CHEMICAL AND SENSORY CHARACTERIZATION OF COMMERCIAL SAUERKRAUT[1]

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ABSTRACT

Canned sauerkraut from eight U.S. companies was analyzed for salt, titratable acidity (TA), fermentation substrates and end products, volatile sulfur compounds and sensory characteristics. The TA ranged from 0.9–1.5%, while salt content ranged from 1.4–2.0%, which was lower than in previous surveys. High performance liquid chromatography (HPLC) was used to monitor lactic, acetic, malic, succinic, propionic and butyric acids; mannitol, ethanol, propanol, glycerol, glucose, fructose and sucrose. Low concentrations of propionic acid, propanol and glycerol were found. These three compounds are not characteristic of lactic acid fermentations. No butyric acid was detected. GC analysis revealed seven main sulfur compounds (hydrogen sulfide, methanethiol, dimethyl sulfide, carbon disulfide, dimethyl disulfide, allyl isothiocyanate (AITC) and dimethyl trisulfide) and six other organic compounds (methanol, ethanol, n-propanol, 2propanol, acetaldehyde and ethyl acetate) in the headspace of sauerkraut juice. A profile panel characterized aroma, flavor and after-taste of sauerkraut with ten distinct notes. The sour, sulfur and salt notes had the greatest impact on sauerkraut flavor.

INTRODUCTION

Production of sauerkraut is a means of preserving cabbage in inexpensive, bulk storage. Ascorbic acid and other nutrients are preserved and desirable

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sensory properties are created by a proper fermentation. Consumption of sauerkraut in the United States has declined since the 1930s (USDA 1983), perhaps due to changing consumer preferences and lack of product uniformity (Fleming and McFeeters 1985). Pederson (1940) compared commercially canned sauerkraut and defined ideal ranges for acidity and salt content as an indication of good quality. Fleming and McFeeters (1985) compared different batches of fully fermented sauerkraut, which they defined as having no fermentable sugars left. Their taste panel results demonstrated a preference for 1–1.5% titratable acidity (TA, calculated as lactic acid) which was consistent with the good quality range of 1.1–1.5% TA cited earlier by Pederson (1940)

Acidity and salt concentrations, as well as the volatile organic components, are important to overall sauerkraut flavor. Lower molecular weight fatty acids of sauerkraut were identified by Vorbeck et al. (1961) using gas chromatography (GC). Of the eight found, n-butyric was found to be the most important compound contributing to off-odor; a taste panel characterized it as cheese-like at 7 ppm (Vorbeck *et al.* 1961). Lee *et al.* (1974) reported that isoamyl alcohol, n-amyl alcohol, acetaldehyde, diethyl acetal, ethylmethylacetal, and ethyl lactate could be responsible for differences in flavor of fermented and unfermented cabbage since the above are lacking in unfermented cabbage. The dominant odor components of both fresh and fermented cabbage were proposed to be allyl isothiocyanate (AITC), cis-hex-3-ene-1-ol, and dimethyl trisulfide (Lee *et al.* 1974). Gail-Eller and Gierschner (1984) detected hydrogen sulfide, dimethyl and diethyl mercaptan, and dimethyl and diethyl sulfide in the headspace of sauerkraut. Chin and Lindsay (1993) reported that in GC analysis of commercial sauerkraut dimethyl sulfide was 75% of the total headspace volatiles. Recently, methyl methanethiosulfinate and methyl methanethiosulfonate were suggested to possess characteristic sauerkraut aroma notes (Chin and Lindsay 1994).

The objective of this study was to characterize commercial sauerkraut currently produced in the United States by chemical and sensory methods. Chemical characterization involved titrimetric, HPLC, and GC analyses. Efforts were made to relate chemical characterization to taste panel evaluation of sauerkraut.

MATERIALS AND METHODS

Commercial sauerkraut from 8 companies (11 total lots) was analyzed for headspace volatiles, organic acids, alcohols, sugars, salt, and flavor. Each company's product was represented by 3 cans for each lot (14–16 oz), except

for lots Al and J which had only 2 cans. Company A was represented by 3 lots (1, 2, and 3), company B by 2 lots (1 and 2), and companies C-H by 1 lot each.

Titrimetric Analysis

Analyses of sauerkraut juice for pH, TA, and salt were carried out as previously described (Fleming *et al.* 1992).

High Performance Liquid Chromatography (HPLC) Analysis

Juice from sauerkraut samples (1.0 mL) was diluted 1:25 with deionized water. Iso-butyric acid and meso-erythritol were added as internal standards for HPLC analysis. Particles were removed from the diluted samples by centrifugation at 8,000 × g for 5 min in an Eppendorf microcentrifuge. HPLC for analysis of organic acids and alcohol was performed with a Phenomenex Resex ROA column (Phenomenex, Torrance, CA) eluted with 1.6 mM heptafluorobutyric acid. Organic acids were detected by a conductivity detector and alcohol by a pulsed amperometric detector. A detailed description of the procedure is given by McFeeters (1993).

Since fructose and mannitol were not resolved by the Resex ROA column, sugars were analyzed with a HPX-87P carbohydrate column with Carbo P (125-0119) and Cation H (125-0129) guard columns (BioRad Laboratories, Richmond, CA). Sample preparation was the same as described for acid analysis. The column was held at 46C and eluted with water. A refractive index detector was used to quantify the sugars.

GC Analysis

Samples of sauerkraut for GC analysis were prepared by weighing 1 g of sauerkraut juice into 10 ml glass headspace vials (Tekmar Company, Cincinnati, OH) and immediately clamping. Replicate samples were prepared, stored at 4C, and analyzed within 12 h of preparation. Juice samples were heated in a Tekmar 7000/7050 headspace autosampler for 5 min at 100C. After heating, the vials were pressurized to 103 kPa for 0.2 min and let equilibrate for 0.2 min. The 2 ml sample loop was filled for 0.5 min with a back pressure of 34 kPa and 0.2 min equilibration. Then the volatiles were injected into the GC using a transfer line heated at 50C. The Shimadzu 9A GC with flame ionization (FID) and flame photometric (FPD) detectors (Shimadzu Co., Columbia, MD) was equipped with a pre-injection stream splitter (9:1; FID:FPD). Dual 1 m ×

2 mm I.D. glass column packed with 80–100 mesh Porapack P (Waters, Milford, MA) with no packing in the injector or detector was used to separate compounds. The column had an initial temperature of 105C, initial hold time of 0.5 min, program ramp of 15C/min, final temperature of 225C, and a final hold of 0.6 min. Both flame ionization (FID) and flame photometric (FPD) detectors were used, with an attenuation of 5 and a range of 10^2.

From each lot of sauerkraut, triplicate samples of juice from three separate cans were analyzed. Means of these analyses are reported. A heating trial was performed on one sauerkraut lot (A2) to determine if the sulfur compounds reported were naturally present or the result of heat-induced artifacts. Duplicate samples were analyzed using preheating injection temperatures of 40, 50, 70, 80, 90, and 100C for 5 min with the other GC conditions as previously described.

External standards were obtained by sampling headspace volatiles from standard compounds using a 5.0 μl gas tight syringe (Hamilton Co., Reno, NV). Volatiles were injected into the 10 ml glass headspace vials which were then immediately clamped. Vials were then heated on the headspace autosampler for 1 min at 100C and the headspace volatiles injected as described for juice samples.

Methanol, acetaldehyde, ethanethiol, n-propanol, 2-propanol, 2-butanol, dimethyl sulfide, carbon disulfide, dimethyl disulfide, and AITC were purchased from Aldrich Chemical Co. (Milwaukee, WI). Ethanol was purchased from Midwest Grain Products Co. (Pekin, IL), dimethyl trisulfide from Eastman Fine Chemicals (Rochester, NY), and toluene and ethyl acetate from Fisher Scientific Co. (Atlanta, GA). A.C.S. reagent grade chemicals were used. Hydrogen sulfide was generated by reacting sodium sulfide (Aldrich) with weak 0.5 N sulfuric acid. Methanethiol was tentatively identified based upon past studies with the same GC system.

Mass Spectrometry (MS)

Sauerkraut juice was analyzed using an electron ionization mass spectrometer (model HP 5985B) and RTE VI data system (Hewlett-Packard, Palo Alto, CA) with a Tekmar LSC-3 purge and trap concentrator inlet (Tekmar, Cincinnati, OH). Sampler glass tubes with a volume of 150 ml were half filled with juice and held at 40C for 15 min. Juice was purged with N_2 gas for 20 min at a flow rate of 4 ml/min. Volatiles were trapped on a Tenax column (Supelco, Philadelphia, PA), which was heated to send vapors to the 30 M, 0.25 μM film thickness, DB-5 capillary column (J & W Scientific, Inc., Folsom, CA). The column had an initial temperature of −20C, initial hold time of 3 min, program ramp of 4C/min, to a final temperature of 220C.

Sensory Evaluation

Sauerkraut samples were evaluated for aroma, flavor, and after-taste using a flavor profile panel of six to eight people trained to evaluate intensity attributes for both commercial canned sauerkraut and raw cabbage. The flavor profile panel had been trained using methods outlined by Oupadissakoon and Young (1984). The notes for aroma, flavor, and after-taste are listed in order of appearance during evaluation (Table 4). Panelists used a scale of 0 (not present) to 14 (strong). Write-in notes were used for any sensory characteristic not already present.

Statistics

Overall differences in GC compounds and taste panel notes among lots of sauerkraut were evaluated by analysis of variance. Variability of GC compounds within lots of sauerkraut (among the three cans per lot) was evaluated using t-tests of least squared means. Comparisons of taste panel scores among different lots of sauerkraut were evaluated using least significant difference (LSD) analysis (Steel and Torrie 1980). A standard deviation of the GC compounds for the three replicates per can and three cans per lot (total of nine analyses) of sauerkraut was calculated as outlined in Steel and Torrie (1980). A correlation was run between the means of lots for GC sulfur compounds and sulfur taste panel notes for aroma, flavor, and aftertaste.

SAS software was used for all statistical computations (SAS Institute, Cary, NC).

RESULTS

Chemical Characterization

Results of titrimetric analyses are shown in Table 1. The range for percent TA within companies A and B was relatively small, but the range for percent salt varied (1.4–2.0% for A, 1.5–1.9% for B) as much within as among companies. The resultant salt/acid ratio for all companies varied from 1.0–1.8. The pH of all samples ranged between 3.4 and 3.7.

HPLC analyses of sauerkraut samples are summarized in Table 2. Ranges in concentrations of compounds resulting from lactic acid fermentation of hexoses were lactic acid (111–178 mM), acetic acid (31–83 mM), mannitol

TABLE 1.
TITRIMETRIC ANALYSES OF COMMERCIAL SAUERKRAUT[a]

Company Code	Acidity, %[b]	Salt, %	Salt/Acid	pH
A1	1.2	1.4	1.2	3.4
A2	1.2	1.6	1.3	3.4
A3	1.2	2.0	1.7	3.4
B1	1.3	1.9	1.5	3.4
B2	1.5	1.5	1.0	3.5
C	1.1	2.0	1.8	3.5
D	1.1	1.5	1.4	3.5
E	1.5	1.8	1.2	3.5
F	1.4	2.0	1.4	3.6
G	0.9	1.4	1.6	3.7
H	1.1	1.7	1.5	3.5
Range	0.9-1.5	1.4-2.0	1.0-1.8	3.4-3.7
Average	1.2	1.7	1.4	3.5
CV (%)[c]	15	19	17	2.5

[a]Values are means of three samples/can and three cans, except for lots G and H, which consisted of two cans. Company codes are identified by letters A-H, and sublots for companies A and B by numbers.

[b]Calculated as lactic acid.

[c]Coefficient of variation.

(10–84 mM), and ethanol (15–82 mM). Relatively small (<2 mM) concentrations of malic, succinic, and propionic acids were present. No butyric acid was detected. Propanol (4.9–8.4 mM) was present in only 3 samples, and glycerol (0–3.4 mM) in all but one sample. Residual glucose was present in all but one sample, and averaged 31 mM. Residual fructose averaged 5 mM. No residual sucrose was detected in any of the samples. The lactic/acetic ratio range was 1.4–4.0. TA percent (Table 1) was generally consistant with lactic acid concentrations as measured by HPLC (Table 2).

GC with FID revealed 6 major compounds, including methanol, acetaldehyde, ethanol, n-propanol, 2-propanol, and ethyl acetate. Seven major compounds were detected by FPD, including hydrogen sulfide, methanethiol,

TABLE 2.
CHEMICAL COMPOSITION OF COMMERCIAL SAUERKRAUT AS DETERMINED BY HPLC[a]

Company Code	Concentration, mM[b]									
	Lactic Acid	Acetic Acid	Lactic/ Acetic	Propionic Acid	Glucose	Fructose	Mannitol	Ethanol	Propanol[c]	Glycerol
A1	116	83	1.4	0.0	3	0	10	49	0	0
A2	132	38	3.0	0.2	0	2	26	15	0	0.8
A3	133	37	4.0	0.1	49	3	64	41	0	3.1
B1	128	43	3.0	0.2	57	4	84	41	0	2.5
B2	178	68	3.0	0.3	49	3	45	56	8.4	1.8
C	118	41	3.0	0.8	21	2	46	16	0	1.4
D	117	46	2.5	0.1	32	0	71	48	0	2.8
E	167	40	4.0	0.8	18	2	45	82	4.9	3.4
F	162	48	3.0	0.3	26	3	40	34	0	2.6
G	104	37	3.0	0.1	53	18	46	26	0	2.1
H	111	31	4.0	0.2	35	22	26	37	4.9	0.5
Range	111-178	31-83	1.4-4.0	0-0.8	0-57	0-22	10-84	15-82	0-8.4	0-3.4
Average	136	46	3	0.3	31	5	46	41	1.7	1.9
CV (%)[d]	18	34	25	90	64	148	46	52	175	59

[a]Malic and succinic acids were detected in low concentrations in some samples. Butyric acid and sucrose were not detected in any of the samples.

[b]Values are averages of 3 cans, except for lots A1, G, and H, which had 2 cans.

[c]Propanol was detected by GC in all of the samples.

[d]Coefficient of variation.

dimethyl sulfide, carbon disulfide, dimethyl disulfide (DMDS), allyl isothiocyanate (AITC), and dimethyl trisulfide (DMTS). Chromatograms for lots A2 and C are shown in Fig. 1 for both FID and FPD detectors. Statistically significant differences ($P \leq 0.05$) occurred in concentrations of these compounds analyzed by GC among different lots of sauerkraut, except for AITC (data not shown). These samples of commercial sauerkraut contained either none or relatively low concentrations of AITC compared with other volatile compounds detected. All 5 of the sulfur compounds (hydrogen sulfide, methanethiol, dimethyl sulfide, DMDS, and DMTS) present when the company A2 juice was heated at 100C were present at the other injection temperatures of 40, 50, 70, 80, and 90C. AITC was not present at any of these temperatures in the A2 samples used to conduct the heating study; however, it was present in the A2 sample shown in Fig. 2. The heating study indicated that sauerkraut juice should be heated to at least 70C for adequate vaporization of the sulfur compounds present because at the lower temperatures results were not

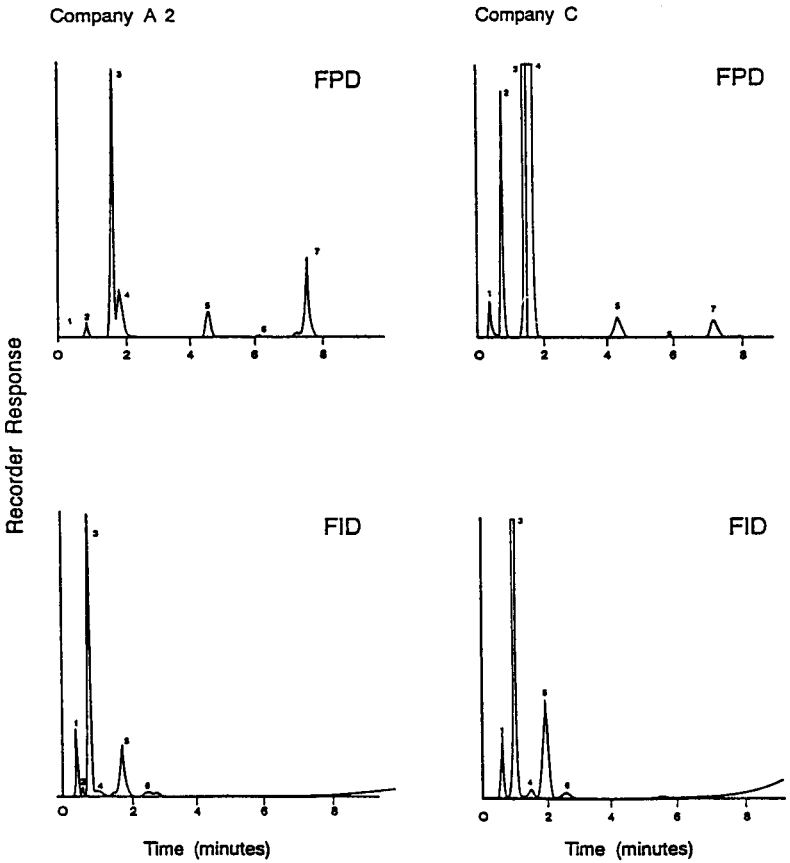

FIG. 1. GAS CHROMATOGRAMS FROM HEADSPACE ANALYSIS OF SAUERKRAUT JUICE
The juice was from companies A2 and C. Peak identification for FPD: 1 = hydrogen sulfide, 2 = methanethiol, 3 = dimethyl sulfide, 4 = carbon disulfide, 5 = dimethyl disulfide, 6 = allyl isothiocyanate, 7 = dimethyl trisulfide. Peak identification for FID: 1 = methanol, 2 = acetaldehyde, 3 = ethanol, 4 = 2-propanol, 5 = N-propanol, 6 = ethyl acetate.

reproducible. The duplicate samples injected at 90C had the lowest coefficient of variation when compared with the whole range of injection temperatures studied.

Lot A1 sauerkraut was also analyzed by GC/MS. Results from the MS analysis are shown in Table 3 which compares results from MS analysis with the results from the headspace GC system that involved use of external standards for peak identification. Ethanethiol, 2-butanol, and toluene were not found in the headspace GC system in any of the sauerkraut lots, including A1, even though

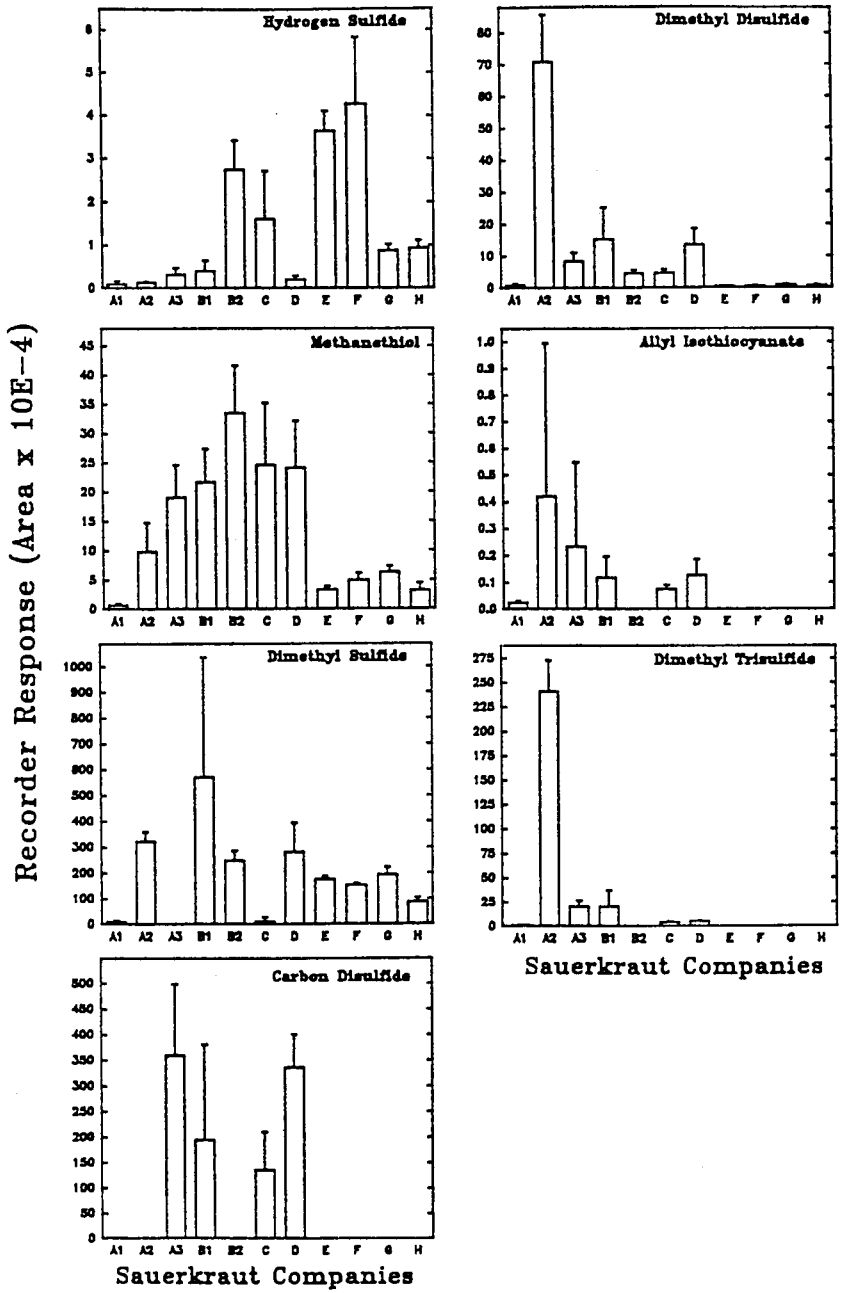

FIG. 2. VARIATIONS IN VOLATILE SULFUR COMPOUNDS AMONG LOTS OF COMMERCIAL SAUERKRAUT

Error bars represent one standard deviation from the mean of three cans of sauerkraut, three samples per can.

TABLE 3.
COMPARISON OF VOLATILE ORGANIC COMPOUNDS DETECTED BY DIFFERENT GC SYSTEMS IN COMMERCIAL SAUERKRAUT

Compounds Identified[a]	Identification System[b]	
	Purge and Trap, GC/mass spec.	Headspace, GC
Sulfur compounds		
Hydrogen sulfide	-	+
Methanethiol	-	+
Ethanethiol	+	-
Dimethyl sulfide	-	+
Carbon disulfide	+	+
Ethane thiotic-S-methyl ester	+	0
Dimethyl disulfide	+	+
Allyl isothiocyanate	+	+
Dimethyl trisulfide	+	+
Other compounds		
Methanol	-	+
Ethanol	+	+
n-Propanol	+	+
2-Propanol	+	+
2-Butanol	+	-
Acetaldehyde	+	+
Propanol	+	-
2-Butanone	+	-
Toulene	+	-
Ethyl acetate	+	+
Acetic acid methyl ester	+	0
Propionic acid propyl ester	+	0
No. of unidentified peaks	13	2

[a]+ = detected compound; - = undetected compound; 0 = standard not run, so presence uncertain.

[b]See Materials and Methods for detailed description of these systems.

these compounds were detected using purge and trap GC\MS. Four of the sulfur compounds, carbon disulfide, DMDS, AITC, and DMTS, were identified by two distinct GC columns, those for the headspace and for the purge and trap systems. Also, all of the alcohols and aldehydes detected, except methanol and 2-butanol, were identified on both systems.

Data in Fig. 2 indicate variability in sulfur compounds among the 11 lots of sauerkraut. Lots A2, A3, and B1 were high in DMTS and DMDS and low in hydrogen sulfide. In contrast, lots E, F, G, and H were low in both DMTS and DMDS and high in hydrogen sulfide. Lots B2 and C also had low concentrations of DMTS and DMDS and greater concentrations of methanethiol and hydrogen sulfide. It is interesting to note that in each of the above nine lots, samples containing relatively high concentrations of DMTS and DMDS contained relatively low concentrations of hydrogen sulfide, and vice versa. Only lots A1 and G deviated from this trend.

Sensory Evaluation

Panelists evaluated all lots except for lot H, which arrived too late for inclusion. Lots A1 and A2 were established as reference samples. Overall, the sour, sulfur, and salt notes had the greatest impact in characterization of sauerkraut flavor. These notes were the first perceived in the panelist's mouth and received the highest intensity scores (Table 4). The sulfur note scores for aroma were significantly different ($P \leq 0.004$) among lots. Sulfur scores in flavor ($P \leq 0.07$) or after-taste ($P \leq 0.28$) were not. The highest sulfur aroma notes were observed in lots A1, A2, and F, whereas the higher flavor sulfur notes were found in lots A2 and B2. Data in Fig. 2 do not indicate a specific or group of sulfur compounds responsible for these higher sulfur scores. A correlation analysis between taste panel notes and GC sulfur volatiles showed no evidence of any single sulfur compound being linked to the taste panel sulfur notes. Also, the correlations between the total concentrations of sulfur compounds in the headspace of sauerkraut juice and the taste panel sulfur scores were not significant ($P \geq 0.05$).

The panel could not differentiate between TA of 1.3–1.5, but could pick out the lower acidity products. The same was true for salt concentration where panelists distinguished salt concentrations of 1.4% or below but not concentrations between 1.5 and 2.0%. Significant differences in sweetness ($P \leq 0.006$) seem to be more related to lower acidity than to concentration of sugars present. Exceptions were lots B1 and G, which had the highest sweet flavor and contained relatively larger amounts of glucose and fructose than other lots.

TABLE 4.
SENSORY EVALUATION OF COMMERCIAL SAUERKRAUT[a]

Notes	Probability of difference among lots[b]	Company means A1	A2	A3	B1	B2	C	D	E	F	G	LSD (P = 0.05)[c]
Aroma												
Sour	0.0001	10.0	8.5	7.3	6.6	6.7	6.5	6.5	6.4	7.9	6.0	0.97
Sulfur	0.004	9.0	7.8	6.8	6.8	7.1	6.5	6.7	6.3	7.7	6.1	0.89
Green	0.2	1.0	1.2	1.2	1.0	1.6	1.5	1.2	1.1	1.0	1.7	0.48
Sweet	0.06	2.0	2.7	1.7	2.3	2.6	2.3	1.7	3.0	2.6	2.4	0.76
Metallic	0.0001	3.0	2.0	1.0	1.0	2.7	1.0	1.3	1.3	2.0	2.4	0.54
Flavor												
Sour	0.0001	12.0	11.0	11.2	9.8	10.6	9.7	11.8	10.9	11.0	7.7	0.98
Sulfur	0.07	8.0	8.5	8.0	7.7	8.6	7.5	8.2	7.4	8.3	7.0	0.96
Salt	0.0001	8.0	9.0	9.8	8.5	8.7	9.2	9.8	9.0	9.7	6.6	0.82
Green	0.87	2.0	1.5	1.1	1.5	1.6	1.8	1.5	1.7	1.3	1.6	0.63
Sweet	0.006	2.0	1.2	1.8	2.5	1.9	1.8	1.7	2.0	1.9	2.3	0.51
Bitter	0.21	4.0	4.0	4.0	3.2	4.4	3.7	3.5	3.7	3.4	3.7	0.67
Metallic	0.22	3.0	2.0	1.8	1.7	2.9	2.2	1.8	2.3	2.6	2.7	0.80
Astringent	0.21	5.0	4.5	4.7	4.0	4.0	3.8	4.7	4.6	4.6	3.7	0.72
T & T burn[d]	0.81	4.0	3.7	3.5	3.3	3.7	3.0	3.3	4.0	3.7	3.9	0.88
After-taste												
Sour	0.0001	9.0	8.3	9.8	8.2	8.9	8.3	9.7	9.1	9.1	6.1	1.13
Sulfur	0.28	7.0	7.5	6.7	6.3	7.3	6.3	6.5	7.0	7.1	6.3	0.87
Bitter	0.01	3.0	4.2	3.3	2.7	4.1	3.3	2.7	3.4	4.1	3.9	0.81
Metallic	0.0006	3.0	2.3	1.7	1.2	3.0	1.7	1.3	2.3	3.0	2.7	0.77
T & T burn	0.63	4.0	3.7	3.5	3.5	3.7	2.8	3.2	3.7	3.6	3.1	0.76

[a]Scale 1-14; see Materials and Methods for explanation.

[b]Probability of difference.

[c]LSD = least significant difference at the 5% level of probability.

[d]Tongue and throat burn.

DISCUSSION

This study of 11 lots of commercially canned sauerkraut revealed several differences from similar previous studies (Table 5). Concentrations of acidity and salt were lower than earlier surveys, with TA ranging from 0.9–1.5% and salt ranging from 1.4–2% in the present study. Only one of the lots from the present study was outside of the ideal range of TA (1.1–1.5%), as suggested by Pederson (1940). He concluded that sauerkraut out of this range tends to be of

TABLE 5.
COMPARISON OF CURRENT FINDINGS WITH PUBLISHED REPORTS FOR ACIDITY AND SALT IN COMMERCIAL SAUERKRAUT

Researcher	Lots tested	Acidity, %[a]	Salt, %	Salt/acid ratio[b]	Lactic/acetic ratio
Pederson (1940)	332				
Range - found		0.8-1.6	0.7-3.4	0.9-2.7	1.4-6.0
Range - ideal		1.1-1.5	1.7-2.4	1.0-1.7	3.0-5.0
Fleming and McFeeters (1985)	10				
Range		1.2-2.3	0.7-2.3	0.5-1.0	4.0-5.0
Current study	11				
Range		0.9-1.5	1.4-2.0	1.0-1.8	1.4-4.0

[a]Calculated as lactic acid.

[b]Data for salt/acid ratio is from the same study as Pederson (1940), but published in Pederson et al. (1956); for other researchers, data is taken from listed study.

poorer quality. The current range in acidity found was smaller than that reported by Fleming and McFeeters (1985). The range of salt percentages in the present study had a smaller variability and a lower overall concentration than in preceding surveys. The percent salt range was even lower than the ideal range established by Pederson (1940). Even though salt content was lower than in earlier reports, the salt to acid ratio was higher since acidity was also lower. Pederson (1940) also used the lactic to acetic ratio as an indicator of good quality sauerkraut and reported that samples within a range of 5:1–3:1 were preferred, with samples below the 2:1 ratio being less preferred by sensory criteria. All but two of the present commercial lots were within the 5:1–3:1 range, as shown in Table 2. Variations in acetic acid concentrations could be responsible for the varying lactic/acetic ratios.

Of the compounds monitored by HPLC, several showed high variability among lots, including acetic acid, mannitol, ethanol, and glucose. In addition to lower salt concentrations which could lead to more variation in the *Leuconostoc mesenteroides* fermentation end-products, larger concentrations of glucose in some lots indicates that the sauerkraut was packed before fermentation was completed. Stopping the fermentation before all sugar was utilized might have led to the overall lower acidity products. Overall, commercial sauerkraut analyzed in the present study contained less acidity and salt than that in earlier reports (Pederson 1940 or Fleming and McFeeters 1985). Compared with earlier studies, we found more uniformity, with no butyric acid detected in any of the sauerkraut lots.

Even though the concentrations of the seven sulfur compounds varied significantly among lots, there was no noticeable trend linking differences to flavor (Fig. 2). The fact that we were unable to demonstrate a direct relationship between the detected sulfur compounds and sulfur flavor may be explained by four plausible possibilities. First, perhaps none of the GC sulfur compounds individually are essential for the sulfur notes present in sauerkraut. Perhaps a combination of these compounds needs to be present. Secondly, perhaps a compound(s) not detected by our analytical system, such as thiosulfinate or thiolsulfonate compounds suggested by Chin and Lindsay (1994), is an essential contributor to sulfur aroma and flavor in sauerkraut. Thirdly, perhaps the essential sulfur compounds detected are present at levels well above threshold. Flavor differences at higher concentrations of these compounds may not be easily distinguished by sensory evaluation. A study of the threshold concentrations for the sulfur and other compounds detected (as can be found in references such as Schutte 1974 and Fazzalari 1978) might be helpful in assessing the relative importance of volatile components to flavor. One or more of the sulfur compounds could dominate or mask odors of other sulfur compounds. An average percentage of sulfur compounds in the headspace of commercial sauerkraut was 1% hydrogen sulfide, 5% methanethiol, 63% dimethyl sulfide, 26% carbon disulfide, 2% DDS, 0.03% AITC, and 2% DTS. A fourth possibility is that the taste panel used in this study did not properly identify the characteristic sauerkraut sulfur notes since the total sulfur concentration did not correlate significantly ($P \geq 0.05$) with the panel sulfur aroma notes.

Since the present research, Kyung and Fleming (1994a) suggested the occurrence of 1-cyano-2,3-epithiopropane in fresh, disrupted cabbage. Subsequently, they found that 1-cyano-2,3epithiopropane rather than AITC is the primary hydrolysis product of sinigrin in fresh, disrupted cabbage (Kyung and Fleming 1994b). Important questions are raised by these recent findings. First, does fermentation influence the formation of AITC? We found low concentrations of AITC in this study in some but not all samples of sauerkraut tested. Secondly, is 1-cyano-2,3-epithiopropane present in sauerkraut, and does it have an important role in flavor? Unfortunately, we were unaware of the possible significance of this compound when this work was done and did not search for its presence. The possible role of 1-cyano-2,3-epithiopropane in sauerkraut flavor is still undetermined.

Further research is needed to determine the various factors influencing the development of sauerkraut flavor, including method of fermentation, salting treatment, and cabbage cultivar. Perhaps such studies will reveal improved methods for achieving more desirable and consistent sauerkraut flavor.

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