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Development of High-Performance Liquid Chromatography−Time-of-Flight Mass Spectrometry for the Simultaneous Characterization and Quantitative Analysis of Gingerol-Related Compounds in Ginger Products

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ABSTRACT: Liquid chromatography−time-of-flight mass spectrometry (LC-TOF/MS) was established for the simultaneous separation, identification, and quantification of gingerol-related compounds in ginger products. The established method has been shown to provide a satisfactory linearity ($r > 0.999$) in a wide range (5−5000 ng/mL), low limits of detection and quantification, high precision, and inter- and intraday repeatability. The detection sensitivity of gingerols and shogaols by TOF/MS was 70−100 times higher than conventional UV detection at 288 nm. In this study, 19 ginerol-related compounds in the samples were identified and quantified by the established LC-TOF/MS method. The dried ginger powder products contained the highest quantity of gingerol-related compounds (7126.3−13789.0 μg/g), followed by fresh ginger products (2007.9−2790.0 μg/g), powdered ginger tea products (77.29−81.75 μg/g), and hot water ginger extracts (54.59−123.23 μg/mL). Shogaols were not found in fresh gingers. This paper represents the first report on the LC-TOF/MS analysis for the simultaneous characterization and quantification of gingerol-related compounds in ginger products.

KEYWORDS: *gingerol, shogaol, high-performance liquid chromatography, time-of-flight mass spectrometry*

INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) has been used as a spice, tea, and medicine for over 2000 years.[1] Ginger is a common additive in a number of commercial foods, beverages, and pharmaceutical supplements due to a high concentration of pungent constituents (gingerol-related compounds).[1,2] The gingerol-related compounds in gingers reportedly are active components for a range of biological functionalities such as antitumor, antiplatelet activator, antioxidative, and anti-inflamatory activities.[3−9]

Several high-performance liquid chromatographic (HPLC)[10−15] and gas chromatograph−mass-spectrometric (GC/MS) methods[16,17] have been used for the analysis of gingerols, shogaols, and their related compounds. There are distinct disadvantages associated with GC and GC/MS methods for analyzing these compounds due to their low volatility and thermal instability. It has been reported that the gas chromatographic column temperatures used for the analyses of the gingerols resulted in significant conversion of gingerol to shogaol.[16,17] Thus, HPLC might be more suitable for the qualitative and quantitative analysis of gingerols. The LC-MS analytical methods primarily were used for the identification of pungent compounds in ginger.[12,13] HPLC−diode array detection (DAD) was mainly used for the quantification of the components in ginger products.[10−13] However, this method is not a robust analytical tool for the identification and quantification of the compounds due to the lack of selectivity, especially in the presence of interferences in the matrix. There was a report on the quantification of gingerol-related compounds by LC-tandem MS spectrometry with a multiple reaction monitoring mode.[18] With this method, however, the contents of only selected components (6-gingerol, 8-ginerol, 10-ginerol, 6-shogaol, 8-shoagol, and 10-shogaol) in the dietary supplements were analyzed. The analytical methods employed for monitoring of target compounds in foods should be capable of measuring low levels and must provide unambiguous evidence to confirm both the identity and the quantity of the components detected. In this sense, HPLC−time-of-flight mass spectrometry (TOF/MS) offers the capability of unequivocal identification (simultaneously provided by exact mass measurements, fragment ion patterns, and isotope ion peaks) and quantification of the components at low levels. Furthermore, the use of LC-TOF/MS allows the capability of nontarget identification with the full spectrum recorded at all times, which is not possible with LC-tandem MS with a multiple reaction monitoring mode. It has been previously reported that LC-TOF/MS was an effective tool for the identification of gingerols, shogaols, and their related compounds in the ginger products.[13,15] However, no attempt has been made to develop an LC-TOF/MS analytical method for the simultaneous identification and quantification of gingerols, shogaols, and their related compounds in ginger products. Thus, the objectives of this research were (1) to develop the LC-TOF/MS analytical method for the simultaneous identification and quantification of the gingerol-related compounds in ginger products and (2) to determine the gingerols, shogaols, and their related compounds in fresh, powdered gingers, hot water ginger extracts, and powdered ginger teas by the newly established HPLC-TOF/MS method.

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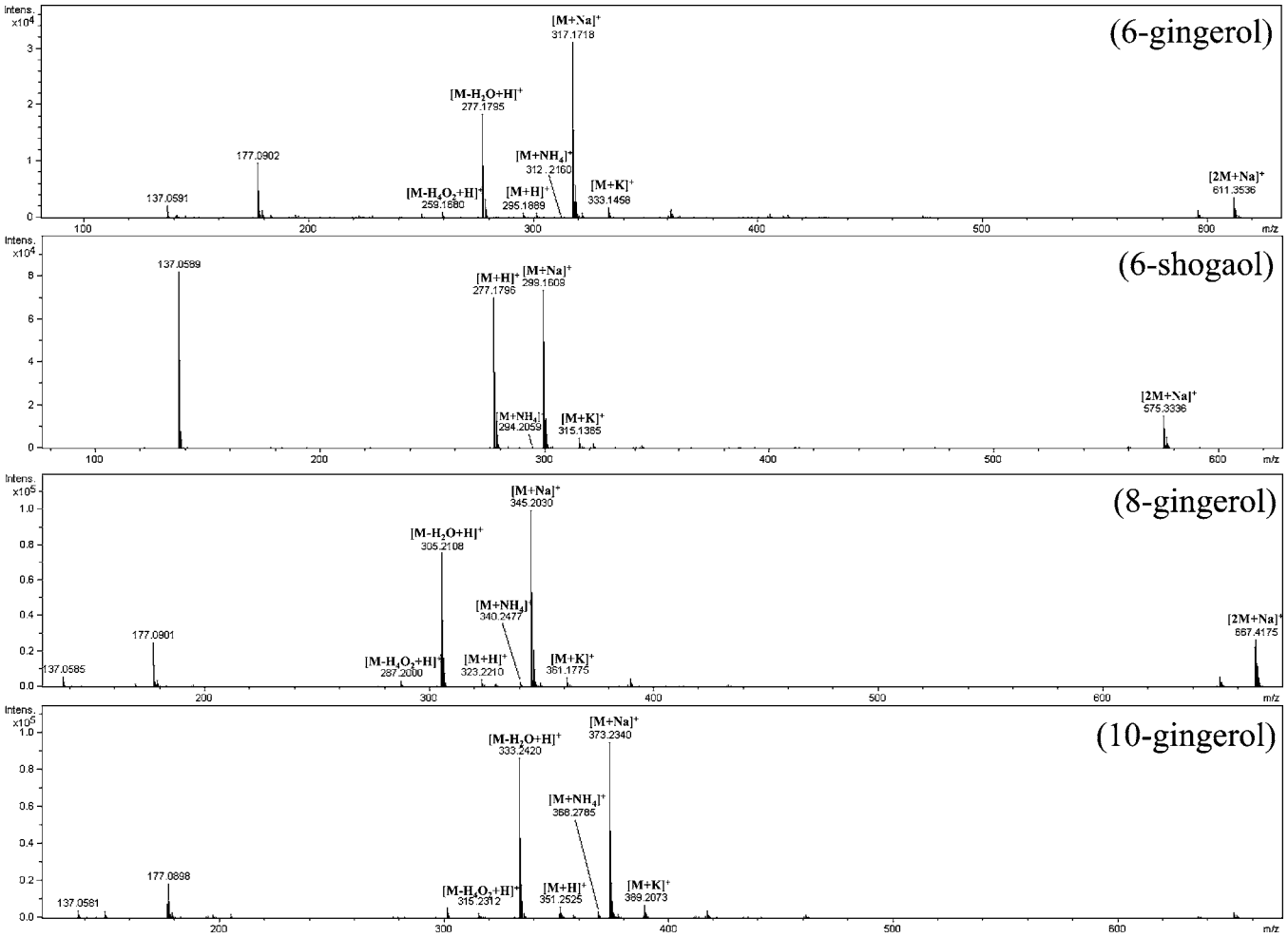

Figure 1. Full-scan mass spectra of authentic 6-gingerol, 8-ginerol, 10-gingerol, and 6-shogaol obtained by LC-TOF/MS analysis.

MATERIALS AND METHODS

Chemicals. 6-Gingerol, 8-gingerol, 10-gingerol, and 6-shogaol were obtained from Sigma Chemical Co. (St. Louis, MO). HPLC-grade acetonitrile, water, and ethyl acetate were obtained from Fisher Scientific (Fair Lawn, NJ). Methanol was obtained from J.T. Baker Chemical (Phillipsburg, NJ). Ammonium formate and formic acid were obtained from Sigma Chemical Co. Fresh gingers (two different varieties) were obtained from the ginger farms located in two different cultivating areas (ginger 1, Gaeryang variety cultivated at a farm located in the Bongdong area; ginger 2, Tojong variety cultivated at a farm located in the Bongdong area; ginger 3, Togong variety cultivated at a farm located in the Bongdong area; ginger 4, Togong variety cultivated at a farm located in the Seosan area; and ginger 5, Gaeryang variety cultivated at a farm in the Seosan area). Powdered dry gingers and powdered ginger teas were commercial products obtained from local markets. Hot water ginger extracts were the commercial products that were manufactured by heating gingers with water in an electric heating jar at the farms.

Extraction Procedure. The ginger-related compounds were extracted from fresh and powdered dry gingers, hot water ginger extracts, and ginger teas with ethyl acetate according to the previous reports.[10,12] Fresh gingers were ground for 3−5 min by using a mixer (GREEN-MIX, Daesung Artlon, Republic of Korea). Powered samples were used directly for the extraction. One hundred milligrams of the samples was weighed, in duplicate, in a 15 mL capacity tube. Then, ethyl acetate (3 mL) was added to the sample tubes. The tubes were capped, mixed briefly, and then placed on a shaker (EYELA MMV-1000W, Tokyo, Japan) at a speed of 325 rpm for about 30 min. Then, the samples were centrifuged at 2224.5*g* (Combi-514R, Hanil Science, Republic of Korea) for 20 min at 25 ± 4 °C. The supernatant ethyl acetate layer was collected. The extraction process was repeated two more times. The collected ethyl acetate layers were pooled and brought to 10 mL with acetonitrile. For the extraction from liquid samples (hot water ginger extracts), the ginger extracts (10 mL) were transferred into a 50 mL capacity tube. Then, ethyl acetate (10 mL) was added to the sample tubes. The tubes were capped, mixed briefly, and then placed on a shaker (EYELA MMV-1000W) at speed of 325 rpm for about 30 min. Then, the samples were centrifuged at 2224.5*g* (Combi-514R, Hanil Science) for 20 min at 25 ± 4 °C. The supernatant ethyl acetate layer was collected. The extraction process was repeated two more times. The collected ethyl acetate layers were pooled and brought to 10 mL with acetonitrile. If necessary, the sample solutions were further diluted with acetonitrile to obtain an appropriate concentration for the LC-TOF/MS analysis.

Preparation of Standard Solution Containing 6-, 8-, and 10-Gingerols and 6-Shogaol. 6-Gingerol, 8-gingerol, 10-gingerol, and 6-shogaol were weighed and dissolved in methanol to make stock standard solutions (1.0 mg/mL). Working standard solutions were made by a serial dilution of the stock standard solutions. The standards solutions were stored at −20 °C until used.

HPLC-TOF/MS Analysis. HPLC-TOF/MS analysis of the ginger extracts was performed with a HPLC (UltiMate 3000 Series system, DIONEX Technologies, Sunnyvale, CA) equipped with a time-of-flight mass spectrometer (micro QTOF-Q II, Bruker Daltonik, Bremen, Germany). The column used was a reverse phase column (Zorbax 300SB-C18 analytical column, 2.1 mm × 250 mm, 5.0 μm particle, Waters Inc., Milford, MA). The mobile phase was a gradient prepared from 5 mM ammonium formate and 0.1% formic acid in water (A) and acetonitrile (B). The gradient program for the HPLC

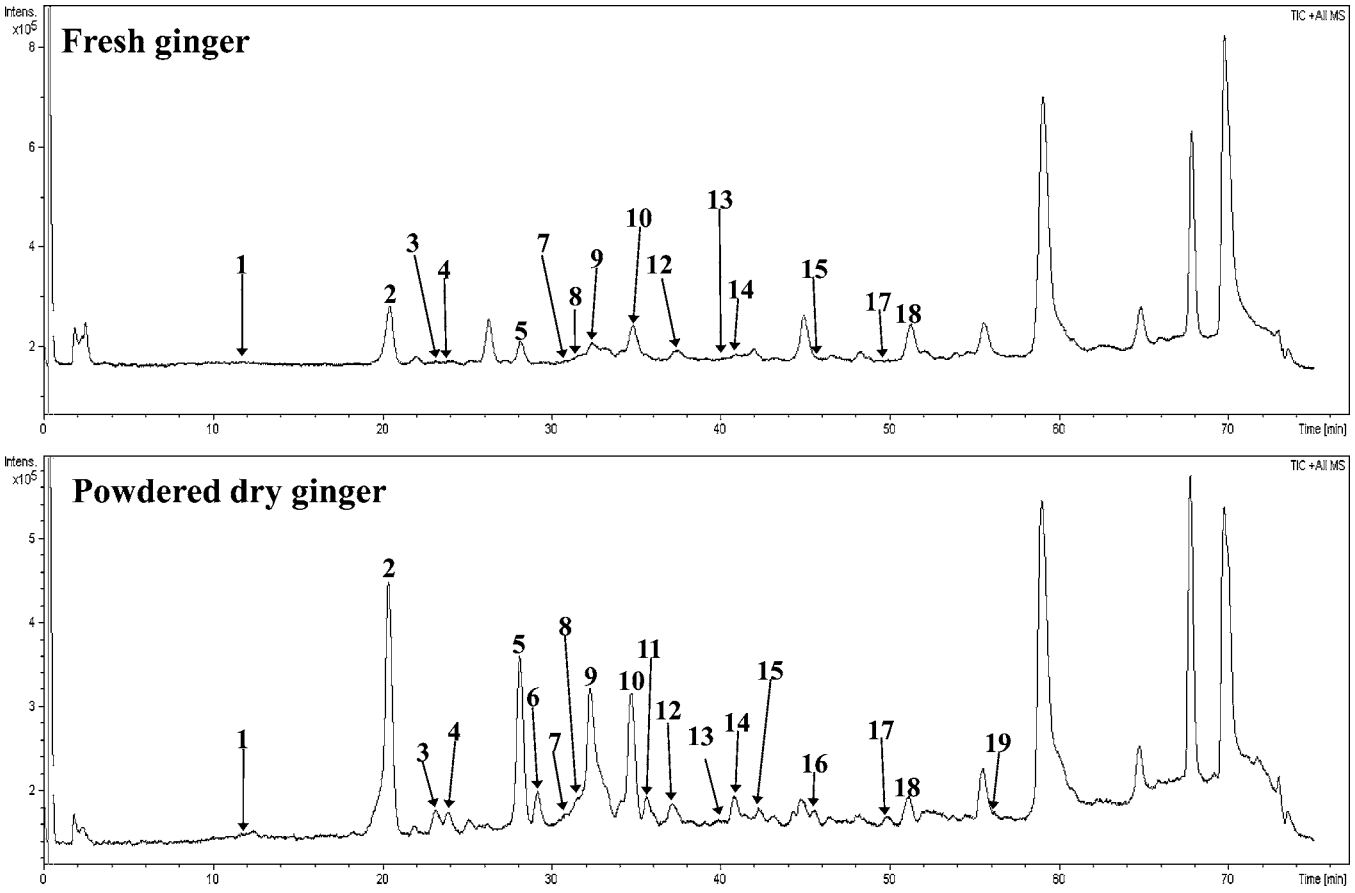

Figure 2. TICs of LC-TOF/MS analysis of fresh ginger and powdered dry ginger.

was as follows: 0−5 min, 0−20% B; 5−69 min, 20−100% B; 69−70 min, 100% B; 70−71 min, 100−20% B; and 71−75 min, 100% B; and the flow rate was 0.5 mL min^{-1}. The injection volume was 10 μL, and the column temperature was maintained at 30 °C. Mass spectra in the m/z range 50−700 were obtained by an electrospray ionization with a positive-ion mode. The mass spectrometric conditions were optimized as follows: gas temperature, 220 °C; drying gas flow rate, 10.0 L min^{-1}; nebulizer gas pressure, 1.5 bar; and capillary and fragmentor potentials, 4000 and 220 V, respectively. The mass axis was calibrated using the internal calibration solution (lithium formate solution).

RESULTS AND DISSCUSSION

Identification by LC-TOF/MS. Mass spectrometric conditions such as capillary and fragmentor potential, nebulizer gas pressure, and drying gas flow rate were optimized to achieve maximum sensitivity for the components. The gingerol-related compounds were unequivocally identified by the protonated molecular ions ($[M + H]^+$), and H_2O subtracted protonated molecular ion ($[M - H_2O + H]^+$) along with their adducts and other ions ($[M + Na]^+$, $[M + K]^+$, $[M + NH_4]^+$, $[M - H_4O_2 + H]^+$, and $[2M + Na]^+$) by comparing with those of the selected 133 target compounds. Besides exact mass measurements, the abundances of the isotope peaks and fragment ions were also used to confirm the identities of compounds. We carried out the LC-TOF/MS analysis with the authentic samples of 6-gingerol, 8-gingerol, 10-gingerol, and 6-shogaol. Figure 1 shows the full-scan mass spectra of these authentic compounds. It was found that gingerols showed high intensity of $[M - H_2O + H]^+$ and $[M + Na]^+$ ions but very low intensity of $[M + H]^+$ ion (Figure 1). However, shogaol showed a high intensity of $[M + H]^+$ and $[M + Na]^+$ ions but very low intensity of $[M - H_2O + H]^+$ ion (Figure 1). The ion intensity of the gingerol-related compounds was closely related to their molecular structures. If there was −OH (hydroxyl group) in the alkyl side chain, $[M - H_2O + H]^+$ ion was predominant (Figure 1). However, if there was only =O (keto group) in the alkyl chain, $[M + H]^+$ ion was predominant (Figure 1). This result was consistent with that of the previous report.[14] This mass spectral behavior would be very useful for the identification of the gingerol-related compounds by LC-MS analysis.

Figure 2 shows the total ion chromatograms (TICs) of fresh ginger and powdered dry ginger obtained by LC-TOF/MS analysis. Among the 133 selected target components, 19 compounds were identified in the ginger samples by a target analysis (Table 1). Gingerols, methyl-gingerols, and dehydrogingerols in the ginger samples showed a high intensity of $[M - H_2O + H]^+$ and $[M + Na]^+$ but a very low intensity of $[M + H]^+$ ion (Table 2 and Figure 3). The peak at a retention time (RT) of 20.38 min (peak 2) showed the elemental compositions of the ions at m/z 295.1897, 312.2153, 317.1728, 611.3548, 333.1474, 277.1797, and 259.1694, which were calculated as $C_{17}H_{27}O_4$, $C_{17}H_{30}O_4N$, $C_{17}H_{26}O_4Na$, $C_{34}H_{52}O_8Na$, $C_{17}H_{26}O_4K$, $C_{17}H_{25}O_3$, and $C_{17}H_{23}O_2$, respectively. These corresponded to the ions of $[M + H]^+$, $[M + NH_4]^+$, $[M + Na]^+$, $[2M + Na]^+$, $[M + K]^+$, $[M - H_2O + H]^+$, and $[M - H_4O_2 + H]^+$, respectively. The mass accuracy of the experimental mass data compared with the theoretical value was less than 5 ppm. The relative mass peak intensities of $[M + Na]^+$, $[M - H_2O + H]^+$, and $[M + H]^+$ were 100, 54.75, and 2.19%, respectively, indicating the presence of a hydroxyl group in the side chain of its molecule. The molecular

Table 1. Mass Spectrometric Characterization and Retention Times of Gingerol-Related Compounds in Ginger Samples Analyzed by LC-TOF/MS

peak no.	retention time (min)	compd	formula	ions	*m/z* exptl	*m/z* theor	error (ppm)	relative mass peak intensity (%)
1	11.03	4-gingerol	$C_{15}H_{22}O_4$	$[M + H]^+$	267.1600	267.1591	−3.4	45.32
				$[M + Na]^+$	289.1418	289.1410	−2.8	100
				$[M - H_2O + H]^+$	249.1487	249.1485	−0.6	100
2	20.38	6-gingerol	$C_{17}H_{26}O_4$	$[M + H]^+$	295.1897	295.1904	−2.2	2.19
				$[M + NH_4]^+$	312.2153	312.2169	−5.0	0.98
				$[M + Na]^+$	317.1728	317.1723	−1.6	100
				$[2M + Na]^+$	611.3548	611.3554	1.1	10.06
				$[M + K]^+$	333.1474	333.1463	3.6	5.26
				$[M - H_2O + H]^+$	277.1797	277.1798	0.6	54.75
				$[M - H_4O_2 + H]^+$	259.1694	259.1696	−0.5	3.25
3	23.14	dehydro-6-gingerol	$C_{17}H_{24}O_4$	$[M + H]^+$	293.1741	293.1747	2.2	9.98
				$[M + Na]^+$	315.1556	315.1567	3.4	29.87
				$[M + K]^+$	331.1312	331.1306	−1.9	15.25
				$[M - H_2O + H]^+$	275.1647	275.1642	−1.9	100
4	24.04	Me-6-gingerol	$C_{18}H_{28}O_4$	$[M + H]^+$	309.2074	309.2060	4.5	1.97
				$[M + Na]^+$	331.1883	331.1878	0.9	27.50
				$[M + K]^+$	347.1629	347.1419	2.9	13.14
				$[M - H_2O + H]^+$	291.1968	291.1955	4.5	100
5	28.00	8-gingerol	$C_{19}H_{30}O_4$	$[M + Na]^+$	345.2022	345.2036	4.0	100
				$[2M + Na]^+$	667.4173	667.4180	1.2	8.48
				$[M + K]^+$	361.1786	361.1776	2.8	7.68
				$[M - H_2O + H]^+$	305.2107	305.2111	1.3	61.00
				$[M - H_4O_2 + H]^+$	287.2006	287.2006	1.8	2.72
6	29.10	6-shogaol	$C_{17}H_{24}O_3$	$[M + H]^+$	277.1795	277.1798	−1.1	100
				$[M + Na]^+$	299.1608	299.1618	3.2	95.77
				$[2M + Na]^+$	575.3362	575.3343	3.3	11.25
				$[M + K]^+$	375.1922	375.1932	−2.6	3.95
				$[M - H_2O + H]^+$	259.1681	259.1693	−4.1	0.45
7	30.66	dehydro-8-gingerol	$C_{19}H_{28}O_4$	$[M + H]^+$	321.2056	321.2060	1.4	14.95
				$[M + Na]^+$	343.1882	343.1880	−0.7	43.01
				$[M - H_2O + H]^+$	303.1946	303.1955	3.0	100
8	31.30	Me-8-gingerol	$C_{20}H_{32}O_4$	$[M + Na]^+$	359.2194	359.2193	−0.3	40.93
				$[M + K]^+$	375.1922	375.1932	−2.6	12.52
				$[M - H_2O + H]^+$	319.2283	319.2268	−4.8	100
9	33.30	dehydro-6-gingerdione	$C_{17}H_{22}O_4$	$[M + H]^+$	291.1583	291.1591	2.8	100
				$[M + Na]^+$	313.1395	313.1410	5.0	26.64
				$[2 M + Na]^+$	603.2906	603.2928	3.6	2.01
				$[M + K]^+$	329.1152	329.1150	−0.8	6.85
10	34.66	10-gingerol	$C_{21}H_{34}O_4$	$[M + H]^+$	351.2513	351.2530	4.7	10.77
				$[M + NH_4]^+$	368.2791	368.2795	−1.1	4.05
				$[M + Na]^+$	373.2349	373.2349	0.0	35.45
				$[M + K]^+$	389.2094	389.2089	1.3	26.59
				$[M - H_2O + H]^+$	333.2412	333.2424	3.7	100
				$[M - H_4O_2 + H]^+$	315.232.	315.2319	0.3	2.20
11	36.05	8-shogaol	$C_{19}H_{28}O_3$	$[M + H]^+$	305.2113	305.2111	−0.4	90.90
				$[M + Na]^+$	327.1933	327.1931	−0.7	100
				$[M + K]^+$	343.1686	343.1670	−4.7	14.52
12	37.06	dehydro-10-gingerol	$C_{21}H_{32}O_4$	$[M + H]^+$	349.2359	349.2373	−4.0	20.33
				$[M + NH_4]^+$	366.2627	336.2639	−3.3	9.43
				$[M + Na]^+$	371.2201	371.2193	−2.1	37.43
				$[M + K]^+$	387.1922	387.1932	−2.6	23.73
				$[M - H_2O + H]^+$	331.2251	331.2268	−5.0	100
13	39.68	dehydro-8-gingerdione	$C_{19}H_{26}O_5$	$[M + H]^+$	319.1891	319.1904	4.1	100
				$[M + Na]^+$	341.1731	341.1723	2.3	40.40
14	40.82	12-gingerol	$C_{23}H_{38}O_4$	$[M + H]^+$	379.2825	379.2843	4.7	29.40
				$[M + Na]^+$	401.2643	401.2662	4.9	100
				$[M - H_2O + H]^+$	361.2745	361.2737	2.2	87.74
15	42.33	10-shogaol	$C_{21}H_{32}O_3$	$[M + H]^+$	333.2413	333.2424	−4.0	100

Table 1. continued

peak no.	retention time (min)	compd	formula	ions	m/z exptl	m/z theor	error (ppm)	relative mass peak intensity (%)
				$[M + Na]^+$	355.2243	355.2244	0.2	97.63
16	45.55	dehydro-10-gingerdione	$C_{21}H_{30}O_4$	$[M + H]^+$	347.2212	347.2217	1.3	100
				$[M + Na]^+$	369.2022	369.2036	4.0	25.14
				$[M - H_2O + H]^+$	385.1788	385.1776	−3.2	9.39
17	50.14	dehydro-12-gingerol	$C_{23}H_{36}O_4$	$[M + NH_4]^+$	394.2941	394.2950	−2.8	19.88
				$[M + Na]^+$	399.2506	399.2506	0.0	55.15
				$[M + K]^+$	415.2247	415.2245	0.5	14.12
				$[M - H_2O + H]^+$	359.2588	359.2581	1.9	100
18	51.14	dehydro-12-gingerdione	$C_{23}H_{34}O_4$	$[M + H]^+$	375.2537	375.2530	1.9	100
				$[M + NH_4]^+$	392.2792	392.2795	−0.8	3.93
				$[M + Na]^+$	397.2344	397.2349	−1.3	20.41
19	56.34	dehydro-14-gingerdione	$C_{25}H_{38}O_4$	$[M + H]^+$	403.2843	403.2843	0.0	100
				$[M + Na]^+$	425.2665	425.2662	0.7	25.08

Table 2. Calibration Curves, Correlation Coefficients, snd Limits of Detection and Quantification for Four Authentic Compounds

gingerol	standard curve	r	test range (ng/mL)	μg/mL LOD	μg/mL LOQ
6-gingerol	$Y = 1310.778008x + 54361.796812$	0.9995	5−5000	0.01	0.033
8-gingerol	$Y = 1377.210157x + 46207.216711$	0.9997	5−5000	0.007	0.021
10-gingerol	$Y = 1541.574982x + 9515.418702$	0.9999	5−5000	0.007	0.021
6-shogaol	$Y = 1370.127156x + 88101.407112$	0.9994	5−5000	0.01	0.033

formula of the compound corresponding to the peak at 20.38 min can be inferred as $C_{17}H_{26}O_4$. The compound furnishing the peak at RT 20.38 min (peak 2) was, therefore, tentatively assigned as 6-gingerol. The fragment ion at m/z 177.0908 supported its structural identification (Figure 3), which was formed by the loss of a neutral alkyl moiety from $[M - H_2O + H]^+$ and rearrangement[14] as shown in Figure 4. The theoretical isotope information (exact mass and ratio of isotope peak) was obtained from a software (DataAnalysis Version 4.0 sp 4, Bruker Daltonik GmbH) and compared with the experimental data. The experimental mass data and abundance of isotope ions for $[M - H_2O + H]^+$ ion in samples were exactly matched with the theoretical values within the tolerable error range (Figure 5). This is additional evidence for the confirmation of its structure. Similarly, peaks 1, 5, 10, and 14 were assigned as 4-gingerol, 8-gingerol, 10-gingerol, and 12-gingerol, respectively. The identifications of 6-, 8-, and 10-gingerols were further confirmed by the comparisons of their retention times and mass spectral data of authentic samples.

The peak 3 (RT, 23.14 min) showed the ions at m/z 293.1741, 315.1556, 331.1312, and 275.1647, which referred to $C_{17}H_{25}O_4$, $C_{17}H_{24}O_4Na$, $C_{17}H_{24}O_4K$, and $C_{17}H_{25}O_3$, respectively (Figure 3). These ions corresponded to $[M + H]^+$, $[M + Na]^+$, $[M + K]^+$, and $[M - H_2O + H]^+$, respectively. The relative intensity of the $[M + H]^+$, $[M + Na]^+$, $[M + K]^+$, and $[M - H_2O + H]^+$ ion peaks was 9.98, 29.87, 15.25, and 100%, respectively (Table 2), indicating the presence of a −OH group in the alkyl chain of this molecule. The molecular formula of the compound corresponding to the peak at 23.14 min can be inferred as $C_{17}H_{24}O_4$. There are two candidates for the peak assignment, which was dehydro-6-gingerol and 6-gingerdione, both having the same molecular formula of $C_{17}H_{24}O_4$. However, 6-gingerdione, which does not have a −OH group in the side chain, was easily excluded because of the low intensity of $[M + H]^+$ ion and the high intensity of $[M - H_2O + H]^+$ ion peak (Figure 3). Therefore, peak 3 was tentatively assigned as 1-dehydro-6-gingerol. The experimental mass data and relative abundance of isotope ions for $[M - H_2O + H]^+$ ion in samples were matched with the theoretical values within a tolerable error range (data not shown), which confirmed the structural identification. Similarly, peaks 7, 12, and 17 were also assigned as 1-dehydro-8-gingerol, 1-dehydro-10-gingerol, and 1-dehydro-12-gingerol, respectively.

Peak 4 (RT, 24.04 min) showed the ions with m/z 309.2074, 331.1883, 347.1629, and 291.1968, which were calculated as $C_{18}H_{29}O_4$, $C_{18}H_{28}O_4Na$, $C_{36}H_{56}O_8Na$, $C_{18}H_{28}O_4K$, and $C_{18}H_{27}O_3$, respectively (Figure 3). These represent $[M + H]^+$, $[M + Na]^+$, $[M + K]^+$, and $[M - H_2O + H]^+$ ions, respectively. The relative intensity of the $[M + H]^+$, $[M + Na]^+$, $[M + K]^+$, and $[M - H_2O + H]^+$ ion peaks was 1.97, 27.50, 13.14, and 100%, respectively, indicating the presence of a −OH group in the side chain of this molecule. The molecular formula of the compound corresponding to peak 4 can be inferred as $C_{18}H_{28}O_4$, which was therefore assigned as methyl-6-gingerol. The fragment ion at m/z 191.1063, which was formed by the loss of a neutral alkyl moiety from $[M - H_2O + H]^+$ and rearrangement[14] as shown in Figure 4, confirmed the identity of its structure. The experimental mass data and relative intensities of isotope ions for $[M - H_2O + H]^+$ ion in samples were also matched with the theoretical values (data not shown), which provide further confirm of the structural identification. In a similar manner, peak 8 was also assigned as methyl 8-gingerol.

The elemental compositions of the ions for peak 6 (RT, 29.10 min) were m/z 277.1794, 299.1608, 575.3362, 375.1922, and 299.1681, which were calculated as $C_{17}H_{25}O_3$, $C_{17}H_{24}O_3Na$, $C_{34}H_{56}O_6Na$, $C_{17}H_{24}O_3K$, and $C_{17}H_{23}O_2$, respectively (Figure 3). These corresponded to the ions of $[M + H]^+$, $[M + Na]^+$, $[2M + Na]^+$, $[M + K]^+$, and $[M - H_2O + H]^+$, respectively. The molecular formula of the compound corresponding to the peak 6 can be inferred as $C_{17}H_{24}O_3$. The relative mass peak intensities of $[M + Na]^+$, $[M - H_2O + H]^+$, and $[M + H]^+$ were 95.77, 0.45, and 100%, respectively, indicating the absence of a −OH group in the side chain of the

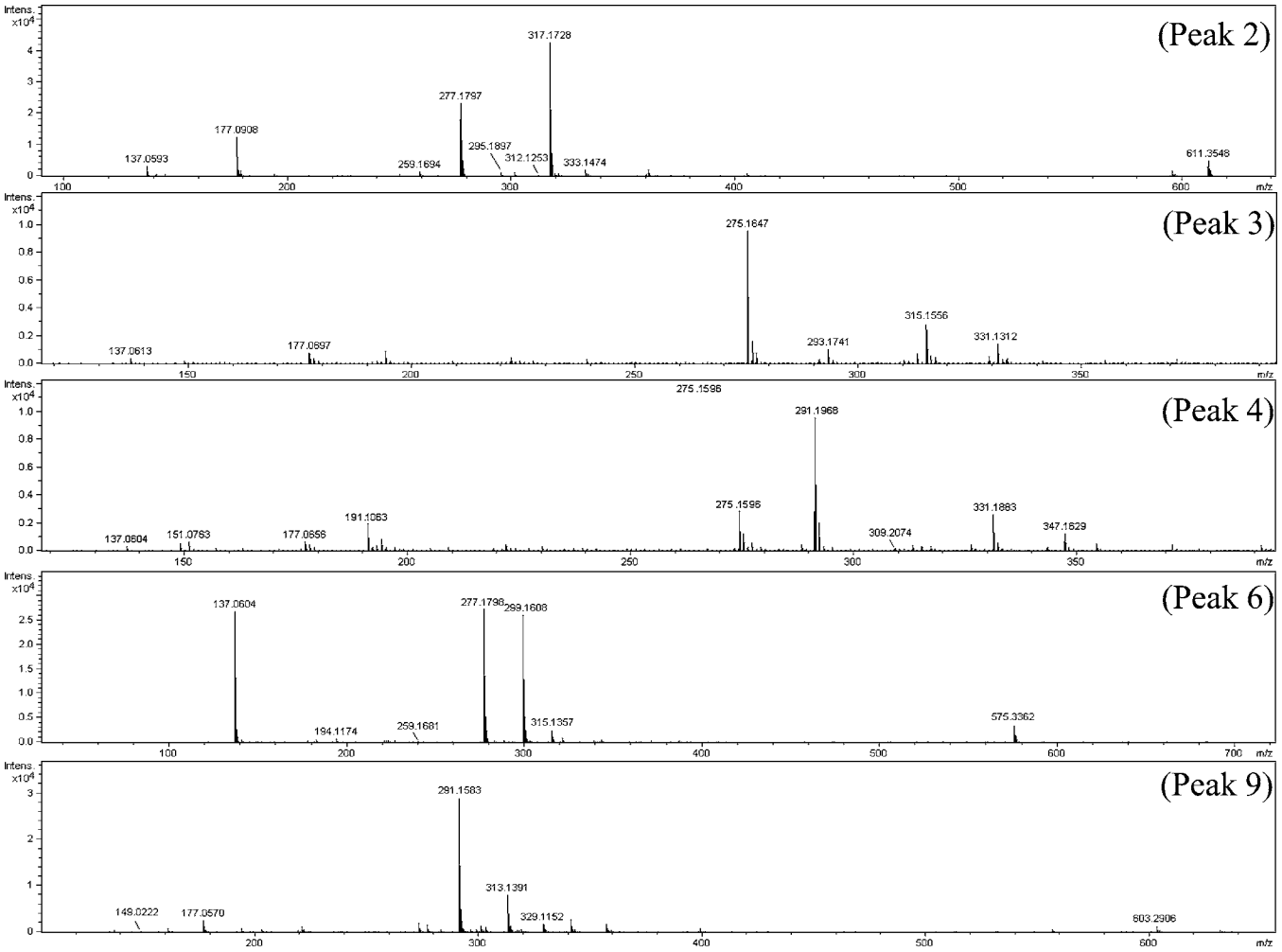

Figure 3. Full-scan mass spectra of peaks 2–4, 6, and 9 in ginger products obtained by LC-TOF/MS analysis.

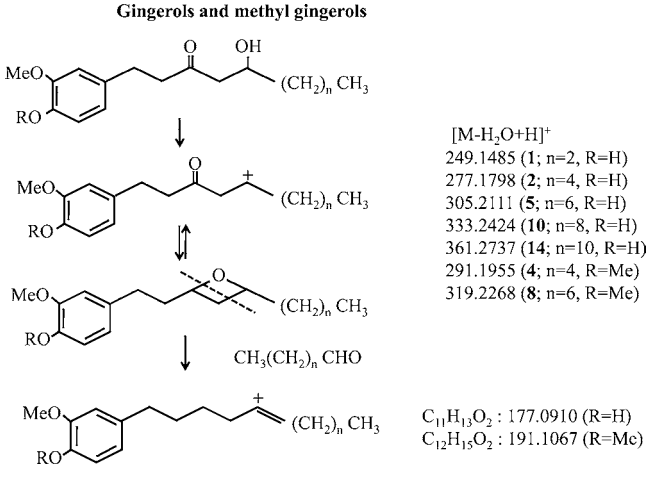

Figure 4. Fragmentation pathway of $[M - H_2O + H]^+$ ion of gingerol and methyl gingerols (peaks 1, 2, 5, 10, 14, 4, and 8).[14]

molecule. Thus, the compound at RT 29.10 min (peak 6) was tentatively assigned as 6-shogaol. The ion at m/z 137.0604 (Figure 3), which was a fragment ion from shogaols as shown in Figure 6, provides additional evidence for its structural identification. The experimental mass data and relative intensities of isotope ions for $[M - H_2O + H]^+$ ion in samples were matched with the theoretical values (data not shown), which provide further confirm of the structural identification. In a similar manner, peaks 11 and 15 were also assigned as 8-shogaol and 10-shogaol, respectively. The identification of 6-shogaol was further confirmed by the comparison of its retention time and mass spectral data of authentic compound.

The ions at m/z 291.1583, 313.1950, 603.2906, and 329.1152 of peak 9 (RT, 33.30 min) were calculated as molecular formulas of $C_{17}H_{23}O_4$, $C_{17}H_{22}O_4Na$, $C_{34}H_{44}O_4Na$, and $C_{17}H_{22}O_4K$, which corresponded to the ions of $[M + H]^+$, $[M + Na]^+$, $[2M + Na]^+$, and $[M + K]^+$, respectively (Figure 3). The molecular formula of the compound corresponding to the peak at 33.30 min can be inferred as $C_{17}H_{22}O_4$. The relative mass peak intensities of $[M + H]^+$, $[M - Na]^+$, $[2M + Na]^+$, and $[M + K]^+$ were 100, 26.64, 201, and 6.85%, respectively (Table 2 and Figure 3), indicating the absence of a −OH group in the side chain of the molecule. The compound of the peak 9 was tentatively assigned as 1-dehydro-6-gingerdione. The fragment ion at m/z 177.0570 showed evidence for its identification as dehydrogingerdione (Figure 7).[14] It also provided the information on the double bond position at the carbon number 1 in its alkyl side chain. Similarly, peaks 13, 16, 18, and 19 were also assigned as 1-dehydro-6-gingerdione, 1-dehydro-8-gingerdione, 1-dehydro-10-gingerdione, and 1-dehydro-12-gingerdione, respectively. The characterization of gingerol-related compounds in ginger or ginger products has been previously reported by LC-TOF/MS.[13,15] Cheng et al.[13]

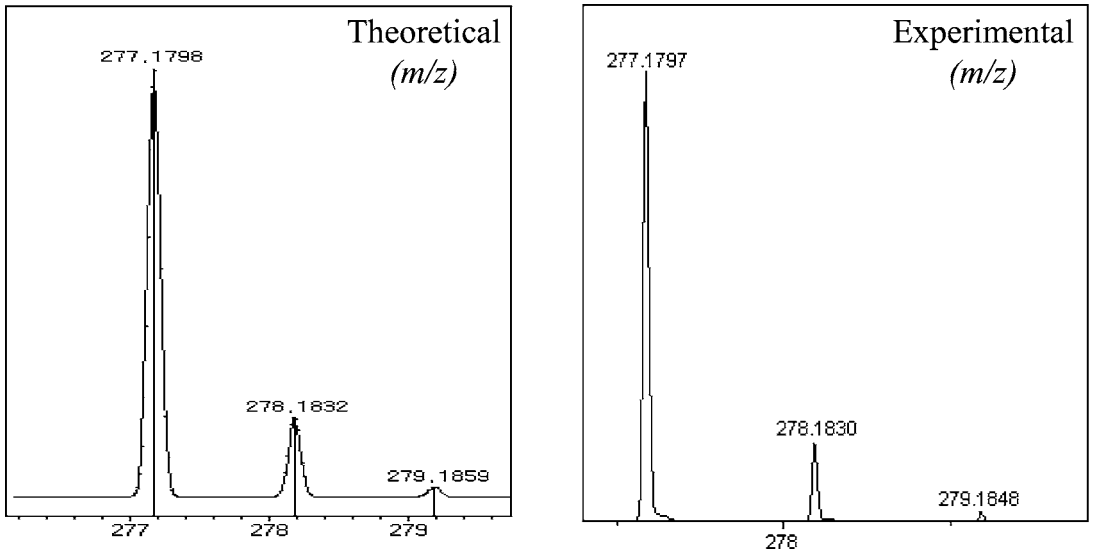

Figure 5. Theoretical and experimental isotope mass data and their abundances of 6-gingerol and peak 2.

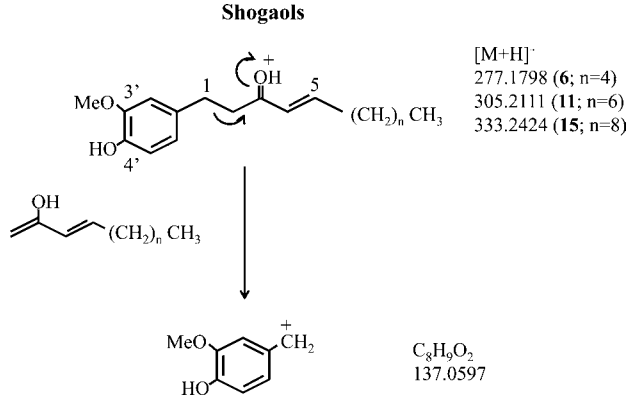

Figure 6. Fragmentation pathway of $[M + H]^+$ ion of shogaols (peaks 6, 11, and 15).[14]

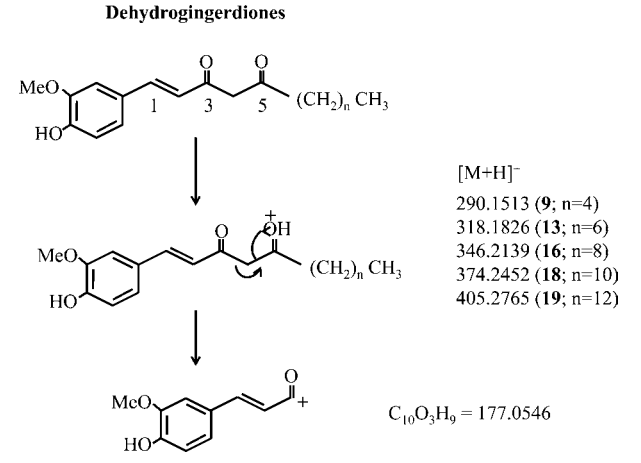

Figure 7. Fragmentation pathway of $[M + H]^+$ ion of 1-dehydrogingerdione (peaks 9, 13, 16, 18, and 19).[14]

characterized 12 gingerol-related compounds in the steamed ginger by LC-TOF/MS. Li et al.[15] identified 10 gingerol-related compounds in the dried ginger by LC-TOF/MS. Characterization of gingerol-related compounds in gingers by LC-MS or LC-MS/MS also has been reported.[12,14,18]

Calibration Curve, Limit of Detection (LOD) and Limit of Quantification (LOQ), Recovery, Reproducibility, Matrix Effect, and Intra- and Interday. For the quantitative analysis of gingerols, dehydroginerols, and methylgingerols, their $[M - H_2O + H]^+$ ions were selected as extracted mass ions, due to their high ion peak intensity. For the quantitative analysis of shogaols and dehydrogingerdiones, their $[M + H]^+$ ions were selected as extracted mass ions. Figure 8 shows the extracted ion chromatograms (EIC) with an overlay mode obtained by a HPLC-TOF/MS for the gingerol-related compounds in gingers. Table 3 shows the calibration curves, correlation coefficients, and LOD and LOQ of authentic standards obtained by LC-TOF/MS analysis with an EIC mode. The calibration curves offered satisfactory linearity ($r >$ 0.9994) in a wide linear range (5−5000 ng/mL) for all of the authentic standards. It is interesting to note that the slopes of the calibration curves for the different standards were very similar to each other, indicating the similar detector responses to the gingerols and shogaols at the same concentration. The LODs and LOQs were determined as the analyte concentrations that gave a signal-to-noise ratio of 3 and 10, respectively, as calculated empirically by analyzing the authentic mixtures at the various concentration levels. The LODs and LOQ for the standards are in the range of 0.007−0.01 and 0.033−0.021 μg/mL, respectively (Table 2). We compared the sensitivity of this LC-TOF/MS method with those of the conventional UV method by analyzing the mixed standard solutions with various concentrations. The UV channel was selected at 280 nm as the specified wavelength for the detection of gingerols and shogaol as previously reported.[12] The LOD of the 6-gingerol, 8-gingerol, 10-gingerol, and 6-shogaol by HPLC-UV detection was 0.5, 1.0, 1.0, and 1.0 μg/mL, respectively. The results suggested that the LC-TOF/MS method was about 70−100 times more sensitive for the detection of gingerol-related compounds to the ordinary HPLC-UV detection method. It is also known that LC-MS/MS (QQQ) is one of the most sensitive techniques for quantifying gingerol-related compounds.[18] However, we could not directly compare the sensitivity of the present LC-TOF/MS with that of LC-MS/MS. Nevertheless, our results clearly showed the high sensitivity of the present method for the

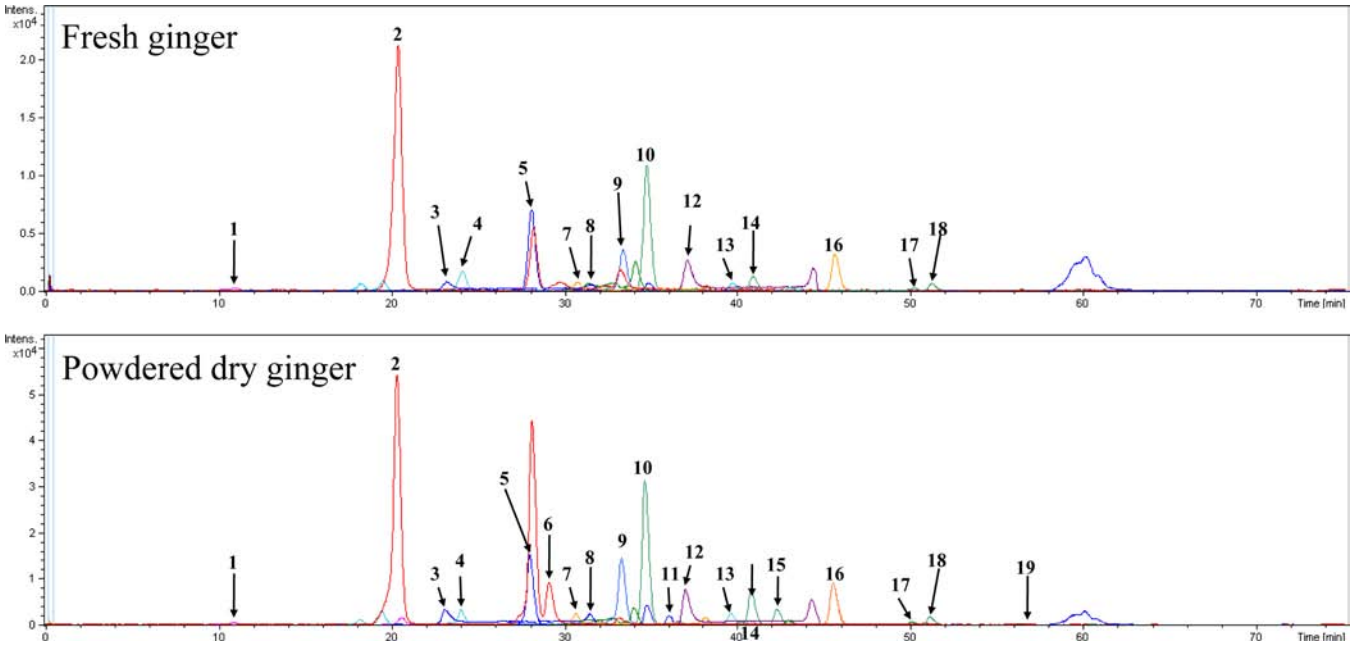

Figure 8. Overlaid extracted ion chromatograms (EIC) for the gingerol-related compounds in gingers as obtained by a HPLC-TOF/MS.

Table 3. RSD of Authentic Standard Substances Obtained from Six Repeated Analysis

	peak area			
trial	6-gingerol	8-gingerol	10-gingerol	6-shogaol
1	712793	711846	698203	816418
2	714127	698651	712236	799218
3	703928	683028	692827	842737
4	688591	632636	685554	741105
5	694571	623782	680517	789165
6	690472	606218	650392	796243
mean	700747	659360	686621	797481
SD	11186.9	43960.8	20879.3	33641.3
RSD (%)	1.6	6.67	3.04	4.22

analysis of gingerol-related compounds. The repeatability of the gingerol analysis by HPLC-TOF/MS was tested with authentic standards (Table 3). The results showed that relative standard deviation (RSD) was less than 6.67%, indicating the high precision of data analysis. We used the previously established extraction method with ethyl acetate as an extracting solvent,[10,12] which showed recoveries of 6-, 8-, 10- and 6-shogaol over 94.7% from ginger products.[10] To confirm the recovery data, we carried out the analysis of spiked authentic 8-gingerol in a representative matrix of fresh ginger. It was found that the recovery for 8-gingerol ($C_{19}H_{30}O_4$) was 91.304% with 5.072% RSD (data not shown). We also carried out the analysis with commercial fresh ginger at four different dates (duplicate analysis for each day) to study the intra- and interday repeatability and precision of the analytical method (Table 4). The RSD of interday analysis of total gingerol-related in the commercial fresh ginger was 1.36%. These results clearly suggested that the present HPLC-TOF/MS analytical method had a high intra- and interday precision and reproducibility for the analysis of gingerol-related compounds in commercial ginger products. The matrix effect is another important parameter for the quantification of certain analyst in mass spectrometry. The matrix effect can both reduce or enhance the responses of analysts in matrix-matched samples when compared to those in neat solvents. Matrix effects depend on the instrument and interface used, the analytes, the matrix, and the sample pretreatment procedure.[19] The matrix effects can be expressed as a ratio of analyte response in matrix-matched standard to its response in solvent standard. In this work, fresh ginger was selected for the evaluation of matrix effects. The ginger extracts with the known amount of added standards and the standards in solvents were analyzed with LC/TOF-MS. The responses of standard in ginger samples and in solvent were compared for the study of matrix effects. The ratios of the responses of matrix-matched 6-gingerol, 8-gingerol, 10-gingerol, and 6-shogaol to their responses in pure solvent were 102.5, 100.6, 105.8, and 105.1%, respectively (data not shown). The results clearly showed that there was no considerable matrix suppression or enhancement for all of the tested authentic samples.

Applications in Commercial Ginger Products. Fresh gingers, powered dry gingers, hot water ginger extracts, and powdered ginger tea products were analyzed by the established HPLC-TOF/MS to determine the composition and contents of gingerol compounds after extraction with ethyl acetate. Among the 19 gingerol-related compounds indentified, only four authentic components (6-, 8-, 10-gingerols and 6-shogaol) were commercially available. Thus, we could obtain the calibration curves only for the commercially available authentic components. Thus, the estimated quantities of the other components were obtained with the available calibration curves of components with a similar molecular structure. For example, the quantities of 4-gingerol and 12-gingerol were obtained with calibration curves of 6-gingerol and 10 gingerol, respectively. The quantities of methyl gingerols and dehydrogingerols were calculated with calibration curves of their structurally similar gingerols. The quantifications of 8-, 10-, and 12-shogaols, gingerdiones, and dehydrogingerdione were obtained with calibration curves of 6-shogaol. Tables 5−8 show the contents of individual and total gingerol-related compounds in fresh ginger, dried ginger powders, hot water ginger extracts, and

Table 4. Intra- and Interday Analytical Data for the Gingerol-Related Compounds in Fresh Ginger

	contents of gingerols and related compounds (μg/1 g fresh ginger)					
compds	day 1	day 2	day 3	day 4	mean	RSD (%)
4-gingerol	16.89 ± 0.30	16.76 ± 0.29	16.96 ± 0.52	15.64 ± 0.16	16.96 ± 0.52	3.72
6-gingerol	1553.00 ± 12.70	1523.39 ± 33.53	1493.21 ± 23.75	1459.79 ± 15.47.	1493.21 ± 23.75	2.65
dehydro-6-gingerol	65.76 ± 0.26	64.92 ± 0.08	62.94 ± 0.25	63.77 ± 0.18	64.35 ± 1.23	1.92
Me-6-gingerol	92.88 ± 1.92	85.13.74 ± 2.86	83.56 ± 2.00	81.72 ± 0.86	83.56 ± 2.00	5.71
8-gingerol	279.00 ± 0.54	285.31.13 ± 0.34	277.87 ± 1.03	273.41 ± 2.83.	27.87. ± 1.03	1.75
6-shogaol	ND	ND	ND	ND	ND	ND
dehydro-8-gingerol	35.60 ± 022	34.59 ± 0.19	35.75 ± 0.22	32.74 ± 0.34	34.97 ± 0.86	2.46
Me-8-gingerol	10.30 ± 0.54	10.75.92 ± 0.41	10.59 ± 0.66	10.81 ± 0.75	10.59 ± 0.66	2.16
dehydro-6 gingerdione	180.51 ± 6.62	203.45.13 ± 4.92	204.05 ± 9.54	191.27 ± 12.74	204.05 ± 9.54	5.75
10-gingerol	405.42 ± 8.16	402.71.77 ± 0.15	399.40 ± 10.31	417.29 ± 4.29	399.40 ± 10.31	1.91
8-shogaol	ND	ND	ND	ND	ND	ND
dehydro-10-gingerol	118.31 ± 0.32	117.97 ± 0.19	118.51 ± 0.22	118.21 ± 0.29	118.25 ± 0.22	0.19
dehydro-8-gingerdione	27.18 ± 6.18	29.24.68 ± 1.26	30.09 ± 0.60	32.74 ± 0.34	30.09 ± 0.60	7.72
12-gingerol	14.03 ± 0.20	13.95.48 ± 0.24	13.83 ± 0.31	13.70 ± 0.15	13.83 ± 0.31	1.02
10-shogaol	ND	ND	ND	ND	ND	ND
dehydro-10-gingerdione	109.72 ± 5.18	125.67.12 ± 2.20	128.64 ± 3.73	126.06 ± 5.62	128.64 ± 3.73	7.04
dehydro-12-gingerol	11.81 ± 0.02	11.82 ± 0.02	11.81 ± 0.88	11.83 ± 0.01	11.81 ± 0.08	0.06
dehydro-12-gingerdione	22.97 ± 0.38	24.37.69 ± 1.03	23.07 ± 0.73	26.52 ± 2.00	23.07 ± 0.73	6.82
dehydro-14-gingerdione	ND	ND	ND	ND	ND	ND
total gingerol	2813.30 ± 27.61	2820.30 ± 53.14	2780.04 ± 5.51	2746.73 ± 10.04	2790.09 ± 33.82	1.21

Table 5. Contents and Compositions of Gingerol-Related Compounds in Commercial Fresh Gingers Obtained in Korea as Determined by LC-TOF/MS

	contents of gingerols and related compounds in fresh gingers[a] (μg/1 g fresh ginger)				
	Bongdong area			Seosan area	
compds	ginger 1 (Gearyang)	ginger 2 (Tojong)	ginger 3 (Tojong)	ginger 4 (Gearyang)	ginger 5 (Tojong)
4-gingerol	12.08 ± 0.38	16.96 ± 0.52	11.88 ± 0.17	12.25 ± 0.13	11.97 ± 0.03
6-gingerol	1292.16 ± 91.45	1493.21 ± 23.75	1047.35 ± 6.76	1050.44 ± 8.17	1069.91 ± 26.93
dehydro-6-gingerol	68.07 ± 0.69	64.35 ± 1.23	43.63 ± 0.09	35.20 ± 0.02	50.95 ± 0.02
Me-6-gingerol	75.48 ± 0.07	83.56 ± 2.00	62.02 ± 2.43	81.77 ± 1.31	79.42 ± 1.55
8-gingerol	238.28 ± 5.56	278.7 ± 1.03	218.98 ± 3.92	260.02 ± 3.26	144.78 ± 0.40
6-shogaol	ND	ND	ND	ND	ND
dehydro-8-gingerol	36.64 ± 1.03	34.97 ± 0.86	28.88 ± 0.28	25.01 ± 0.10	22.16 ± 0.58
Me-8-gingerol	8.42 ± 0.02	10.59 ± 0.66	7.71 ± 0.22	9.43 ± 0.01	7.91 ± 0.01
dehydro-6 -gingerdione	265.96 ± 28.69	204.05 ± 9.54	211.04 ± 7.70	147.72 ± 0.53	199.20 ± 8.24
10-gingerol	349.20 ± 35.38	399.40 ± 10.31	296.69 ± 6.88	335.95 ± 16.03	230.44 ± 6.24
8-shogaol	ND	ND	ND	ND	ND
dehydro-10-gingerol	84.94 ± 0.31	118.25 ± 0.22	73.99 ± 0.26	77.69 ± 0.03	58.02 ± 0.63
dehydro-8-gingerdione	37.72 ± 1.35	30.09 ± 0.60	36.15 ± 2.15.	32.57 ± 0.74	26.23 ± 0.49
12-gingerol	10.73 ± 0.55	13.83 ± 0.31	14.11.33 ± 0.10	14.92 ± 0.10.	8.92 ± 0.09
10-shogaol	ND	ND	ND	ND	ND
dehydro-10-gingerdione	143.10 ± 10.60	128.64 ± 3.73	115.14 ± 3.29	125.56 ± 0.43	77.34 ± 2.24
dehydro-12-gingerol	9.04 ± 0.02	11.81 ± 0.08	9.50 ± 0.05	8.00 ± 0.07	6.36 ± 0.05
dehydro-12-gingerdione	15.65 ± 1.04	23.07 ± 0.73	21.06 ± 0.04	19.40 ± 0.27.	14.33 ± 0.38
dehydro-14-gingerdione	ND	ND	ND	ND	ND
total gingerol	2648.50 ± 177.04	2790.09 ± 33.82	2198.20 ± 18.73	2236.01 ± 19.39	2007.99 ± 47.06

[a]Ginger 1, Gaeryang variety cultivated at a farm in the Bongdong area; ginger 2, Tojong variety cultivated at a farm in the Bongdong area; ginger 3, Togong variety cultivated at a farm in the Bongdong area; ginger 4, Gaeryang variety cultivated at a farm in the Seosan area; and ginger 5, Tojong variety cultivated at a farm in the Seosan area.

ginger tea products, respectively. The total contents of gingerol-related compounds in the analyzed ginger products varied greatly from 54.59 to 13789.04 μg/g products. The dried ginger powder products contained the highest quantity of gingerol-related compounds (7126.3−13789.0 μg/g ginger), followed by fresh ginger products (2007.9−2790.0 μg/g), powdered ginger tea products (77.29−81.75 μg/g), and hot water ginger extracts (54.59−123.23 μg/mL extracts). 6-Gingerol, 8-gingerol, 10-gingerol, and dehydro-6-ginerdione were the major components in all ginger products. In fresh ginger, 6-gingerol was the most abundant component, representing about 50% of total gingerol-related compounds, which was in consist with previous reports.[2,19−24] The 6-gingerol contents in fresh gingers were in the range of 1047.3−1493.2 μg/g fresh ginger. There were great variations of the reported contents of 6-gingerol (132−2100 μg/g fresh ginger) in fresh gingers. Our result for the 6-

Table 6. Contents and Compositions of Gingerol-Related Compounds in Commercial Powdered Dry Ginger Obtained in Korea as Determined by LC-TOF/MS

compds	contents of gingerols and related compounds in powdered dry gingers[a] (μg/1 g ginger powder)		
	powdered ginger 1	powdered ginger 2	powdered ginger 3
4-gingerol	37.78 ± 0.16	52.04 ± 2.87	20.52 ± 0.03
6-gingerol	5035.35 ± 113.79	5208.52 ± 715.47	2739.51 ± 54.73
dehydro-6-gingerol	283.83 ± 11.14	92.47 ± 0.82	56.27 ± 0.26
Me-6-gingerol	266.67 ± 8.37.	307.09 ± 38.83	262.97 ± 0.77.
8-gingerol	1073.48 ± 41.91	1358.44 ± 105.09	775.49 ± 3.29
6-shogaol	622.43 ± 1.81	1423.75 ± 80.13	353.20 ± 1.40
dehydro-8-gingerol	169.94 ± 0.41	57.92 ± 0.46	49.32 ± 0.51
Me-8-gingerol	25.56 ± 0.69	45.17 ± 3.52	36.94 ± 0.43.
dehydro-6-gingerdione	1251.50 ± 37.12	821.77 ± 9.06	486.79 ± 5.82
10-gingerol	1882.98 ± 45.52	2080.85 ± 381.51	1362.30 ± 11.19
8-shogaol	114.44 ± 0.56	367.15 ± 12.81	64.40 ± 0.06.
dehydro-10-gingerol	421.10 ± 2.59	181.75 ± 0.39	156.02 ± 0.88
dehydro-8-gingerdione	223.18 ± 5.99	148.89 ± 15.98	105.93 ± 3.90
12-gingerol	64.41 ± 2.49	69.38 ± 4.43	62.94 ± 1.04
10-shogaol	222.31 ± 6.78	663.09 ± 52.11	155.96 ± 2.43
dehydro-10-gingerdione	680.57 ± 17.02	521.26 ± 86.89	327.32 ± 2.43
dehydro-12-gingerol	55.83 ± 0.16	21.57 ± 0.06	23.34 ± 0.41
dehydro-12-gingerdione	113.94 ± 4.53	75.42 ± 7.73	73.93 ± 1.84
dehydro-14-gingerdione	19.35 ± 1.42	13.38 ± 1.08	13.17 ± 0.17
total gingerol	12564.72 ± 245.40	13789.04 ± 1106.63	7126.37 ± 80.41

[a]Powdered dry gingers (1−3) were the commercial products manufactured by different companies in Korea.

gingerol content in fresh ginger was within the range of the previously reported values. There are two major varieties of gingers (gaeryang and tojong) cultivated and two major growing areas (Bongdong and Seosan) in Korea. Our results showed that there was no considerable difference in total quantity and compositions of gingerol-related compounds regardless of varieties and cultivating regions. Shogaols were not found in any detectable quantity in fresh gingers. However, shogaols were found in dried ginger powder, ginger extracts, and ginger teas, supporting the previous hypothesis that shogaols are not native constituents of fresh ginger but artifacts converted from gingerols by a dehydration reaction during heat treatment.[25] In commercial powdered dry gingers, 6-gingerol represented about 39% of total gingerol-related compounds, showing significantly lower portions than that (50%) in fresh ginger. The total quantities of shogaols in dry gingers were in the range of 573.5−2453.9 μg/g, showing the great variation in its content (Table 6). The variation in the shogaols contents in dried gingers may be due to the difference in the heat exposure during the drying process. Among the shogaols, 6-shogaol was the most predominant component, followed by 10-shogaol and 8-shogaol. Shao et al.[25] reported that ground ginger powder contained 6-shogaol, ranging from 1156.7 to 1495.4 μg/g. Powered ginger teas also contained high portion of shogaols (Table 7). The total contents of gingerol-related compounds in hot water extract vary greatly in the range of 54.59−123.23 μg/mL (Table 8). For the preparation of hot water extract, gingers with added water were heated in an electric jar for about 24 h. The variation in gingerol contents in hot water ginger extract seemed to be mainly due to the ratio of water added to the gingers during the manufacturing process. The quantities of gingerol-related compounds in ginger products have been analyzed by GC-FID, GC/MS, and HPLC-DAD. There are distinct disadvantages associated with GC and GC/MS methods for analyzing these compounds due to their low volatility and thermal instability. A report on the quantification of gingerol-related compound by LC-tandem MS spectrometry with a selected reaction monitoring mode has been published

Table 7. Contents and Compositions of Gingerol-Related Compounds in Commercial Powdered Ginger Teas Obtained in Korea as Determined by LC-TOF/MS

compds	contents of gingerols and related compounds in ginger teas[a] (μg/1 g ginger tea)		
	ginger tea 1	ginger tea 2	ginger tea 3
4-gingerol	ND	0.11 ± 0.02	0.11 ± 0.008
6-gingerol	7.67 ± 0.04	20.90 ± 0.12	23.45 ± 0.02
dehydro-6-gingerol	0.48 ± 0.0003	0.32 ± 0.002	0.36 ± 0.003
Me-6-gingerol	ND	1.06 ± 0.01	1.14 ± 0.04
8-gingerol	1.36 ± 0.004	5.23 ± 0.01	5.93 ± 0.02
6-shogaol	35.66 ± 0.84	18.13 ± 0.02	18.30 ± 0.12
dehydro-8-gingerol	0.29 ± 0.0005	0.19 ± 0.0007	0.27 ± 0.0004
Me-8-gingerol	ND	ND	ND
dehydro-6-gingerdione	1.39 ± 0.04	2.59 ± 0.007	3.02 ± 0.07
10-gingerol	2.31 ± 0.02	8.46 ± 0.001	9.24 ± 0.07
8-shogaol	9.35 ± 0.05	4.96 ± 0.008	4.53 ± 0.01
dehydro-10-gingerol	2.36 ± 0.0003	1.98 ± 0.0002	2.11 ± 0.008
dehydro-8-gingerdione	ND	0.29 ± 0.006	0.41 ± 0.007
12-gingerol	ND	0.33 ± 0.0002	0.35 ± 0.01
10-shogaol	17.44 ± 0.34	8.45 ± 0.14	7.92 ± 0.02
dehydro-10-gingerdione	1.36 ± 0.03	1.71 ± 0.02	1.88 ± 0.05
dehydro-12-gingerol	0.35 ± 0.003	0.21 ± 0.002	0.23 ± 0.001
dehydro-12-gingerdione	ND	2.45 ± 0.15	2.50 ± 0.0078
dehydro-14-gingerdione	ND	ND	ND
total gingerol	80.36 ± 1.12	77.29 ± 0.10	81.75 ± 0.32

[a]Ginger teas (1−3) were the commercial products manufactured by different companies in Korea.

Table 8. Contents and Compositions of Gingerol-Related Compounds in Commercial Hot Water Ginger Extracts Obtained in Korea as Determined by LC-TOF/MS

compds	contents of gingerols and related compounds in ginger extract[a] (μg/1 mL ginger extract)			
	ginger extract 1	ginger extract 2	ginger extract 3	ginger extract 4
4-gingerol	0.82 ± 0.07	0.62 ± 0.06	0.76 ± 0.07	0.48 ± 0.35
6-gingerol	52.24 ± 1.61	35.13 ± 1.38	40.45 ± 1.61	32.26 ± 1.75
dehydro-6-gingerol	2.27 ± 0.005	0.70 ± 0.002	1.12 ± 0.005	0.50 ± 0.007
Me-6-gingerol	3.77 ± 0.1.84	2.36 ± 0.36	2.49 ± 0.18	1.70 ± 0.05
8-gingerol	14.13 ± 0.62	7.94 ± 0.49	6.75 ± 0.62	3.96 ± 0.33
6-shogaol	0.64 ± 0.03	0.81 ± 0.03	0.56 ± 0.03	0.87 ± 0.04
dehydro-8-gingerol	1.31 ± 0.005	0.51 ± 0.005	0.51 ± 0.005	0.24 ± 0.004
Me-8-gingerol	0.74 ± 0.04	0.47 ± 0.04	0.36 ± 0.04	0.24 ± 0.01
dehydro-6-gingerdione	7.76 ± 0.47	4.03 ± 0.24	4.49 ± 0.47	2.92 ± 0.22
10-gingerol	24.28 ± 0.82	14.41 ± 0.69	11.75 ± 0.82	6.91 ± 0.48
8-shogaol	0.12 ± 0.005	0.13 ± 0.007	0.09 ± 0.005	0.11 ± 0.01
dehydro-10-gingerol	3.9 ± 0.02	1.69 ± 0.004	1.68 ± 0.002	0.77 ± 0.002
dehydro-8-gingerdione	1.40 ± 0.08	0.75 ± 0.04	0.64 ± 0.08	0.39 ± 0.02
12-gingerol	0.48 ± 0.02	0.27 ± 0.01	0.26 ± 0.02	0.17 ± 0.004
10-shogaol	0.24 ± 0.01	0.26 ± 0.01	0.17 ± 0.01	0.19 ± 0.01
dehydro-10-gingerdione	7.37 ± 0.36	5.09 ± 0.32	3.17 ± 0.36	2.33 ± 0.22
dehydro-12-gingerol	0.39 ± 0.006	0.16 ± 0.0006	0.20 ± 0.006	0.09 ± 0.0001
dehydro-12-gingerdione	1.37 ± 0.01	0.72 ± 0.04	0.68 ± 0.01	0.38 ± 0.01
dehydro-14-gingerdione	0.30 ± 0.04	0.16 ± 0.008	0.16 ± 0.04	0.08 ± 0.006
total gingerol	123.23 ± 4.11	76.21 ± 3.16	76.29 ± 1.97	54.59 ± 2.78

[a]Hot water ginger extracts (1−3) were commercial products obtained from different farms.

previously.[18] However, the LC-MS/MS with SRM method allowed only six gingerol-related compounds (6-gingerol, 8-gingerol, 10-gingerol, 6-shogaol, 8-shogaol, and 10-shogaol) in gingers. The LC-MS/MS with SRM method can only monitor the selected target compounds. The analytical methods employed for monitoring of target compounds in foods should be capable of measuring low levels and must provide unambiguous evidence to confirm both the identity and the quantity of the components detected. LC-TOF/MS instruments also offer the capability of unequivocal identification (simultaneously provided by exact mass measurements, fragment ion patterns, and isotope ion peaks) and quantification of the components at low levels. Furthermore, the TOF/MS analysis provides the full spectrum recorded at all times, which allows the capability of nontarget identification. It also has been previously reported that HPLC-TOF/MS was an effective tool for the identification of gingerols, shogaols, and their related compounds in the ginger products.[13,15] However, no attempt has been made to develop an LC-TOF/MS analytical method for the simultaneous identification and quantification of gingerol related compounds in ginger products.

In a brief summary, an LC-TOF/MS method has been established for simultaneous characterization and quantification of the gingerol-related components of fresh and powered dry gingers, ginger extracts, and powdered ginger tea products. Nineteen compounds (4-, 6-, 8-, 10-, and 12-gingerols, methyl-6-, methyl-8-, and dehydro-6-, dehydro-8-, dehydro-10-, and dehydro-12-gingerols, dehydro-6-, dehydro-8-, dehydro-10-, dehydro-12-, dehydro-14-gingerdione, and 6-, 8-, and 10-shogaols) were identified in ginger products by LC-TOF/MS. The LC-TOF/MS method was an effective analytical method for simultaneous characterization and quantification of gingerols and shogaols in ginger products. The established method provided a satisfactory linearity in a wide range, low LOD and LOQ, a high precision, and high inter- and intraday repeatability. The LC-TOF/MS method was about 70−100 times more sensitive than conventional HPLC-UV method. This method would be a valuable tool for the analysis of gingerols, especially in the samples containing low quantity of gingerols, shogaols, and their related compounds.

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Notes

The authors declare no competing financial interest.

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