JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Total Phenol, Catechin, and Caffeine Contents of Teas Commonly Consumed in the United Kingdom

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Levels of total phenol, catechins, and caffeine in teas commonly consumed in the United Kingdom have been determined using reversed phase high-performance liquid chromatography. Tea bags or tea leaves were purchased from local supermarkets and extracted in boiling water for 5 min. The resulting data showed considerable variability in both total phenols [80.5−134.9 mg/g of dry matter (DM) in black teas and 87−106.2 mg/g of DM in green teas] and catechins (5.6−47.5, 51.5−84.3, and 8.5−13.9 mg/g of DM in black, green, and fruit teas, respectively); this was most probably a result of differing agronomic conditions, leaf age, and storage during and after transport, as well as the degree of fermentation. Caffeine contents of black teas (22−28 mg/g of DM) were significantly higher than in less fermented green teas (11−20 mg/g of DM). The relative concentration of the five major tea catechins ranked EGCG > ECG > EC > EGC > C. The estimated U.K. dietary intakes of total tea catechins, calculated on the basis of an average tea consumption of three cups of tea (200 mL cup, 1% tea leaves w/v), were 61.5, 92.7, and 405.5 mg/day from fruit teas, black teas, and green teas, respectively. The coefficients of variation were 19.4, 88.6, and 17.3%, respectively, indicating the wide variation in these intakes. The calculated caffeine intake ranged between 92 and 146 mg/day. In addition, many individuals will consume much larger quantities of tea, of various strengths (as determined by the brewing conditions employed). This broad spread of U.K. daily intakes further emphasizes the need for additional research to relate intake and effect in various population groups.

KEYWORDS: Tea; *Camellia sinensis*; phenol; catechins; caffeine; dietary intake

INTRODUCTION

Tea (*Camellia sinensis*) is one of the most popular beverages in the world because of its taste, aroma, and, lately, its reported health effects. Hundreds of different teas are now produced, mainly in Southeast Asia and Central Africa, and exported throughout the world. According to data published by The Tea Council (*1*), global production in 1998—the latest year reported—was the highest for a decade (2.963×10^6 tonnes), but figures from the U.S. Food and Drug Administration (*2*) suggest a subsequent fall in 1999 (2.872×10^6 tonnes).

Increased public awareness of the health protective characteristics of tea, which are generally considered to be associated with the high flavonoid content of the leaves and extracts, has contributed to the public's general attitude toward the beverage. In experimental studies based largely on isolated cells and animal models, tea flavonoids have been reported to exhibit anticarcinogenic, antimutagenic, and cardioprotective effects that are generally associated with their antioxidant (free radical scavenging and metal chelation) properties. Although these findings are not wholly supported by epidemiological studies, a significant body of research is directed toward elucidating the relationship between dietary flavonoid intake and reduction in the incidence of cancer and heart disease (*3*, *4*). Of the dietary flavonoids examined, catechins, such as the flavanols, (−)-epigallocatechin gallate (EGCG) and (−)-epicatechin gallate (ECG), reportedly show the strongest positive effects, suggesting that teas with higher contents of these compounds may exhibit especially beneficial properties.

Catechins, which also contribute significantly to the overall flavor and astringent characteristics of tea (*5*), constitute 16−30% of nonfermented green tea and 3−10% of fully fermented black tea (both figures expressed on a dry matter basis); in agreement with this trend, partially fermented teas, such as oolong tea, contain intermediate (8−20%) levels of catechins (*1*, *6*). In addition to fermentation, tea production includes a series of process operations that include withering, rolling, and drying (*7*, *8*). Optimization of the degree of fermentation within the overall process operation is required to produce the finest quality tea.

The Tea Council (*1*) reports U.K. tea imports to originate primarily from India and Kenya and contribute to an apparent consumption of 148000 tonnes (an average figure based on the past three years). Two-thirds of the U.K. population above 10 years of age (∼37 million people) are reported to drink tea daily, on average three cups, and 90% of such tea is prepared from

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10.1021/jf010153l CCC: $22.00
Published on Web 01/04/2002

tea bags. Because tea consumed in the United Kingdom has been imported from various countries, it is probable that its composition will vary according to variety, leaf composition, and age, agronomic factors, processing conditions, and storage (during transport, retailing, and within the home) as well as degree of fermentation.

The future commercial exploitation of tea as a health food, nutraceutical, or therapeutic drug will, therefore, demand knowledge of the levels of bioactive tea components in different varieties/brands of raw and processed tea, in addition to the necessary evidence of efficacy and regulatory compliance. Reliable compositional data on commonly consumed teas are also essential for calculating dietary intakes for epidemiological, intervention, and clinical studies aimed at understanding and predicting the health protective effects of tea. Results are reported here, for the first time, on the contents of total phenolics and catechins in a selection of teas commonly consumed in United Kingdom.

MATERIALS AND METHODS

Tea Samples. Commonly consumed teas, including green, oolong, black, and fruit teas, were purchased from supermarkets or specialized tea outlets in the United Kingdom.

Chemicals. Pure standards of catechin (C), EGCG, ECG, (−)-epigallocatechin (EGC), (−)-epicatechin (EC), caffeine, and gallic acid were purchased from Sigma Chemical Co. (St. Louis, MO). Folin−Ciocalteu reagent was purchased from Merck Ltd. (Lutterworth, U.K.). All solvents were of AnalaR or HPLC grade.

Tea Extraction. One hundred milliliters of water at 100, 80, and 60 °C, 80% methanol, or 70% ethanol was added to tea leaves (1 g) in a Thermos flask; the mixture was shaken at 0, 2, and 4 min for 30 s each time. After 5 min, the pH was adjusted to 3.2 with citric acid, and the supernatant was filtered through a 0.45 μm filter. After appropriate dilution, aliquots were taken and analyzed by reversed phase high-performance liquid chromatography (RP-HPLC) without additional pretreatment. All extracts were prepared in duplicate, and two analyses were carried out on each extract.

Total Phenolics. The level of total phenols was determined using Folin−Ciocalteu reagent (*9*), and the results are expressed as gallic acid equivalents (GAE). Standard concentrations of gallic acid between 0 and 800 μg/mL were used to prepare calibration curves.

Catechins and Caffeine. Tea extracts were analyzed for catechins and caffeine according to previously published methods (*10*, *11*), using a Merck-Hitachi model D-7000 HPLC with System Manager (HSM) software (version 3.1). A Prodigy-ODS-2 column (150 × 4.6 mm; Phenomenex), fitted with a C18 guard column, an L-7100 pump, an L-7300 column oven, an L-7200 autosampler, and an L-7450 diode array detector were employed.

In brief, the separation was carried out with 5% acetonitrile (eluant A) and 25% acetonitrile (eluant B) in phosphate buffer (0.025 M, pH 2.4). The gradient employed was as follows: 0−5 min, 15% B; 5−20 min, linear gradient 15−80% B; 20−23 min, 80% B; 23−25 min, 15% B. The flow rate was 1 mL/min (10 μL injection volume), and the column oven was set at 30 °C. Stock solutions of pure standards of C, EC, ECG, EGCG, EGC, and caffeine [1 mg/mL in methanol containing citric acid (80 mg/100 mL)] were stored at 4 °C and used within 1 week. External standards (10−100 mg/L) were freshly prepared for each series of analyses. Detection was carried out at 278 nm; all peaks were plotted and integrated using the dedicated software. The area and the retention time of the analyte peak were compared with those of respective standards.

RESULTS

Total Phenolics. The level of total phenolics in selected black teas varied between 80.5 and 134.9 mg/g and was significantly lower (65.8−106.2 mg/g) in green tea (Table 1). Ceylon black tea contained the highest content, whereas Japanese green tea contained the lowest. Hoff and Singleton (*12*) have also reported similar levels of total phenolics in both black (67.7 mg/g) and green teas (62.3 mg/g). On the other hand, Manzocco et al. (*13*) found green tea to contain higher total phenols (95.4 mg/g) than black tea (80.1 mg/g). The present results confirm that the level of total phenols in different teas is very variable and that comparison of data from different studies on different teas (especially on unnamed brands or extracted/fractionated tea products) may be insufficient to conclude that a certain type of tea is, in general, rich or poor in total phenols. A comparison of total phenols and catechins among different green teas analyzed in this study showed most of the phenolics determined by Folin−Ciocalteu reagent to be catechins (Table 1).

Table 1. Total Phenols in Some Selected Brands of Tea

type of tea	total phenols[a] (mg of GAE/g of dry matter)	contribution of catechins[b] (%)
black tea		
PG-Tips	80.5 ± 3.0	10.1
Yorkshire Gold	97.4 ± 4.0	15.2
Ceylon	134.9 ± 4.1	35.2
Darjeeling	98.8 ± 2.4	37.3
av	**103.0 ± 22**	
green tea		
India	106.2 ± 2.5	50.4
Chun mee, China	87.0 ± 2.2	83.8
Bandia, Japan	65.8 ± 2.5	98.0
av	**86.3 ± 20**	

[a] Results are expressed as mean ± SD of three to six determinations. [b] Represents the combined amounts of EGCG, ECG, EGC, EC, and C.

Catechins and Caffeine. A mixture of five catechins (EGC, C, EC, EGCG, and ECG) and caffeine from commercial products (green, oolong, black, fruit, and instant teas) purchased in the United Kingdom was separated by gradient RP-HPLC, as described above.The HPLC separation was achieved in 23 min, with a total run time of 35 min, as described by Khokhar et al. (*10*). The results showed that the levels of major catechins were lower in most black teas, with the exception of Darjeeling and Ceylon teas (Table 2). This could be due to varying amounts of oxidation during fermentation (likely to be an underfermentation) and handling.

All of the commonly consumed commercial black teas reported in this study are classified as fully fermented teas. Catechin levels in these teas varied between 5.6 and 47.5 mg/g. Ceylon tea contained the highest amounts followed by Darjeeling and Twinings, with Lapsang the lowest; all showed an overall similar trend among individual catechins (EGCG > ECG > EC > EGC > C). The catechin compositions of Ceylon (high in catechins) and PG Tips (low in catechins) teas purchased in the United Kingdom in 1996 (*10*), and in the present study, were similar; their lower catechin contents may thus reflect the composition of the plant and the manufacturing process.

The amounts of caffeine were similar (25−28 mg /g) for all black teas, except Darjeeling (22 mg/g), a difference that may reflect variation in the degree of fermentation. It is likely that the highest quality teas (that is, the more expensive specialized brands, Darjeeling and Ceylon), are produced according to more strictly controlled fermentation and drying processes than is the case for teas of lower quality, which possess stronger color due to increased catechin oxidation. Fernández et al. (*14*) reported the caffeine content of black teas from a variety of origins to range between 25.7 and 34.2 mg/g, whereas two samples of instant tea analyzed for 36.9 and 38.3 mg of caffeine/g. So-

Table 2. Levels of Catechins and Caffeine in Black Teas (Milligrams per Gram of Dry Matter)

brand	total catechins	EGC	C	EC	EGCG	ECG	caffeine
PG Tips	8.1 ± 0.01	0.2 ± 0.01	0.5 ± 0.01	1.4 ± 0.02	3.9 ± 0.02	2.1 ± 0.01	27.3 ± 0.5
Yorkshire	8.2 ± 0.01	1.0 ± 0.06	0.8 ± 0.02	2.1 ± 0.01	2.7 ± 0.01	2.6 ± 0.02	25.7 ± 0.2
Yorkshire Gold	14.8 ± 0.06	0.5 ± 0.02	1.0 ± 0.02	2.5 ± 0.02	6.8 ± 0.01	4.0 ± 0.02	26.0 ± 0.3
Ceylon	47.5 ± 2.2	6.3 ± 0.2	1.7 ± 0.03	5.6 ± 0.04	25.2 ± 0.4	8.6 ± 0.07	26.4 ± 0.6
Darjeeling	36.9 ± 1.8	3.0 ± 0.05	0.7 ± 0.01	2.3 ± 0.01	24.9 ± 0.2	5.9 ± 0.01	22.1 ± 0.2
Nilgiri	17.8 ± 0.8	1.6 ± 0.08	ND[a]	3.9 ± 0.01	6.2 ± 0.03	0.7 ± 0.01	24.8 ± 0.2
Tetley (decaffeinated)	6.3 ± 0.03	0.6 ± 0.01	ND	2.1 ± 0.02	3.2 ± 0.01	1.8 ± 0.02	2.7 ± 0.01
Twinings	11.0 ± 0.05	0.7 ± 0.03	ND	3.1 ± 0.02	4.4 ± 0.02	3.3 ± 0.1	24.4 ± 0.4
Twinings-Lapsang	5.6 ± 0.01	0.4 ± 0.01	ND	1.1 ± 0.01	3.2 ± 0.01	0.5 ± 0.01	25.1 ± 0.4
Kenya	9.2 ± 0.02	0.8 ± 0.01	ND	2.1 ± 0.04	4.4 ± 0.02	1.9 ± 0.02	28.0 ± 0.6
Pickwick	9.5 ± 0.01	0.7 ± 0.02	ND	2.5 ± 0.03	4.5 ± 0.02	1.6 ± 0.02	25.4 ± 0.3
Earl Grey	9.4 ± 0.03	0.4 ± 0.01	ND	1.9 ± 0.02	3.4 ± 0.01	3.8 ± 0.05	25.2 ± 0.4
av[b]	**15.4**						**25.5 ± 6.7**

[a] ND = not detectable. [b] Average value for caffeine excluding decaffeinated.

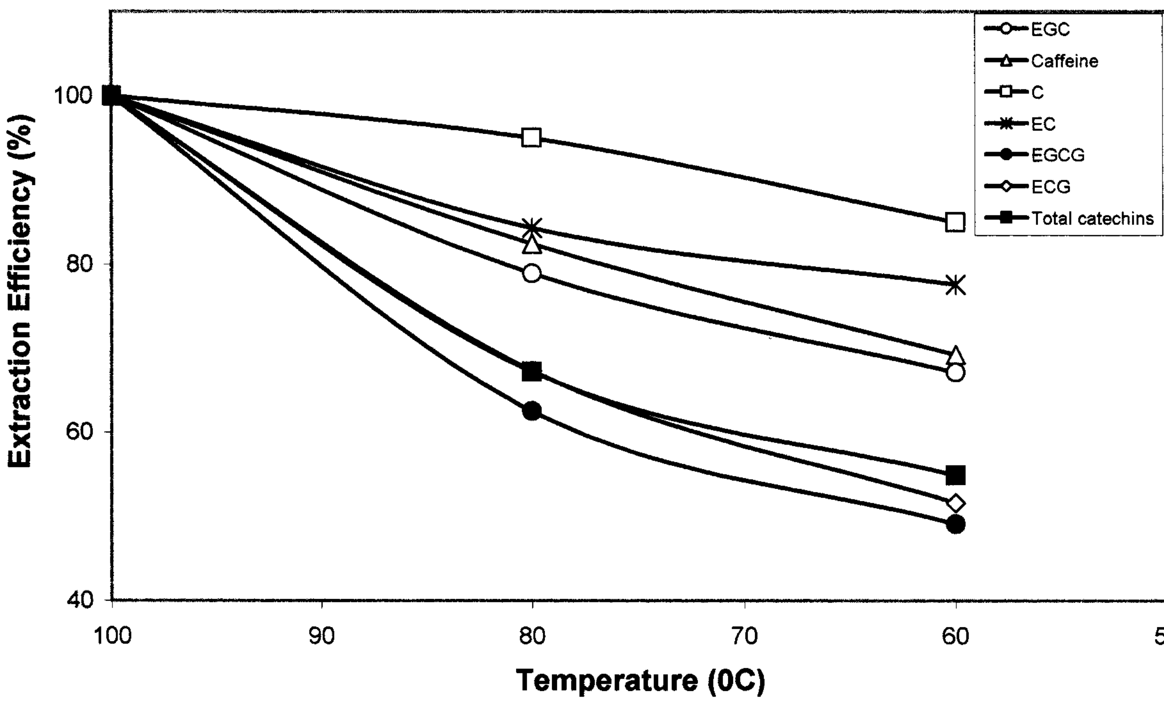

Figure 1. Extraction efficiency of catechins and caffeine from PG-Tips, as an example, at different temperatures (100, 80, and 60 °C) in 5 min.

called "decaffeinated" tea contained much reduced levels (2.7 mg/g) of caffeine rather than a complete absence of this compound.

The levels of catechins in the green teas varied from 51.5 to 84.3 mg/g (Table 2). EGCG was the major constituent of the Chinese and Indian teas, and the trends of their individual catechin contents (EGCG > EGC > ECG > EC > C) were similar. In contrast, the Japanese teas (except Osaka-Fu, a tea product) contained higher levels of EGC and EC and an overall trend of EGC > EGCG > EC > ECG > C. Lin et al. (*14*) have also reported higher levels of EGC and EC in Japanese green teas and higher levels of ECG in Chinese green tea.

The caffeine content of green teas varied between 11 and 20 mg/g and was found to be higher in the Indian and Chinese teas as compared to those from Japan; these contents are lower than most reported by Fernández et al. (*14*), which range from 7.74 to 34.1 mg/g. Lin et al. (*15*) reported that levels of caffeine were significantly elevated in fermented teas, which may suggest a very mild fermentation in green teas from India and China. Generally, fermentation has little effect on caffeine levels in the leaf; the variation could, therefore, be due to the variety of tea and the structure of the leaf that can influence the kinetics of the infusion process.

The fruit-flavored teas examined all possessed similar contents of catechins (8.5−13.9 mg/g) and caffeine (24−25 mg/g). This might be expected as all were of the same brand (Pickwick) and presumably reflects the addition of different flavors to a common tea base.

Effect of Temperature on Catechins and Caffeine Extraction. This was studied by extracting the teas at 100, 80, or 60 °C for 5 min (Figure 1). The levels of total phenols, individual catechins, and caffeine increased with extraction temperature and were greatest for teas that were aqueous extracted at 100 °C for 5 min. Catechin contents increased by 30−40% when teas were extracted for an extended period of 10 min (typically, domestic tea infusions are prepared in much less than 5 min). The compounds most sensitive to extraction conditions were EGCG and ECG. Chen et al. (*16*) have studied the effects of extraction temperature and time on the polyphenol content of oolong tea and found an increase in catechin content with

Table 3. Levels of Catechins and Caffeine in Green Tea and Tea Products (Milligrams per Gram of Dry Matter)

tea	total catechins	EGC	C	EC	EGCG	ECG	caffeine
Indian green tea[a]	53.5 ± 1.5	19.0 ± 0.09	1.3 ± 0.02	4.4 ± 0.03	23.4 ± 0.05	5.6 ± 0.03	19.5 ± 0.3
Chun mee (China)	72.9 ± 1.7	21.7 ± 0.05	1.0 ± 0.01	5.7 ± 0.04	35.1 ± 0.1.0	8.5 ± 0.02	18.4 ± 0.2
Bandia (Japan)	64.5 ± 1.6	34.6 ± 0.06	0.7 ± 0.01	6.0 ± 0.04	20.3 ± 0.08	3.7 ± 0.04	12.8 ± 0.2
Chinese green tea[a]	51.5 ± 1.4	16.2 ± 0.07	ND[b]	4.7 ± 0.04	26.2 ± 0.08	4.4 ± 0.04	18.1 ± 0.1
Japanese green tea[a]	69.5 ± 1.8	31.4 ± 0.04	ND	8.1 ± 0.06	26.6 ± 1.0	3.4 ± 0.01	14.7 ± 0.2
Japanese green tea[a]	72.7 ± 2.0	32.0 ± 0.05	ND	8.2 ± 0.06	28.8 ± 1.0	3.7 ± 0.01	12.1 ± 0.1
Osaka-Fu	84.3 ± 2.1	26.0 ± 0.05	ND	9.5 ± 0.05	42.6 ± 1.2	6.2 ± 0.02	11.5 ± 0.1
av	**67 ± 11**						**15.3 ± 3.3**

[a] Teas sold with no brand name. [b] ND = not detected.

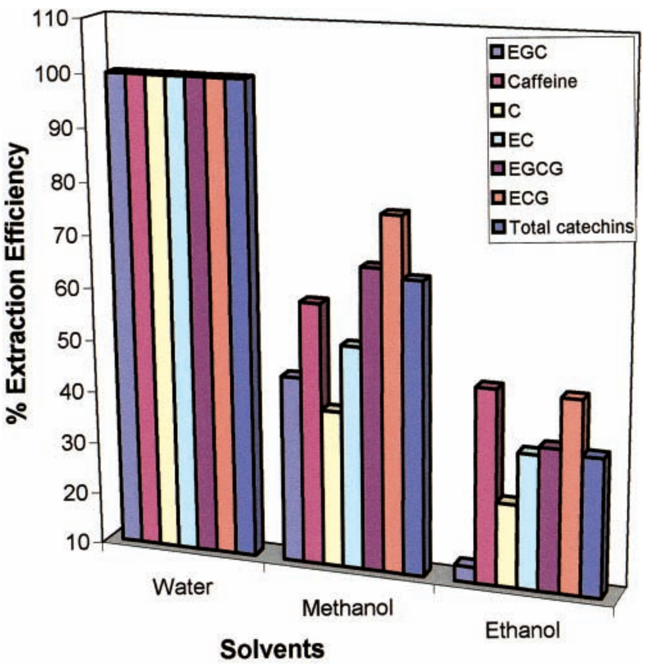

Figure 2. Extraction efficiency of catechins and caffeine from PG-Tips, as an example, in distilled water, methanol (80%), and ethanol (70%).

increasing extraction temperature; these authors suggested that the total polyphenol levels were highest when extracted at 77−80 °C.

Effect of Solvents on Catechin and Caffeine Extraction. Teas were extracted with boiling water, 80% methanol, or 70% ethanol (Figure 2). These solvents are commonly used for the analyses of catechins and flavonoids from plant foods. Water proved to be the best solvent for all of the catechins as well as caffeine, the lowest extraction being observed with 70% ethanol. Kallithraka et al. (*17*), however, found pure methanol to be best for extracting grape seed catechins. Our observations are consistent with those of Wang et al. (*18*), who reported decreasing ethanol or methanol concentration to increase the efficiency of catechin extraction; 15% ethanol was optimal for extracting catechins from tea, with water much better than 30% ethanol.

Estimated U.K. Dietary Intake of Catechins and Caffeine. The daily intake was calculated on the basis of three cups of tea (1% tea w/v) consumed on a daily basis (*1*) and the average polyphenol, catechin, and caffeine contents (see Tables 1−4). Figure 3 shows daily total catechin consumption was 61.5, 92.7, and 405.5 mg/day from fruit teas, black teas, and green teas, respectively. However, the respective coefficients of variation (CVs) were 19.4, 88.6, and 17.3%, respectively, indicating the wide variation in dietary intakes that might be expected on the basis of the teas analyzed in this study. Despite its claimed health properties, green tea is still relatively little consumed in the United Kingdom, and black tea will make the overwhelming contribution to the levels of catechins consumed.

Caffeine intakes are shown in the inset of Figure 3. Many individuals will consume much larger quantities of tea daily; in the absence of published data, anecdotal evidence suggests that drinking six to nine cups of tea per day is unexceptional in the United Kingdom. The tea drunk is of variable strength (as determined by the brewing conditions employed), and so the figures obtained would not be expected to be very large overestimates. This broad spread of U.K. daily intakes further emphasizes the need for research to relate intake and effect in various population groups.

DISCUSSION

In previous studies, tea has been calculated to contribute 19.7−25.6 mg of catechins (including flavones) to the U.K. adult average daily intake of 29.8 mg, depending upon brewing conditions (*19*); compared with this contribution (66−85%), those reported from studies in The Netherlands [48% (*20*, *21*)] and Finland [21% (*22*)] are much lower. The choice of tea varies in different countries, and dietary intake of catechins and consequent health benefits will differ between, and among, populations. For instance, most Europeans, Americans, and Asians from the Indian subcontinent have a strong preference for black, fermented tea, whereas the preference among Japanese and Chinese is for green, unfermented tea. Recent trends, partially in response to claims of health benefits associated with the beverage, show an increased preference for fruit and herbal teas in continental Europe and to a lesser degree in the United Kingdom; however, black tea with added milk (white tea) remains by far the most common form consumed in the United Kingdom (*1*).

The brewing conditions, including the temperature of the extracting water, the ratio of leaf to water, the structure of the leaf, the period of extraction, and the nature and extent of any agitation, stirring, or squeezing of the teabag, will all contribute to the nature and amount of the flavonoids extracted into the tea liquor. Addition of milk might reduce the levels of biologically available flavonoids by complexation and precipitation reactions, and other losses may result from caffeine complexation (creaming) and possible absorption to the surface of the cup. These factors would require detailed study to prioritzse them in order of importance. The aim of the present study was, specifically, to determine the contents of total phenolics and catechins in a selection of teas commonly consumed in United Kingdom.

The nature and variation of tea phenols, including catechins, in the developing plant, within different parts of the plant, and their fate during processing of black tea have all been extensively studied as a result of their significance for tea quality

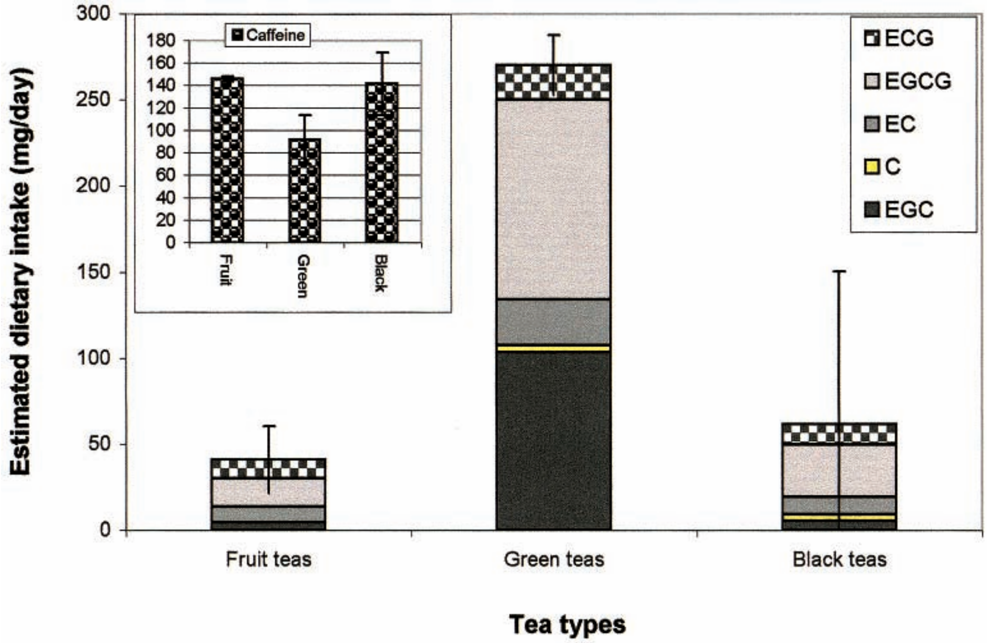

Figure 3. Variations in the estimated polyphenols, catechins, and caffeine intake from teas commonly consumed in the United Kingdom. Data are given as milligrams per day intake on the basis of an average of three cups (600 mL) per capita.

Table 4. Levels of Catechins and Caffeine in Fruit Teas[a] (Milligrams per Gram of Dry Matter)

fruit tea	total catechins	EGC	C	EC	EGCG	ECG	caffeine
strawberry	9.6 ± 0.01	1.0 ± 0.02	ND[b]	2.0 ± 0.01	3.9 ± 0.02	2.7 ± 0.02	23.8 ± 0.3
lemon	8.6 ± 0.01	1.1 ± 0.01	ND	2.0 ± 0.03	3.4 ± 0.02	2.2 ± 0.01	24.1 ± 0.4
cherry	10.1 ± 0.02	1.1 ± 0.03	ND	2.3 ± 0.02	4.0 ± 0.01	2.7 ± 0.01	25.0 ± 0.6
forest fruit	8.5 ± 0.01	0.9 ± 0.01	ND	2.0 ± 0.02	3.3 ± 0.02	2.3 ± 0.02	23.6 ± 0.5
blackcurrent	13.9 ± 0.02	1.3 ± 0.01	ND	3.0 ± 0.01	6.1 ± 0.01	3.6 ± 0.03	24.6 ± 0.6
orange	10.6 ± 0.01	1.0 ± 0.01	ND	2.5 ± 0.01	4.2 ± 0.01	2.9 ± 0.01	24.8 ± 0.8
av	**10.2 ± 2.0**						**24.3 ± 0.6**

[a] All teas were of Pickwick brand. [b] ND = not detected.

(*3*). However, there remains a lack of data on individual teas, commonly consumed in various parts of the world; hence, predictions of flavonoid intake and their health effect may not be valid. The present study of the phenolic composition of typical teas consumed in the United Kingdom is a first attempt to identify these variables. In these studies, 1 g of tea leaf or powder extracted for 5 min was considered to be the upper limit for extraction of catechins; preliminary taste panel studies had also shown this strength of beverage to be acceptable, and so the intake figures calculated on this basis are likely to be reliable estimates.

It is known that the amount and the proportion of various catechins depend on the agronomic conditions, leaf age, and degree of fermentation, which are directly correlated with the final quality of the beverage (*15*). It is considered that the finest teas are made from the young tea shoots containing the highest levels of catechins (*23*). Green tea prior to black tea manufacturing generally contains a high catechin content, which may also account for some of the variation in catechin contents.

The results presented here demonstrate that catechin levels vary to a significant extent in different teas and that teas such as PG Tips and Yorkshire, which are popular due to their aroma and strong color, contained the lowest amounts of catechins, whereas among the other black teas, Ceylon and Darjeeling contained the highest. The large variations in the estimated dietary intake data in this study suggest that health effects of tea could also vary depending on the type of tea consumed by the individuals; such effects are under investigation in this laboratory.

In a recent study, Lakenbrink et al. (*24*) reported potential intakes of 86.7−103.5 mg of catechins/theaflavins/flavonol and flavone glycosides (not subdivided); these data were based upon an extraction time of 40−60 s, compared to the 5 min employed in the present study. The large variation observed in the estimated dietary intakes due to differences in the composition of different tea also emphasizes the importance of differing dietary preferences. Black teas, namely, Ceylon and Darjeeling, contained the highest levels of catechins among black teas and, therefore, contributed to highest levels of estimated dietary intake of catechins.

ACKNOWLEDGMENT

We thank Keith Price, Institute of Food Research, Norwich, U.K., for helpful suggestions during the preparation of the manuscript.

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Received for review February 6, 2001. Revised manuscript received July 31, 2001. Accepted August 1, 2001. Financial support from North of England Food Centre is greatly appreciated.

JF010153L