Flavonol Glycoside Content and Composition of Tea Infusions Made from Commercially Available Teas and Tea Products

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The composition and content of flavonol glycosides (FGs) have been measured in infusions of a range of black tea and black tea products. Tea contains a mixture of glycosides of quercetin, kaempferol, and myricetin and the total level of these glycosides, in infusions prepared in a normal domestic manner, for the leaf teas varied from 36.5 to 88.3 mg/L, although greater variation was observed for the tea products, from 7.0 to 428.1 mg/L. Altogether seven quercetin, five kaempferol, and two myricetin glycosides were detected; their relative amounts varied significantly in the different samples. The significance of these differences in relation to the bioavailability and potential bioactivity of these compounds is discussed.

Keywords: *Tea; flavonol; glycoside; HPLC; quercetin; kaempferol; myricetin*

INTRODUCTION

Recent epidemiological studies have demonstrated an inverse relationship between the incidence of degenerative diseases and intake of fruit and vegetables (Block et al., 1992). The molecular basis for such protective effects is not understood, but several classes of compounds have been postulated as potential protective factors, one of which is the flavonoids (Rice-Evans et al., 1994). Several epidemiological studies (Hertog et al., 1993; Keli et al., 1996; Knekt et al., 1996; Rimm et al., 1996) have been made on the dietary effect of one class of flavonoids, the flavonols, and, after allowing for a range of confounding factors, provide evidence which suggests that a high dietary intake of flavonols is correlated with a reduced risk of coronary heart disease. The latest study into this relationship, conducted in the U.K. (Hertog et al., 1997) provides conflicting data and would suggest, together with other findings (Hertog, 1995), that the type of flavonol rather than the flavonols as a class may be important to the understanding of this relationship between flavonol intake and reduced heart disease (Hollman et al., 1995).

The flavonols exist in plant foods as conjugates of aglycones such as quercetin, kaempferol, and myricetin and have several biological properties, for example, inhibition of oxidation of low-density lipoprotein in vitro and reduction of both platelet aggregation and plasma cholesterol (Cheng et al., 1993; Gryglewski et al., 1987), which are consistent with a protective role against coronary heart disease.

The chemical form of the flavonols, both during and after digestion, is now recognized as being an important factor in determining their bioavailability and bioactivity during digestion. Since one of the major sources of flavonols in the U.K. is tea, this paper reports on the levels and composition of the glycosides of quercetin, kaempferol, and myricetin present in both black leaf teas and tea products, commonly consumed in the U.K., as a necessary prerequisite for a fuller understanding of their role in the diet.

MATERIALS AND METHODS

Materials. Tea was purchased from either a supermarket or a speciality tea store locally either in loose form or in tea bags. Six varieties of tea, namely, Lapsang souchong, Assam, Darjeeling, Keemun, Ceylon, and Nunjo, five blended black leaf teas, two instant freeze-dried tea products, a decaffeinated tea, and seven tea products were studied. Daidzein, rutin (Q-3-*O*-glu-rha), hyperin (Q-3-*O*-gal), isoquercitrin (Q-3-*O*-glu), quercitrin (Q-3-*O*-rha), avicularin (Q-3-*O*-ara), quercetin (Q), and kaempferol (K) were purchased from Apin Chemicals Ltd., Abingdon, U.K., and all solvents were of AnalaR grade or HPLC grade where appropriate.

Kaempferol 3-*O*-glucosylrhamnosylgalactoside (K-3-*O*-gal-rha-glu) was a gift from Professor Engelhardt, Institut fur Lebensmittelchemie der Technischen Universitat, Braunschweig, Germany.

Methods. *Extraction.* For the six regional teas, five blended tea samples, two flavored leaf teas, and decaffeinated tea, a 3.00 g equivalent to one tea bag or one teaspoonful was used. Weights taken for the two freeze-dried teas was 1.00 g; the flavored products 1, 2, and 3 were 5.00, 10.00, and 3.00 g, respectively, which represent the amounts to be added to a cup recommended by the manufacturers. For iced peach tea (product 4), an iced tea liquid drink, 50 mL was taken. Apart from the latter sample where the whole sample was applied directly to the SPE cartridge, all were added to boiling water (200 mL), stirred, allowed to stand for 4 min and finally stirred a second time. Two 20 mL portions were decanted and each applied to a preconditioned (20 mL of MeOH followed by 60 mL of water) polyamide (1 g) SPE cartridge. The cartridge was washed with water (20 mL) followed by MeOH (40 mL). Daidzein (1.6 mL of a 0.101 mg/mL solution) was added to each of the MeOH eluates which were then evaporated to dryness in vacuo at a temperature below 40 °C, redissolved in MeOH (2 mL), and filtered prior to HPLC analysis using an injection volume of 10 μL. The elution of the SPE cartridge procedure gave a quantitative recovery of the flavonol glycosides since no further FGs were detected in a second MeOH eluate of the cartridge or in the preceding water eluate.

High-Pressure Liquid Chromatography. (a) Preparative HPLC. A Dynamax reversed phase (C18) silica column 250

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Table 1. Compound Identification Data[a]

compd	RT (min)	compd name	UV (d or s)
1	nd	M glu-rha	d
2	6.3	M-gal	d
3	6.6	M-glu	d
4	8.2	Q-gal-rha-glu	d
5	8.5	Q-glu-rha-glu	d
6	9.3	K-gal-rha-glu	s
7	9.4	Q-glu-rha	d
8	9.8	K-glu-rha-glu	s
9	10.5	Q-gal	d
10	11.3	Q-glu	d
11	10.8	K-glu-rha	s
12	11.3	K-gal	s
13	11.6	Q-rha	d
14	11.8	K-glu	s
15	12.1	Q-ara	d
16	18.7	quercetin	d
17	21.2	kaempferol	s

[a] nd = not detected; d = doublet maximum in the 255−270 nm region; s = singlet maximum in the 260−275 nm region; glu = glucose; gal = galactose; rha = rhamnose; ara = arabinose.

× 21.2 mm i.d. (Anachem Ltd., Luton, U.K.) was used with a binary solvent gradient, at a flow rate of 5 mL/min, comprising 15% B increasing to 30% B over 45 min, where solvent A was 0.1% trifluoroacetic acid (TFA) in water and solvent B was acetonitrile. The column effluent was monitored at 270 nm and fractions collected using a Gilson fraction collector.

(b) Analytical HPLC. A Hewlett-Packard 1050 system comprising autosampler and quaternary pump coupled to a diode array detector and controlled by Chemstation software was used with a solvent gradient of A (water−tetrahydrofuran (THF)−TFA = 98:2:0.1) and B (acetonitrile) used in the proportion of 17% B for 2 min increasing to 25% B after 5 min, to 35% B after a further 8 min, and to 50% B after 5 min. A column clean up stage was used by increasing B to 90% after a further 5 min and finally reequilibration for 20 min at 17% B. The column used was packed with Prodigy 5u ODS3 reversed phase silica (250 mm by 4.6 mm i.d.; Phenomenex Ltd., Macclesfield, U.K.), and the effluent (1 mL/min) was monitored by a diode array detector (200−450 nm).

Mass Spectrometry. Atmospheric pressure chemical ionization (APCI) spectra were obtained by flow injection in positive ion mode on a Platform benchtop mass spectrometer (Micromass, Manchester, U.K.) using a mobile phase of 60:40 water−acetonitrile at a flow of 200 μL/min with a corona of 3.00 kV, a high-voltage lens of 0.10 kV, a cone of 10 V, a source temp of 130 °C, and the APCI probe temperature at 550 °C.

Quantification. Quercetin and kaempferol were calibrated against daidzein as internal standard over a range of 50 ng to 3.0 μg injected using a wavelength of 270 nm for detection. The response factor for quercetin was used for quantification of the myricetin glycosides.

RESULTS

Identification of the Individual Flavonol Glycosides in the Tea Infusion Extracts. The elution sequence of the main flavonol glycosides from black tea on analytical reversed phase HPLC has been determined (Table 1) on the basis of our own studies and that of published work (Engelhardt et al., 1992). The use of a diode array detector, which enables the tentative identity of the aglycon portion of kaempferol derivatives to be distinguished from those of quercetin and myricetin since the kaempferol derivatives exhibit a single sharp maximum in the 260−275 nm region whereas those of quercetin and myricetin exhibit a doublet in the 255−270 nm region.

Preparative HPLC of an extract of the China tea Keemun yielded four major peaks, compounds **4**−**6** and **8** (Table 1) which were subjected to mass spectrometry and identified as two quercetin and two kaempferol triglycosides. Compounds **4** and **5** gave identical mass fragments of *m*/*z* 773 ($M + H^+$), 611 ($M + H -$ hexose$^+$), 465 ($M + H -$ hexose − deoxyhexose$^+$) and 303 ($M + H - 2 \times$ hexoses − deoxyhexose$^+$) and by comparison with HPLC retention times were identified as quercetin 3-*O*-glucosyl-(1→3)-rhamnosyl-(1→6)-galactoside and quercetin 3-*O*-glucosyl-(1→3)-rhamnosyl-(1→6)-glucoside, respectively. Compounds **6** and **8** gave identical mass fragments of *m*/*z* 757 ($M + H^+$), 595 ($M + H -$ hexose$^+$), 449 ($M + H -$ hexose − deoxyhexose$^+$), and 287 ($M + H - 2 \times$ hexoses − deoxyhexose$^+$) and again by comparison with HPLC retention times were identified as kaempferol 3-*O*-glucosyl-(1→3)-rhamnosyl-(1→6)-galactoside and kaempferol 3-*O*-glucosyl-(1→3)-rhamnosyl-(1→6)-glucoside, respectively. Additionally, compound **6** had an identical retention time to the authentic compound. Rutin (compound **7**, quercetin 3-*O*-rhamnosyl-(1→6)-glucoside) was identified as a coelutant running as a tail in the peak of compound **6**. Two peaks eluting before compound **4** (at 6.3 and 6.6 min) exhibited UV spectra consistent with the presence of myricetin and were assigned as compounds **2** and **3**. Compound **1**, myricetin 3-*O*-rhamnosylglucoside, which was listed as a minor constituent of the flavonols in tea by Engelhardt et al. (1992), was not detected in any of the samples analyzed in this study.

From all these data, together with the HPLC of the standard compounds, it was possible to assign each of the peaks found in the tea extracts to the compounds listed in Table 1.

Quantitative Analysis. Quantitative analysis was carried out using daidzein as an internal standard and the results expressed as concentrations of aglycon equivalents of the FGs present in tea. The detector response was linear over the range tested with correlation coefficients (r^2) of 0.99982, 0.99973, and 0.99991 for quercetin, kaempferol, and daidzein, respectively. Response factors were 2.138, 1.520, and 1.000 for quercetin, kaempferol, and daidzein, respectively, with each sample spiked with 162 μg of daidzein (=800 ng injected) as an internal standard. The response factor for quercetin was used for quantification of the myricetin glycosides.

The maximum error for the duplicate extractions of each infusion as a mean for all the components was ±6.3%, while the mean for this value from the 23 duplicates was ±2.9% (minimum, ±0.7%; maximum, ±6.3%). Error bars for the graphs were therefore set at ±6.3%.

The detection limit was defined as a peak having a height three times the baseline noise. For quercetin this equated to 5 ng injected. Using the conditions as described above the detection limit was calculated as 10 μg, expressed as quercetin, for a 200 mL infusion.

Quantitative data on the levels of flavonols present in tea can be expressed in different ways depending on the method of extraction. In the U.K. a tea cup holds approximately 200 mL and a cup of tea is normally prepared from one tea bag or 1 teaspoon of loose tea which was found to contain between 2.5 and 3.1 g of tea. The flavonol content has therefore been calculated as milligrams of flavonol per liter using an infusion derived from 3.00 g of tea for the regional and blended teas in 200 mL of boiling water. For the tea products, the weight taken was the amount recommended on the packet which ranged from 1 g (1 teaspoon) for the freeze-

Table 2. Total Levels of Flavonol Glycosides in Tea Samples (Expressed as Aglycon, Milligrams per Liter of Infusion)[a]

tea sample	FG content (mg/L)	tea sample	FG content (mg/L)
Lapsang souchong	50.7	freeze-dried 1	87.2
Assam	37.0	freeze-dried 2	94.7
Darjeeling	75.8	decaffeinated	75.9
Keemun	36.5	flavored leaf 1	55.0
Ceylon	46.3	flavored leaf 2	51.2
Njuno	56.6	product 1	14.4
blend 1	46.2	product 2	7.1
blend 2	44.9	product 3	52.3
blend 3	68.6	product 4	428.1
blend 4	56.1		
blend 5	88.3		

[a] For the processing of the data and error values in the tables, see Quantitative Analysis section.

dried teas to up to 10 g (2 teaspoons) for one of the flavored products.

The data presented here are from single individual samples of the teas purchased and therefore do not give an indication of differences which may arise from factors such as batch to batch variation, age of the sample, or time in the harvest season. The error bars, therefore, are a measure of the variation inherent in the analytical procedure

Tea Leaf Samples. The 11 samples of tea leaf infusions had levels of flavonol glycoside (expressed in terms of total aglycon) of 36.5−75.8 mg/L for the regional teas and from 45.0 to 88.3 mg/L for the blended teas (Table 2). These values are similar to the values for FGs (30−45 mg/L) found in comparable black tea samples by Hertog et al. (1993).

Tea Products. The decaffeinated tea sample was the only tea leaf analyzed which was found to contain significant amounts of myricetin glycosides. (1.0 and 2.0 mg/L of compounds **2** and **3**, respectively).

Among the tea products, the iced tea drink had the highest total flavonol content of 428.1 mg/L followed by the three freeze-dried teas with 87.0 and 94.6 mg/L (Table 2), but the level was much lower in the products more heavily diluted with other ingredients, such as products **1** and **2**, whose levels were 7.0 and 14.4 mg/L, respectively. The iced tea contained a high proportion of myricetin (2.7%) which was near to that in the decaffeinated tea sample (3.7% of total). The peach extract added to this product would contribute to the overall flavonol glycoside composition (Henning and Herrmann, 1980). However, the profiles of both the quercetin and the kaempferol glycosides in this iced tea product are very similar to those in the tea blends. This similarity would suggest that the high levels of flavonol glycosides in the iced tea sample were due to addition of tea extract rather than peach extract.

Analysis of the Flavonol Glycoside Mixture in Tea and Tea Products. *Tea Leaf Samples.* The distribution of the three major classes of flavonol conjugates present in the regional and blended tea samples is shown in Figure 1. Myricetin glycosides were detected in only 4 of the 11 samples tested, and in these their content was quite varied, ranging from 6 to 32% of the total flavonol content. The quercetin glycosides were the major group in all samples (50−76% of the total) except in the China black tea Keemun where they represented only 36% of the flavonols. Kaempferol glycosides are significant components in all the teas studied and were dominant only in the variety, Keemun, where they represented 45% of the total.

The distribution of the individual quercetin glycosides among the various samples is given in Table 3 and that for the kaempferol glycosides in Table 4. In only four samples (Lapsang souchong, Assam, Keemun, and Darjeeling) were significant amounts of either of the free aglycons detected, but even in these teas the aglycons form only a very small proportion (0.9, 0.5, and 0.3%, respectively) of the total flavonol fraction with free quercetin absent in the variety Keemun. In all other teas the free aglycons were not detected. Seven individual quercetin glycosides were detected in the tea samples, but only in Lapsang souchong and Assam teas were all eight forms of quercetin found together. These compounds represent mono-, di-, and triglycosidic derivatives of quercetin. The triglycoside (Q-3-*O*-gal-rha-glu; see compound 4 in Table 1) was the major component in Darjeeling tea, while rutin (Q-3-*O*-glu-rha) was the dominant component in Lapsang souchong and Njuno and absent in Keemun. Hyperin (Q-3-*O*-gal) was the main quercetin conjugate in Ceylon tea. The blended teas (**1**−**5**) all showed a profile similar to each other with rutin being the dominant quercetin glycoside present.

The profile of kaempferol glycosides (Table 4) showed marked differences for all the regional teas. The two triglycosides (compounds **6** and **8**) are major kaempferol derivatives in Keemun and Darjeeling teas, but absent in Njuno, while K-3-*O*-glu-rha-glu (**8**) alone is a major glycoside in Ceylon tea. The kaempferol analogue of rutin (K-3-*O*-glu-rha, compound **11**) and the simple glucoside (**14**) are the dominant forms in Lapsang souchong, Assam, and Njuno (note compounds **11** and **14** were dominant in the latter teas, while compounds **8** and **11** were dominant in Darjeeling).

As with the quercetin glycoside profile, the blended teas all showed a profile similar to the 3-*O*-rutinoside and 3-*O*-glucoside of kaempferol as the dominant conjugates except for blend 2. Blend 1 was the only one to have significant amounts of both the triglycosides (compounds **6** and **8**).

It has been suggested that the quercetin glucoside (**10**) arises during fermentation as a degradation product of quercetin rutinoside (**7**) which in turn is a degradation product of the quercetin triglycoside (compound **5**). Changes in the relative proportions of these compounds could be a measure of the degree of degradation during fermentation of the tea leaf (Engelhardt et al., 1992). In our work the proportion of the quercetin triglycoside (compound **5**) was lowest at 8% in Njuno, a dark colored highly fermented tea, but was 47% in Darjeeling, which contains a mixture of brown and green leaf fragments. The highest proportion was found in Keemun tea at 67% which had no detectable levels of the intermediate, rutin (**7**) but did have a high content of both triglycosides. The blended teas all had similar proportions of five of the glycosides for quercetin and of four of the glycosides of kaempferol. The quercetin glycoside profile, where rutin and the glucoside predominate, is similar to those for Lapsang, Assam, and Njuno.

The kaempferol glycoside profile however differs for blend 1 which is the only blend to possess both triglycosides (**6** and **8**).

Tea Products. The proportion of the quercetin glycosides in the flavonol mixture varied less than that in

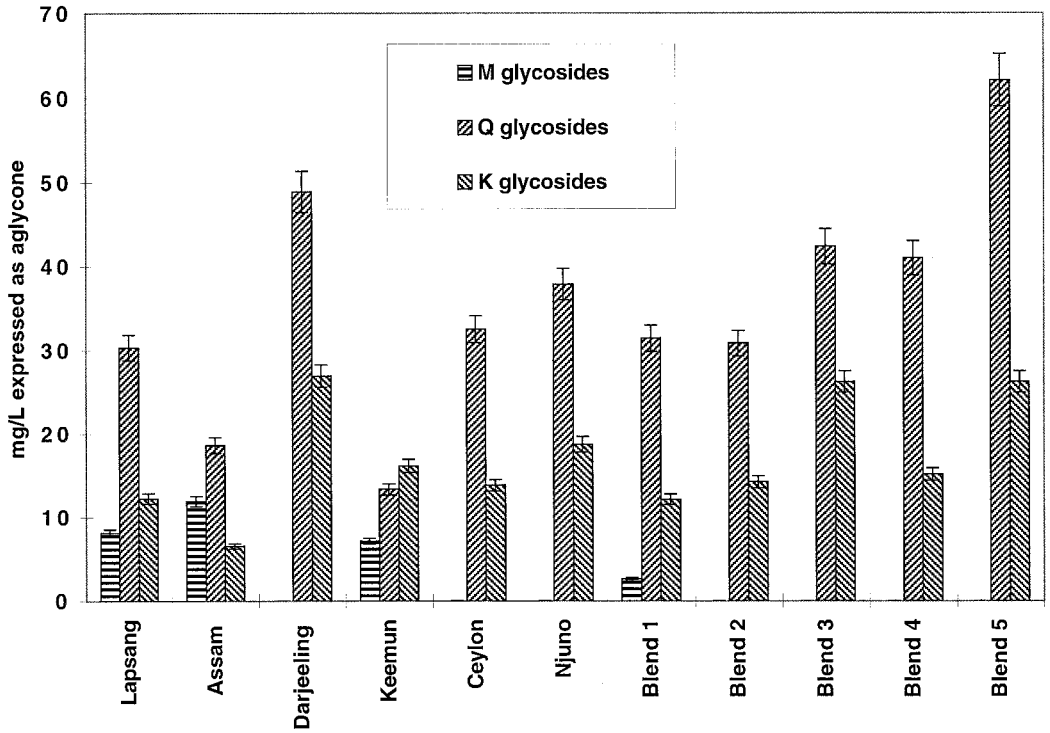

Figure 1. Distribution of flavonol glycosides in tea leaf.

Table 3. Distribution of Quercetin Glycosides in Tea Leaf Samples

compd	Lapsang	Assam	Darjeeling	Keemun	Ceylon	Njuno	blend 1	blend 2	blend 3	blend 4	blend 5
Q-gal-rha-glu	1.8	1.6	5.9	5.4	3.5	1.5	1.6	1.2	2.1	2.6	1.7
Q-glu-rha-glu	6.1	1.6	17.1	4.2	2.8	2.3	2.7	1.7	2.3	3.5	3.1
Q-glu-rha	9.8	5.6	9.7	0	3	15.5	11.8	10.3	16.6	14.7	24.1
Q-gal	3.7	2.8	5.4	1.9	13.5	6.3	4.3	6.7	6.5	6.2	10.0
Q-glu	7.1	6.2	9.9	1.8	9.7	12.3	10.5	10.5	14.2	13.5	22.4
Q-rha	0.5	0.2	0.8	0.0	0.0	0.0	0.6	0.4	0.8	0.5	0.8
Q-ara	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
total	30.3	18.5	48.9	13.3	32.5	37.9	31.5	30.8	42.5	41.0	62.1

Table 4. Distribution of Kaempferol Glycosides in Tea Leaf Samples

compound	Lapsang	Assam	Darjeeling	Keemen	Ceylon	Njuno	blend 1	blend 2	blend 3	blend 4	blend 5
K-gal-rha-glu	0.0	0.0	4.3	6.1	0.0	0.0	1.3	0.0	0.0	0.0	0.0
K-glu-rha-glu	3.1	0.6	8.3	6.5	3.8	0.0	1.8	0.7	0.8	1.1	1.3
K-glu-rha	4.5	2.5	6.6	1.2	0.0	6.9	2.8	2.1	10.5	6.3	10.2
K-gal	1.1	0.8	2.5	1.4	2.8	3.2	1.4	2.4	3.1	1.9	3.2
K-glu	3.3	2.6	5.1	0.7	7.2	8.6	4.8	8.9	11.7	5.8	11.5
K	0.3	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
total	12.3	6.6	26.9	16.1	13.8	18.7	12.1	14.1	26.1	15.1	26.2

the leaf samples, ranging from 57% in product 2 to 77% in flavored leaf 1 (Figure 2) and were within the range found for the tea blends. The iced tea sample contained myricetin, quercetin, and kaempferol glycosides at much higher levels of 11.4, 230.4, and 186.3 mg/L, respectively, and the proportions of the individual glycosides are listed under product 4 in Tables 5 and 6). The differing proportions of the individual flavonol glycosides are shown in Table 5 for the quercetin glycosides and in Table 6 for the kaempferol glycosides. Free quercetin was found in only three samples, decaffeinated tea and the flavored leaf samples 1 and 2 (0.4, 1.6, and 1.6%, respectively). The dominant glycoside in all cases was rutin (**7**) followed by isoquercitrin, the 3-*O*-glucoside (**10**), hyperin, the 3-*O*-galactoside (**9**) and the triglycoside (**5**) except for the two flavored leaf samples where the triglycoside (**5**) was at a higher level than hyperin (**9**). The kaempferol glycoside profile showed more variation although free kaempferol was also present in the same three samples which contained free quercetin. The dominant glycoside in seven of the samples was the rutin analogue of kaempferol (compound **11**) similarly followed by the isoquercitrin analogue (compound **14**). In the two samples of flavored leaf (1 and 2), the dominant glycoside was the kaempferol triglycoside (compound **8**) followed by the rutin analogue of kaempferol (**11**). Flavored leaf 2 was alone in containing the triglycoside (**6**) while all samples contained the 3-*O*-galactoside of kaempferol (**12**). The differences shown here could be explained in part by the use of different teas and also by the effects of extraction required to produce concentrated tea extracts.

DISCUSSION

These studies clearly show very marked differences both in the overall level of FGs and in the composition of the flavonol fraction between different tea varieties

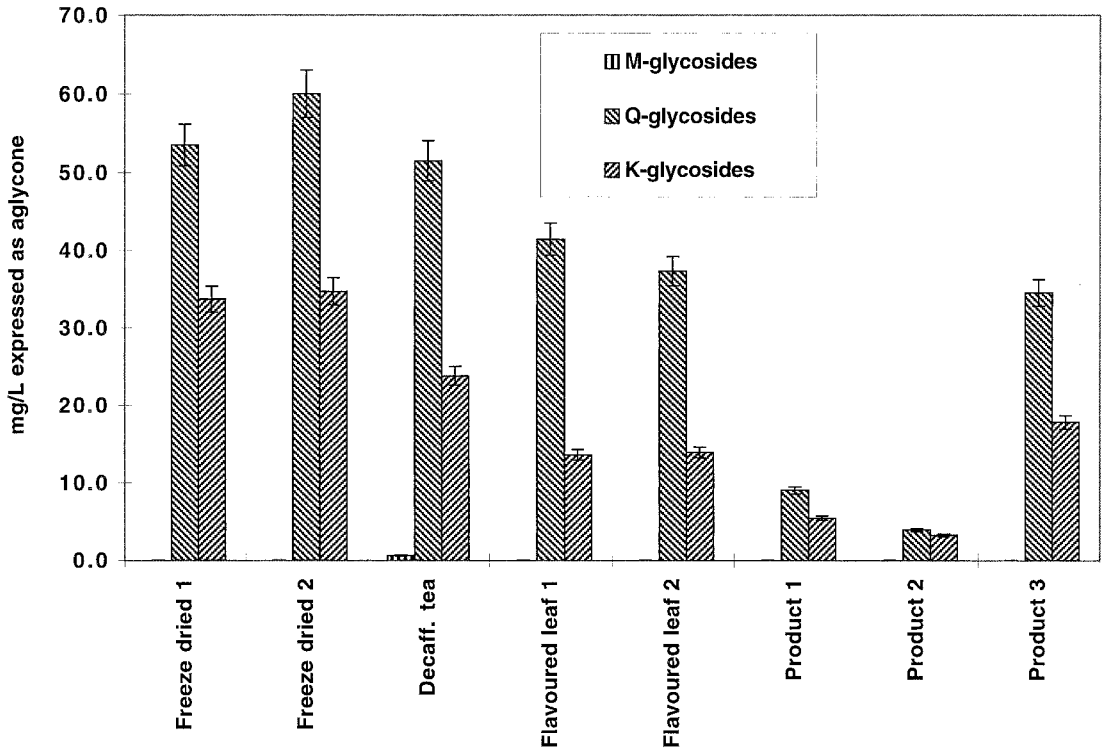

Figure 2. Distribution of flavonol glycosides in tea products.

Table 5. Distribution of Quercetin Glycosides in Tea Products

compd	freeze-dried 1	freeze-dried 2	decaff tea	flavored leaf 1	flavored leaf 2	product 1	product 2	product 3	product 4
Q-gal-rha-glu	4.3	4.4	4.5	3.4	3.7	0.0	0.0	1.6	2.5
Q-glu-rha-glu	4.4	5.3	3.7	9.2	8.0	0.0	0.0	1.9	25.5
Q-glu-rha	19.2	21.5	17.9	15.6	12.3	4.8	2.0	13.8	97.3
Q-gal	7.7	8.7	7.8	3.7	3.6	1.2	0.5	4.9	27.2
Q-glu	17.0	19.3	16.6	8.2	8.8	3.0	1.4	11.9	70.8
Q-rha	0.9	0.8	0.8	0.7	0.4	0.0	0.0	0.4	6.3
Q-ara	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q	0.0	0.0	0.2	0.6	0.5	0.0	0.0	0.0	0.9
total	53.5	60.0	51.5	41.4	37.3	9.0	3.9	34.5	230.5

Table 6. Distribution of Kaempferol Glycosides in Tea Products

compd	freeze-dried 1	freeze-dried 2	decaff tea	flavored leaf 1	flavored leaf 2	product 1	product 2	product 3	product 4
K-gal-rha-glu	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
K-glu-rha-glu	1.8	1.8	1.8	4.8	4.5	0.0	0.0	0.9	3.9
K-glu-rha	14.3	14.5	10.6	3.7	4.5	3.0	1.3	8.7	83.6
K-gal	4.0	3.9	2.6	1.1	0.7	0.5	1.4	1.7	19.7
K-glu	13.6	14.5	8.6	3.7	2.7	1.9	0.5	6.5	77.9
K	0.0	0.0	0.2	0.3	0.3	0.0	0.0	0.0	1.3
total	33.7	34.7	23.8	13.6	13.9	5.4	3.2	17.8	186.4

and tea products. Tea, generally, is the major dietary source of FGs in tea drinking countries. The present work shows that the intake of flavonol from tea can vary significantly depending on the type of tea or tea product drunk. Underlying these gross differences in FG level are very marked differences in the distribution of individual FGs between teas. For instance in the variety Keemun, the two kaempferol triglycosides are the major components while rutin is only a very minor compound. In contrast to this in other teas (e.g., the blends) rutin is the major FG and the triglycosides are minor components, if present at all. These differences in composition may themselves have dietary significance.

Hollman et al. (1995) have shown that there are major differences in the bioavailability of different FGs, those from onions and apples being significantly more bioavailable than those typical of tea such as rutin. These authors suggest the uptake of onion FGs, the principal of which are quercetin 4′-*O*-glucoside and quercetin 3,4′-*O*-diglucoside, occurs in the small intestine, and these two compounds which have a terminal glucose substituent are taken up across the small bowel wall by interacting with the sodium dependent glucose transport receptors. Evidence that such transport of quercetin glucosides may occur via this system has been provided in a recent report in gut transport studies by Gee et al. (1998), where it has been shown that the glucosides of quercetin interact with the transporter while the rhamnoside does not. The major FGs in tea such as rutin have a terminal rhamnose substituent, and this may explain their slow absorption in the gut. What absorption of rutin that does occur is delayed compared to that of the onion compounds and may occur after deconjugation by colonic bacteria with subsequent uptake, in the large bowel, of the resulting aglycon,

quercetin. In contrast to teas rich in rutin, the FGs of a variety such as Keemun with a high proportion of FGs with a terminal glucose may be preferentially absorbed. It is clear from these compositonal studies that the source of tea and quite probably the processing procedure to which it has been exposed influence the types and levels of FGs consumed and this in turn may affect the extent of their bioavailability. This in turn may affect the extent to which they may reach sites in the body and protect against processes such as LDL oxidation which can lead to arterial plaque accumulation and to coronary heart disease (Gryglewski et al., 1987).

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