Food & Function

Cite this: DOI: 10.1039/c1fo10240k

www.rsc.org/foodfunction

PAPER

Espresso coffees, caffeine and chlorogenic acid intake: potential health implications

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Received 29th October 2011, Accepted 13th November 2011
DOI: 10.1039/c1fo10240k

HPLC analysis of 20 commercial espresso coffees revealed 6-fold differences in caffeine levels, a 17-fold range of caffeoylquinic acid contents, and 4-fold differences in the caffeoylquinic acid : caffeine ratio. These variations reflect differences in batch-to-batch bean composition, possible blending of *arabica* with *robusta* beans, as well as roasting and grinding procedures, but the predominant factor is likely to be the amount of beans used in the coffee-making/barista processes. The most caffeine in a single espresso was 322 mg and a further three contained >200 mg, exceeding the 200 mg day^{-1} upper limit recommended during pregnancy by the UK Food Standards Agency. This snap-shot of high-street expresso coffees suggests the published assumption that a cup of strong coffee contains 50 mg caffeine may be misleading. Consumers at risk of toxicity, including pregnant women, children and those with liver disease, may unknowingly ingest excessive caffeine from a single cup of espresso coffee. As many coffee houses prepare larger volume coffees, such as Latte and Cappuccino, by dilution of a single or double shot of expresso, further study on these products is warranted. New data are needed to provide informative labelling, with attention to bean variety, preparation, and barista methods.

1. Introduction

Coffee is an extremely popular beverage with more than 300 million cups being consumed each day in the US alone. Reflecting its popularity, in economic terms coffee is a most valuable agricultural product with exports by third world and developing countries, amounting to ~7.2 million metric tonnes in 2009.[1] Coffee beans are produced from the cotyledons of seeds of plants belonging to the genus *Coffea*. Commercial production mainly exploits the seeds of *Coffea arabica* (so-called *arabica* coffees) which represent ~70% of the world market, while *Coffea canephora* (*robusta* coffees), which has a more bitter taste than *arabica*, is used principally with instant coffees and in espresso blends to promote the formation of "crema".

The value of coffee as a human beverage was initially recognised from the invigorating effect of wild coffee berries on goats in Abyssinia, sometime around 850 AD.[2] This action, subsequently attributable to its caffeine content, has led to the extraordinary attraction of the beverage to many consumers who exhibit increased alertness and a capacity to remain awake for longer periods without sleep. Caffeine can, however, have unpleasant symptoms, and, in excess, can lead to a state of excitement and anxiety. Dose-responses vary. For some people even a single cup may be acutely unpleasant and cause sleeplessness with a racing mind. For others, through tolerance to increasing exposure, drinking ten times this amount may still be pleasant, partly reflecting genetic variation in susceptibility.[3]

The half-life of caffeine in adults is around 5 h, but can be up to 30 h, with extended retention in the body by women taking an oral contraceptive, pregnant women, the developing fetus, young children, and those with liver disease. These groups are thus more susceptible to the effects of caffeine toxicity.[4] Current advice in the UK from the Food Standards Agency is for pregnant women to restrict caffeine to below 200 mg day^{-1}, or four cups of strong coffee each with an assumed caffeine content of 50 mg.[5] For the general public assessing caffeine intake is difficult. Current guideline figures suggest that an 8 oz (~225 mL) cup of instant coffee contains 60–85 mg of caffeine, and a 1 oz (~28 mL) espresso 30–50 mg.[6] However, despite the increasing number of coffee shops on the high street and in airports, there appear to be no recent publications on the caffeine contents of the various types of commercially prepared coffees.

As well as caffeine, coffee contains substantial amounts of a family of conjugated hydroxycinnamates collectively referred to as chlorogenic acids. The main chlorogenic acids are 5-*O*-caffeoylquinic acid (5-CQA) and its isomers 3-*O*-caffeoylquinic acid (3-CQA) and 4-*O*-caffeoylquinic acid (4-CQA) (Fig. 1) and together these account for 80% of the total chlorogenic acids.[7] Although the CQAs in coffee have antioxidant properties, and *in vitro* are able to scavenge free radicals, which in humans have been linked to conditions such as Parkinson's disease and cardiovascular disease, there is much speculation but only limited evidence of coffee consumption being linked to protective

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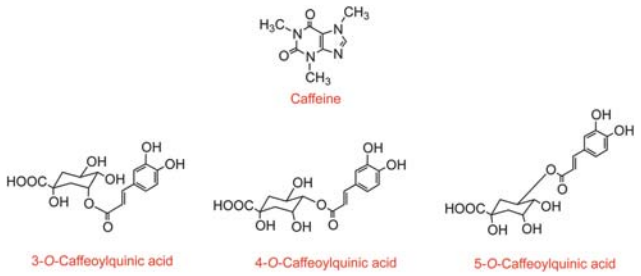

Fig. 1 Structures of caffeine and the chlorogenic acids, 5-*O*-caffeoylquinic acid, 3-*O*-caffeoylquinic acid and 4-*O*-caffeoylquinic acid.

effects on human health.[8] Epidemiological evidence and some intervention studies do, however, indicate that coffee consumption may reduce the risk of type 2 diabetes[8] and one recent report provides evidence that coffee decreases the risk of depression among women with the effect being attributed to caffeine intake.[9]

It is against this background that HPLC analysis has revealed substantial variations in the caffeine and chlorogenic acid content of espresso coffees purchased from coffee shops in the west end of Glasgow near the University of Glasgow.

2. Results and discussion

The caffeine and 3-, 4- and 5-CQA contents of single servings of espresso coffee from 20 different outlets are presented in Table 1. The cup size ranged from 23–70 mL. The amount of caffeine that a consumer would ingest per serving ranged from 51 to 322 mg, while the CQA content varied from 24–422 mg. The main chlorogenic acid in all the coffees was 5-CQA with smaller amounts of 3- and 4-CQA. Both the caffeine and total CQA content were highest in coffee from Pattiserie Francoise and lowest in Starbucks espresso which contained ~6–fold less caffeine and ~17-fold less total CQA. There was also substantial variation in the total CQA : caffeine ratio of the coffees which ranged from 0.47 to 1.94 (Fig. 2).

It is evident from the data presented in Table 2 that the quoted figures for caffeine content of espresso coffee in the 2008 IFIC Review,[6] which are widely cited in the popular press, do not provide a realistic picture. The levels of caffeine per serving varied more than 6-fold from 51 to 322 mg. At the low level, a pregnant woman and others with a need to restrict caffeine consumption, might safely drink 4 cups per day without significantly exceeding the recommended caffeine intake. In marked contrast, at the higher end of the scale, drinking even one cup of espresso will be well in excess of the advised limit of 200 mg day^{-1}.

Responses to caffeine vary. Those habituated to the purine alkaloid suffer headaches when caffeine is withdrawn. At the other extreme, doctors not uncommonly see patients with a range of rather non-specific symptoms grouped as "caffeinism" which are resolved when caffeine is removed from the diet. These

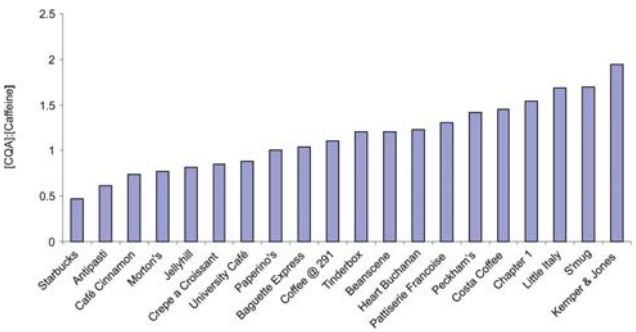

Fig. 2 Variation in the total CQA : caffeine ratio of 20 espresso coffees purchased from outlets in the west end of Glasgow.

Table 1 Quantities of caffeine and CQAs in servings of espresso coffee. Data expressed as mean values ($n = 3$), standard error <7% of mean values

				As a percentage of total CQA		
Source	Serving size (mL)	Caffeine (mg/serving)	Total CQA (mg/serving)	3-CQA	4-CQA	5-CQA
Pattiserie Francoise	52	322	422	23%	26%	51%
University Cafe	49	260	230	36%	23%	41%
Café Cinnamon	59	242	179	23%	28%	49%
Paperino's	50	205	207	31%	26%	43%
S'mug	32	173	294	21%	27%	52%
Costa Coffee	25	157	227	21%	27%	52%
Heart Buchanan	24	156	127	17%	30%	53%
Jellyhill	63	151	122	21%	33%	46%
Baguette Express	45	140	145	21%	28%	51%
Chapter1	26	140	215	22%	27%	51%
Peckham's	70	140	199	13%	29%	58%
Little Italy	23	129	217	17%	27%	56%
Coffee @ 291	49	98	108	21%	29%	50%
Crepe á Croissant	34	95	81	21%	28%	51%
Kember & Jones	43	90	175	21%	26%	53%
Beanscene	48	77	93	20%	28%	52%
Tinderbox	25	75	90	22%	27%	51%
Morton's	35	73	56	23%	29%	49%
Antipasti	36	72	44	18%	34%	48%
Starbucks	27	51	24	21%	29%	50%
Median value	**43**	**140**	**145**	**21**	**28**	**51**
Range	**23–100**	**51–322**	**24–422**	**13–36%**	**23–34%**	**43–58%**

Table 2 Details of coffee beans and roasting procedures[a]

Coffee	Origin	Roasting temp. (°C)	Roasting time (s)	Roasting
Washed *arabica*	Colombia	—	—	—
	Colombia	350	244	H-S
	Colombia	270	595	L-L
Unwashed *arabica*	Ethiopia	—	—	—
	Ethiopia	350	247	H-S
	Ethiopia	270	612	L-L

[a] H-S: high temperature, short roast; L-L: low temperature, long roast.

problems would only be suspected if caffeinated soft-drinks or coffee intake were high: our data show that one cup of high-caffeine coffee could cause as much difficulty to these susceptible consumers as six cups of coffee to another.

This large variability in caffeine and CQA content could be due to a number of factors with the amount of coffee used to prepare a serving of espresso probably being substantially less for the low-caffeine coffees than for those at the upper end of the scale (Table 1). Other factors that could impact on the caffeine and CQA content, arguably to a lesser degree, are (i) batch-to-batch differences in the *arabica* beans, (ii) roasting procedures, (iii) grinding conditions and (iv) the coffee-making/barista process (temperature of water/steam in the extraction vessel, its duration, coffee : water/steam ratio *etc*.).

To investigate the possible impact of roasting techniques on the CQA and caffeine contents of coffee, infusions were prepared from two batches of espresso coffees. One was a washed Columbia coffee and the other unwashed beans from Ethiopia. Unroasted coffees were included along with samples which had been roasted (i) at a high temperature for a short time (H-S) and (ii) at a low temperature for a longer time (L-L) as outlined in Table 2. After grinding the beans, 100 mL of boiling water was added to 5 g of coffee and brewed for 5 min before filtering. The CQA and caffeine contents of the infusions prepared in this manner are presented in Table 3. The caffeine content of brews from both coffees declined by ~80% with both the H-S and L-L roasts. There was a bigger loss of CQAs in the infusions with 11.0% and 13.3% recoveries after H-S and 8.0% and 6.8% following L-L roasting conditions. This was associated with reduced CQA : caffeine ratios of the coffees.

During roasting, the chlorogenic acids are subjected to a complex series of reactions including acyl migration which results in 3-CQA and 4-CQA being destroyed more slowly than 5-CQA[10] while caffeine is lost through sublimation.[7,11] The data in Table 3, including the total CQA : caffeine ratios, indicate that CQAs are lost more rapidly than caffeine, especially during L-L roast conditions. This is in keeping with the long held use of the CQA : caffeine ratio as a rule of thumb index of the extent of roasting.[12] The CQA : caffeine ratios in Table 3 are much higher than those obtained with the commercial espresso coffees (Fig. 2), probably because the beans used to prepare the various espresso coffees were roasted for longer periods of time resulting in enhanced breakdown of CQA compared to losses of caffeine. *Robusta* coffee beans contain almost twice as much caffeine as *arabica*[13] so if any of the espressos were produced from an *arabica–robusta* blend, as opposed to being 100% *arabica*, this would also contribute to a lower the CQA : caffeine ratio. Batch to batch variation in coffee beans is also likely to have an impact on this ratio.

3. Experimental

3.1. Coffees

Single shot espresso coffees were purchased from 20 different outlets in the west end of Glasgow. The volume of the coffee servings was measured after which aliquots were diluted 50-fold with methanol and stored at −80 °C prior to analysis of caffeine and CQA levels. In addition, in order to explore one possible reason for variation in the micronutritient contents of coffees, six samples of ground espresso *arabica* coffee, prepared from beans subjected to different roasting profiles, as outlined in Table 2, were supplied by Finlay Beverages (South Elmsall, London WF9 2XS). In Glasgow, 100 mL of boiling water was added to 5 g of

Table 3 Effect of washing and roasting conditions on the CQA and caffeine content of *arabica* coffee beans. One hundred mL of boiling water was added to 5 g of ground beans and after 5 min samples were filtered and the caffeine and CQA content of the filtrate analysed by HPLC. Data expressed as mean values in mg mL^{-1} ($n = 3$). Standard error <7% of mean values. Figures in parentheses represent mean values for total CQAs and caffeine as a percent of the unroasted value[a]

		As a percentage of total CQA					
Coffee	Roast	3-CQA	4-CQA	5-CQA	Total CQAs	Caffeine	Total CQA : caffeine ratio
Washed *arabica*	—	11%	16%	71%	11.3 (100%)	1.90 (100%)	5.9
	H-S	22%	27%	51%	1.45 (13.3%)	0.39 (20.6%)	3.7
	L-L	23%	27%	50%	0.92 (8.0%)	0.37 (19.6%)	2.5
Unwashed *arabica*	—	8%	10%	81%	14.6 (100%)	1.94 (100%)	7.5
	H-S	22%	25%	51%	1.59 (11.0%)	0.37 (19.2%)	4.3
	L-L	24%	26%	50%	1.06 (6.8%)	0.35 (18.6%)	3.0

[a] H-S - high temperature, short roast; L-L - low temperature, long roast (see Table 2).

the ground beans which was brewed for 5 min before filtering, dilution 50-fold with methanol and storage at −80 °C prior to analysis.

3.2. Analytical procedures

Five μL volumes of the diluted coffee infusions were analysed in triplicate using reversed phase HPLC with PDA detection according to procedures previously outlined.[14,15] Caffeine was quantified at 280 nm and the three CQAs at 325 nm in 5-CQA equivalents.

4. Conclusions

Our data represent only a snap-shot of the caffeine contents of espresso coffees, but the range and scale of the results is sufficient to demonstrate that there is a problem, unlikely to be restricted to Glasgow, as coffee connoisseurs can unwittingly ingest very large amounts of caffeine. A single serving of high caffeine espresso could well place at risk individuals who are more susceptible to the effects of caffeine toxicity, including women who are pregnant or taking an oral contraceptive, young children, and those with liver disease. In addition, as many coffee houses prepare Latte and Cappuccino, and other larger volume coffees, by dilution a single or double shot of expresso, further study on these products is warranted. The data we have gathered indicate the need for a definitive study of caffeine content and consumption of coffees, with a view to improving consumer information.

5. Acknowledgements

The authors wish to thank Thomas Blackwall of Findlay Beverages for kindly providing the samples of roasted coffees listed in Table 2. This project, which has its origins in undergraduate laboratory class in Plant Science taught by A. C. at the University of Glasgow, was carried out as part of T. W. M. C.'s Hyndland Secondary School (Glasgow) Advanced Higher Chemistry research project.

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