Production and Characterization of a Swiss Cheese-Like Product from Modified Vegetable Oils

Liangping Yu and Earl G. Hammond*

Department of Food Science and Human Nutrition, Center for Designing Foods to Improve Nutrition and Center for Crops Utilization Research, Iowa State University, Ames, Iowa 50011

ABSTRACT: Seven types of Swiss cheese-like products were made by recombining skim milk with various fat sources: high-oleic sunflower oil (HOSO), milk fat, randomized milk fat, HOSO with commercial short-chain fatty acids (C_4–C_{10}) (SCFA) interesterified at 100 and 120% of the levels in the milk fat, HOSO with interesterified milk fat SCFA, and HOSO with dissolved free SCFA. Sensory, chemical, and physical analyses were conducted to evaluate the flavor and texture of the cheeses. All cheeses made from HOSO with interesterified SCFA were not significantly different from milk fat controls in typical Swiss flavor and volatile flavor. HOSO with interesterified SCFA scored significantly higher in these flavors than unmodified HOSO. Swiss flavor was positively correlated with sweetness (0.805), volatile flavor (0.737), caramelized flavor (0.703), non-fat solids (0.663), and SCFA (0.639), and negatively correlated with fat (−0.645) and salt (−0.482) content. A linear regression model was established for typical Swiss flavor that included fat, salt, titratable acidity, and medium- and long-chain fatty acids as variables (R^2 = 0.91). Instrumental texture profile analysis indicated no differences among the treatments in texture attributes except cohesiveness. The production of a good-flavored Swiss cheese-like product from HOSO with interesterified SCFA appears to be commercially feasible.

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KEY WORDS: Cheese flavor, cheese texture, filled cheese, high-oleic sunflower oil, Swiss cheese-like product, vegetable oil.

Milk fat has been considered hypercholesterolemic because it contains cholesterol and a generous proportion of saturated long-chain fatty acids (1). Consumer demand for healthful and nutritionally balanced products has led to the development of a number of fat-free and low-fat cheese products, but the flavor, texture, and shelf life of these cheeses has been optimistically described as "lacking," "changing," or "improving with further research" (2–5). Attempts to use vegetable oils in place of milk fat in the manufacture of cheeses have been made (6,7). Such substitutions could be advantageous because the vegetable oils are cholesterol-free, usually cheaper, sometimes more stable, and less subject to seasonal variation than milk fat (8,9). However, vegetable oil cheeses have been reported to have an oily off-flavor, less volatile fatty acids (10), depressed sensory scores, and a soft and crumbly texture (8, 11–13). Whitehouse (14) and Johnson (15) made Swiss cheese-like products using vegetable oils that had been modified by interesterification with short-chain fatty acids (SCFA). Their results showed great promise for making a quality Swiss cheese-like product with modified vegetable oils.

SCFA have been successfully incorporated into high-oleic sunflower oil (HOSO) to give a SCFA composition closely resembling that of milk fat (16). In this study, products resembling Iowa-style Swiss cheese were produced from modified HOSO and skim milk, and their sensory, chemical, and physical characteristics were compared with those of controls made from unmodified HOSO, milk fat, or randomized milk. Furthermore, this study explored the possibility of making cheese from skim milk and HOSO with certain amounts of dissolved rather than interesterified free SCFA in the HOSO.

EXPERIMENTAL PROCEDURES

Preparation of fat sources. High-oleic sunflower oil (Trisun 80, RBD) was purchased from AC Humko (Memphis, TN). Seven types of fat were prepared in 6-kg amounts. Milk fat was isolated from U.S. Department of Agriculture Grade AA sweet butter (Prize of Iowa, Mid-America Farms, Springfield, MO) according to the method described by Yu and Hammond (16).

Mixtures of HOSO with commercial SCFA (butyric, caproic, caprylic, and capric acids) incorporated at 100 and 120% of the levels in milk fat, as well as HOSO with SCFA from milk fat, incorporated, were prepared as described by Yu and Hammond (16).

HOSO with dissolved commercial SCFA (Sigma Chemical Co., St. Louis, MO) was prepared just prior to cheese making by adding free SCFA in the amounts normally found in Swiss cheeses (17). The amount of butyric acid used was increased by 7% to compensate for loss to the whey during the cheese-making procedure. Thus, for 2.8 kg HOSO, 3.66 g of butyric, 0.57 g of caproic, 0.57 g of caprylic, and 1.13 g of capric acid were added.

Randomized milk fat was prepared according to the methods described by Kuksis *et al.* (18,19). Milk fat was dried using Drierite (W.A. Hammond Drierite Company Ltd., Xenia, OH), filtered, and randomized for 2 h at 100°C with

*To whom correspondence should be addressed at Department of Food Science and Human Nutrition, 2313 Food Sciences Building, Ames, IA 50011. E-mail: hammond@iastate.edu

0.5% by weight of sodium methoxide while stirring under nitrogen. Next, 15 mL of 20% aqueous citric acid was added to neutralize the sodium methoxide, the fat was washed with hot water several times and then dried on a rotary evaporator for 40 min at 90°C. The randomized milk fat was deodorized at 200°C for 1.5 h using a lab-scale steam deodorizer (20).

Preparation of cultures used for cheese making. *Lactobacillus bulgaricus* AR2, *Streptococcus thermophilus* AC2, and *Propionibacterium shermanii* P19 were obtained from the culture collection of the Department of Food Science and Human Nutrition at Iowa State University. To obtain uniform cultures for the cheese making, *L. bulgaricus* AR2 and *S. thermophilus* AC2 were inoculated (1%) into separate flasks of 10% reconstituted nonfat dry milk (Carnation Co., Los Angeles, CA) and incubated 48 h at 40 and 37°C, respectively. *Propionibacterium shermanii* P19 was inoculated (2%) in sodium lactate broth and incubated at 32°C for 48 h. After two additional transfers, 18-h cultures of each organism were mixed with pure glycerol at a 2:1 ratio, 1-mL amounts were distributed aseptically to plastic tubes, and the tubes were stored at −70°C. For use in cheese making, the frozen cultures were transferred three times using 1% inoculum in the media indicated above and incubated for 36 h for the first transfer and 18 h for subsequent transfers. A commercial mesophilic DVS Freeze-dried culture R-704 was purchased from Chr. Hansen's Inc. (Milwaukee, WI). The culture was distributed aseptically into plastic tubes at 2 g or 15 units/tube and stored at −40°C until used by direct addition to the cheese vat.

Homogenization of fat sources into skim milk. Skim milk (Anderson & Erickson, Des Moines, IA) was purchased locally and homogenized with the various test fats using a Gaulin two-stage homogenizer (model 18M-8TA; AVI Gaulin Corp., Wilmington, DE). The first stage of the homogenizer was set at 140 kg/cm^2 and the second at 50 kg/cm^2. The oil was warmed to 60°C in an oven. Gum acacia (TIC Gums, Belcamp, MD), which was used as an emulsifier, was stirred into the oil at 1.5% of the oil weight. The skim milk was heated to 60°C in an electrically heated kettle (model TDC/TA/40; Groen Company, Elk Grove, IL). Half of the skim milk (50 kg) was pumped continuously from the kettle to the homogenizer using a peristaltic pump (Masterflex I/P; Cole-Parmer Instrument Company, Vernon Hills, IL) fitted with a model 7529-10 Easy-Load pump head and #6419-73 Masterflex Tygon food-grade tubing at 0.84 L/min. At the same time, the oil was pumped to the homogenizer using a second peristaltic pump (Masterflex model 7520-00; Cole-Parmer Instrument Company) fitted with a model 7018-52 pump head and #6419-17 Masterflex Tygon food-grade tubing at 0.047 kg/min. The milk and oil in the feed vessel were mixed vigorously at 300 rpm by a mixer head (Model 745-5010; Barnant Co., Burlington, IL). The homogenized milk was collected in a sanitized milk can and mixed with the remaining skim milk in the cheese vat.

Cheese making. Seven types of Swiss cheese-like products were made in duplicate in random order by the method described by Reinbold (21) for Iowa-style Swiss cheese (Table 1).

Packaging of cheese. After brine salting, the cheese block was allowed to dry at 4°C. Then the block was vacuum-packed using a Koch vacuum package machine (Koch Supplies, Inc., Kansas City, MO) in a Curlon grade 861 polyethylene pouch (Curwood, Oshkosh, WI). After 3 mon ripening, the cheese blocks were cut into twenty 1-lb portions, samples were removed for the texture profile analysis (TPA), and the remaining portions were repackaged under vacuum in 8 × 12 Curlon grade 861 polyethylene pouches and stored at −20°C until analyzed.

Texture profile analysis. A TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) with Texture Expert for Windows (Version 1.0 software) installed was used

TABLE 1
Procedure for Manufacture of Iowa-Style Swiss Cheese (21)

Operation	Time	Temperature (°C)	Remarks
Fill vat		32	Approx. 107 kg skim milk with 2.8% various fats
Add starters		32	2 g lactic culture, 4.1 g *Lactobacillus bulgaricus,* 240 g *Streptococcus thermophilus,* 14.6 g *Propionibacterium shermanii*
Ripening	30 min	32	
Rennetting	30 min	32	Add 19.8 mL rennet in 594 mL water
Cutting	10 min	32	0.64 cm knives
Foreworking	10 min	32	
Whey removal		32	26 kg whey removed
Cooking		41	Replace whey with 26 kg 145°F water
Stir-out	2 h from start of cut	41	
Vat press	30 min under whey, 30 min without whey		23 kg weight
Hoop press	Approx. 18 h	22–26 room	9 kg Wilson hoops
Brine salting	2 d	4	
Drying	Few hours	4	
Packaging			Vacuum packaging
Cold room	10 d	4	
Warm room	Approx. 3 wk	22 room	
Finished cooler	3 mon from start day	4	

for TPA (22). Samples were taken from ripened unfrozen cheese using portions without eyes and at least 1 cm from the outer edges. Cylindrical samples (25-mm diameter × 23-mm height) were sealed in plastic bags and tempered at 23°C for 2 h before analysis (23,24).

A two-cycle compression test was performed at room temperature. The machine was calibrated with a 5-kg loading cell. Each sample was compressed to 80% of its initial height by using a 37-mm diameter flat plate probe. The crosshead speed was 18 mm/min (24,25). Ten samples were tested for each treatment. The texture parameters (hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness) were calculated from the textural profile curves by Texture Expert software. Hardness was defined as the maximum force (N) recorded during the first compression cycle. Adhesiveness was the negative force area for the first cycle, representing the work necessary to pull the compressing plunger away from the sample. Springiness was the ratio of the width of the down stroke of the second cycle to the width of the down stroke of the first cycle. Cohesiveness was the ratio of the positive area during the second compression to that during the first compression. Gumminess was the product of hardness × cohesiveness, and chewiness was the product of gumminess × springiness.

Sample preparation for free fatty acids and other chemical analysis. Samples for free fatty acids and gross composition were prepared according to the AOAC Official Method 955.30 (26). Cheeses were thawed at 4°C overnight, then the portion representing the center from all directions of the original cheese block was cut into strips and grated.

Sensory analysis of cheese. Cheeses were thawed overnight at 4°C, and samples were taken at least 2 cm from the outer edges of the cheese block and cut into 1-cm cubes. The cubes were tempered in plastic bags for 0.5 h at room temperature, and each sample was given a random number. Fourteen panelists were trained in four 1-h sessions. Panelists were familiarized with the score card and the flavor attributes of Swiss cheese using cheeses that represented a wide range of flavor attributes. Line scales (15 cm) were used to evaluate sweetness, saltiness, sourness, bitterness, volatiles, typical Swiss-cheese flavor, and caramelized flavor (14,15,17). The absence of a flavor scored 0 and a strong flavor 15. A maximum of four samples was evaluated in each tasting session. The panelists were supplied with distilled water and unsalted crackers to cleanse their palates between samples. Samples were presented to the panel in random order in individual sensory booths. After all the cheeses had been evaluated once, they were evaluated a second time in random order.

Free fatty acids analysis. Free fatty acids were extracted from the cheese by the method of de Jong and Badings (27). Duplicate 1.0-g samples of the grated cheese were ground with 3.0 g anhydrous sodium sulfate (Fisher Scientific, Fair Lawn, NJ) using a mortar and pestle. The sample was treated with 0.3 mL 2.4 M sulfuric acid, and 1.0 mL of an internal standard solution containing valeric, tridecanoic, and heptadecanoic acids (Sigma Chemical Co.) was added. The mixture was extracted three times with 3 mL of diethyl ether/heptane (1:1, vol/vol), and the extract was clarified by centrifugation at 15 × g for 2.5 min. The upper layers were combined and dried with 1.0 g sodium sulfate. The combined solvent extracts were applied on a 500-mg Extract Clean NH_2 cartridge (Alltech Associates, Inc., Deerfield, IL) that was preconditioned with 10 mL heptane (Fisher Scientific). The neutral lipids were eluted from the cartridge with 4 mL chloroform/2-propanol (2:1, vol/vol), and free fatty acids were eluted with three 2-mL lots of 2% formic acid (Sigma Chemical Co.) in diethyl ether. The free fatty acids in the eluate were neutralized by shaking with 1.5 mL 10% sodium carbonate solution for 5 min, the diethyl ether was evaporated under nitrogen, and water was evaporated on a steam bath (28). Next, 300 μL decanol and 100 μL concentrated sulfuric acid were added and, after mixing, the reaction mixture was incubated at 56°C overnight. After reaction, 0.5 mL water and 0.5 mL hexane were added, and the mixture was centrifuged at 1500 × g for 2 min. The hexane phase was applied to a 900-mg Maxi-clean silica cartridge (Alltech Associates, Inc.) that was preconditioned with 5 mL hexane, and the decyl esters were eluted from the column with 6 mL 5% ether in hexane solution. The solvent was removed under nitrogen, and the residue was dissolved in 0.5 mL hexane and analyzed by gas chromatography (GC) as described by Yu and Hammond (16).

Gross cheese composition. The moisture, fat, salt, pH, and titratable acidity (TA) of the cheeses were determined in duplicate. Moisture was determined according to the AOAC method 926.08 and fat by the AOAC method 933.05 (26). Salt content was determined by using a DiCromet Salt Analyzer (Model DSA-1000; Diamond Crystal Salt Company, St. Clair, MI) using 10 g of cheese blended with 100 mL of water and filtered through a drip coffee filter paper. The pH was measured with a pH meter (model SA 720; Orion Research Inc., Beverly, MA) on the same filtrate. For TA (AOAC Official Method 920.124) (26), 25 g of the cheese filtrate was titrated with 0.1 N NaOH using phenolphthalein as an indicator. The results were expressed as percentage of lactic acid.

Statistical analysis. Analysis of variance (ANOVA) (29) was used to analyze the sensory, chemical, and physical analysis data. When F-values were significant, least significant differences (LSD) at $P \leq 0.05$ were calculated. Principal component analysis was performed for fatty acid data using SAS FACTOR procedures. Correlation analysis was performed to correlate sensory results with those of instrumental analysis using the SAS CORR procedure. Multiple linear regression was performed using the SAS REG procedure to generate a model for volatile and typical Swiss flavor.

RESULTS AND DISCUSSION

Flavor characteristics and free fatty acid content of the cheeses. The data from sensory and free fatty acid analyses are presented in Tables 2 and 3, respectively. The flavors of

TABLE 2
Flavor Characteristics of Swiss Cheese-Like Products Made with Various Fats[a]

Cheeses	Sweet	Salty	Sour	Bitter	Volatile	Swiss-cheese flavor	Caramelized
HOSO control	$5.50^{d,c}$	$4.67^{a,b}$	$5.84^{a,b,c}$	4.26	$5.71^{d,c}$	5.08^{c}	3.33
MF control	$6.00^{b,c}$	$3.83^{b,c}$	$5.20^{b,c}$	3.70	$6.69^{b,c}$	$8.38^{a,b}$	3.70
RDM MF control	$6.38^{a,b,c}$	5.17^{a}	6.99^{a}	4.71	$7.38^{a,b}$	7.72^{b}	3.19
Modified HOSO with 100% commercial SCFA	7.55^{a}	$4.71^{a,b}$	$6.66^{a,b}$	3.45	$7.49^{a,b}$	9.11^{a}	3.77
Modified HOSO with 100% MF SCFA	$7.21^{a,b}$	4.92^{a}	$5.93^{a,b,c}$	3.56	$7.58^{a,b}$	$8.78^{a,b}$	4.00
Modified HOSO with 120% Commercial SCFA	5.89^{c}	4.93^{a}	7.15^{a}	4.38	8.73^{a}	$7.96^{a,b}$	4.22
HOSO with SCFA dissolved	4.57^{d}	3.61^{c}	4.57^{c}	3.39	4.71^{d}	5.17^{c}	2.71

[a]Means of two replications and 14 panelists, where 0 represents no flavor and 15 an intense flavor. Means within columns followed by the same superscript roman letter are not significantly different ($P \leq 0.05$). Abbreviations: HOSO, high-oleic sunflower oil; MF, milk fat; RDM MF, randomized milk fat; SCFA, short-chain fatty acids.

cheeses made with HOSO with interesterified SCFA were not significantly different from the control cheeses that were made from milk fat or randomized milk fat. All cheeses made from interesterified HOSO had significantly higher sensory scores in volatile flavor and in typical Swiss flavor than cheeses made from unmodified HOSO or HOSO with SCFA dissolved in the oil. Modification of HOSO by interesterifying SCFA into it greatly improved the flavor of the cheeses. Bitterness and caramelized flavor were not significantly different among the treatments, in agreement with Johnson (15).

No major flavor differences were found between cheeses made from milk fat and randomized milk fat except that cheeses made from randomized milk fat were rated significantly more salty and sour. Thus, the more randomized distribution of SCFA in randomized milk fat did not cause major changes in cheese flavor. Consequently, we would not expect the random distribution of acyl groups in the interesterified HOSO to affect cheese flavor. Actually, we found that cheeses made from HOSO interesterified with SCFA at levels similar to milk fat had slightly higher scores in typical Swiss-cheese flavor and higher free SCFA than milk fat controls. However, the milk fat control was made by homogenizing isolated milk fat into skim milk, and such cheeses generally do not taste quite as good as cheese made from the natural milk emulsion (13–15). Possibly the milk fat globule membrane plays a significant role in cheese flavor development (14,15). The cheeses that were made from modified HOSO with SCFA interesterified at 120% that of milk fat scored the highest in both volatile flavor and sourness. The greater free SCFA in this type of cheese might contribute to the higher scores in these flavor attributes.

Cheeses made from unmodified HOSO (HOSO control and HOSO with SCFA dissolved) had the lowest scores in typical Swiss flavor and volatiles. This lack of flavor may be attributed to the very low SCFA (4:0 to 10:0) in the unmodified HOSO cheeses as shown in Table 3.

There were no significant differences in any flavor attribute among the three types of modified HOSO cheeses except in sweetness. Cheeses made from HOSO with 100% interesterified SCFA had the highest sweetness scores, whereas cheese made from HOSO with 120% SCFA incorporated had significantly lower sweetness scores.

The acetic and propionic acid contents in all the cheeses were within normal ranges (Table 3) (30,31), indicating a normal *Propionibacterium* fermentation (32).

The low amounts of free SCFA in the cheese produced from HOSO with SCFA dissolved might explain the poor flavor scores of this type of cheese. Possibly, the added SCFA were metabolized during cheese ripening and could not be replaced by hydrolysis of the cheese triglyceride to maintain their concentration in the cheese.

Chemical characteristics of cheese. Results from chemical analyses of cheeses other than for fatty acids are presented in Table 4. The moisture contents in the cheeses ranged from 38.27 to 40.97%, which was very close to the 39–41% moisture range reported as typical for Iowa-style Swiss cheese

TABLE 3
Free Fatty Acid Contents (mg/g) of Swiss Cheese-Like Products Made with Various Fats[a]

Cheeses	2:0	3:0	4:0	6:0	8:0	10:0	12:0	14:0	16:0	Pooled C_{18}	Pooled C_{20}
HOSO control	2.269	$6.921^{a,b,c}$	0.005^{e}	0.000^{c}	0.000^{c}	0.004^{b}	0.000^{c}	0.000^{c}	0.069^{d}	0.412^{d}	0.006^{d}
MF control	3.206	8.974^{a}	0.123^{d}	$0.008^{b,c}$	0.005^{c}	0.080^{b}	0.032^{b}	0.099^{b}	0.268^{b}	$0.768^{c,d}$	$0.043^{c,d}$
RDM MF control	2.219	$5.721^{b,c,d}$	$0.159^{c,d}$	0.064^{b}	$0.078^{a,b}$	0.122^{b}	0.138^{a}	0.378^{a}	0.886^{a}	$1.332^{b,c}$	$0.055^{b,c,d}$
Modified HOSO with 100% commercial SCFA	2.079	3.682^{d}	0.268^{b}	0.132^{a}	$0.076^{a,b}$	0.193^{b}	$0.012^{b,c}$	0.017^{c}	0.190^{c}	3.041^{a}	$0.129^{a,b,c}$
Modified HOSO with 100% MF SCFA	2.431	$8.081^{a,b}$	$0.203^{b,c}$	$0.050^{b,c}$	$0.036^{b,c}$	0.126^{b}	0.000^{c}	0.000^{c}	0.185^{c}	2.001^{b}	$0.139^{a,b}$
Modified HOSO with 120% SCFA	3.203	$7.740^{a,b}$	0.348^{a}	0.177^{a}	0.127^{a}	0.765^{a}	0.000^{c}	0.000^{c}	$0.130^{c,d}$	1.170^{c}	0.172^{a}
HOSO with SCFA dissolved	2.141	$4.028^{c,d}$	0.019^{e}	$0.001^{b,c}$	0.003^{c}	0.063^{b}	0.004^{c}	0.006^{c}	0.067^{d}	0.413^{d}	0.003^{d}

[a]Means of two replications. Means within columns followed by the same superscript roman letter are not significantly different ($P \leq 0.05$). See Table 2 for abbreviations.

TABLE 4
Chemical Analyses of Swiss Cheese-Like Products Made with Various Fats[a]

Cheeses	Moisture (%)	Fat (%)	Salt (%)	pH	TA (% lactic acid)	Nonfat solids (%)[b]
HOSO control	40.76[a]	27.92[b]	1.99[a]	5.33[a,b]	0.89[a]	31.32[b]
MF control	39.44[b,c]	28.42[a,b]	1.59[c]	5.39[a]	0.78[b,c]	32.15[b]
RDM MF control	40.13[a,b]	28.43[a,b]	1.77[b]	5.30[a,b]	0.81[a,b,c]	31.44[b]
Modified HOSO with 100% commercial SCFA	40.64[a,b]	26.20[b,c]	1.78[b]	5.28[a,b]	0.88[a,b]	33.16[b]
Modified HOSO with 100% MF SCFA	38.27[c]	24.97[c]	1.80[b]	5.37[a]	0.78[b,c]	36.76[a]
Modified HOSO with 120% commercial SCFA	39.47[b,c]	27.86[b]	1.59[c]	5.16[c]	0.77[c]	32.67[b]
HOSO with SCFA dissolved	40.97[a]	30.73[a]	1.82[b]	5.23[b,c]	0.81[a,b,c]	28.30[c]

[a]Means of two replications. Means within columns followed by the same superscript roman letter are not significantly different ($P \leq 0.05$).
[b]Calculated values. TA, titratable acidity. See Table 2 for other abbreviations.

(21). The fat contents ranged from 24.97 to 30.73% of total cheese weight. Generally, modified vegetable oil cheeses had slightly lower fat contents than did the unmodified vegetable oil and milk fat control cheeses, but this did not seem to cause any flavor or texture defects in the cheeses. The salt, pH, and TA of all cheeses were similar to those of other studies (15,30).

Principal component analysis. To reduce the number of variables and to identify groups of correlated variables, free fatty acids were subjected to a principal component analysis (33). Table 5 shows the factors produced by principal component analysis of fatty acids in whole cheese. The tabulated values are the factor loadings indicating the contribution of each fatty acid to the factors. The first three factors were retained because they had an eigenvalue larger than one, and they accounted for 83% of the total variance. Factor 1 was composed mainly of SCFA of chain length greater than 3, that is, the group of fatty acids used to modify the vegetable oils.

TABLE 5
Principal Component Analysis for Free Fatty Acids in Swiss Cheese-Like Products Made from Various Fats[a]

Fatty acids	Factor 1[b]	Factor 2[c]	Factor 3[d]
2:0	0.406	–0.276	0.805[e]
3:0	0.180	–0.251	0.852[e]
4:0	0.972[e]	0.070	–0.048
6:0	0.953[e]	0.072	–0.137
8:0	0.910[e]	0.246	0.033
10:0	0.837[e]	–0.080	0.035
12:0	–0.074	0.955[e]	0.259
14:0	–0.076	0.930[e]	0.310
16:0	0.042	0.967[e]	0.226
Pooled C_{18}	0.476	0.197	–0.593
Pooled C_{20}	0.768	–0.074	–0.095
22:0	–0.097	0.759	–0.264
Eigenvalue	4.42	3.55	2.04
Cumulative variance (%)	36.83	66.39	83.41

[a]Values in the table are the factor loading indicating the contribution of each fatty acid to the factors.
[b]Factor 1 was dominated by SCFA of chain length greater than 3.
[c]Factor 2 was dominated by medium- and long-chain fatty acids.
[d]Factor 3 was dominated by acetic and propionic acids produced by fermentation.
[e]Fatty acids that were regarded as high loadings for each factor. See Table 2 for abbreviation.

The medium- and long-chain fatty acids were grouped together in Factor 2. The first two members of this group are present only in milk fat. Factor 3 consisted mainly of the acetic and propionic acids produced by fermentation. Johnson (15) reported similar factor groups.

Correlation analysis. A simple correlation analysis was conducted within as well as between sensory and chemical parameters using the factors derived from principal component analysis, and the results are in Tables 6 through 8. Sensory sweetness, volatiles, Swiss-cheese flavor, and caramelized flavor were all correlated (Table 6), which was not surprising since these flavor notes were all considered components of typical Swiss-cheese flavor (14,15,17). Saltiness, sourness, and volatiles were correlated. Bitterness, which was considered a flavor defect (34), was not correlated to any other flavor parameters.

Moisture was positively correlated to salt content and TA and negatively to nonfat solids (Table 7). The higher moisture content might favor salt retention and provide more lactose for acid production. Fat content was negatively correlated to nonfat solids and Factor 1. Since fat and nonfat solids make up the solids of the cheese, their negative correlation is not surprising. These correlations are in agreement with results reported by Johnson (15). Salt content was correlated with TA and Factor 1. Nonfat solids content was correlated with Factor 1. The correlations among Factors 1 through 3 were zero, as expected of independent components (33).

Sensory sweetness, saltiness, sourness, volatiles, Swiss-cheese flavor, and caramelized flavor were negatively correlated with fat content (Table 8). Sweetness, volatile flavor, Swiss-cheese flavor, and caramelized flavor were correlated with nonfat solids content. Factor 1 (SCFA) was correlated with sourness, volatile flavor, Swiss flavor, and caramelized flavor. Factor 2 (medium and long-chain fatty acids) was not correlated to any of the other parameters. Factor 3 (acetic and propionic acids) weakly correlated with bitterness.

Multiple linear regression. Volatile flavor and typical Swiss-cheese flavor were regressed on all chemical parameters including the three fatty acids factors. A stepwise procedure was used as the model selection method to pick up any variables that were significant at the 0.150 level (35). The linear models generated for volatile and typical Swiss-cheese flavor were as follows:

TABLE 6
Correlation Coefficients Among Sensory Parameters for Swiss Cheese-Like Products Made from Various Fats[a]

Parameters	Sweetness	Saltiness	Sourness	Bitterness	Volatiles	Swiss-cheese flavor
Saltiness	0.312					
Sourness	0.380	0.716[b]				
Bitterness	–0.060	0.151	0.295			
Volatiles	0.652[b]	0.568[b]	0.648[b]	0.236		
Swiss-cheese flavor	0.805[b]	0.332	0.319	–0.188	0.737[b]	
Caramelized flavor	0.622[b]	0.172	0.227	0.064	0.724[b]	0.703[b]

[a]Correlation coefficients ≥0.532 were significant at 5% significance level (df = 12); correlation coefficients ≥0.458 were significant at 10% significance level.
[b]Correlation coefficients that were significant at $P \leq 0.05$.

TABLE 7
Correlation Coefficients Among Chemical Parameters for Swiss Cheese-Like Products Made from Various Fats[a]

Parameters	Moisture (%)	Fat (%)	Salt (%)	pH	TA (% lactic acid)	Nonfat solids (%)	Factor 1	Factor 2
Fat (%)	0.303							
Salt (%)	0.535[b]	–0.172						
pH	–0.075	–0.350	0.258					
TA (% lactic acid)	0.574[b]	–0.184	0.686[b]	–0.033				
Nonfat solids (%)	–0.700[b]	–0.893[b]	–0.124	0.297	–0.134			
Factor 1	–0.266	–0.500[c]	0.469[c]	–0.413	–0.197	0.501[c]		
Factor 2	0.071	0.072	0.277	–0.006	–0.047	–0.088	0.000	
Factor 3	–0.240	0.068	0.137	0.239	–0.124	0.063	0.000	0.000

[a]Correlation coefficients ≥0.532 were significant at 5% significance level (df = 12); correlation coefficients ≥0.458 were significant at 10% significance level.
[b]Correlation coefficients that were significant at $P \leq 0.05$.
[c]Correlation coefficients that were significant at $P \leq 0.10$. See Table 4 for abbreviation.

TABLE 8
Correlation Coefficients Among Sensory and Chemical Parameters for Cheese-Like Products Made From Various Fats[a]

Parameters	Sweetness	Saltiness	Sourness	Bitterness	Volatiles	Swiss-cheese flavor	Caramelized flavor
Moisture (%)	–0.369	0.130	0.144	–0.326	–0.343	–0.380	–0.515[c]
Fat (%)	–0.762[b]	–0.569[b]	–0.549[b]	0.166	–0.595[b]	–0.645[b]	–0.507[c]
Salt (%)	–0.144	0.318	0.143	–0.134	–0.394	–0.482[c]	–0.455
pH	0.172	0.007	–0.033	–0.228	–0.192	0.030	–0.250
TA (% lactic acid)	0.118	0.417	0.217	–0.187	–0.005	–0.089	–0.113
Nonfat solids (%)	0.746[b]	0.365	0.343	0.030	0.608[b]	0.663[b]	0.623[b]
Factor 1	0.396	0.469[c]	0.526[c]	0.123	0.756[b]	0.639[b]	0.613[b]
Factor 2	0.253	0.276	0.343	0.411	0.190	0.247	–0.147
Factor 3	–0.346	0.137	0.042	0.462[c]	0.117	–0.135	–0.104

[a]Correlation coefficients ≥0.532 were significant at 5% significance level (df = 12); correlation coefficients ≥0.458 were significant at 10% significance level.
[b]Correlation coefficients that were significant at $P \leq 0.05$.
[c]Correlation coefficients that were significant at $P \leq 0.10$. See Table 4 for abbreviation.

$$\text{volatile} = 6.90 + 1.04\ (\text{Factor 1}) \quad [1]$$

$$\text{typical Swiss-cheese flavor} = 34.27 - 0.64\ (\%\ \text{fat}) - 8.72\ (\%\ \text{salt}) + 7.96\ (\%\text{TA}) + 0.40\ (\text{Factor 2}) \quad [2]$$

The model for volatiles had an R^2 of 0.57, and the model for Swiss-cheese flavor had an R^2 of 0.91.

Texture characteristics of cheese. The texture profile analysis of the experimental Swiss cheese-like products is presented in Table 9. Differences were noted only in cohesiveness. Cheeses made with milk fat or randomized milk fat were significantly less cohesive than the HOSO control cheeses. The cohesiveness value of all interesterified HOSO cheeses fell between those of the unmodified HOSO and the milk fat control cheeses. Strugnell (8) indicated that the Ched-

TABLE 9
Texture of Swiss Cheese-Like Products Made from Various Fats[a]

Cheeses	Hardness (N)	Adhesiveness (N)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N)
HOSO control	15.81	0.70	0.92	0.88[a]	13.87	12.77
MF control	16.14	1.30	0.88	0.85[b,c]	13.63	11.90
RDM MF control	20.16	1.95	0.87	0.84[c]	16.80	14.61
Modified HOSO with 100% commercial SCFA	13.27	1.05	0.91	0.87[a,b]	11.52	10.50
Modified HOSO with 100% MF SCFA	12.73	1.17	0.89	0.87[a,b]	10.99	9.73
Modified HOSO with 120% commercial SCFA	14.81	0.65	0.89	0.86[a,b]	12.73	11.31
HOSO with SCFA dissolved	17.01	0.93	0.90	0.87[a,b]	14.78	13.25

[a]Means of two replications. Means within columns followed by the same superscript roman letter are not significantly different ($P \leq 0.05$). See Table 2 for abbreviations.

dar cheese made with sunflower oil was soft and more crumbly than control cheeses made with milk fat. Whitehouse (14) found that interesterified HOSO cheeses were significantly harder but more crumbly than the control cheeses made with milk fat.

Commercial feasibility of production of Swiss cheese from modified HOSO. The cost for the synthesis of short-chain triglycerides from commercial SCFA is estimated to be $5.01/kg based on the current costs of free fatty acids [(36) and KIC Chemicals Inc., Armonk, NY], glycerol (36), *p*-toluenesulfonic acid (Sigma Chemical Co.), and toluene (Sigma Chemical Co.). The current price of HOSO (AC Humko) is $1.34/kg. Therefore, the cost of HOSO interesterified with SCFA at 100% of the level in milk fat is calculated around $1.91/kg for the material, and this cost might be reduced to $1.67/kg if *p*-toluenesulfonic acid and toluene could be recycled. Processing cost might add $0.10 to $0.20/kg to the cost of modified HOSO. The price of butterfat shifts continuously and depends on import restrictions. Between 1992 and 1997 world prices ranged from $1.85 to $2.76/kg and averaged $2.20/kg (37). In 1998, the U.S. butterfat price was extremely high and averaged $4.86/kg for the year (38). Therefore, using modified HOSO instead of butterfat in cheese manufacture would frequently be economically advantageous.

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