# Distribution of Catechins, Theaflavins, Caffeine, and Theobromine in 77 Teas Consumed in the United States

MENDEL FRIEDMAN, SOO-YEUN KIM, SIN-JUNG LEE, GYEONG-PHIL HAN, JAE-SOOK HAN, KAP-RANG LEE, AND NOBUYUKE KOZUKUE

ABSTRACT: To help define the composition of commercial teas consumed in the United States, we have developed and validated an high-performance liquid chromatography (HPLC) method to analyze levels of catechins, theaflavins, and alkaloids in 77 commercial black, green, specialty (brown rice, white, oolong), and herbal teas extracted with hot water to simulate home use. The following 13 compounds were separated in a single analysis on an Inertsil ODS-3v column with acetonitrile/potassium dihydrogen phosphate as the mobile phase: (–)-epigallocatechin, (+)-catechin, (–)-epicatechin, (–)-epigallocatechin-3-gallate, (–)-gallocatechin-3-gallate, (–)-epicatechin-3-gallate, (–)-catechin-3-gallate, theaflavin, theaflavin-3-gallate, theaflavin-3'-gallate, theaflavin-3, 3'-digallate, caffeine, and theobromine. The data show that (1) extraction time from 3 min to 20 min did not significantly affect measured levels of tea compounds and (2) there was a wide variation in the composition of the tea compounds both within each tea category and among categories: black teas contained both theaflavins and catechins, green and white teas contained catechins and trace amounts of theaflavins, herbal teas contained very low amounts of all tea compounds. A statistical profile of the distribution of catechins, theaflavins, caffeine, and theobromine in the evaluated teas offers consumers a choice of teas containing high levels of health-promoting compounds.

Keywords: HPLC, catechins, theaflavins, caffeine, theobromine, teas, *Camelia sinensis*

## Introduction

Plants, including tea leaves from *Camelia sinensis* (Beecher 2003), produce secondary metabolites, organic compounds that are involved in the defense of the plants against invading pathogens, including insects, bacteria, fungi, and viruses. In the case of tea leaves, these metabolites include polyphenolic catechins and theaflavins and the alkaloids caffeine and theobromine. Commercial teas can be classified into several major categories: unfermented green, semi-fermented oolong, and fully fermented black. Inactivation of phenol oxidases in green tea prevents oxidations of the catechins, whereas phenolase-catalyzed oxidation of catechins in green tea results in the formation of dimeric theaflavins and polymeric thearubigins, which impart the black color to black tea (Schwimmer 1981; Bonoli and others 2003; Sang and others 2004; Shahidi and Naczk 2004). White tea is produced only in a province of China from tip buds of a special tea plant. Herbal teas are derived from plants other than *Camelia sinensis*.

Depending on the stereochemical configuration of the of the 3', 4'-dihydroxyphenyl and hydroxyl groups at the 2- and 3-positions of the C-ring, tea catechins can exist as 2 geometrical isomers: *trans*-catechins and *cis*-epicatechins (Figure 1). Each of the isomers, in turn, exists as 2 optical isomers: (+)-catechin and (–)-catechin and (+)-epicatechin and (–)-epicatechin, respectively. (–)-Catechin can

be modified by esterification with gallic acid to form (–)-catechin-3-gallate, epicatechin-3-gallate, (–)-epigallocatechin-3-gallate, and (–)-gallocatechin-3-gallate, respectively. Oxidative coupling of different catechins forms the 4 theaflavins.

Antioxidative tea components are reported to have beneficial protective effects against cancers (Michels and others 2005), cholesterol (Maron and others 2003; Vinson and others 2004), cerebral damage (Suzuki and others 2004), diabetes (Vinson and Zhang 2005), smoking (Schwarz and others 2005), and pathogenic bacteria (Yoda and others 2004; Friedman and others 2005). Green and black teas also contain the central nervous system stimulant caffeine and the diuretics/vasodilators theobromine (Fisone and others 2004) and theophylline (Fernandez and others 2002). Black teas also contain the polymeric thearubigin pigments of undefined structure (Menet and others 2004). A need exists to relate the composition of commercial teas to beneficial effects.

A wide variety of extraction conditions and analysis methods have been used resulting in a wide variety in measured concentrations of tea compounds. Previous studies include the following observations:

Lee and Ong (2000) measured 4 catechins and theaflavins (extracted with boiling water and incubated at 90 °C for 30 min) in 8 teas sold in Singapore using high-performance liquid chromatography (HPLC) and electrophoresis. The mobile phase used consisted of acetonitrile/trifluoroacetic acid. Although the analysis by electrophoresis was faster, it was only 1/5 as sensitive as HPLC.

Lin and others (Lin and others 2003) used an isocratic HPLC procedure with a mobile phase consisting of ethanol/$H_2O$/formic acid to determine caffeine and 5 catechins in 31 Taiwanese tea leaves and tea flowers. Some of the flowers extracted with 75% ethanol at 60 °C for 30 min contained greater amounts of total catechins than

did extracts obtained with boiling water for 30 min and others contained lower amounts.

Khokhar and Magnusdottir (Khokhar and Magnusdottir 2002) used HPLC with acetonitrile as the eluent to determine the content of 5 catechins and caffeine in 4 black, 3 green, and 6 fruit teas (extracted in boiling water for 5 min) consumed in the U.K. The amount of catechins and caffeine extracted in water increased in the range 60 °C to 100°C and was greatest at 100 °C for 5 min. The total catechin content ranged from 5.6 to 47.5 mg/g in black teas and from 51.5 to 84.3 mg/g in green teas. The estimated dietary intake of total tea catechins was 92.7 mg/d from black teas and 405.5 mg/d from green teas. The range for caffeine was from 92 to 146 mg/d.

Fernandez and others (Fernandez and others 2002) used HPLC with water/acetonitrile/formic acid as the mobile phase to measure catechin and xanthine profiles of 13 green and 42 black and red teas (extracted with 60:40 acetonitrile/water at room temperature for 1 h) originating from China, Japan, Kenya, India, and Sri Lanka. Their results suggest that catechin, gallic acid, and the methyl-xanthine content may be used to differentiate the geographic origin of specific teas.

Cabrera and others (Cabrera and others 2003), using an HPLC method with a photodiode array detector, measured 4 catechins and caffeine levels in 15 black, green, and oolong teas sold in Spain (extracted with 80% methanol for 3 h and then twice more with 80% methanol containing 0.15% HCl for 3 h). They observed a wide variation in the content of catechins among these teas. Red teas had the lowest levels.

Analysis by HPLC-MS of catechins, theaflavins, and purine alkaloids in Indonesian green and black tea infusions extracted with boiling water for 3 min (Del Rio and others 2004) gave the following results for green tea (in mg/L): total catechins, 4572; theobromine, 57; caffeine, 866; total theaflavins, 0. The values for black tea were 26, 224, 25, and 541, respectively.

In related studies, Sakakibara and others (2003) extracted polyphenols from vegetables, fruits, and teas with 90% methanol/0.5% acetic acid; Zhu and others (2004) analyzed tea compounds by GS-MS after steeping the tea leaves in water at 80 °C for 30 min; and Bonoli and others (2003) extracted teas with boiling water for 5 min.

Other studies describe the analysis of tea polyphenols by HPLC with different detectors (Beecher and others 1999; Lee and others 2000) by micellar electrokinetic chromatography (Bonoli and others 2003), as well as by mass spectrometry (Menet and others 2004) and by HPLC/electrospray-mass spectrometry (Zhu and others 2004). Using UV spectroscopy, we previously showed that (–)-catechin and (–)-epigallocatechin resisted degradation at high pH (Friedman and Jürgens 2000). Catechins added to dough also resisted heat-degradation during the bread baking (Wang and Zhou 2004).

Units used to report results from analyses of teas include: mg/g dry wt of tea, % of dry matter (DM) (Leung and others 2001), μmol/100 g tea leaves (Sakakibara and others 2003), mg/L of tea infusions (Del Rio and others 2004), μg/mL of canned tea drinks (Fernandez and others 2002; Bonoli and others 2003), gallic acid equivalents (GAE) for total phenolics, and epicatechin equivalents (ECE) for total flavonoids (Rechner and others 2002; Lee and others 2003; Stevanato and others 2004).

As the previously cited studies show, a plethora of solvents, temperatures, and times have been used to extract tea leaves before analysis. Therefore, comparison of data from studies using different extraction methods may not always be justified. There is an urgent need to standardize extraction/analysis methods and units of measurement, preferably extraction with boiling water for 5 min to simulate home use of teas, analysis by HPLC, and units that re-

port the results in mg/g of original weight of tea or as mg/L for tea infusions and commercial tea drinks.

The main objectives of this study were (1) to validate a new HPLC method for the analysis of 13 tea compounds (7 catechins, 4 theaflavins, and the alkaloids caffeine and theobromine) in a single run; and (2) to compare the levels of tea constituents extracted with hot water under conditions that would simulate what would be present in the teas prepared by consumers.

## Materials and Methods

### Materials

Black, green, specialty, and herbal teas were purchased in local markets and restaurants in the Albany-San Francisco area of California and from the The Stash Tea Co. (Portland, Oreg., U.S.A.). (–)-Epigallocatechin, (+)-catechin, (–)-epicatechin, (–)-epigallocatechin gallate, (–)-gallocatechin gallate, (–)-epicatechin gallate, (–)-catechin gallate, caffeine, and theobromine were obtained from Sigma (St. Louis, Mo., U.S.A.). Theaflavin, theaflavin-3-gallate, theaflavin-3′-gallate, and theaflavin-3, 3′-digallate were obtained from Wako (Osaka, Japan). HPLC-grade solvents were filtered through a 0.45-μm membrane (Millipore, Bedford, Mass., U.S.A.) and degassed in an ultrasonic bath before use.

### Extraction and analysis of teas

For extraction with distilled water, each tea sample (about 1.5 g) was placed into a 250-mL flask to which was added 250 mL of water previously brought to the boiling point. The sample was then stirred slowly with a magnetic stirrer for 5 min, cooled, and centrifuged at $18000 \times g$ for 10 min at 1 °C. The supernatant was filtered on a 0.45-μm Millipore nylon filter before analysis. The same procedure was used to determine the effect of extraction time (3, 5, 10, 15, or 20 min) on the levels of extracted tea compounds.

HPLC was carried out on a Hitachi liquid chromatograph model 665-II equipped with an Autosampler (model 655A-40). The stainless-steel column (250 mm × 4.0 mm inner dia) was packed with Inertsil ODS-3v (5-μm particle diameter) (GL Sciences, Tokyo Japan). The column temperature was maintained constant with a Shimadzu column oven CTO-10vp (Shimadzu, Kyoto, Japan). The gradient system consisted of a mixture of acetonitrile and 20 m$M$ $KH_2PO_4$. The flow rate was 1 mL/min at a column temperature of 30 °C. A Shimadzu photo diode array UV-VIS detector (model SPD-10Avp) was set from 200 to 700 nm. The tea extract (10 μL) was injected directly into the column. Analyses, each in triplicate, were carried out with 3 extracts prepared from 3 different tea bags for each sample.

The initial composition of the mobile phase consisting of 7% acetonitrile (A) and of 93% of 20 m$M$ $KH_2PO_4$ (B) (v/v) was maintained for 6 min. Solvent A was then increased linearly to 10% in 20 min, 15% in 25 min, 20% in 30 min, and 25% in 45 min to 70 min. Programming was then continued in the isocratic mode as follows: 40% A in 70.1 to 75.0 min and 7% A in 76.1 to 90.1 min (1 cycle ends).

Identification and quantification was accomplished by comparing integrated chromatographic peak areas from the test samples to peak areas of known amounts of standard compounds using the Hitachi Chromato-integrator model D-2500. Each peak was identified by comparing the retention times and absorption spectra of unknowns to those of standards. Identification was confirmed by spiking sample peaks with respective standards. Because cooling the infusions during centrifugation may result in precipitation of some material, what is being measured is the recovery of the compounds during centrifugation and filtration steps needed to prepare the samples for HPLC analysis.

For tests of recoveries of spiked samples, tea extracts were analyzed before and after addition of known amounts of standard compound. Recovery (%) = (concentration of each compound in spiked sample)/(concentration of endogenous compound + spike) × 100.

## Statistical analysis

The square root or log transformation was used to stabilize the variances before 1-way analyses of variance between teas among the respective sums of 7 catechins, 4 theaflavins, and 11 catechins and theaflavins. Zeros were deleted (and data values <1 for caffeine) from the 1-way analyses (ANOVA) because they would result in a negative bias of the error variance estimates. Dunnett's 1-tailed test was used to test for decreases from the 10th highest ranked tea.

# Results and Discussion

## Analytical aspects

The HPLC-UV detection method was adapted, after extensive experimentation to optimize the analyses, from previously described procedures for the separation of potato and tomato glyco-

alkaloids (Friedman and others 2003; Kozukue and others 2004). Examination of the dependence of retention times of mixtures of standards on column temperature in the range 20 °C to 40 °C indicated that a column temperature of 30 °C resulted in optimum separation of chromatographic peaks. The mobile phase, consisting of mixtures of acetonitrile and 20 m$M$ potassium dihydrogen phosphate and programmed in linear/isocratic modes, successfully separated all 13 catechins, theaflavins, caffeine, and theobromine (Figure 1 and 2). The method responded linearly over the concentration range shown in Table 1. The retention (elution) times ranged from 7.86 min for theobromine to 63.10 min for theaflavin-3, 3′-digallate. The limits of detection (LOD) ranged from 1.95 ng for theobromine to 12.58 ng for (+)-catechin. Recoveries from extracts spiked with authentic standards were quantitative for caffeine
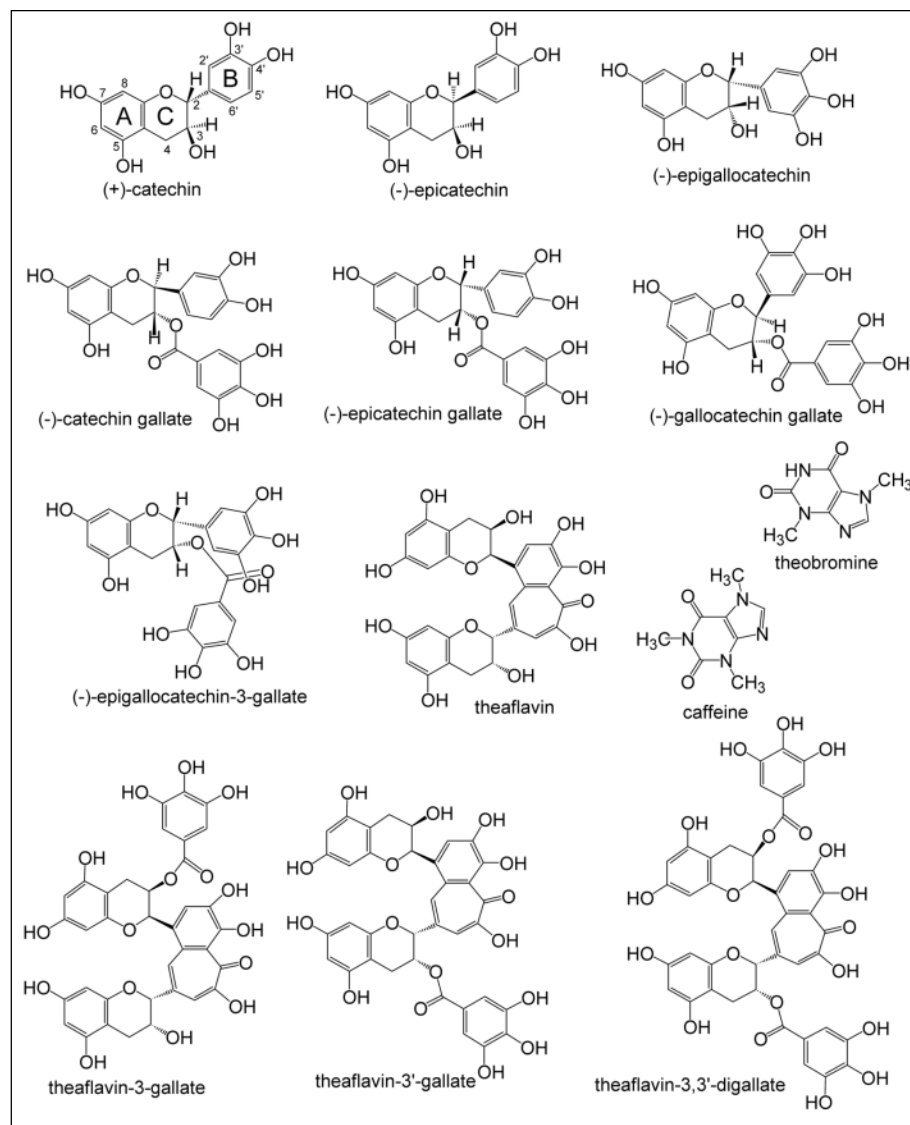


Figure 1—Structures of catechins, theaflavins, and alkaloids evaluated in this study gallate
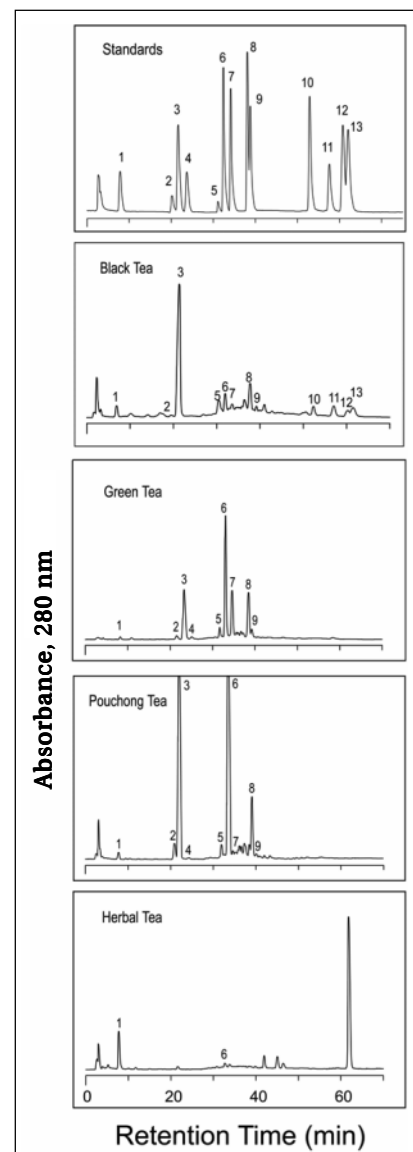


**Figure 2—High-performance liquid chromatography (HPLC) chromatograms with UV detection at 280 nm of a mixture of 13 standards listed in Table 1 and of selected teas. Peak 1, theobromine; 2, (–)-epigallocatechin; 3, caffeine; 4, (+)-catechin; 5, (–)-epicatechin; 6, (–)-epigallocatechin gallate; 7, (–)-gallocatechin gallate; 8, (–)-epicatechin gallate; 9, (–)-catechin gallate; 10, theaflavin; 11, theaflavin 3-gallate; 12, theaflavin 3′-gallate; 13, theaflavin 3,3′-digallate**

**Table 1—High-performance liquid chromatography (HPLC) of standards listed in order of elution: retention times, limits of detection, tests for linearity, and recoveries after spiking of tea**

| Compound | Retention times on HPLC column (min) | Limits of detection (ng) | Linearity range[a] (ng) | Recovery after spiking (%) |
|---|---|---|---|---|
| Theobromine | 7.86 ± 0.03 | 1.95 | 0-800 | 101.3 ± 2.6 |
| (−)-Epigallocatechin (EGC) | 20.62 ± 0.03 | 14.64 | 0-800 | 82.4 ± 1.2 |
| Caffeine | 22.35 ± 0.01 | 2.40 | 0-800 | 99.8 ± 1.7 |
| (+)-Catechin (C) | 24.23 ± 0.06 | 12.58 | 0-2000 | 91.9 ± 1.5 |
| (−)-Epicatechin (EC) | 31.06 ± 0.08 | 3.03 | 0-1500 | 82.4 ± 2.6 |
| (−)-Epigallocatechin-3-gallate (EGCG) | 32.70 ± 0.06 | 4.61 | 0-1500 | 79.6 ± 4.6 |
| (−)-Gallocatechin gallate (GCG) | 34.35 ± 0.08 | 5.95 | 0-2500 | 92.3 ± 5.3 |
| (−)-Epicatechin gallate (ECG) | 38.30 ± 0.07 | 6.50 | 0-5500 | 99.6 ± 0.7 |
| (−)-Catechin gallate (CG) | 39.04 ± 0.05 | 1.36 | 0-3300 | 103.8 ± 1.3 |
| Theaflavin (TF) | 53.34 ± 0.01 | 6.03 | 0-3300 | 74.2 ± 2.1 |
| Theaflavin-3-gallate (TF3G) | 58.27 ± 0.22 | 5.85 | 0-1400 | 86.6 ± 1.0 |
| Theaflavin-3′-gallate (TF3′G) | 61.60 ± 0.28 | 5.15 | 0-1800 | 81.8 ± 1.2 |
| Theaflavin-3,3′-digallate (TF3,3′G) | 63.10 ± 0.65 | 6.78 | 0-1800 | 89.1 ± 1.4 |

[a]Range of linear plots of concentration versus peak area in mvolts; $n = 3$; $r^2 = 0.99$ for all 13 plots.

**Table 2—Teas and their sources**

| Tea name | Company name |
|---|---|
| **Black teas** | |
| 1    Orange Spice Tea | Safeway, Inc. |
| 2    Earl Grey Tea | Safeway, Inc. |
| 3    Classic Wissotzky Tea | Wissotzky Tea Co., Israel |
| 4    Ten Ren Black Tea | Ten Ren Tea Co., Taipei |
| 5    Sweet-Touch-Nee Orange Pekoe & Pekoe Cut Black Tea | Consolidated Tea, N.Y., U.S.A. |
| 6    Forrelli Apple Cinnamon Tea | Pure Ceylon Tea, Switzerland |
| 7    Maxwell House Orange Pekoe, Pekoe and Cut Black Tea | Kraft Foods Inc. |
| 8    Tai Mahal Indian Assam Tea | Wissotzky Tea Co., Israel |
| 9    Earl Grey | R. C. Bigelow, Inc, U.S.A. |
| 10   Orange Pekoe and Pekoe Cut Black | Lipton Tea Co. |
| 11   English Breakfast Tea | Twinings of London, England |
| 12   English Teatime | R. C. Bigelow, Inc, U.S.A. |
| 13   Ceylon Orange Pekoe Tea | Twinings of London, England |
| 14   Gold Genuine Ceylon Tea Blend | Wissotzky Tea Co. |
| 15   Original India Spice (100% Natural Chai Tea) | Celestial Seasonings |
| 16   Exotica Osmanthus | The Stash Tea Co., Oregon |
| 17   English Breakfast Black | The Stash Tea Co., Oregon |
| 18   Orange Spice Black | The Stash Tea Co., Oregon |
| 19   Earl Grey Black & Green, Organic | The Stash Tea Co., Oregon |
| 20   Earl Grey Black | The Stash Tea Co., Oregon |
| 21   Lemon Spice Green (and Black) | The Stash Tea Co., Oregon |
| 22   Nilgiri Black | The Stash Tea Co., Oregon |
| 23   Exotica Assam Breakfast | The Stash Tea Co., Oregon |
| 24   Breakfast Blend, Organic | The Stash Tea Co., Oregon |
| 25   Exotica Reserve Blend | The Stash Tea Co., Oregon |
| 26   Darjeeling Black | The Stash Tea Co., Oregon |
| 27   Exotica Ceylon Estate Earl Grey | The Stash Tea Co., Oregon |
| 28   Darjeeling Spring | The Stash Tea Co., Oregon |
| 29   Exotica Golden Darjeeling | The Stash Tea Co., Oregon |
| 30   Kopili Assam Black | The Stash Tea Co., Oregon |
| 31   Darjeeling Summer | The Stash Tea Co., Oregon |
| 32   Darjeeling Black, Organic | The Stash Tea Co., Oregon |
| **Green teas** | |
| 33   Green Tea with Roasted Brown Rice Tea (Decaf. Genmai-cha) | YamaMOTOYama of America |
| 34   Green Tea (Orange, Passionfruit, & Jasmine) | Lipton Tea Co. |
| 35   Organic Green Tea | YamaMOTOYama of America |
| 36   Jasmine Tea | Ten Ren Tea Co., Taipei |
| 37   Green Tea | Celestial Seasonings, USA |
| 38   Organic Moroccan Mint Green Tea | Green Restaurant, San Francisco |
| 39   Green Tea | YamaMOTOYama of America |
| 40   Green Tea & Herbal Infusion | The Reincarnation of Tea (Zen) |
| 41   Kukicha | The Stash Tea Co., Oregon |
| 42   Japanese Green Tea | Midori Tea & Ginseng Co., New York (Product of China) |
| 43   Organic Jasmine Green Tea | Green Restaurant, San Francisco |
| 44   Green Tea (100% Natural) | Lipton Tea Co. |
| 45   Premium Green, Decaffeinated | The Stash Tea Co., Oregon |
| 46   China Green Tea | Herb Enterprise, San Francisco |

*(continues on next page)*

C: Food Chemistry & Toxicology

**Table 2—Teas and their sources** (*continued from page 4*)

| Tea name | Company name |
|---|---|
| **Green teas** | |
| 47 Organic Green Tea (with an Essence of Peach) | Green Restaurant, San Francisco |
| 48 Green Tea | Ten Ren Tea Co., Taipei |
| 49 Moroccan Mint Green | The Stash Tea Co., Oregon |
| 50 Jasmine Blossom Green | The Stash Tea Co., Oregon |
| 51 Exotica Dragonwell Green | The Stash Tea Co., Oregon |
| 52 Premium Green | The Stash Tea Co., Oregon |
| 53 Sencha Japanese Green Tea | Peet's Coffee and Tea, California |
| 54 Green Organic | The Stash Tea Co., Oregon |
| 55 Sushi Bar Mild Green | The Stash Tea Co., Oregon |
| 56 Darjeeling Green, Organic | The Stash Tea Co., Oregon |
| **Specialty teas** | |
| 57 Roasted Tea (Hoji-cha) | YamaMOTOYama of America |
| 58 Brown Rice Tea (Genmai-cha) | YamaMOTOYama of America |
| 59 Pu-erh Oolong | The Stash Tea Co., Oregon |
| 60 White Tea | Ten Ren Tea Co., Taipei |
| 61 Oolong Tea | Ten Ren Tea Co., Taipei |
| 62 Pouchong Tea | Ten Ren Tea Co., Taipei |
| 63 Chinese Jasmine Tea | Madys Tea Co., San Francisco |
| 64 Fusion Red & White | The Stash Tea Co., Oregon |
| 65 Jasmin Tea | Tenfu Tea Industry Co., China |
| 66 China Oolong | The Stash Tea Co., Oregon |
| 67 Exotica China White | The Stash Tea Co., Oregon |
| 68 Exotica Champagne Oolong | The Stash Tea Co., Oregon |
| 69 Fusion Green & White | The Stash Tea Co., Oregon |
| 70 Exotica Silver Jasmine | The Stash Tea Co., Oregon |
| **Herbal teas** | |
| 71 Orange & Spice Herb Tea | R. C. Bigelow, Inc., U.S.A. |
| 72 Chamomile Tea | Safeway, Inc. |
| 73 Wild Raspberry Herbal | The Stash Tea Co., Oregon |
| 74 Chamomile Herbal | The Stash Tea Co., Oregon |
| 75 Evening Delight Tea | Safeway, Inc. |
| 76 Peppermint Tea | Safeway, Inc. |
| 77 Peppermint Herbal | The Stash Tea Co., Oregon |

and theobromine and ranged from 79.6% to 103.8% for the catechins and from 74.2% to 89.1% for the theaflavins. See also earlier comment regarding recovery. These observations demonstrate both the sensitivity and utility of the analyses. The LOD values and recoveries were of the same order reported by other investigators mentioned subsequently.

### Catechin, theaflavin, caffeine, and theobromine content of teas

Figure 3 shows that varying the extraction from 3 to 20 min did not significantly influence the levels of all tea compounds. We selected a time of 5 min for the water extractions of the 77 teas listed in Table 2 to represent as closely as possible the time used to prepare tea infusions in the home. To facilitate comparisons, the sums of the concentrations of the 7 catechins and 4 theaflavins calculated from the individual values listed in Table 3 are illustrated in Figure 4 and 5 in terms of bar graphs. A subset of 10 teas containing the highest amounts of catechins, theaflavins, caffeine, and theobromine was selected to define a statistical profile for all teas (see footnotes to Table 3).

For the 32 black teas, the sum of all catechins and theaflavins extracted with water under the conditions studied here ranged (in mg of compound/g dry tea) from 6.5 to 72.5. With few exceptions, the black teas contained both catechins and theaflavins. For the 24 green teas, the corresponding ranges are 4.4 to 100.0. These values are for
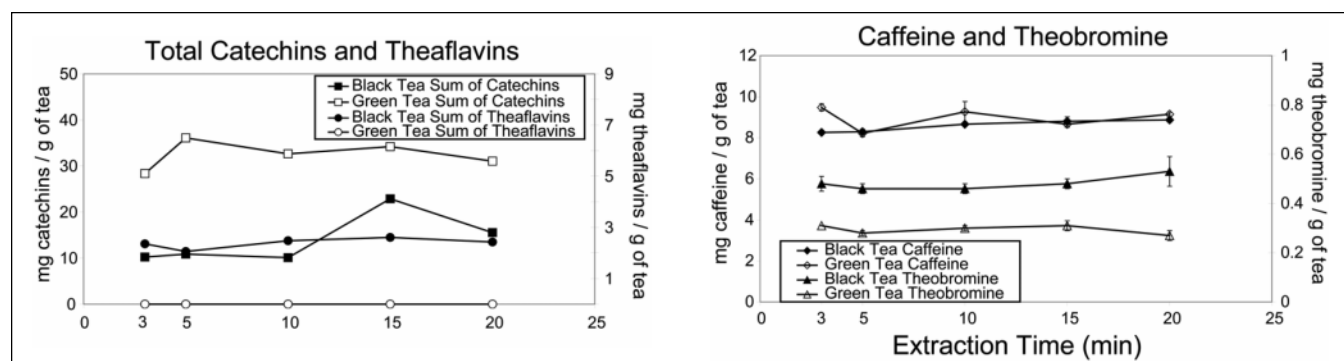


**Figure 3—Effect of extraction time on levels of tea compounds in Lipton Orange Pekoe and Pekoe Cut Black Tea (nr 10) and Ten Ren Green Tea (nr 48) analyzed by high-performance liquid chromatography (HPLC)**

**Table 3–Content of 7 individual catechins, their sum (total CATS), 4 theaflavins, their sum (total TFS), sum of 7 catechins and 4 theaflavins (total flavonoids, FLAV), theobromine (Theo), and caffeine in black, green, specialty, and herbal teas**

| No | EGC | C | EC | EGCG | GCG | ECG | CG | Total CATS | TF | TF3G | TF3'G | TF33'G | Total TFS | Total FLAV | Theo | Caffeine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Black** | | | | | | | | | | | | | | | | |
| 1 | nd | nd | 0.4±0.08 | 1.9±0.14 | 1.2±0.23 | 1.9±0.27 | nd | 5.4 | 0.1±0.08 | 0.3±0.03 | 0.2±0.03 | 0.5±0.04 | 1.1 | 6.5 | 0.2±0.03 | 3.5±0.28 |
| 2 | 0.7±0.31 | 0.6±0.14 | 1.2±0.28 | 0.9±0.16 | 0.9±0.03 | 1.7±0.39 | 0.2±0.05 | 6.2 | 0.4±0.10 | 0.4±0.08 | 0.1±0.03 | 0.6±0.06 | 1.5 | 7.7 | 0.5±0.15b | 6.1±0.78 |
| 3 | nd | nd | 0.4±0.11 | 2.1±0.63 | 1.3±0.17 | 3.9±0.32 | 0.02±0 | 7.7 | 1.2±0.09 | 0.8±0.03 | 0.3±0.04 | 0.7±0.01 | 3.0 | 10.7 | 0.4±0.06 | 8.2±0.16 |
| 4 | nd | nd | 0.4±0.01 | 0.6±0.02 | 3.0±0.24 | 7.0±1.70 | nd | 11.0 | 0.2±0.01 | 0.2±0.03 | 0.1±0 | 0.2±0.02 | 0.7 | 11.7 | 0.4±0.01 | 9.6±0.17 |
| 5 | nd | nd | 0.6±0.34 | 3.2±0.16 | 1.2±0.14 | 4.7±0.29 | nd | 9.7 | 0.7±0.14 | 0.6±0.06 | 0.2±0.03 | 0.5±0.05 | 2.0 | 11.7 | 0.5±0.02 | 8.6±0.29 |
| 6 | nd | nd | 0.5±0.08 | 2.0±0.07 | 2.5±0.14 | 4.7±0.32 | nd | 9.7 | 0.4±0.10 | 0.5±0.07 | 0.1±0.03 | 1.4±0.14 | 2.4 | 12.1 | 0.6±0.01 | 9.5±0.22 |
| 7 | 1.0±0.67 | 0.9±0.09 | 0.6±0.41 | 1.9±0.08 | 1.5±0.17 | 3.6±0.04 | 0.5±0.11 | 10.0 | 0.7±0.19 | 0.6±0.19 | 0.1±0.03 | 0.7±0.02 | 2.1b | 12.1 | 0.4±0.27 | 8.5±0.23 |
| 8 | 1.2±0.80 | 1.6±0.00 | 1.3±1.00 | 1.4±0.07 | 1.4±0.92 | 2.4±0.28 | 0.4±0.13 | 9.7 | 0.6±0.13 | 0.8±0.04 | 0.3±0.01 | 1.3±0.05 | 3.0 | 12.7 | 1.1±0.03 | 11.3±0.1 |
| 9 | nd | nd | 0.6±0.03 | 3.7±0.16 | 2.1±0.15 | 4.9±0.49 | 0.1±0.10 | 11.4 | 0.4±0.08 | 0.4±0.09 | 0.1±0.03 | 0.5±0.02 | 1.4 | 12.8 | 0.9±0.02c | 11.4±0.2 |
| 10 | nd | nd | 0.7±0.19 | 2.4±0.13 | 3.3±0.51 | 4.5±0.23 | nd | 10.9 | 0.6±0.01 | 0.7±0.04 | 0.2±0.02 | 0.6±0.05 | 2.1 | 13.0 | 0.5±0.02 | 8.3±0.13 |
| 11 | 1.7±0.13 | nd | 0.8±0.20 | 1.5±0.25 | 1.8±0.16 | 4.5±0.37 | 0.6±0.10 | 10.9 | 0.9±0.10 | 1.0±0.05 | 0.3±0.02 | 1.1±0.06 | 3.3 | 14.2 | 0.6±0.01 | 9.4±0.05 |
| 12 | 0.1±0.02 | nd | 0.3±0.06 | 4.9±1.09 | 2.0±1.36 | 5.3±0.45 | nd | 12.6 | 0.4±0.06 | 0.6±0.01 | 0.2±0.01 | 0.7±0.05 | 1.9 | 14.5 | 1.0±0.01 | 10.8±0.1 |
| 13 | 0.1±0.04 | nd | 0.8±0.18 | 2.1±0.37 | 4.2±0.35 | 4.8±0.08 | 0.01±0 | 12.0 | 0.9±0.09 | 1.1±0.2 | 0.3±0.01 | 1.1±0.07 | 3.4 | 15.4 | 0.7±0.01 | 9.0±0.37 |
| 14 | nd | nd | 0.5±0.32 | 4.3±1.34 | 5.4±1.21 | 6.5±1.48 | nd | 16.7 | 0.8±0.02 | 0.9±0.18 | 0.3±0.05 | 1.0±0.19 | 3.0 | 19.7 | 0.6±0.11 | 11.2±2.1 |
| 15 | 2.0±0.49 | 0.5±0.16 | 6.3±0.11 | 0.5±0.05 | 1.4±0.03 | 4.2±0.85 | 1.5±1.13 | 16.4 | 5.4±1.34 | 0.01±0 | 0.2±0.03 | 0.4±0.02 | 6.0b | 22.4 | tr | 7.4±0.65 |
| 16 | 2.2±0.05 | 3.7±0.63 | 0.9±0.01 | 9.9±0.02 | 3.7±0.16 | 7.8±0.04 | 0.6±0.01 | 28.8 | 0.2±0.01 | 0.2±0.03 | 0.1±0 | 0.5±0.02 | 1.0 | 29.8 | 1.2±0.03 | 21.4±0.5c |
| 17 | 3.4±1.16 | 3.0±0.94 | 2.3±0.14 | 6.6±0.53 | 2.4±0.31 | 10.1±2.5 | 0.7±0.05 | 28.5 | 1.2±0.01 | 1.6±0.08 | 0.6±0.02 | 2.0±0.04 | 5.4b | 33.9 | 2.4±0.16b | 22.3±0b |
| 18 | 1.9±0.67 | 3.0±0.08 | 1.7±0.18 | 6.0±0 | 1.5±0.14 | 10.8±0.2 | 1.0±0.37 | 25.9 | 1.2±0 | 1.4±0 | 0.4±0 | 5.8±0.09 | 8.8b | 34.7 | 1.8±0.05 | 15.4±0.7 |
| 19 | 2.8±0.11 | 4.3±0.13 | 2.3±0.03 | 9.0±0.68 | 1.8±0.02 | 11.0±0.3 | 0.8±0.02 | 32.0 | 1.2±0.01 | 1.4±0 | 0.5±0.01 | 1.2±0.02 | 4.3b | 36.3 | 1.4±0.01 | 18.0±0.1 |
| 20 | 6.4±0 | 5.0±0.07 | 2.1±0.05 | 5.2±0.04 | 2.3±0.07 | 10.0±0.2 | 0.7±0 | 31.7 | 1.0±0.01 | 1.6±0.04 | 0.6±0 | 1.8±0.09 | 5.0 | 36.7 | 2.1±0.02b | 19.9±0.4 |
| 21 | 3.4±0 | 2.8±0.19 | 1.4±0.01 | 12.9±0.3 | 2.9±0.01 | 11.7±0 | 0.4±0.01 | 33.5 | 0.6±0 | 0.6±0.02 | 0.8±0.03 | 0.6±0.03 | 2.6 | 38.1 | 1.3±0 | 15.0±0.3 |
| 22 | 2.3±0.03 | 8.1±0.50 | 2.4±0.03 | 6.1±0.01 | 1.9±0.03 | 11.8±0.5 | 0.6±0.02 | 33.2 | 1.2±0.01 | 1.5±0.03 | 0.6±0 | 1.8±0.02 | 5.1b | 38.3 | 2.5±0.13b | 20.2±0.9 |
| 23 | 2.3±0.09 | 7.1±0.43 | 2.6±0.12 | 9.5±0.07 | 1.6±0 | 16.1±0.2 | 0.5±0.02 | 39.7 | 1.2±0.05 | 2.1±0.05 | 0.9±0.02 | 3.0±0.04 | 7.2b | 46.9 | 2.6±0.05b | 24.3±0.3b |
| 24 | 2.5±0.09 | 7.4±0.19 | 2.5±0.07 | 12.7±0.9 | 2.1±0.11 | 14.5±0.6 | 0.6±0.01 | 42.3 | 1.7±0.08 | 1.3±0.05 | 0.6±0.03 | 1.5±0.02 | 5.1b | 47.4 | 1.4±0.03 | 19.7±0.6 |
| 25 | 3.0±0.04 | 4.6±0.06 | 2.3±0.04 | 16.9±0.1 | 4.1±0.02 | 16.8±0.4 | 0.5±0.01 | 48.2 | 0.8±0.05 | 1.1±0.04 | 0.4±0.01 | 1.4±0.05 | 3.7c | 51.9 | 2.7±0.09b | 21.9±0.4 |
| 26 | 4.2±0.22 | 0.8±0.10 | 1.4±0.04 | 27.0±0.8 | 4.2±0.04 | 20.2±0.5 | 0.4±0.02 | 58.2 | 0.7±0.02 | 0.4±0.02 | 0.2±0.02 | 0.5±0.03 | 1.8 | 60.0 | 1.3±0.04 | 21.3±0.7c |
| 27 | 10.3±0.20 | 2.7±0 | 4.3±0.06 | 23.0±0.1 | 1.1±0.10 | 20.6±0.5 | 0.5±0.01 | 62.5c | nd | nd | nd | nd | 0 | 62.5 | 1.3±0 | 17.7±0.1 |
| 28 | 4.1±0.30 | 1.2±0.07 | 2.0±0 | 28.4±0.7 | 4.4±0.18 | 22.9±0.6 | 0.4±0.01 | 63.4c | 0.7±0.01 | 0.4±0.01 | 0.1±0 | 0.4±0.02 | 1.6 | 65.0 | 1.9±0.05b | 20.8±0.2c |
| 29 | 5.2±0.00 | 1.7±0.01 | 2.3±0.01 | 28.2±0.2 | 3.2±0.06 | 24.2±0.3 | 0.7±0.01 | 65.5b | nd | nd | nd | nd | 0 | 65.5c | 1.1±0 | 22.0±0.3b |
| 30 | 2.3±0.10 | 6.7±0.06 | 4.2±0.03 | 13.3±0.4 | 6.7±0.13 | 24.4±0.5 | 1.3±0.06 | 58.9 | 0.8±0.11 | 1.8±0.02 | 0.8±0.01 | 3.5±0.07 | 6.9b | 65.8b | 3.2±0.03b | 26.7±0.5b |
| 31 | 5.1±0.19 | 4.9±0.09 | 2.2±0.08 | 26.8±0.8 | 3.0±0.23 | 20.9±0.8 | 0.1±0.01 | 63.0c | 0.8±0.01 | 0.6±0.04 | 0.3±0.02 | 6.4±0.28 | 8.1b | 71.1 | 1.6±0.10c | 22.8±0.8b |
| 32 | 3.1±0.02 | 5.3±0.05 | 4.1±0.24 | 23.5±0.2 | 6.1±0.26 | 26.8±0.6 | 0.6±0 | 69.5b | 0.9±0.03 | 0.8±0 | 0.2±0.01 | 1.1±0.03 | 3.0 | 72.5b | 1.8±0.01b | 21.8±0.1b |
| **Green** | | | | | | | | | | | | | | | | |
| 33 | 0.6±0.11 | nd | 0.1±0.02 | 2.2±0.10 | 0.3±0.10 | 1.2±0.16 | nd | 4.4 | nd | nd | nd | nd | 0 | 4.4 | 0.04±0 | 0.3±0.03 |
| 34 | 0.1±0 | nd | 0.5±0.14 | 7.3±0.95 | 0.02±0.01 | 3.1±0.52 | 0.03±0.01 | 11.1 | 0.2±0.02 | nd | nd | nd | 0.2 | 11.1 | 0.1±0.03 | 4.0±0.46 |
| 35 | 0.1±0.04 | nd | 0.6±0.05 | 9.1±0.61 | 1.1±0.78 | 3.3±0.31 | nd | 14.2 | nd | nd | nd | nd | 0 | 14.2 | 0.1±0.01 | 3.3±0.19 |
| 36 | 1.8±0.50 | 1.0±0.29 | 0.4±0.16 | 8.8±0.70 | 0.4±0.24 | 5.8±0.20 | nd | 18.2 | nd | nd | nd | nd | 0 | 18.2 | 0.4±0.02 | 5.2±0.11 |
| 37 | nd | nd | 0.7±0.01 | 13.8±0.6 | 0.8±0.05 | 4.0±0.10 | nd | 19.3 | nd | nd | nd | nd | 0 | 19.3 | 0.7±0.02 | 6.0±0.05 |
| 38 | 1.9±0.50 | 0.1±0.01 | 0.7±0.05 | 8.9±0.09 | 1.8±0.14 | 6.5±0.54 | nd | 19.9 | nd | nd | nd | nd | 0 | 19.9 | 0.5±0.04 | 5.1±0.12 |
| 39 | 0.1±0 | 0.6±0.03 | 0.8±0.04 | 14.0±0.5 | 1.0±0.11 | 4.5±0.24 | nd | 20.9 | nd | nd | nd | nd | 0 | 20.9 | 0.2±0.05 | 5.6±0.07 |
| 40 | 0.1±0 | nd | 0.4±0.01 | 15.7±0.4 | 0.8±0.03 | 5.5±0.05 | nd | 22.5 | nd | nd | nd | nd | 0 | 22.5 | 0.3±0.01 | 7.8±0.10 |
| 41 | 1.1±0.04 | 3.5±0.07 | 0.5±0.01 | 7.4±0.07 | 6.3±0.18 | 5.0±0.04 | 0.1±0.01 | 23.9 | nd | nd | nd | nd | 0 | 23.9 | 1.1±0.01 | 12.5±0.1 |
| 42 | 0.1±0.03 | nd | 1.0±0.20 | 17.4±1.1 | 1.4±0.07 | 5.8±0.44 | nd | 25.7 | nd | nd | nd | nd | 0 | 25.7 | 0.3±0.02 | 8.8±0.11 |

*(continues on next page)*

**Table 3—Content of 7 individual catechins, their sum (total CATS), 4 theaflavins, their sum (total TFS), sum of 7 catechins and 4 theaflavins (total flavonoids, FLAV), theobromine (Theo), and caffeine in black, green, specialty, and herbal teas (continued from page 6)**

| No | EGC | C | EC | EGCG | GCG | ECG | CG | Total CATS | TF | TF3G | TF3'G | TF33'G | Total TFS | Total FLAV | Theo | Caffeine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Green** | | | | | | | | | | | | | | | | |
| 43 | nd | nd | 0.9±0.16 | 18.3±1.2 | 1.1±0.11 | 5.7±0.29 | nd | 26.0 | nd | nd | nd | nd | 0 | 26.0 | 0.3±0.11 | 9.5±0.41 |
| 44 | nd | nd | 1.3±0.02 | 18.4±1.5 | 0.8±0.14 | 8.3±0.54 | 0.02±0 | 28.8 | nd | nd | nd | nd | 0 | 28.8 | 0.3±0.02 | 8.2±0.07 |
| 45 | 4.8±0.09 | 4.4±0.05 | 0.8±0.02 | 13.5±0.2 | 2.7±0.01 | 6.0±0.12 | 0.3±0 | 32.5 | nd | nd | nd | nd | 0 | 32.5 | 0.6±0.02 | 3.8±0.13 |
| 46 | 0.1±0.08 | nd | 0.7±0.02 | 18.3±0.6 | 5.7±0.47 | 8.9±0.45 | nd | 33.7 | nd | nd | nd | nd | 0 | 33.7 | 0.3±0.01 | 10.1±0.1 |
| 47 | 0.2±0 | nd | 0.9±0.15 | 24.4±1.0 | 0.3±0.04 | 10.2±1.0 | nd | 36.0 | nd | nd | nd | nd | 0 | 36.0 | 1.1±0.01 | 10.6±0.1 |
| 48 | 0.1±0 | 2.0±0.05 | 1.5±0.07 | 19.4±0.9 | 1.2±0.04 | 12.0±1.0 | nd | 36.2 | nd | nd | nd | nd | 0 | 36.2 | 0.3±0.01 | 8.2±0.16 |
| 49 | 1.0±0.03 | 33.2±0.4 | 1.3±0.11 | 6.7±0.37 | 3.2±0.11 | 7.7±0.19 | 0.4±0.24 | 53.5 | nd | nd | nd | nd | 0 | 53.5 | tr | tr |
| 50 | 6.4±2.17 | 6.2±0.02 | 0.9±0.05 | 29.4±3.1 | 5.0±1.17 | 15.9±1.7 | 0.3±0.04 | 64.1c | nd | nd | nd | nd | 0 | 64.1 | 1.1±0 | 18.7±0.1 |
| 51 | 0.7±0.01 | 7.9±0.06 | 1.1±0 | 43.6±0.5 | 1.7±0.01 | 19.2±0.3 | 0.2±0.01 | 74.4b | nd | nd | nd | nd | 0 | 74.4b | 1.7±0.01b | 23.9±0.1b |
| 52 | 13.6±0.8 | 2.0±0.09 | 0.9±0.09 | 38.4±0.4 | 5.1±0.09 | 15.9±0.2 | 0.1±0.01 | 76.0b | nd | nd | nd | nd | 0 | 76.0b | 0.8±0.02 | 15.1±0.1 |
| 53 | 14.2±0.02 | 4.0±0.75 | 2.4±0.47 | 35.7±1.1 | 5.4±0.41 | 14.3±1.0 | 0.2±0.01 | 76.2b | nd | nd | nd | nd | 0 | 76.2b | 0.6±0 | 16.7±0.1 |
| 54 | 13.9±5.2 | 1.7±0.01 | 1.7±0.45 | 41.8±8.4 | 2.4±1.08 | 18.6±2.2 | 0.1±0.01 | 80.2b | nd | nd | nd | nd | 0 | 80.2b | 0.8±0.18 | 13.5±3.0 |
| 55 | 13.8±0.5 | 5.8±0.20 | 2.6±0.04 | 41.2±0.5 | 5.1±0.13 | 18.4±0.2 | 0.2±0 | 87.1b | nd | nd | nd | nd | 0 | 87.1b | 0.8±0.02 | 14.0±0.1 |
| 56 | 8.1±0.30 | 5.1±0.29 | 1.9±0.06 | 53.6±1.7 | 3.9±0.03 | 27.1±0.6 | 0.3±0.01 | 100.0b | nd | nd | nd | nd | 0 | 100.0b | 1.9±0b | 22.1±1.0c |
| **Specialty** | | | | | | | | | | | | | | | | |
| 57 | 0.2±0.01 | nd | 0.1±0.08 | 1.0±0.18 | 1.5±0.24 | 0.5±0.08 | 0.1±0.02 | 3.4 | nd | nd | nd | nd | 0 | 3.4 | 0.1±0.01 | 2.7±0.16 |
| 58 | nd | nd | 0.3±0.04 | 4.5±0.23 | 0.4±0.16 | 1.9±0.18 | nd | 7.1 | nd | nd | nd | nd | 0 | 7.1 | 0.1±0 | 2.1±0.07 |
| 59 | tr | 1.5±0.17 | 0.4±0.01 | 2.1±0.03 | 1.7±0.05 | 1.3±0.07 | 0.3±0.02 | 7.3 | nd | nd | nd | nd | 0 | 7.3 | 1.3±0 | 20.8±0.1c |
| 60 | 0.3±0.13 | tr | 0.5±0.39 | 6.8±2.01 | 0.7±0.48 | 5.4±1.42 | nd | 13.7 | nd | nd | nd | nd | 0 | 13.7 | 0.3±0.07 | 6.1±1.46 |
| 61 | nd | 0.6±0.26 | 0.5±0.02 | 12.3±0.2 | 0.6±0.05 | 3.9±0.07 | nd | 17.9 | nd | nd | nd | nd | 0 | 17.9 | 0.2±0.01 | 8.3±0.12 |
| 62 | nd | 0.3±0.03 | 0.5±0.14 | 12.3±0.2 | 0.6±0.07 | 4.8±0.26 | nd | 18.5 | nd | nd | nd | nd | 0 | 18.5 | 0.3±0.01 | 6.2±0.21 |
| 63 | nd | 0.1±0.03 | 0.6±0.10 | 13.9±0.1 | 0.1±0.01 | 8.0±0.73 | 0.02±0 | 22.7 | nd | nd | nd | nd | 0 | 22.7 | 0.3±0 | 8.7±0.09 |
| 64 | 1.6±0.04 | 2.3±0.01 | 1.1±0.01 | 11.4±0.1 | 4.8±0.01 | 9.1±0 | nd | 30.3 | nd | nd | nd | nd | 0 | 30.3 | 0.6±0.04 | 9.6±0.21 |
| 65 | nd | nd | 1.5±0.36 | 22.1±0.5 | 1.6±0.3 | 14.9±0.8 | nd | 40.1 | nd | nd | nd | nd | 0 | 40.1 | 0.6±0.01 | 10.5±0.2 |
| 66 | 5.7±0.29 | 5.7±0.16 | 2.5±0.01 | 23.2±0.04 | 3.5±0.2 | 2.2±0.04 | 2.3±0.07 | 45.0 | nd | nd | nd | nd | 0 | 45.0 | 0.9±0 | 16.7±0.2 |
| 67 | 2.1±0.16 | 4.2±0.07 | 1.3±0.05 | 30.4±1.1 | 2.9±0.08 | 19.2±0.7 | 0.4±0.02 | 60.5 | nd | nd | nd | nd | 0 | 60.5 | 1.3±0.02 | 29.7±0.4b |
| 68 | 2.9±0.58 | 0.8±0.01 | 1.1±0.17 | 37.5±0.1 | 4.4±1.11 | 18.2±0.3 | 0.5±0.13 | 65.4b | nd | nd | nd | nd | 0 | 65.4c | 0.7±0.10 | 27.7±0.1b |
| 69 | 5.8±0.25 | 6.2±0.09 | 2.5±0.03 | 33.5±0.4 | 2.7±0.04 | 16.1±0.2 | 0.2±0 | 67.0 | nd | nd | nd | nd | 0 | 67.0b | 1.4±0.02 | 19.4±0.5 |
| 70 | 6.1±0.17 | 7.9±0.36 | 2.9±0.11 | 36.3±0.2 | 2.7±0.17 | 26.9±0.1 | 0.3±0.02 | 83.1b | nd | nd | nd | nd | 0 | 83.1b | 1.6±0.06c | 23.4±0.2b |
| **Herbal** | | | | | | | | | | | | | | | | |
| 71 | 0.1±0 | nd | 0.1±0.03 | 0.2±0 | 0.5±0.08 | 0.3±0.19 | nd | 1.2 | nd | nd | nd | nd | 0 | 1.2 | 0.9±0.71 | 0.1±0 |
| 72 | nd | nd | nd | 0.5±0.13 | 0.3±0.04 | 0.8±0.2 | nd | 1.6 | nd | nd | nd | nd | 0 | 1.6 | 0.02±0 | nd |
| 73 | tr | 1.4±0.36 | 0.2±0.01 | 0.7±0.01 | 0.6±0.04 | 0.4±0.01 | 0.2±0.02 | 3.5 | nd | nd | nd | nd | 0 | 3.5 | 0.6±0.04 | tr |
| 74 | nd | nd | 0.2±0.01 | 2.1±0.01 | 0.9±0.12 | 1.8±0.39 | 0.3±0.01 | 5.3 | nd | nd | nd | nd | 0 | 5.3 | nd | nd |
| 75 | nd | nd | 0.3±0.02 | 0.2±0.01 | 0.1±0.01 | 5.7±0.67 | 1.2±0.12 | 7.5 | nd | nd | nd | nd | 0 | 7.5 | 0.01±0 | 0.2±0.01 |
| 76 | nd | nd | nd | nd | nd | 6.2±1.97 | 1.5±0.04 | 7.7 | nd | nd | nd | nd | 0 | 7.7 | 0.02±0.01 | nd |
| 77 | 0.8±0.39 | 1.0±0.26 | nd | nd | nd | 24.6±0.5 | nd | 26.4 | nd | nd | nd | nd | 0 | 26.4 | nd | nd |

aNumbers in 1st column correspond to teas listed in Table 2; values in mg/g ± SD (n = 3); nd = not detected. All values have been rounded off to 1 decimal point.
bTop 10 highest values.
cNot significantly < the 10th highest mean at P > 0.05 using Dunnett's test. Those without superscripts are significantly < 10th highest (P < 0.05).

catechins only because the green teas contained no theaflavins. For the 14 specialty teas, the corresponding ranges are 3.4 to 83.1. These values are for catechins only because the specialty teas contained no theaflavins. For the 7 herbal teas, the corresponding ranges are 1.2 to 26.4. These teas contained no or very low amounts of theaflavins.

These results demonstrate that the measured catechin content of green teas varied about 6-fold. For the sum of catechins and theaflavins, the variation was about 11-fold. For the specialty teas, the corresponding variations are 25-fold. Herbal teas contained low amounts or no catechins or theaflavins.
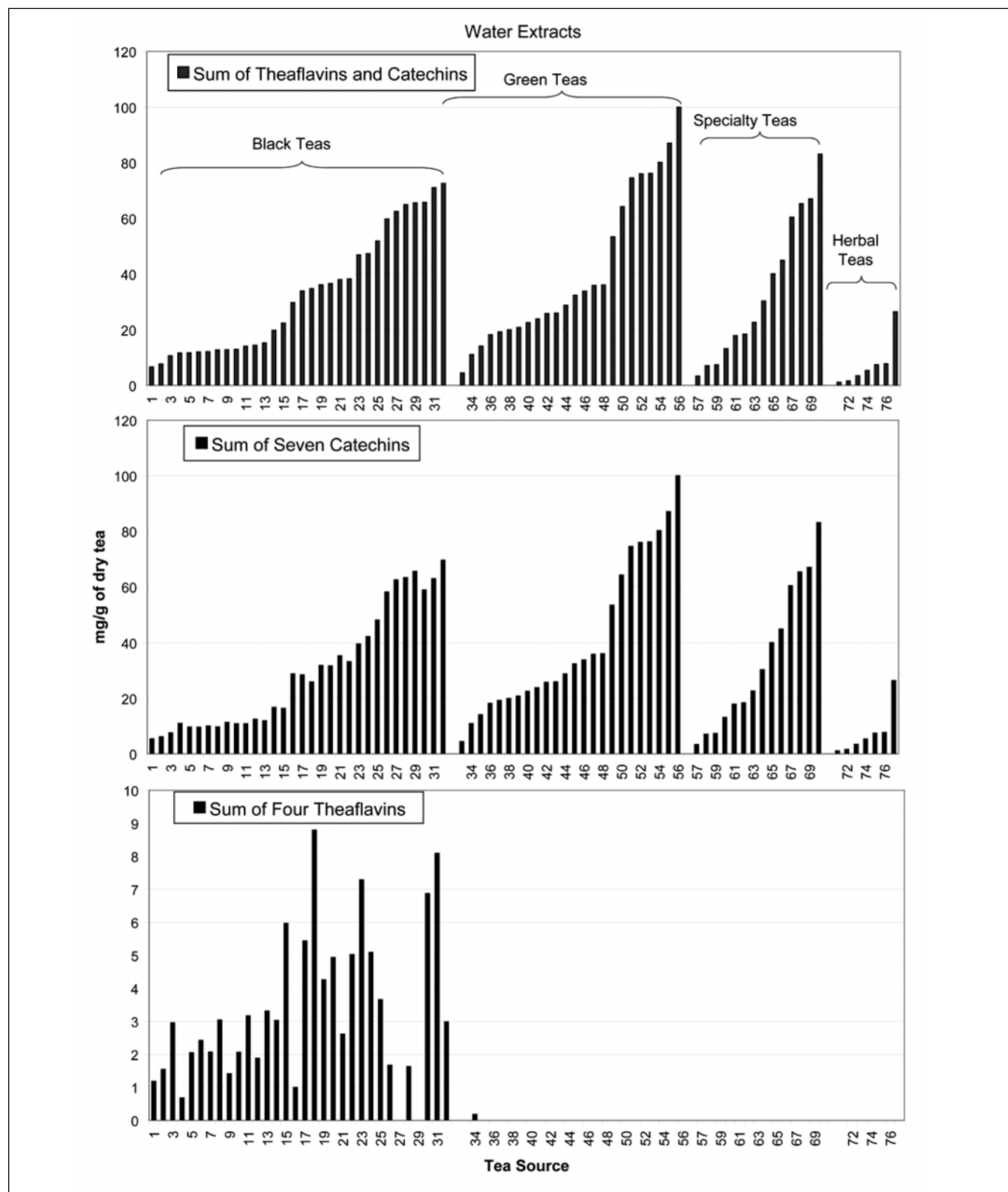


**Figure 4—Bar graphs of tea catechin and theaflavin levels extracted with water based on data listed in Table 3**

The variability in the levels of caffeine among the teas was much narrower than that of catechins and theaflavins. The content of theobromine is on average about 1/10 that of caffeine. Its distribution in teas showed much greater variability than that of caffeine. Herbal teas contained little or no caffeine or theobromine.

The data on various tea categories complement and extend the information on the composition of teas outlined earlier. Our results suggest that the consumer may be able to select teas containing high levels of beneficial catechins and theaflavins and avoid those containing low amounts of these compounds. However, it needs to be emphasized that we do not know whether the biological activities of individual tea compounds consumed in pure form differ from those exhibited by the same compound in teas, where there is the possibility of additive, synergistic (Morre and others 2003), and antagonistic interactions among the different tea constituents. Moreover, because black teas contain high levels of theaflavins and varying levels of catechins, while green teas contain high amounts of catechins and no theaflavins, consumption of both tea types may produce greater health benefits than consumption of either black or green teas alone. Because health effects may depend on the type of tea consumed and because there is a lack of composition data on individual teas consumed in different parts of the world, there is a need to know the catechin and theaflavin content of teas (Khokhar and Magnusdottir 2002). The results of this study on the composition of 77 teas consumed in the United States extend efforts designed to meet this very need (Peterson and others 2004).

A major aim of this study was to discover teas with high levels of catechins and theaflavins. The 10 green teas with the highest content of catechins (64 to 100 mg/g) were as follows: Darjeeling Green Organic (highest value), Sushi Bar Mild Green, Green Organic; Sen-cha Japanese Green; Premium Green, Exotica Dragonwell Green; Darjeeling Black Organic, Exotica Golden Darjeeling, Jasmine Blossom Green, and Darjeeling Summer.

The following 10 black teas had the highest amounts of theaflavins (3.7 to 8.8 mg/g): Orange Spice Black (highest value), Darjeeling Summer, Exotica Assam Breakfast, Kopili Assam Black, Original India Spice, English Breakfast Black, Breakfast Blend Organic, Nilgiri Black, Earl Grey Black, Earl Grey Black & Green Organic, and Exotica Reserve Blend.

The water extracts of the following 10 black teas contained the highest total (sum) of catechins and theaflavins (46.9 to 72.5 mg/g): Darjeeling Black Organic (highest value), Darjeeling Summer, Kopili Assam Black, Exotica Golden Darjeeling, Darjeeling Spring, Exotica Ceylon Estate Earl Grey, Darjeeling Black, Exotica Reserve Blend, Breakfast Blend Organic, and Exotica Assam Breakfast.

## Conclusions

The results we obtained in this study extend our knowledge about the composition of a large number of teas consumed in the United States and allow the consumer to select tea brands with the highest content of beneficial compounds. Because a variety of factors including agricultural practices, geographical origin, post-harvest processing, and brewing methods are all reported to influence the nature and amounts of flavonoids in teas (Fernandez and others 2002; Beecher 2003; Peterson and others 2004), labeling teas for catechin and theaflavin content may benefit tea consumers.

## Acknowledgments

## References

Beecher GR. 2003. Overview of dietary flavonoids: nomenclature, occurrence and intake. J Nutr 133:3248S–54S.

Beecher GR, Warden BA, Merken H. 1999. Analysis of tea polyphenols. Proc Soc Exp Biol Med 220:267–70.

Bonoli M, Colabufalo P, Pelillo M, Gallina Toschi T, Lercker G. 2003. Fast determination of catechins and xanthines in tea beverages by micellar electrokinetic chromatography. J Agric Food Chem 51:1141–7.

Cabrera C, Gimenez R, Lopez MC. 2003. Determination of tea components with antioxidant activity. J Agric Food Chem 51:4427–35.

Del Rio D, Stewart AJ, Mullen W, Burns J, Lean ME, Brighenti F, Crozier A. 2004. HPLC-MSn analysis of phenolic compounds and purine alkaloids in green and black tea. J Agric Food Chem 52:2807–15.

Fernandez PL, Pablos F, Martin MJ, Gonzalez AG. 2002. Study of catechin and xanthine tea profiles as geographical tracers. J Agric Food Chem 50:1833–9.

Fisone G, Borgkvist A, Usiello A. 2004. Caffeine as a psychomotor stimulant: mechanism of action. Cell Molec Life Sci 61:857–72.

Friedman M, Henika PR, Levin CE, Mandrell RE, Kozukue N. 2005. Antibiotic activities of tea catechins and teas against the foodborne pathogen Bacillus cereus. San Francisco, Calif.: Am Soc Microbiol Abstr ASM1235.

Friedman M, Jürgens HS. 2000. Effect of pH on the stability of phenolic compounds. J Agric Food Chem 48:2101–10.

Friedman M, Roitman JN, Kozukue N. 2003. Glycoalkaloid and calystegine contents of eight potato cultivars. J Agric Food Chem 51:2164–73.

Khokhar S, Magnusdottir SG. 2002. Total phenol, catechin, and caffeine contents of teas commonly consumed in the United Kingdom. J Agric Food Chem 50:565–70.

Kozukue N, Han JS, Lee KR, Friedman M. 2004. Dehydrotomatine and α-tomatine content in tomato fruits and vegetative plant tissues. J Agric Food Chem 52:2079–83.

Lee BL, Ong CN. 2000. Comparative analysis of tea catechins and theaflavins by high-performance liquid chromatography and capillary electrophoresis. J Chromatogr A 881:439–47.

Lee KW, Kim YJ, Lee HJ, Lee CY. 2003. Cocoa has more phenolic phytochemicals and a higher antioxidant capacity than tea and red wine. J Agric Food Chem 51:7292–5.

Lee MJ, Prabhu S, Meng X, Li C, Yang CS. 2000. An improved method for the determination of green and black tea polyphenols in biomatrices by high-performance liquid chromatography with coulometric array detection. Anal Biochem 279:164–9.

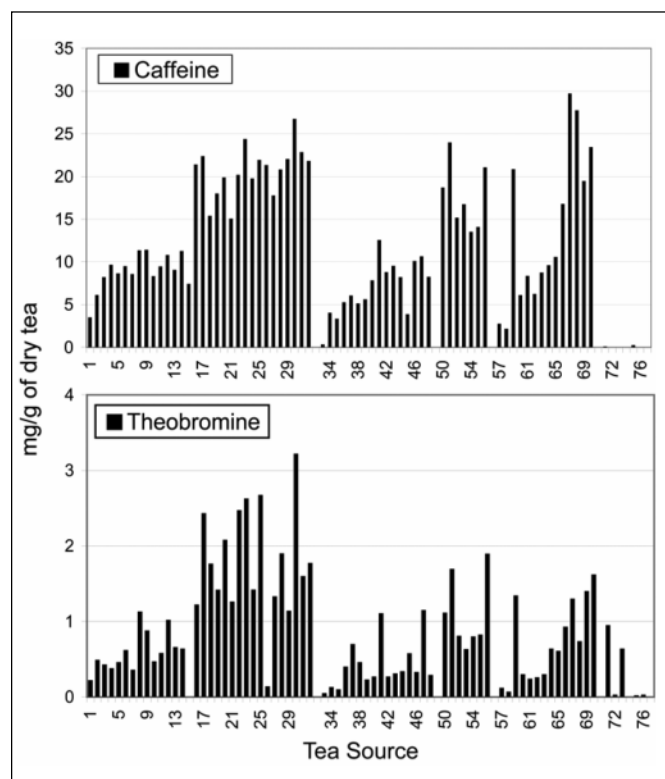Leung LK, Su Y, Chen R, Zhang Z, Huang Y, Chen ZY. 2001. Theaflavins in black tea and



**Figure 5—Bar graphs of caffeine and theobromine levels of teas are based on data listed in Table 3. The numbers shown on the horizontal axis correspond to the names of the teas listed in Table 2.**

catechins in green tea are equally effective antioxidants. J Nutr 131:2248–51.

Lin YS, Wu SS, Lin JK. 2003. Determination of tea polyphenols and caffeine in tea flowers (*Camellia sinensis*) and their hydroxyl radical scavenging and nitric oxide suppressing effects. J Agric Food Chem 51:975–80.

Maron DJ, Lu GP, Cai NS, Wu ZG, Li YH, Chen H, Zhu JQ, Jin XJ, Wouters BC, Zhao J. 2003. Cholesterol-lowering effect of a theaflavin-enriched green tea extract: a randomized controlled trial. Arch Intern Med 163:1448–53.

Menet MC, Sang S, Yang CS, Ho CT, Rosen RT. 2004. Analysis of theaflavins and thearubigins from black tea extract by MALDI-TOF mass spectrometry. J Agric Food Chem 52:2455–61.

Michels KB, Willett WC, Fuchs CS, Giovanucci E. 2005. Coffee, tea, and caffeine consumption and the incidence of colon and rectal cancer. J Natl Cancer Inst 97:282–92.

Morre DJ, Morre DM, Sun H, Cooper R, Chang J, Janle EM. 2003. Tea catechin synergies in inhibition of cancer cell proliferation and of a cancer cell surface oxidase (ECTO-NOX). Pharmacol Toxicol 92:234–41.

Peterson J, Dwyer J, Jacques P, Rand W, Prior R, Chui K. 2004. Tea variety and brewing techniques influence flavonoid content of black tea. J Food Comp Anal 17:397–405.

Rechner AR, Wagner E, Van Buren L, Van De Put F, Wiseman S, Rice-Evans CA. 2002. Black tea represents a major source of dietary phenolics among regular drinkers. Free Rad Res 36:1127–35.

Sakakibara H, Honda Y, Nakagawa S, Ashida H, Kanazawa K. 2003. Simultaneous determination of all polyphenols in vegetables, fruits, and teas. J Agric Food Chem 51:571–81.

Sang S, Lambert JD, Tian S, Hong J, Hou Z, Ryu JH, Stark RE, Rosen RT, Huang MT, Yang CS and, Ho CT. 2004. Enzymatic synthesis of tea theaflavin derivatives and their anti-inflammatory and cytotoxic activities. Bioorg Med Chem 12:459–67.

Schwarz JL, Baker V, Larios E, Chung FL. 2005. Molecular and cellular effects of green tea on oral cells of smokers: a pilot study. Molec Nutr Food Res 49:43–51.

Schwimmer S. 1981. Desirable enzymatic browning. In: Handbook of food enzymology. Westport, Conn.: AVI. p 291–7.

Shahidi F, Naczk M. 2004. Phenolic Compounds of Beverages. *Phenolics in Food and Neutraceuticals*. Boca Raton, Fla.: CRC Press. p 241–8.

Stevanato R, Fabris S, Momo F. 2004. New enzymatic method for the determination of total phenolic content in tea and wine. J Agric Food Chem 52:6287–93.

Suzuki M, Tabuchi M, Ikeda M, Umegaki K, Tomita T. 2004. Protective effects of green tea catechins on cerebral ischemic damage. Med Sci Monit 10:BR166–74.

Vinson JA, Teufel K, Wu N. 2004. Green and black teas inhibit atherosclerosis by lipid, antioxidant, and fibrinolytic mechanisms. J Agric Food Chem 52:3661–5.

Vinson JA, Zhang J. 2005. Black and green teas equally inhibit diabetic cataracts in a streptozotocin-induced rat model of diabetes. J Agric Food Chem 53:3710–3.

Wang R, Zhou W. 2004. Stability of tea catechins in the breadmaking process. J Agric Food Chem 52:8224–9.

Yoda Y, Hu ZQ, Zhao WH, Shimamura T. 2004. Different susceptibilities of *Staphylococcus* and Gram-negative rods to epigallocatechin gallate. J Infect Chemother 10:55–8.

Zhu X, Chen B, Ma M, Luo X, Zhang F, Yao S, Wan Z, Yang D, Hang H. 2004. Simultaneous analysis of theanine, chlorogenic acid, purine alkaloids and catechins in tea samples with the help of multi-dimension information of on-line high performance liquid chromatography/electrospray-mass spectrometry. J Pharm Biomed Anal 34:695–704.

C: Food Chemistry & Toxicology