) from each treatment (control, 12 pass UV, and 12 pass no UV) was transferred into 40-mL glass bottles covered with aluminum foil. Bottles were fitted with Teflon-coated septa and held at $\leq 4^\circ\text{C}$ until analyses were conducted.

Volatile compound analysis was completed in triplicate for each treatment within 6 h of processing. The solid-phase microextraction fiber was inserted through the septum and positioned approximately 1 cm above the milk surface to allow maximum exposure to milk headspace, and exposed for 22 min at 45°C with magnetic stirring. The loaded solid-phase microextraction fiber unit was placed into the injector port of a Hewlett Packard gas chromatograph (model 5890 Series II Plus, Hewlett Packard, Avondale, PA) equipped with ChemStation (Agilent Technologies, Palo Alto, CA; van Aardt et al., 2001). Volatile compounds were separated using a 30 m $\times$ 0.32 mm, 1.05 μ m, Rtx-S capillary column (Restek Corp., Bellefonte, PA), and helium as the carrier gas with flow rates of 1.8 mL/min. Injector temperature was 280°C, and flame ionization detector temperature was 300°C. Temperature program was 30 s at 35°C, 15°C per min to 180°C, hold 30 s, 20°C per min to 260°C, hold 30 s.

Fatty Acid Analysis

Fatty acid analyses were conducted in duplicate on fresh, raw goat milk (control), 12 pass UV, and 12 pass no UV samples to indicate if profiles among treatments changed as a result of UV processing. This test was completed for one replication of the study because the natural variations in milk composition between collections could create differences in fatty acid profile, potentially masking the effect of the process.

Milk samples were frozen and maintained at -80°C until analyses were conducted. The procedure for extraction and methylation was as follows: milk was thawed, warmed, and gently mixed to provide a uniform sample. Milk (1 mL) was weighed into a 50-mL extraction tube. Lipid was extracted using a modified Folch

procedure (Folch et al., 1957). Lipid residue was weighed after drying at 40 to 45°C under a stream of nitrogen. Fatty acids were transesterified to methyl esters with 0.5 N NaOH in methanol and 14% BF₃ (Park and Goins 1994). Undecenoic acid (Sigma-Aldrich Corp., St. Louis, MO) was added prior to methylation as an internal standard.

Chromatographic analysis was conducted on prepared samples. All samples were analyzed in duplicate on a 6890N gas chromatograph with a 7683 autoinjector, split/splitless capillary injector and flame ionization detector (Agilent Technologies). Ultrapure H₂ was used as the carrier gas with gas velocity set at 30 cm/sec, flow rate at 1.5 mL/min, injection volume 0.5 µL, and split ratio 100:1. A Chrompack CP-Sil 88 100 m × 0.25 mm id capillary column (Varian Inc., Palo Alto, CA) was used to separate fatty acids and methyl esters. Temperature program for separations began at 70°C, held for 1 min, increased to 100 at 5°C/min, held for 3 min, increased to 175°C at 10°C/min, held for 45 min, increased to 220°C at 5°C/min and held for 15 min. Total runtime was 86.5 min. Temperatures for injector and detector were 250 and 300°C, respectively. A customized mixture of pure methyl ester standards as described by Loor and Herbein (2003) was used to identify peaks and determine individual response factors. Data were integrated and quantified using ChemStation (Agilent Technologies).

Statistical Analysis

The data for each triangle test were analyzed by the number of correct responses vs. the total number of responses. Because 2 sets of 3 samples were presented to each panelist, responses were considered correct only when the panelist was able to identify the odd sample for both presentations. Parameters were defined at $n = 24$, $\alpha = 0.05$, $\beta = 0.05$, and $p_d = 50\%$; the critical number of correct responses for significance was 13 out of 24 (Meilgaard et al., 1999). One test was administered per repetition, and tests were not replicated.

One-way ANOVA, Tukey's honestly significant difference, and linear regression were used to analyze the data. A P -value of < 0.05 was considered to be significant. Data were analyzed using Jmp In (Version 4.04, SAS Institute, Cary, NC) software.

RESULTS AND DISCUSSION

Composition of Goat Milk

Milk composition was typical, averaging 92% moisture and 8% solids for each replication. Fat and protein contents were 4.1% (± 0.09) and 2.9% (± 0.03), respectively.

Table 1. Triangle test responses for odor differences in UV irradiated raw goat milk (12 pass UV), pumped raw goat milk (12 pass no UV), and untreated fresh goat milk (control)

Treatment ¹	No. of correct responses ²	Result ³
Control vs. 12 pass UV	19	Significant
Control vs. 12 pass no UV	12	Not significant
12 pass UV vs. 12 pass no UV	18	Significant

¹Control: fresh goat milk; 12 pass UV: goat milk exposed to a targeted UV dose of 15.8 ± 1.6 mJ/cm² using a commercial fluid processor; 12 pass no UV: goat milk processed using commercial fluid processor with no UV exposure.

² $n = 24$ observations.

³Critical correct response number = 13; $\alpha = 0.05$; $\beta = 0.05$; and $p_d = 50\%$.

Sensory Changes

Fresh, high quality milk has a delicate odor and flavor, so minor variations in chemical composition could render it unacceptable by consumers (Walstra and Jenness, 1984). The odor of fresh, raw goat milk (control) was different ($P < 0.05$) from goat milk that had been exposed to UV light (12 pass UV) but not different from milk that was passed through the processor 12 times without being exposed to UV (12 pass no UV; Table 1). Based on these comparisons, it is evident that the UV exposure did cause changes in the milk that affected the milk odor. Panelists did not describe any off-odors for the control or 12 pass no UV samples; however, some panelists described the odors from the 12 pass UV samples as manure, stinky, barnyard, and goaty, suggesting that the changes were not positive.

Chemical Analyses

In general, the fatty acid profile was not significantly altered by UV treatment (Table 2). There was a change in the conjugated linoleic acids (CLA) after UV processing ($P < 0.05$). Compared with fresh goat milk (control), the 12 pass UV treated milk showed a 52% decrease of C18:2 *cis*-9, *trans*-11 and a 1,050% (10-fold) increase of C18:2 *trans*, *trans*. Timmons and others (2001) reported that as concentrations of unsaturated fatty acids in milk increase, particularly of PUFA C18:2 and C18:3, milk becomes more susceptible to oxidation. Kim et al. (2003) reported that volatile compounds were formed in goat milk cheese stored under fluorescent light for 2 d at 30°C. Sensory evaluation confirmed that samples stored under these lighted conditions had more off-flavors than samples stored in the dark. Kim et al. (2003) concluded that the light-induced volatile compounds were formed from singlet oxygen oxidation of oleic acid in the cheese. In this

Table 2. Average fatty acid profile of fresh, raw goat milk (control); milk that was pumped through the machine but not exposed to the UV source (no UV); and UV processed milk (UV)¹

FA	Control	No UV	UV
C4:0	1.77	1.86	1.87
C6:0	2.03	2.09	2.10
C8:0	3.05	3.08	3.08
C10:0	10.75	10.71	10.66
C12:0	5.11	5.061	5.05
C14:0	9.93	9.87	9.88
C14:1 <i>cis</i> -9	0.14	0.14	0.14
C15:0	0.79	0.78	0.79
C16:0	23.12	23.10	23.17
C16:1 <i>trans</i> -9	0.69	0.67	0.69
C16:1 <i>trans</i> -11	0.13	0.11	0.11
C16:1 <i>cis</i> -9	0.88	0.88	0.87
C16:1 <i>cis</i> -11	0.04	0.04	0.03
C17:0	0.70	0.70	0.70
C18:0	10.78	10.79	10.82
C18:1 <i>trans</i> -6, <i>trans</i> -7	0.36	0.36	0.36
C18:1 <i>cis</i> -7, <i>trans</i> -12	0.28	0.28	0.28
C18:1 <i>cis</i> -6, <i>trans</i> -13	0.72	0.73	0.73
C18:1 <i>trans</i> -4	0.02	0.03	0.02
C18:1 <i>trans</i> -5	0.03	0.03	0.03
C18:1 <i>trans</i> -9	0.39	0.39	0.39
C18:1 <i>trans</i> -10	0.64	0.64	0.64
C18:1 <i>trans</i> -11	3.15	3.16	3.16
C18:1 <i>trans</i> -14	0.18	0.20	0.17
C18:1 <i>trans</i> -16	0.29	0.29	0.29
C18:1 <i>cis</i> -9	18.63	18.59	18.68
C18:1 <i>cis</i> -11	0.56	0.57	0.57
C18:1 <i>cis</i> -12	0.48	0.49	0.49
C18:1 <i>cis</i> -13	0.11	0.11	0.11
C18:1 <i>cis</i> -15	0.12	0.13	0.13
C18:2 <i>trans</i> -9, <i>trans</i> -12	0.01	0.02	0.01
C18:2 <i>cis</i> -9, <i>trans</i> -12	0.08	0.09	0.08
C18:2 <i>trans</i> -9, <i>cis</i> -12	0.04	0.04	0.04
C18:2 <i>cis</i> -9, <i>cis</i> -12	1.60	1.59	1.60
C18:2 <i>cis</i> -9, <i>trans</i> -11	1.24	1.23	0.64
C18:2 <i>cis</i> -9, <i>cis</i> -11	0.00	0.00	0.08
C18:2 <i>trans</i> -11, <i>trans</i> -13	0.02	0.02	0.01
C18:2 <i>trans trans</i>	0.04	0.04	0.42
C18:3 <i>cis</i> -6, <i>cis</i> -9, <i>cis</i> -12	0.05	0.04	0.05
C18:3 <i>cis</i> -9, <i>cis</i> -12, <i>cis</i> -15	0.30	0.29	0.30
C20:0	0.17	0.16	0.17
C20:1 <i>cis</i> -11	0.08	0.08	0.08
C20:2 <i>cis</i> -11, <i>cis</i> -14	0.04	0.04	0.03
C20:3 <i>cis</i> -8, <i>cis</i> -11, <i>cis</i> -14	0.03	0.03	0.03
C20:4 <i>cis</i> -5, <i>cis</i> -8, <i>cis</i> -11, <i>cis</i> -14	0.24	0.24	0.24
C20:5 <i>cis</i> -5, <i>cis</i> -8, <i>cis</i> -11, <i>cis</i> -14, <i>cis</i> -17	0.01	0.01	0.01
C22:1 <i>cis</i> -13	0.01	0.00	0.01
C22:4 <i>cis</i> -7, <i>cis</i> -10, <i>cis</i> -13, <i>cis</i> -16	0.03	0.03	0.03
C22:5 <i>cis</i> -4, <i>cis</i> -7, <i>cis</i> -10, <i>cis</i> -13, <i>cis</i> -16	0.01	0.01	0.01
C22:5 <i>cis</i> -7, <i>cis</i> -10, <i>cis</i> -13, <i>cis</i> -16, <i>cis</i> -19	0.09	0.09	0.09
C22:6 <i>cis</i> -4, <i>cis</i> -7, <i>cis</i> -10, <i>cis</i> -13, <i>cis</i> -16, <i>cis</i> -19	0.03	0.03	0.02
24:0	0.03	0.04	0.04
24:1 <i>cis</i> -15	0.01	0.00	0.00

¹Values are expressed as a percentage of total fatty acid (Dairy Forage Lab, Virginia Tech).

current study, differences in oleic acid concentrations were not detected between UV-treated and non-UV-treated samples; however, sensory differences were detected.

The TBARS values increased as UV dose increased in goat milk samples ($P < 0.05$; $R^2 = 0.93, 0.97$, and 0.95 for replications 1, 2, and 3, respectively). The slope

of the line was very similar for each replication; however, when data were combined from the 3 replications, a low R^2 value, or low predictive power, resulted. This may be attributed to natural variations in the composition of milk, most likely milkfat, between milk collections caused by lactation stage and season. The TBARS values of milk processed with no UV exposure indi-

Table 3. Thiobarbituric acid-reactive substances (TBARS) values (mean $\pm$ SD) and acid degree values (ADV; mean $\pm$ SD) of fresh, raw goat milk in response to increasing doses of UV light

Approximate UV dose (mJ/cm ²)	Number of passes	TBARS (mg/L)	ADV (mEq/100 g)
		Mean $\pm$ SD	
0.0	0 ¹	0.31 ^a $\pm$ 0.09	0.1 ^a $\pm$ 0.05
0.0	12 ²	0.34 ^a $\pm$ 0.11	0.36 ^b $\pm$ 0.15
5.2	4	0.37 ^a $\pm$ 0.11	0.29 ^a $\pm$ 0.05
7.8	6	0.44 ^{a,b} $\pm$ 0.10	0.36 ^b $\pm$ 0.12
10.4	8	0.50 ^b $\pm$ 0.12	0.31 ^{a,b} $\pm$ 0.11
15.6	12 ³	0.58 ^b $\pm$ 0.11	0.40 ^b $\pm$ 0.09

^{a,b}Values designated with the same letter within a column are not significantly different ($P < 0.05$) as determined by Tukey's honestly significant difference test.

¹Control: fresh goat milk.

²12 pass no UV: goat milk processed using commercial fluid processor with no UV exposure.

³12 pass UV: goat milk exposed to a targeted UV dose of 15.8 $\pm$ 1.6 mJ/cm² using a commercial fluid processor.

cated that milk agitation alone did not cause a measurable increase in secondary products of oxidation, such as malondialdehyde (Table 3). The TBARS values ranged from 0.31 ($\pm$ 0.09) mg/L in the control milk to 0.58 ($\pm$ 0.11) mg/L in UV-irradiated milk. These trends are consistent with those reported by van Aardt and others (2005b) who found that cows' milk exposed to light for 10 h had greater TBARS values (0.92 mg/L) than milk protected from light exposure (0.59 mg/L). The TBARS values reported in this current study are modest when compared with van Aardt et al. (2005b); however, the samples in the previously mentioned study received fluorescent light exposure over the broad visible and UV wavelength spectra, including all the riboflavin excitation wavelengths. Riboflavin absorbs light of specific wavelengths, principally 250, 270, 370, 400, 446, and 570 nm when in foods with

a neutral pH (Kyte, 1995); it is considered to play a significant role as a sensitizer in the photooxidation process of dairy products. Lee (2002) found that the concentration of riboflavin in milk was directly related to the extent of off-flavors when milk was exposed to fluorescent light; our reported TBARS values may be less than other reported values because the concentration of riboflavin in goat milk is less than cows' milk (Souci et al., 2000).

There was no increase in TBARS values in nonUV-treated samples, which implies that UV light exposure was a significant factor for increasing production of oxidation byproducts.

Acid degree values were used as an indicator of hydrolytic rancidity. Initial ADV were less than the values after 6 passes and approximately 7.8 mJ/cm² UV dose ($P < 0.05$). The ADV increased as a result of turbulence (Table 3) regardless of UV exposure. The final ADV for 12 pass UV and 12 pass no UV samples were different than the corresponding control samples as determined by Tukey's honestly significant difference ($P < 0.05$).

Historically, an ADV of >1.0 mEq/100 g in cow milk is indicative of rancid off-flavors. The greatest ADV in this study was 0.51 ± 0.05 mEq/100 g for milk treated with approximately 15.6 mJ/cm² UV dose ($P < 0.05$). According to the Standard Methods for Evaluation of Dairy Product (Marshall, 1993), an ADV of <1.0 mEq/100 g suggests that a sensory change should not be evident. Duncan and Christen (1991) evaluated the relationship between ADV and rancid off-flavors. They found that short-chained fatty acids (C4 to C8) did not enter the fat phase recovered by the ADV procedure in quantities comparable with medium- (C10 to C16) or long-chain (C18:0 to C18:1) fatty acids. Their results implied that the ADV procedure did not measure the fatty acids responsible for rancid flavor (C4 to C12) at

Table 4. Mean relative peak area (area counts) $\pm$ SD (1×10^4) of headspace volatile compounds in goat milk formed as a result of UV irradiation

RT ¹	Volatile compound ²	Fresh goat milk	UV dose (mJ/cm ²) ³		
			0	7.8	15.6
4.46	Pentanal	ND ⁴	ND	0.91 ^a $\pm$ 0.21	1.76 ^b $\pm$ 0.38
6.09	Hexanal	ND	ND	2.03 ^a $\pm$ 0.22	3.07 ^b $\pm$ 0.27
8.35	Heptanal	ND	ND	0.60 ^a $\pm$ 0.07	1.38 ^b $\pm$ 0.32

^{a,b}Values designated with different superscripts within a row are significantly different ($P < 0.05$) as determined by Tukey's honestly significant difference test.

¹RT = retention time in minutes.

²Compounds were identified by comparing retention times of known compounds.

³Milk passed through a Cidersure 3500 UV processor 6 or 12 consecutive times to achieve desired UV dose of 7.8 or 15.6 mJ/cm², respectively. At dose 0 mJ/cm², milk was passed 12 times through the UV apparatus with the UV lights turned off.

⁴ND = not detected; detection limit >100 μ g/mL.

Figure 1. The production of headspace volatile compounds was detected by solid-phase microextraction and gas chromatography of A) fresh, raw goat milk, B) goat milk exposed to a UV dose of approximately 7.8 mJ/cm², and C) goat milk exposed to a UV dose of approximately 15.6 mJ/cm². 1 = pentanal; 2 = hexanal; and 3 = heptanal. Compounds identified by retention time to known standards.

the same rate as the longer chained fatty acids (Duncan and Christen, 1991). Relative to cow milk, goat milk has a greater amount of short-chain fatty acids; therefore, there may have been limitations of the ADV analysis to measure a true hydrolytic rancidity score. Regardless, the results of this study show that the ADV values were not great enough to imply rancidity in fresh goat milk and milk that had been subjected to agitation only; this was consistent with triangle test results.

The temperature of milk is very important during agitation because lipase activity is greatest between 37 and 40°C and least at cold storage temperatures below 5°C (Deeth and Fitz-Gerald, 1995). The processing temperature in this study was maintained at or below 4°C to minimize lipase activity. The turbulent

flow induced by the pumping of the milk through the CiderSure 3500 UV processor was not enough to cause perceivable changes in the odor of the milk in the first 6 h after processing. No shelf life study was conducted to see if changes in odor developed after time.

Gas chromatograms of headspace volatile compounds in fresh, raw goat milk (control) and milk that had been treated with approximate UV doses of 7.8 and 15.6 mJ/cm² are shown in Figure 1. The chromatogram of fresh milk exhibited a large peak after a RT of ~2.92 min and then a much smaller peak after ~3.15 min. These peaks were consistent for each treatment, and there were no statistical differences in peak area for each treatment. The formation of other volatile peaks was displayed on the chromatogram after a UV dose of 7.8 mJ/cm². Pentanal, hexanal, and heptanal

were detected after exposure to UV, but methyl sulfide was not.

The relative peak area (area counts) for volatile compounds identified by gas chromatographic RT in fresh and treated goat milk samples are contained in Table 4. Retention times of known compounds were pentanal (RT 4.46), hexanal (RT 6.09), and heptanal (RT 8.35). There was an increase in peak areas of pentanal, hexanal, and heptanal after 7.8 and 15.6 mJ/cm² UV dose, respectively ($P < 0.05$). A preliminary study indicated that these compounds were formed in goat milk exposed to as little as 1.3 mJ/cm² UV dose. Lee (2002) found that milk stored at 4°C under fluorescent light displayed pentanal and hexanal formation before 2 h and heptanal formation in fewer than 4 h. Marsili (1999) reported that the reaction kinetics of pentanal and hexanal were different and offered that these differences were due to the availability of substrates. Lee (2002) also reported that fat content had an effect on the formation of these volatile compounds; as fat content increased from 0.5 to 1.0, 2.0, and 3.4%, there was an increase in formation of the volatile compounds (Lee, 2002). The peak areas for each compound in photosensitized whole milk (8 h under fluorescent light at 4°C) were consistent with those reported in this current study (Lee, 2002). These compounds were not present in the samples that received zero light exposure.

CONCLUSIONS

The pursuit to find alternative processing technologies to replace or augment traditional thermal methods should begin with an assessment of safety parameters. However, when developing novel technologies, sensory properties and consumer acceptance must also be given serious consideration. Even though we have previously shown that UV treatment is effective for the reduction of the bacterial pathogen *Listeria monocytogenes* in goat milk, the present study indicated that UV irradiation at the wavelength 254 nm had aromatic and chemical consequences.

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