Cinnamaldehyde Content in Foods Determined by Gas Chromatography−Mass Spectrometry[†]

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trans-Cinnamaldehyde, the principal component of cinnamon flavor, is a potent antimicrobial compound present in essential oils such as cinnamon. In the course of studies designed to discover its maximum microbial lethality under food-processing conditions, a gas chromatographic−mass spectrophotometric procedure was developed for the extraction and analysis of essential oil components such as cinnamaldehyde from commercial cinnamon-containing foods (several brands of cinnamon breads, cereals, cookies, puddings, applesauces, and fruit juices). The cinnamaldehyde content ranged from trace amounts in orange juice to 12.2 mg/100 g (122 ppm) in apple cinnamon cereals and 31.1 mg/100 g (311 ppm) for cinnamon swirl bread (highest value). To ascertain the heat stability of cinnamaldehyde, pure cinnamaldehyde, pure eugenol, cinnamon oil, and mixtures consisting of cinnamaldehyde plus eugenol or cinnamon oil were heated at graded temperatures up to 210 °C and 60 min, and then possible compositional changes were examined. Eugenol was stable to heat, as were the components of cinnamon oil: carvone, eugenol, and linalool. In contrast, starting at ∼60 °C, pure cinnamaldehyde undergoes a temperature-dependent transformation to benzaldehyde under the influence of heat. Eugenol, both pure and in cinnamon oil, when added to pure cinnamaldehyde protected the aldehyde against heat destruction. The protection may due to an antioxidative action of eugenol. The possible mechanism of this effect and the significance of these findings for food chemistry and microbiology are discussed.

Keywords: *Carvone; carvacrol; cinnamaldehyde; eugenol, linalool; thymol; food analysis; gas chromatography; mass spectrometry*

INTRODUCTION

A need exists to establish whether plant-derived antimicrobial compounds that are reported to be effective against human pathogens such as *Escherichia coli* and *Salmonella* are stable to food-processing conditions including baking, cooking, frying, and microwaving as well as to prolonged storage after incorporation into food such as apple juice, baked products, and poultry. Studies in this laboratory (Friedman and Mandrell, 2000; Friedman et al., 2000) and elsewhere (Cerrutti et al., 1997; Hammer et al., 1999; Karapinar and Aktug, 1987; Kim et al., 1995; Parish et al., 1997) have found that essential oil constituents such as *trans*-cinnamaldehyde, eugenol, carvone, and carvacrol (all present in cinnamon and other oils) exhibit strong antimicrobial activity against several human pathogens. Because a variety of foods labeled with the word “cinnamon” are currently being consumed, the question arises as to how much cinnamaldehyde and other essential oil constituents are present in these foods. Thus, although cinnamon cereals and cookies may contain enough cinnamaldehyde to impart characteristic flavor, is the amount present sufficient to exert a beneficial antimicrobial effect?

The objectives of this study were to quantify and investigate the retention of the antimicrobial potencies of foods by (a) developing a gas chromatographic−mass spectrophotometric (GC-MS) method for the extraction and analysis of the components of cinnamon and other essential oils, (b) measuring the content of these and other compounds in essential oils and in a wide range of cinnamon-flavored commercial foods, and (c) determining the heat stabilities of cinnamon oil, *trans*-cinnamaldehyde, and eugenol, both individually and as mixtures, over a wide temperature range used in food processing. The results attest to the successful achievement of these objectives.

MATERIALS AND METHODS

Materials. Essential oils were obtained from Yerba Buena Co., Berkeley, CA. Commercial foods listed in Table 1 (cookies, breads, puddings, sauces, and juices) were obtained from local markets. All other compounds were obtained from Sigma.

Sample Preparation. *Cookies.* Five to twenty pieces were finely ground in a mortar. Samples (0.675−2.293 g) were extracted for analysis of components.

Breads. Each bread sample was cut with a knife into small pieces (2−6 mm) and mixed to evenly distribute the crust within the sample. A portion (0.885−1.77 g) of each was removed for extraction.

Puddings and Sauces. Each sample was stirred well with a glass rod, and a portion (1.580−2.98 g) was removed for extraction.

Juices. The sample size for orange and tomato juices was 2 mL and for apple juice, 5 mL.

Extraction of Essential Oil Compounds in Foods. Each sample was transferred to a 25 mL vial. Water (4 mL) was

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† Presented at the Division of Agricultural and Food Chemistry, National Meeting of the American Chemical Society, San Francisco, CA, March 19, 2000; Abstract AGFD 08.

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Published on Web 09/29/2000

Table 1. Foods Evaluated in These Studies

classification	trade name	producer or source	sample size (g)
breads	Apple Cinnamon muffin	Safeway Bakery	1.39−1.77
	Cinnamon Swirl bread	Best Food Baking Co.	1.18−1.42
	Cinnamon Honey Buns	Schwin Family	1.35−1.49
	gingerbread	Andronico's Bakery	0.89−1.00
cereals	Cinnamon Grins	Breadshop Natural Foods	0.92−1.04
	Cinnamon Toast Crunch	General Mills Sales, Inc.	0.87−0.90
	Cinnamon Grahams	General Mills Sales, Inc.	0.82−1.01
	Cinnamon Quaker Oats	The Quaker Oats Co.	0.87−1.08
	Apple Cinnamon Cheerios	General Mills Sales, Inc.	0.68−1.09
cinnamon powder	plain	Morton & Bassett	0.29
	Perfume	McCormick & Co.	0.28
	Spice Island	Burns Philp Food, Inc.	0.28
cinnamon sticks	plain	Morton & Bassett	0.23
	Spice Island	Philip Food, Inc.	0.23
cookies	Cinnamon Honey Hearts	Archway	1.20−1.24
	Chai Tea cookies	Mishelles	0.98−1.26
	Apple Cinnamon Newton/Cobbler	Nabisco	1.60−2.29
	Marie Lu (whole wheat and cinnamon)	M. C. Cookie Co.	0.89−0.93
juices	apple juice	Martinelli Co.	5[a]
	orange juice	Minute Maid Co.	2[a]
	tomato juice	Lucky Market	2[a]
oregano leaves	Spice Islands	Philp Food, Inc.	0.17
	High Mountain Greek	The Spice Hunter, Inc.	0.10
	Schilling Mexican	McCormick & Co.	0.15
puddings	bread pudding	Andronico's Bakery	1.58−1.65
	rice pudding	Andronico's Bakery	2.40−2.98
sauces	cinnamon applesauce	Town House	1.77−2.04
	cinnamon applesauce	Mott's, Inc.	1.53−2.41

[a] Milliliters.

added to each sample; the vials were sealed with a Teflon-lined cap and mixed gently by shaking. After standing for 2 h, each sample was spiked with 100 μL of methyl benzoate internal standard and extracted with ethyl acetate. Each extraction was carried out by vigorous shaking for 2−3 min with 8 mL of ethyl acetate. The samples were then allowed to stand for 30 min prior to transfer of the less dense ethyl acetate layer. Samples were extracted two more times with ethyl acetate. The combined ethyl acetate extracts were reduced to dryness with a stream of nitrogen at room temperature. The residue of each was dissolved in ethyl acetate (100 μL). Aliquots (1 μL) were used for GC-MS. Each experiment was performed in triplicate. Because the test compounds are all high-boiling liquids which are usually isolated from essential oils by steam distillation, it is unlikely that there were any losses during low-temperature concentration of the samples.

Quantitation of Carvone, *trans*-Cinnamaldehyde, Eugenol, Linalool, and Thymol by GC with Methyl Benzoate as the Internal Standard. The internal standard solution was prepared by dissolving 17.47 mg of methyl benzoate in 50 mL of ethyl acetate. To this ethyl acetate solution was then added a constant amount (200 μL) of the analytes [*trans*-cinnamaldehyde, eugenol, thymol, linalool, (*R*)-(−)-carvone, and (*S*)-(+)-carvone]. Aliquots (1 μL) were then injected into the gas chromatograph. The helium flow rate for the GC was 40 cm/s, eqivalent to 1.25 mL/min in a 0.25 mm i.d. column.

The peak area of the methyl benzoate standard and that of each sample were measured. A response factor (RF) for each analyte was calculated according to the following equation and used to quantitate the listed compounds present in essential oils and in commercial foods: RF = (mg of analyte/peak area of analyte) × (peak area of standard/mg of standard).

GC-MS of Essential Oil Components. The method was adapted from those of Biermann and McGinnis (1988), Freeman (1981), and Friedman et al. (1997). A portion of each oil (100 μL) was transferred to a 10 mL volumetric flask. The flasks were weighed in order to accurately determine the amount of oil transferred. Ethyl acetate was added to each flask to bring the volume to 10 mL. A portion (100 μL) of each diluted sample was transferred to a 5 mL vial and evaporated by passing a stream of nitrogen over its surface. The residue was dissolved in 200 μL of ethyl acetate containing methyl benzoate (3.49 mg) as an internal standard. One microliter of each solution was subjected to GC-MS analysis. The mass spectral parameters for the essential oil components were the same as in the experiments for the heat stability of cinnamon oil and eugenol described below.

GC-MS was performed on a GCQ gas−liquid chromatography ion trap mass spectrometer (Finnigan, San Jose, CA). The method was adapted from that of a previous study with other compounds (Friedman et al., 1997). Chromatography was performed using a 0.25 mm × 30 cm, 0.25 μm film, DB-5, fused silica column (J&W Scientific, Folsom, CA) with an average helium carrier gas flow set to a constant velocity of 40 cm/s. The split ratio of the column was 60:1. The injector temperature was set at 240 °C. The column oven temperature was held at 90 °C for 3 min, then programmed to 115 °C at 3 °C /min and then to 220 °C at 6 °C /min, and maintained at 220 °C for 3 min. The spectrometer was operated in the electron ionization mode with a source temperature of 200 °C. Positive ions were monitored while the analyzer was scanned from mass 40 to 500 every 0.75 s. Total ion current profiles were used for quantitation.

Heat Stability of Cinnamon Oil, Eugenol, and *trans*-Cinnamaldehyde. Samples (1.0−1.5 g) of cinnamon oil, eugenol, and *trans*-cinnamaldehyde were each dissolved in ethyl acetate (10 mL) in respective 25 mL flasks. An aliquot (200 μL) was transferred into respective 5 mL vials, and the solvent was evaporated by passing a stream of nitrogen over its surface. The vials were then closed with a sealed Teflon cap and placed in an oven. The samples were heated at different temperatures (50−200 °C) and time periods (5−60 min). After cooling, the residue was dissolved in 500 μL of ethyl

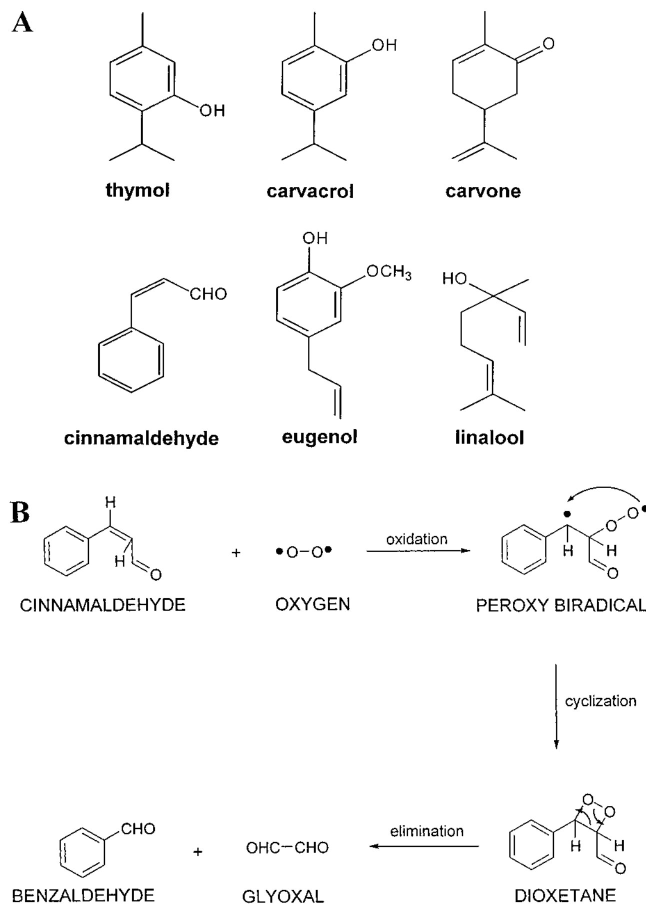

Figure 1. (A) Structures of compounds evaluated in this study. (B) Mechanism of postulated transformation of cinnamaldehyde to benzaldehyde and glyoxal (see text).

acetate. GC-MS analyses were carried out by co-injecting aliquots of this solution (1 μL) with 1 μL of internal standard solution.

Protective Effect of Eugenol against Decomposition of Cinnamaldehyde. Eugenol (245.4 mg) and *trans*-cinnamaldehyde (155.7 mg) were dissolved in ethyl acetate in 25 mL volumetric flasks. Cinnamon leaf oil (102.6 mg) was dissolved in ethyl acetate in a 10 mL volumetric flask. A portion of the ethyl acetate solution of *trans*-cinnamaldehyde (100 μL) was transferred to each of four 5 mL vials, and the ethyl acetate was then evaporated by passing a stream of nitrogen gas over its surface. After this evaporation, eugenol or cinnamon leaf oil (10 μL) was added to each vial and then evaporated under nitrogen gas. The vials were sealed with a Teflon cap and kept in an oven for 30 min at three different temperatures (80, 140, and 200 °C). One sample was kept at room temperature (25 °C). After cooling, the residues were dissolved in 100 μL of ethyl acetate. Aliquots (1 μL) of these solutions were subjected to GC-MS analyses. Two similar sets of experiments were conducted with 50 and 100 μL of eugenol or cinnamon leaf oil.

RESULTS AND DISCUSSION

Analytical Aspects. Figure 1A shows the structures of the essential oil components evaluated in this study. The following experiments were carried out to establish the accuracy and sensitivity of the analytical procedure. Four separate analyses with (*S*)-(+)-carvone were carried out to assess reproducibility. The average RF value for the four analyses was 1.048 ± 0.024. The following are the calculated RF values (average ± SD from triplicate determinations) for the other essential oil components evaluated in this study; (*R*)-(−)-carvone, 0.912 ± 0.036; *trans*-cinnamaldehyde, 0.624 ± 0.011; eugenol, 0.481 ± 0.015; linalool, 0.963 ± 0.012; thymol, 0.394 ± 0.012.

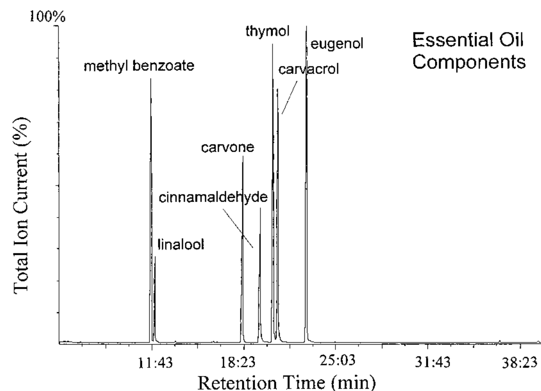

Figure 2. GC response of an artificial mixture of six essential oil components and internal standard methyl benzoate.

Figure 2 shows baseline separation in a gas chromatogram of a mixture of the six essential oil compounds evaluated in this study. Figure 3 shows a plot of concentration versus the ratio of analyte peak area to peak area of methyl benzoate (internal standard) from gas chromatograms for the six compounds. These data show a linear response for the instrument over the range of concentrations used for the GC-MS analyses. The tables also show that the SD values for triplicate analyses ranged from ~±2 to 10%.

Composition of Essential Oils, Cinnamon Powder and Sticks, and Oregano Leaves. Figures 4 and 5 illustrate the elution positions on gas chromatograms of essential oil compounds in cinnamon, oregano, and thyme oils. Identification of each of the peaks was confirmed by mass spectrometric library comparison (results not shown). Note that the GC program for cinnamon oil shown on top of Figure 4 was different from that of the other runs. Sixteen peaks were detected in a commercial cinnamon oil by GLC. Peaks corresponding to carvone, cinnamaldehyde, eugenol, and linalool were quantitated. The minor peaks were not identified.

Table 2 shows the measured values for each of the constituents. Cinnamon leaf oil contained predominantly eugenol. Cinnamon oil contained *trans*-cinnamaldehyde as the major component. Cinnamon bark oil contained both linalool and *trans*-cinnamaldehyde. Thyme oil contained thymol as the main component and small amounts of linalool and carvacrol. Oregano oil contained carvacrol as the main component and a small amount of thymol. The amount of active ingredients listed on w/v and w/w bases in the last two columns of the table show that total amount ranged from 50−60% for thyme oil to ~80% for cinnamon oils. The nature of the other components making up the difference from 100% in the volume or weights of the oils is not known.

Table 3 lists the amounts of *trans*-cinnamaldehyde and thymol measured in three cinnamon powders, two cinnamon sticks, and three oregano leaves purchased in grocery stores. The concentration of cinnamaldehyde in the cinnamon samples ranged from 8.2 to 27.5 mg/g. The three oregano leaf preparations contained thymol (6.2−9.6 mg/g). These data show that different spice products with the same name vary widely in their content of essential oil components.

Content of Essential Oil Components in Commercial Foods. Figures 6−8 show gas chromatograms

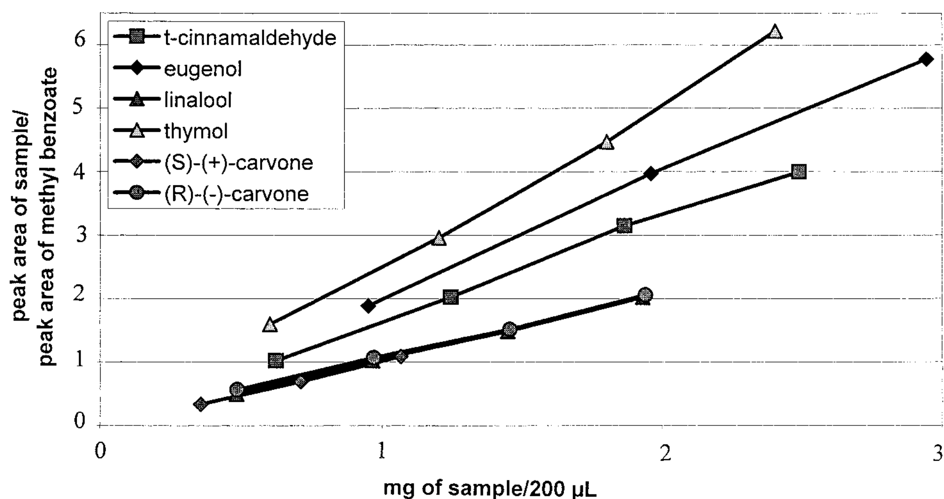

Figure 3. Plot of concentration of analyte versus the ratio of the analyte GC peak area to internal standard peak area for six essential oil components.

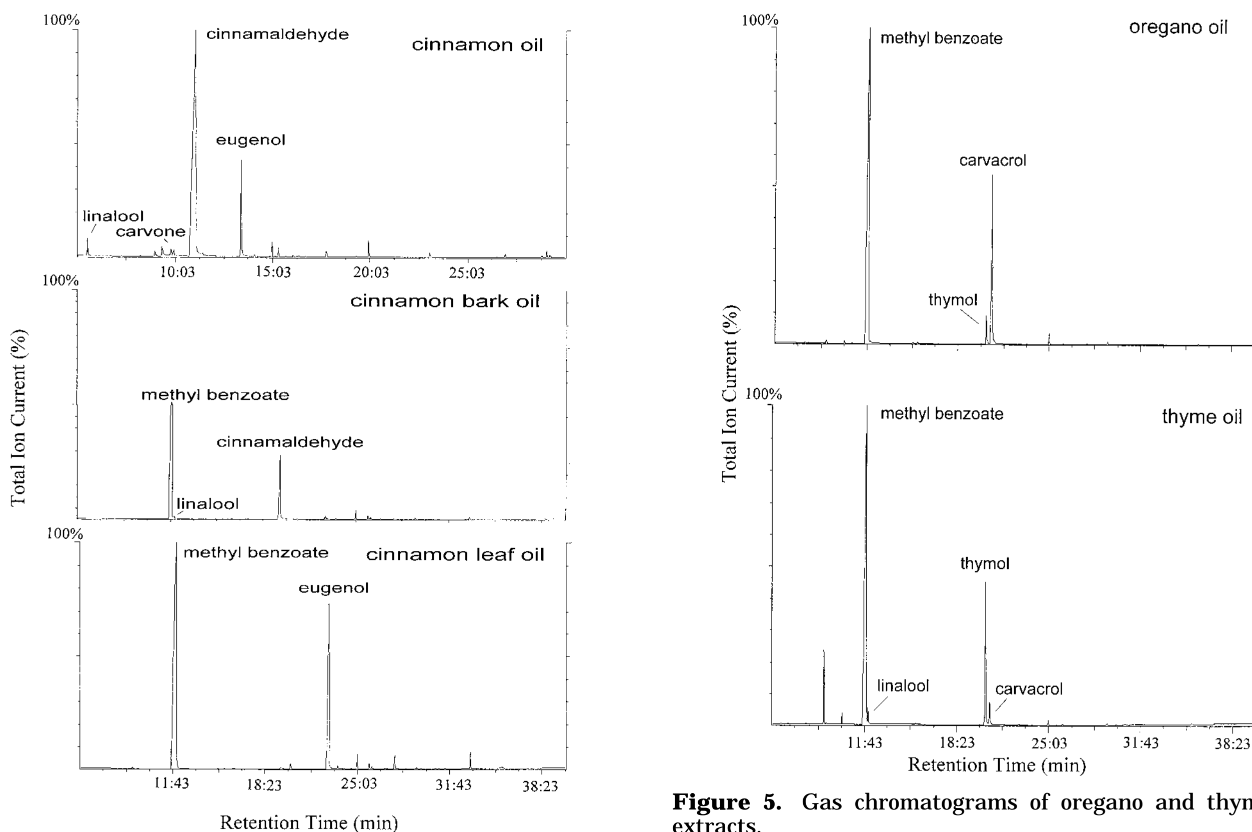

Figure 4. Gas chromatograms of extracts from cinnamon cassia oil, cinnamon oil from leaves, and cinnamon oil from bark.

Figure 5. Gas chromatograms of oregano and thyme oil extracts.

of extracts of cinnamon-containing breads, cookies, breakfast cereals, applesauce, and orange juice. The graphs show good separation of the essential components present in commercial foods. Table 1 lists the various foods evaluated in this study, the names of the manufacturers or distributors, and the amounts extracted for analysis by GC-MS. Table 4 lists the results of the analyses. The amount of cinnamaldehyde found varied widely, ranging from 0.05 mg/100 g (for ppm, multiply by 10) of cinnamon applesauce to 31.1 mg/100 g of cinnamon swirl bread. It is noteworthy that in milligrams per 100 g, the cinnamaldehyde contents of applesauce were 0.05 and 0.39 for the two samples evaluated; in baked goods the values ranged from 0.04 to 31.1 mg/100 g (four samples); in cereals from 1.8 to 21.9 mg/100 g (five samples); in cookies from 0.04 to 15.8 mg/100 g (four samples); and in puddings, the respective contents in the two samples were 0.49 and 1.9 mg/100 g. Only trace amounts were detected in apple and orange juices, and none was found in tomato juice.

Table 4 also shows that small amounts of eugenol (0.18–0.46 mg/100 g) were present in cinnamon applesauce, Apple Cinnamon Cheerios, orange juice, and bread pudding. Larger amounts of eugenol (18–20 mg/100 g) were present in chai tea cinnamon cookies and in cinnamon gingerbread. Vanillin was present in Cinnamon Grahams (10.4 mg/100 g) and cinnamon gingerbread (20 mg/100 g). Apple cinnamon muffins contained ethylvanillin (9.4 mg/100 g).

Table 2. Components in Five Different Essential Oils Identified by GC-MS[a]

oil	linalool	thymol	*trans*-cinnam-aldehyde	eugenol	carvacrol	% total in oil w/v w/v	% total in oil w/v w/w
cinnamon cassia	nd[b]	nd	81 ± 5.0	nd	nd	80.9	84.1
cinnamon bark	6.9 ± 0.7	nd	62 ± 1.6	nd	nd	68.6	68.9
cinnamon leaf	nd	nd	nd	70 ± 6.6	nd	69.9	68.2
oregano	nd	8.0 ± 0.8	nd	nd	62 ± 4.6	69.7	90.5
thyme	9.3 ± 0.8	37 ± 1.8	nd	nd	5.0 ± 0.3	51.2	60.8

[a] Listed values in mg/100 μL are averages of triplicate determinations ± SD. [b] nd, none detected.

Table 3. Essential Oil Components in Commercial Cinnamon Powder and Sticks and Oregano Leaves[a]

classification	trade name	concentration (mg/g) *trans*-cinnamaldehyde	concentration (mg/g) thymol	concentration (mg/g) unidentified substance	%[c]
cinnamon powder	plain	8.2 ± 0.5	nd[d]	nd	0.8
	Perfume	23.4 ±1.3	nd	nd	2.3
	Spice Island	27.5 ± 1.0	nd	nd	2.8
cinnamon sticks	Spice Island	10.3 ± 1.8	nd	nd	1.0
	plain	24.7 ± 1.8	nd	nd	2.5
oregano leaves	Spice Islands	nd	6.2 ± 1.7	16.9 ± 4.2[e]	2.3
	High Mountain Greek	nd	7.6 ± 0.9	1.8 ± 0.2	0.9
	Schilling Mexican	nd	9.6 ± 1.4	7.2 ± 1.2	1.7

[a] Listed values in mg/g are averages of triplicate determinations ± SD. [b] Unidentified substance is expressed as thymol equivalents. [c] Total detected essential oil as weight percent of product. [d] nd, not detected. [e] Cinnemaldehyde equivalent.

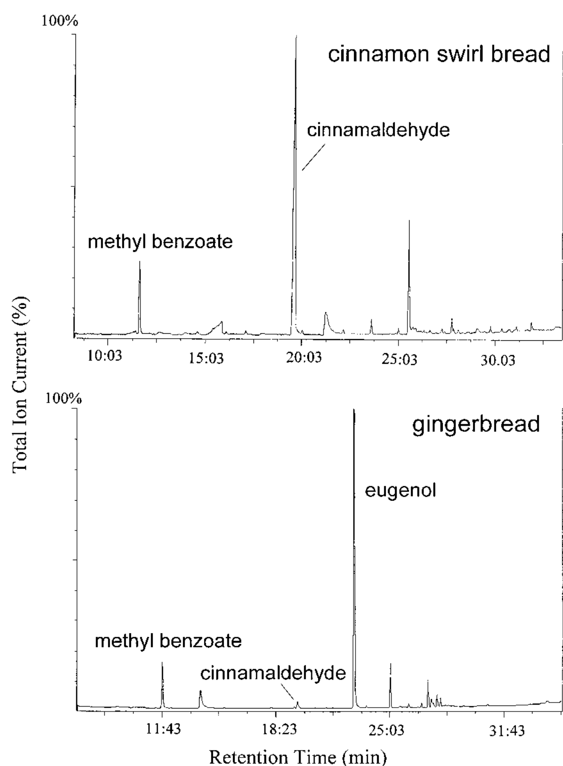

Figure 6. Gas chromatogorams of two cinnamon bread extracts.

These results show that the described extraction–analysis procedure can be used to measure the content of essential oil ingredients in a variety of commercial foods including juices, applesauces, breads, cookies, muffins, cereals, and puddings. They also show a wide ranging content of potential antimicrobial essential oil constituents in these foods. It may be worthwhile to increase the content of these ingredients in different food formulations, if it can be demonstrated that the presence of cinnamaldehyde, eugenol, and vanillin in food can protect the food, the consumer, or both in a dose-related manner against infection by human pathogens.

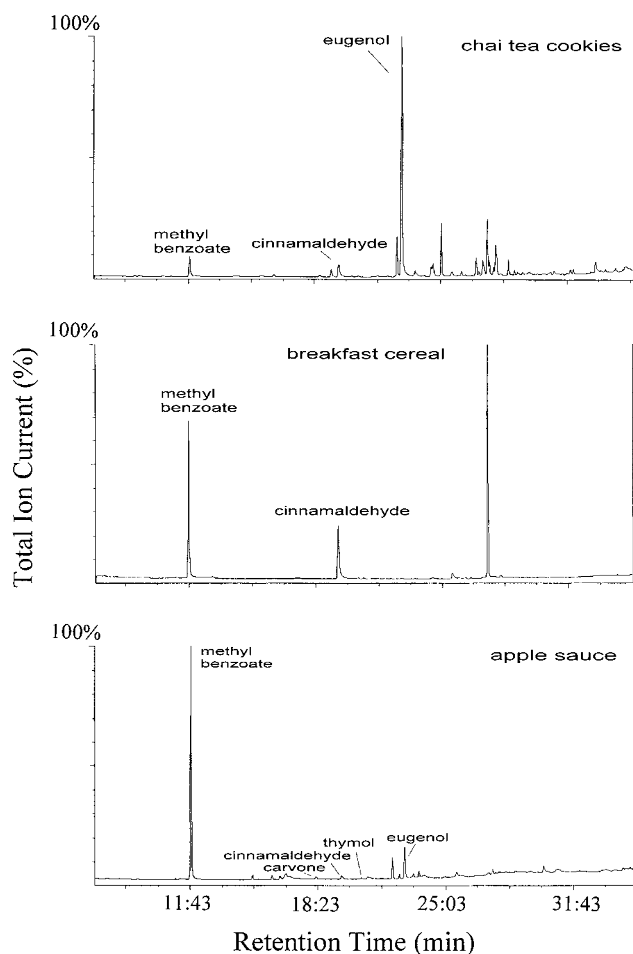

Figure 7. Gas chromatograms of extracts of cinnamon-containing chai tea cookies, breakfast cereal, and applesauce.

Stability of Cinnamaldehyde and Eugenol to Heat. To assess the stabilities of the four components present in cinnamon oil, we heated the pure oil in an oven at several temperatures ranging from 25 to 200 °C for time periods ranging from 5 to 60 min. Figure 9 shows gas chromatograms of extracts of cinnamaldehyde heated in the absence and presence of eugenol.

Table 4. Amount of Essential Oil Constituents in Commercial Food Products Identified by GC-MS (Milligrams per 100 g)[a]

cinnamon-containing product	*trans*-cinnnamaldehyde	eugenol	vanillin	ethylvanillin[b]
applesauces				
cinnamon applesauce (Mott's)[e]	0.05 ± 0.005	0.46 ± 0.18	nd[c]	nd
cinnamon applesauce (Town House)	0.39 ± 0.09	tr[d]	nd	nd
breads				
apple cinnamon muffin	nd	tr	nd	9.4 ± 1.6
gingerbread	0.86 ± 0.05	20.0 ± 1.0	nd	nd
cinnamon honey buns	8.4 ± 0.2	nd	nd	nd
cinnamon swirl bread	31.1 ± 2.8	nd	nd	nd
cereals				
Cinnamon Life	1.8 ± 0.2	nd	nd	nd
Cinnamon Grahams	6.8 ± 1.2	nd	10.4 ± 1.4	nd
Apple Cinnamon Cheerios	12.3 ± 0.6	0.22 ± 0.01	tr	nd
Cinnamon Toast Crunch	18.7 ± 1.4	nd	nd	nd
Cinnamon Grins	21.9 ± 0.9	nd	19.5 ± 1.0	nd
cookies				
Apple Cinnamon Newtons	0.04 ± 0.01	nd	tr	nd
Chai Tea	2.7 ± 0.1	18.0 ± 1.6	nd	nd
Cinnamon Honey Hearts	9.3 ±1.7	nd	nd	nd
whole wheat and cinnamon	15.8 ± 1.3	nd	nd	nd
juices				
tomato	nd	nd		
orange	tr	0.18 ± 0.03		
apple	tr	nd		
puddings				
bread pudding	0.49 ±0.01	0.19 ± 0.01	nd	nd
rice pudding	1.9 ± 0.3	nd	nd	nd

[a] Based on triplicate analyses. [b] Ethylvanillin is expressed as vanillin content. [c] nd, not detected. [d] tr, trace. [e] Carvone and thymol were detected in trace amounts in applesauce.

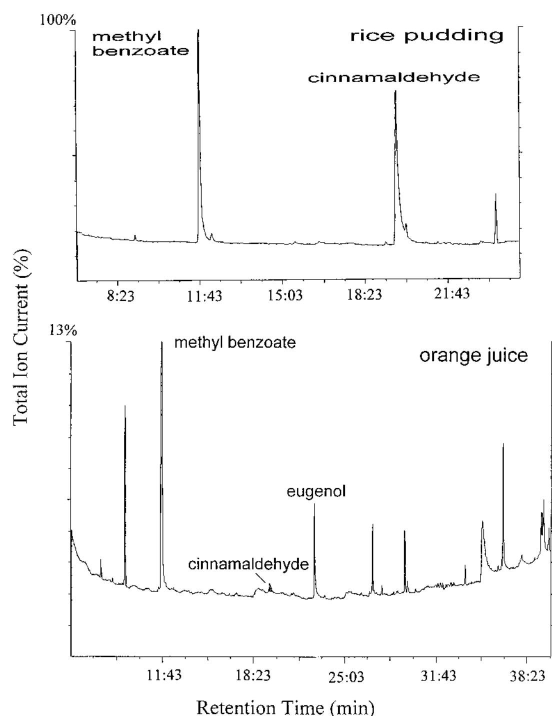

Figure 8. Gas chromatograms of extracts of cinnamon rice pudding and orange juice.

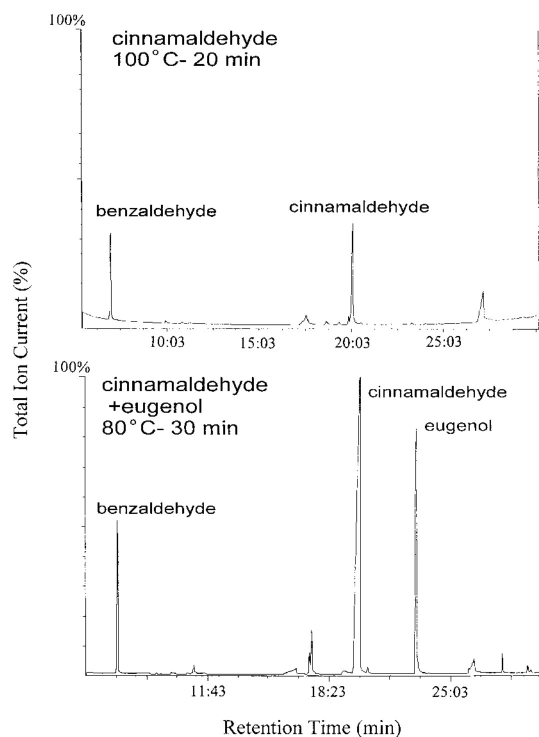

Figure 9. Gas chromatograms of cinnamaldehyde heated in the absence and presence of eugenol.

Table 5 shows that *trans*-cinnamaldehyde appeared to have survived all of the treatments and that carvone, eugenol, and linalool were also stable except at the highest temperature and time used (200 °C for 60 min).

We were therefore surprised to discover that in contrast to *trans*-cinnamaldehyde present in cinnamon oil, similar heat treatment of pure *trans*-cinnamaldehyde results in its partial decomposition. The decrease in cinnamaldehyde content was accompanied by the appearance of benzaldehyde (Table 6). Decomposition of cinnamaldehyde started at ~60 °C and remained the same at the higher temperatures. In contrast, eugenol was resistant to degradation when exposed to similar heat treatments (Table 7).

Because cinnamaldehyde was stable in cinnamon oil containing both cinnamaldehyde and eugenol and because pure cinnamaldehyde but not eugenol was susceptible to heat-induced transformation to benzaldehyde, it was of interest to find out what effect eugenol would have on the stability of cinnamaldehyde. Conse-

Table 5. Effects of Temperature and Time of Treatments on Each Peak Area in Cinnamon Oil Identified by GC-MS[a]

temp (°C)	time (min)	linalool	carvone	*trans*-cinnam-aldehyde	eugenol
25 (initial)		1.64	1.09	85.3	11.9
50	5	1.44	0.99	84.6	13.0
	10	1.33	0.79	84.8	11.9
	15	1.54	0.99	86.0	11.5
	20	1.43	0.97	84.8	12.8
75	5	1.50	0.96	85.5	12.0
	10	1.49	0.83	84.9	12.7
	15	1.74	0.97	84.8	12.5
	20	1.66	1.02	84.7	12.6
100	5	1.81	0.87	84.7	12.6
	10	1.62	1.03	84.3	13.1
	15	1.63	1.01	85.0	12.4
	20	1.49	1.01	84.9	12.6
	60	1.71	0.91	84.9	12.5
120	5	1.52	1.42	84.6	12.5
	10	1.48	0.85	85.1	12.57
	15	1.27	0.77	84.8	13.2
	20	1.51	1.19	84.9	12.4
	60	1.65	0.87	86.0	11.5
140	5	1.49	0.93	84.0	12.9
	10	1.56	0.99	84.9	12.5
	15	1.56	0.84	85.3	12.4
	20	1.60	0.70	85.8	11.7
	60	1.51	0.96	85.8	11.7
150	5	1.37	0.78	85.2	13.3
	10	1.60	0.93	83.5	14.0
	15	1.89	1.00	83.2	13.9
	20	1.60	0.87	85.8	11.7
	60	1.73	1.49	84.7	12.1
180	10	1.92	0.90	85.8	12.2
	20	1.63	1.99	84.4	11.9
	30	1.18	1.61	85.9	11.3
	40	1.16	1.29	86.6	10.9
	60	0.94	0.73	88.3	10.0
200	10	1.68	1.16	85.0	12.2
	20	0.62	1.21	85.3	12.9
	30	1.49	1.38	85.3	11.9
	40	1.36	1.04	85.2	12.2
	60	0.68	0.78	89.3	9.2

[a] The values are expressed as the ratio of each peak area to the sum of four peak areas for the four constituents.

Table 6. Effect of Temperature and Time of Heating on Decomposition of *trans*-Cinnamaldehyde

		% of total	
temp (°C)	time (min)	*trans*-cinnamaldehyde	benzaldehyde
25 (initial)		90.9	9.1
40	20	87.7	12.3
	40	88.2	11.8
	60	87.9	12.1
60	20	72.1	27.9
	40	63.1	36.9
	60	69.1	30.9
100	20	66.1	39.9
	40	57.6	42.4
	60	63.1	36.9
140	20	64.4	35.6
	40	53.7	46.3
	60	57.1	42.9
180	20	62.3	37.7
	40	63.1	36.9
	60	52.2	47.8
200	20	63.1	36.9
	40	64.5	35.5
	60	63.3	36.7
210	20	74.9	25.1
	40	73.4	26.6
	60	77.4	22.6

quently, we heated a mixture of cinnamaldehyde and three concentrations of eugenol and of cinnamaldehyde plus three concentrations of eugenol-containing cinnamon oil. The results (Tables 8 and 9) show that both pure eugenol and eugenol in cinnamon oil protected against heat-induced destruction of cinnamaldehyde. All

Table 7. Effect of Temperature and Time of Heating on Decomposition of Eugenol

		% of total	
temp (°C)	time (min)	eugenol	unidentified compound
initial		100	0
120	20	100	0
	40	100	0
	60	100	0
140	20	100	0
	40	99.6	0.4
	60	99	1
150	20	100	0
	40	98.7	1.3
	60	98.3	1.7
180	20	97.8	2.2
	40	97.8	2.2
	60	96.4	3.6
200	20	98.4	1.6
	40	98.9	1.1
	60	96.9	3.1
210	20	96.1	3.9
	40	97.2	2.8
	60	93.2	6.8

Table 8. Effect of Eugenol on Heat Stability of *trans*-Cinnamaldehyde

		% of total	
temp (°C)/heating time (min)	μL of eugenol	*trans*-cinnam-aldehyde	benzaldehyde
25/0	0	90.9	9.1
80/30	0	68.3	31.7
	10	90.1	9.9
	50	95.7	4.3
	100	90.4	9.6
140/30	0	71.2	28.8
	10	91.3	8.7
	50	90.3	9.7
	100	90.1	9.9
200/30	0	58	42
	10	88.1	11.9
	50	84.7	14.3
	100	89.1	11.9

Table 9. Effect of Eugenol-Containing Cinnamon Oil (Leaf) on Heat Stability of *trans*-Cinnamaldehyde

		% of total	
temp (°C)/heating time (min)	μL of eugenol[a]	*trans*-cinnam-aldehyde	benzaldehyde
25/0	0	90.9	9.1
80/30	0	68.3	31.7
	10	86.8	13.2
	50	90.9	9.1
	100	90.2	9.8
140/30	0	71.2	28.8
	10	85.3	14.7
	50	91.9	8.1
	100	86.5	13.5
200/30	0	58	42
	10	87.7	12.3
	50	88.9	11.1
	100	84.1	15.9

[a] The amount of cinnamon (leaf) oil used that contains the listed values of eugenol was calculated from the eugenol content of the oil given in Table 2.

three levels of eugenol used afforded similar protection; that is, there appears to be no concentration dependence of the protective effect over a 10-fold range of eugenol in the mixture.

Mechanism of the Cinnamaldehyde Reaction. In the presence of oxygen, cinnamaldehyde probably undergoes a heat-induced, carbon−carbon bond cleavage to form benzaldehyde and glyoxal, as illustrated in Figure 1B. The postulated mechanism involves transformation of cinnamaldehyde to an open peroxide. The peroxide biradical then dimerizes to a cyclic dioxetane,

which then undergoes the indicated elimination to form the postulated products. A somewhat different series of events is also plausible. It involves 1,2-cycloaddition of high-energy singlet oxygen to cinnamaldehyde to form the depicted dioxetane, which can either undergo the indicated elimination or be transformed to a 1,4-oxygen biradical that is cleaved to benzaldehyde and glyoxal (Frimer, 1979; Wong, 1989). We did not look for glyoxal (a reactive intermediate also formed during oxidative glucose metabolism; Friedman, 1996; Wells-Knecht et al., 1995).

If eugenol is acting as a phenolic antioxidant, it might scavenge air oxygen, which would prevent that oxygen from reacting with cinnamaldehyde. Eugenol could also trap the postulated free radical intermediates by mechanisms described elsewhere (Friedman, 1997; Friedman and Jürgens, 2000; Lopez-Bote et al., 1998; Takacsova et al., 1995) and thus minimize the destruction of cinnamaldehyde. The mechanism predicts that the reaction will not take place in the absence of oxygen.

CONCLUSIONS

Using methyl benzoate as an internal standard, we developed a quantitative GC-MS procedure to measure the components of pure essential oils and in a variety of processed commercial foods that have the name "cinnamon" on their labels. Using this method, we found that (a) the major components of five essential oils accounted for 51−81% of the total weight of the oils and (b) the cinnamaldehyde content of the 20 widely consumed foods evaluated varied greatly. From the standpoint of food microbiology, it is possible that those foods with a high cinnamaldehyde content might protect both the food and/or the consumer against infection by human pathogens. For example, will the consumption of a high-cinnamon bread or cereal protect the digestive tract against infection by *E. coli* or *Salmonella* that may be present in concurrently consumed meat or eggs?

Additional studies are needed to demonstrate these possibilities because, if this is indeed the case, it may be possible to design safe foods with maximum microbial lethality (antimicrobial foods) compatible with flavor acceptability. Moreover, because cinnamaldehyde protected against chemical mutagenesis in *E. coli* (Ohta et al., 1983), will it also protect higher organisms against adverse effects of mutagens, in view of its rapid elimination from rat blood with a half-life of 9 min (Yuan et al., 1992)?

We also found that *trans*-cinnamaldehyde undergoes a heat-induced decomposition at fairly low temperature ($<$60 °C) to produce benzaldehyde. Addition of eugenol or cinnamon leaf oil containing eugenol to *trans*-cinnamaldehyde prevented the heat-induced decomposition of the aldehyde even after heating at 200 °C for 30 min. Eugenol therefore appears to protect *trans*-cinnamaldehyde by an antioxidative mechanism against thermal decomposition. This observation should be taken into account in studies designed to establish the fate of cinnamaldehyde exposed to food-processing conditions.

ACKNOWLEDGMENT

We thank Prof. Frank R. Stermitz for helpful suggestions about possible mechanisms of the cinnamaldehyde−oxygen reaction and Carol E. Levin for help with the preparation of the figures.

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Received for review May 12, 2000. Revised manuscript received August 25, 2000. Accepted August 25, 2000.

JF000585G