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Review article

Is coffee a functional food?*

José G. Dórea† and Teresa Helena M. da Costa

Department of Nutrition, Faculdade de Ciências da Saúde, Universidade de Brasília, Brazil

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Definitions of functional food vary but are essentially based on foods' ability to enhance the quality of life, or physical and mental performance, of regular consumers. The worldwide use of coffee for social engagement, leisure, enhancement of work performance and well-being is widely recognised. Depending on the quantities consumed, it can affect the intake of some minerals (K, Mg, Mn, Cr), niacin and antioxidant substances. Epidemiological and experimental studies have shown positive effects of regular coffee-drinking on various aspects of health, such as psychoactive responses (alertness, mood change), neurological (infant hyperactivity, Alzheimer's and Parkinson's diseases) and metabolic disorders (diabetes, gallstones, liver cirrhosis), and gonad and liver function. Despite this, most reviews do not mention coffee as fulfilling the criteria for a functional food. Unlike other functional foods that act on a defined population with a special effect, the wide use of coffee-drinking impacts a broad demographic (from children to the elderly), with a wide spectrum of health benefits. The present paper discusses coffee-drinking and health benefits that support the concept of coffee as a functional food.

Coffee: Caffeine: Nutrition: Health promotion: Polyphenols: Antioxidants

Functional food (FF) has neither a precise nor a universal definition; rather, our understanding of FF is based on its beneficial effects on health promotion and/or disease prevention. According to Verschuren (2002), the inherent health-promoting qualities of some foods are derived from the ancient cultural perception that such qualities come from the same source and serve the same purpose as its recognised nourishment. Indeed, both Asian cultures and the Hippocratic principles of Western medicine share this concept (Verschuren, 2002).

At the recent Symposium of the International Institute of Life Sciences, modern concepts of FF were presented in their variety. This variety itself indicates the existence of distinct histories of perceptions of FF by regulatory and scientific bodies, and by the public at large (Saris *et al*. 2002). As a consequence, consumers, health professionals, the food industry and scientists are gaining 'experience and understanding distinctive health aspects of functional foods', and scientific and technological opportunities related to FF are emerging revitalised (Verschuren, 2002). Despite its broad conceptual definition, the common notion is that naturally occurring active components in foods help to define whether or not they are FF. Altogether, the intrinsic properties of whole, fortified, enriched or enhanced foods that deliver health benefits beyond conventional nutrients are taken into account when defining FF.

The varieties of claims surrounding FF have been summarised by Hasler (2002). However, most reviews that list and discuss the health benefits of FF (Hasler, 2002; Halsted, 2003) do not mention coffee even though they discuss tea infusions. Several of the ingredients reported as functional components that are found in tea, such as flavonoids (catechins, anthocyanins), caffeic acid and ferrulic acid (Hasler, 2000), are also found in coffee.

Coffee is a highly popular drink that is traditionally used to complement meals, as well as for hedonistic and psychostimulant purposes but not as nourishment. However, depending on the quantities consumed, it can affect the intake of K, Mg and Mn (Gillies & Birkbeck, 1983). Coffee can provide 8 % of the daily intake of Cr (Santos *et al.* 2004) and can be a substantial source of Mg; a mean of 63·7 μg/cup (100 ml) has been reported (Astier-Dumas & Gounelle de Pontanel, 1974). This is comparable to the upper range of mg concentrations (mean 28·8 μg/ml, range 1·7–95·4 μg/ml) reported for non-alcoholic drinks (Jodral-Segado *et al.* 2003). Indeed, Mg excretion has been positively correlated with Mg intake and coffee consumption (Lowik *et al.* 1993). The food service industry has introduced new, high-energy gourmet coffee beverages (Shields *et al.* 2004). In some circumstances, coffee-brewing can remove toxic metals such as Pb from influent water (Impellitteri *et al.* 2000).

The coffee beverage is rich in biologically active substances such as nicotinic acid, trigonelline, quinolinic acid, tannic acid, pyrogallic acid and, of course, caffeine (Minamisawa *et al.* 2004). Niacin in particular is formed in great amounts from trigonelline during the coffee-bean roasting process (Czok, 1977; Casal *et al.* 2000). The amount of niacin can vary from 2 to 80 mg/100 g coffee, depending

Abbreviations: FF, functional food; MRP, Maillard reaction products.

*This paper is dedicated in memoriam to Professor Luiz Carlos Trugo.

† **Corresponding author:** Professor José G. Dórea, fax + 55 61 368 5853, email dorea@rudah.com.br

on bean origin, roasting and preparation methods (Adrian & Frangne, 1991). Coffee is a rich source of antioxidants of the hydroxycinnamic acids family (caffeic, chlorogenic, coumaric, ferrulic and sinapic acids), which can markedly change the total polyphenol intake (Manach *et al.* 2004). Borrelli *et al.* (2004) recently proposed a by-product of coffee-bean roasting, coffee silverskin, as a new potential functional ingredient because of its content of soluble dietary fibre and marked antioxidant activity.

Owing to its broad application in the food and pharmaceutical industries, caffeine is the most well known and pharmacologically studied component of coffee (Harland, 2000). The specific effects of caffeine on increased mental alertness, faster information-processing, wakefulness, restlessness, reduction of fatigue and delay in the need for sleep are often available in tablet form and are also broadly used in medication and beverages (Harland, 2000). The effects of caffeine *per se* are not the subject of the present paper. These may be found elsewhere (Nawrot *et al.* 2003). Rather, the objective of this discussion is to focus on studies of coffee-drinking that show a positive impact on health promotion or disease prevention.

Coffee-drinking

Coffee-drinking is appreciated worldwide because of its pleasant taste and aroma, and also because of its physiological and psychoactive properties, attributed to compounds such as methylxanthines (Quinlan *et al.* 1997). Some sensory properties of coffee beans are attributed to volatile substances developed during roasting and brewing, which in turn result in a variety of choices for preparing beverages (Lewis, 2004). Greater sensory satisfaction has been provided in some products, for example, espresso (Navarini *et al.* 2004). In industrialised countries, specialised coffee establishments are as visible as restaurants and fast-food chains. In these affluent societies, in addition to a great variety of coffee products, there is a flourishing industry in coffee-making machinery suitable for homes and offices. Thus, coffee preparation and consumption, in all their variety, are easy and available to many.

The coffee infusion is consumed *per se* as part of meals or as an ingredient in snacks and desserts. In Western cultures, it is an obligatory breakfast item thought to impart a positive predisposition to work activities. Smith *et al.* (1999) were able to distinguish profiles (working memory, attention, mood, cardiovascular function) based on coffee and cereals consumed during breakfast. Subjects consuming breakfast cereal had a more positive mood at the start of the test sessions, performed better on a spatial memory task and felt calmer at the end of the test session than those in the no-breakfast condition. The ingestion of caffeine had no effect on initial mood or working memory but it did improve the encoding of new information and counteracted the fatigue that developed over the test session (Smith *et al.* 1999).

Job demands have been shown to increase coffee consumption in the workplace (Steptoe & Wardle, 1999), where it is thought to improve working performance (Jarvis, 1993). Reyner & Horne (2000) suggested that the caffeine dose taken via coffee reduces early morning driver sleepiness for about 30 min following no sleep and for around 2 h after sleep restriction. Because driver sleepiness plays a key role in road accidents, this might be an important and poorly evaluated role of coffee-drinking. Drinking coffee is one of the steps that drivers take to avoid falling asleep while driving (Rey de Castro *et al.* 2004). Indeed, other than stopping driving, taking a nap and/or caffeinated coffee can be effective (Horne & Reyner, 1995). Among airline pilots, combating fatigue to enhance safety includes the use of coffee (Sparaco, 1996).

Coffee's most studied component, caffeine, varies substantially as a function of coffee plant species and the method of bean-roasting and drinks preparation. The caffeine content of caffeinated coffees ranges from 58 to 259 mg/dose. In one study, the mean caffeine content of brewed speciality coffees was 188 mg for a 16 oz (USA) cup (Bell *et al.* 1996). Variability is, however, high. McCusker *et al.* (2003) reported a wide range of caffeine concentration (259–564 mg/dose) in the same coffee beverage obtained from the same outlet on six consecutive days.

The strong pharmacological effects of caffeine have led to consumer demand for caffeine-free coffee beverages. Many decaffeination techniques have been developed. At first, organic solvents were used, but this was discontinued due to their undesirable side-effects. Decaffeination techniques employing supercritical CO_2 are currently used to extract caffeine from coffee beans. McCusker *et al.* (2003) analysed coffee brands sold as decaffeinated and found them to have caffeine concentrations less than 17·7 mg/dose. The ability of newly developed coffee plants (naturally selected or GM) to possess a low caffeine content while keeping the rich flavour and aroma of their caffeinated counterparts holds promise. In fact, these transgenic plants showed a 70 % reduction in caffeine content (Ogita *et al.* 2003), whereas a naturally decaffeinated *Coffea arabica* plant (genetic selection) from Ethiopia showed a 93·7 % reduction in the level of caffeine (Silvarolla *et al.* 2004).

Variations in the concentrations of caffeine and other components, as well as the volume of coffee consumed, are frequently ignored in studies examining coffee consumption and health outcomes. This in part accounts for discrepancies in results reported by epidemiological studies (Stavric *et al.* 1988). Kubo Shlonsky *et al.* (2003) demonstrated conflicting results and confounding factors associated with coffee-drinking. In a study of 12 467 adults, decaffeinated coffee was associated with illness in some but a healthy lifestyle in others. Indeed, cultural preferences in coffee drinks provide a clue to how coffee may be prepared and consumed, and it is these differences that seem to affect health outcomes in studies.

Bean-roasting, brewing technique and coffee consumption vary widely around the world. In France, the roasting process appears to be more intense than that used in the USA (Cirilo *et al.* 2003). Urgert & de Groot (1996) reported a wide variety of preferences in brewing techniques and coffee consumption in eight European countries. The brewing techniques resulted in a wide range of diterpene concentrations. Instant and drip-filtered drinks were poor in diterpenes, while diterpene-rich drinks were found in boiled or Turkish/Greek beverages; espresso, mocha and caffetiene had intermediate diterpene concentrations. Elderly Europeans were daily users of unfiltered coffee brews: Roskilde in Denmark and Culemborg in The Netherlands having figures of 90 %, much more than those in Marki, Poland (12 %) and Coimbra, Portugal (7 %). Overall, drip-filtered drinks were the most prevalent type of coffee beverage, but espresso and mocha were consumed by 31 % of Swiss drinkers and by 100 % of Italian coffee drinkers (Urgert & de Groot 1996). Studies indicate that coffee is consumed unfiltered in Italy (Esposito *et al.* 2003) and Sweden (Lindahl *et al.* 1991). It should be emphasised that coffee-drinking is a dynamic process constantly under the influ-

ence of lifestyle trends. Recently, in Sweden, Lindahl *et al.* (2003) reported pronounced changes in food consumption indicating a decrease in boiled coffee.

Finally, because the chemical and sensory characteristics of infusions are affected by grinding and roasting (Andueza *et al.* 2003), no good markers of coffee consumption exist. However, isoferrulic acid coffee-derived polyphenol may be of limited use (Hodgson *et al.* 2004).

Despite the worldwide use of coffee, especially in Western cultures, there are few studies addressing issues related to coffee preparation and consumption. Soroko *et al.* (1996) assessed the pattern of coffee-drinking in a white, middle-class community in Southern California (Rancho Bernardo), USA. In general, respondents (30–105 years old) reported that they had started drinking coffee at around 20 years of age and had changed to decaffeinated coffee at around the age of 50.

Although coffee may not be considered to be an appropriate beverage for children in the USA (Dewey *et al.* 1997), Barone & Roberts (1996) assessed caffeine intake from coffee consumption and reported that coffee consumption occurs in those between 1 and 5 years of age. In some societies, coffee-drinking is introduced early in life (Karkal, 1975; Dorea & Furumoto, 1992). Dorea & Furumoto (1992) reported that coffee is introduced into infant diets as early as 2 months of age. In South American cultures, especially among coffee-growing countries, coffee consumption is a part of meals, most notably during breakfast. In these countries, there are no restrictions on coffee consumption during pregnancy and lactation (Munoz *et al.* 1988). In fact, coffee is among the first liquids given to infants in Guatemala (Dewey *et al.* 1997). Sugar, coffee and tortilla accounted for one-third of all items mentioned in a dietary survey of poor urban Guatemalan toddlers (Krause *et al.* 1998).

At present, very few studies have dealt with coffee-drinking during lactation. In one study, it was shown that coffee-drinking (145·8 mg caffeine) mothers had a mean breast milk caffeine concentration of 0·29 mg/l (Hildebrandt & Gundert-Remy, 1983). Such caffeine intakes by breast-fed infants did not affect their heart rate and sleeping time (Ryu, 1985). Nehlig & Debry's (1994*a*) review of coffee consumption during gestation and lactation concluded that caffeine does not change breast milk composition but actually stimulates milk production.

Antioxidant and antibacterial properties

Infusions and beverages such as chocolate and tea are cited as a source of flavonoids (Halstead, 2003) or related phenolic compounds. These compounds have been shown to have antioxidant properties in both *in vitro* and *in vivo* studies. Hasler (2002) reviewed the effects of catechins in green and black teas and the risks of gastric cancer and solid tumours. Karakaya *et al.* (2001) measured levels of phenolic compounds in beverages, drinks and infusions, reporting concentrations ranging from 0·07 to 4·16 mg/l in the following order: black tea > instant coffee > coke > red wine > violet carrot juice > apricot nectar > Turkish coffee > white wine. Antioxidant heterocyclic compounds including furans, pyrroles and maltol were also detected in brewed coffee (Yanagimoto *et al.* 2004). In addition, in one study, the antioxidant capacity of coffee and tea infusions was shown to increase the antioxidant capacity of the plasma (Natella *et al.* 2002). In the case of coffee, the antioxidant effects were attributed to an increase in both uric acid and phenolic compounds (Natella *et al.* 2002). Olthof *et al.* (2001) studied the metabolism of phenolic compounds of coffee (chlorogenic acid) and tea (quercetin-3-rutinoside) flavonol and tea phenols. They suspected that the *in vitro* antioxidant activity might be lower than expected during *in vivo* activity since colonic microflora metabolise most of the dietary phenols and therefore significantly alter *in vivo* results. Nevertheless, Namba & Matsuse (2002) suggest that coffee has properties to prevent the deleterious actions of free radicals and viral infections.

Coffee beans and tea both contain phenolic compounds and antioxidant compounds. However, due to the coffee bean-roasting process, phenolic compounds can be lost while compounds with antioxidant properties are being developed. Indeed, overall antioxidant properties may be enhanced by newly formed Maillard reaction products (MRP) during roasting (Nicoli *et al.* 1997, 1999; Anese & Nicoli, 2003). Nicoli *et al.* (1999) studied these products and demonstrated that beans that have been prepared using intermediate roasting conditions have maximum antioxidant activity. Decreases in antioxidant properties seem to be related to high-molecular weight MRP. However, during the storage of ready-to-drink brews, a further development of MRP occurs, but there is a decrease in antioxidant properties (Anese & Nicoli, 2003). Daglia *et al.* (2004) tested *in vitro* and *ex vivo* specific antiradical activity against hydroxyl radicals and found that 5-*O*-caffeoiquinic acid was the most active fraction. Dogasaki *et al.* (2002) reported that brewed coffee possessed antibacterial activities exhibited by caffeic acid, chlorogenic acid and protocatechnic acid (3,4-dihydoxy benzoic acid). Daglia *et al.* (1998, 2002) also reported anti-adhesive properties due to both naturally occurring and roasting-induced molecules.

Del Castillo *et al.* (2002) observed a decrease in antioxidant activity with the degree of roasting. Maximum antioxidant activity was observed for the medium-roasted coffee. Nicoli *et al.* (1997) noticed that thermal treatment during coffee-roasting significantly reduced the levels of natural antioxidants. However, the overall antioxidant properties of the products were maintained and even enhanced by the development of MRP. Some of these products, characterised as melanoidins, exhibit anti-radical activity and are formed in proportion to the intensity of roasting (Borreli *et al.* 2002). Other roasting by-products are biogenic amines (serotonin > spermidine > agmatine), which are also formed in relation to the degree of roasting (Cirilo *et al.* 2003). Differences in roasting preferences are often dictated by cultural traits: for example, French citizens are thought to like more intensely roasted coffee than Americans (Cirilo *et al.* 2003). Differences in brewing might affect antioxidant outcomes in coffee drinkers. The consumption of unfiltered coffee, such as that consumed in Italy, can increase plasma GSH (Esposito *et al.* 2003). In addition, chlorogenic acid undergoes efficient conjugation with GSH (Panzella *et al.* 2003).

Regular coffee ingestion may modestly reduce susceptibility to LDL oxidation, thereby decreasing LDL-cholesterol and malondialdehyde levels (Yukawa *et al.* 2004). The solvent fractionation of coffee followed by multiple-step ultrafiltration revealed that polar compounds with a molecular weight below 1 kDa showed the major inhibitory effect to the *in vitro* peroxidation of linoleic acid. These fractions also affected the predominant chemopreventive enzyme-modulating activity on NADPH-cytochrome c-reductase and glutathione S-transferase in human intestinal Caco-2 cells (Somoza *et al.* 2003). Somoza *et al.* (2003) demonstrated 5-chlorogenic acid to be a powerful antioxidant *in vitro*.

In contrast, chemopreventive effects on glutathione S-transferase activity were attributed to the N-methylpyridinium ion. Coffee melanoidins showed higher antioxidant activity than melanoidins isolated from beer (Morales & Jimenez-Perez, 2004).

Caffeine and its catabolic products theobromine and xanthine exhibit both antioxidant and pro-oxidant properties. Therefore, caffeine and its metabolites may also contribute to the overall antioxidant and chemopreventive properties of caffeine-bearing beverages (Azam *et al.* 2003). Because coffee is rich in biologically active substances, such as polyphenols and antioxidants, it is the main contributor of dietary antioxidant intake in the diet in Bavaria in Germany (Radtke *et al.* 1998), in Spain (Pulido *et al.* 2003), in the USA (Svilaas *et al.* 2004) and most likely in many other countries.

Because of widespread coffee use, the relationship between coffee consumption and the induction of cancer has recently been approached by Porta *et al.* (2003), who hypothesised that coffee acts as an effect modifier that may in some circumstances induce or inhibit tumour formation. Indeed, Vatten *et al.* (1990) suggested that coffee consumption reduces the incidence of breast cancer in lean women, whereas it might have the opposite effect in relatively obese women. Because smokers have a higher coffee consumption than non-smokers (Arnlov *et al.* 2004), it is surprising that there is a paucity of studies examining coffee antioxidant properties and lung cancer in smokers. Kubrik *et al.* (2001) found that cigarette-smoking was the most important factor associated with lung cancer and that coffee-drinking showed an inverse association with cancer risk. Mendilaharsu *et al.* (1998) reported that coffee-drinking had no significant effect on the lung cancer risk of cigarette-smoking lung cancer patients compared with matched controls.

Physiological effects

The effects of coffee on the gastrointestinal tract and the liver and biliary system are known and are attributed to various components, such as caffeine and chlorogenic or caffeic acids. The stimulating effects on these organs can be caused directly or indirectly by the liberation of gastrin or other gastrointestinal hormones (Czok, 1977). There is an inverse association between coffee consumption and liver cirrhosis (Klatsky & Armstrong, 1992; Gallus *et al.* 2002; Tverdal & Skurtveit, 2003). Corrao *et al.* (2001) discussed the hypothesis that coffee, but not other caffeinated beverages, might inhibit the onset of alcoholic and non-alcoholic liver cirrhosis. Coffee-drinking was also associated with a reduced risk of alcohol-associated pancreatitis (Morton *et al.* 2004). An alteration in hepatic microsomal function in liver disease alters caffeine metabolism. Because of this, Wahllander *et al.* (1985) have suggested that, in regular coffee-drinkers, fasting plasma caffeine concentrations might serve as a guide to the severity of functional impairment in chronic liver disease.

Nakanishi *et al.* (2000) reported that coffee consumption was inversely related to serum γ-glutamyltransferase and suggested that coffee might inhibit the inducing effects of ageing and possibly of smoking on serum γ-glutamyltransferase in the liver. In Norway, a decrease in the consumption of boiled coffee was associated with an increase in γ-glutamyltransferase level in women (Nilssen & Forde, 1994), and a negative association of γ-glutamyltransferase level with coffee consumption for both men and women (Arnesen *et al.* 1986).

Human experimental studies by Van Deventer *et al.* (1992) showed that drinking coffee, whether caffeinated or not, sustained a decrease in oesophageal sphincter pressure. This did not occur when coffee was treated with ethyl acetate. Ground, caffeinated coffee stimulated more acid secretion than decaffeinated coffee but not more than steam-treated, caffeinated coffee. Instant coffees did not differ in acid-stimulating ability. Ground, caffeinated coffee resulted in higher blood gastrin levels than other ground coffees. Freeze-dried instant coffee also tends to lead to higher gastrin stimulation (Van Deventer *et al.* 1992). Indeed, induced changes in coffee intake seem to alter the *ad libitum* intake of several foods (Mosdol *et al.* 2002).

A recent study by Johnston *et al.* (2003) indicated that coffee (caffeine and chlorogenic acid) consumption acutely modified gastrointestinal hormone secretion. Both caffeinated and decaffeinated coffee drinks significantly reduced postprandrial glucose-dependent insulinotropic polypeptide production. Svartberg *et al.* (2003) reported that total testosterone was positively associated with coffee consumption in adult men. Indeed, according to Diokno *et al.* (1990), the consumption of at least one cup of coffee per d was significantly associated with a higher prevalence of sexual activity in elderly women and with a higher potency rate in elderly men.

The components of coffee infusions can modulate the metabolic process of gallstone formation. Leitzmann *et al.* (1999) tested this hypothesis in a study of 46 008 men (40–75 years old). They concluded that two to three cups of regular coffee per d and four cups per d had a relative risk of gallstone formation of 0·60 and 0·55, respectively. All coffee-brewing methods showed a decreased risk, whereas decaffeinated coffee did not. The consumption of caffeinated coffee was also associated with the prevention of symptomatic gallstone disease in women (Leitzmann *et al.* 2002). Ruhl & Everhart (2000) found that coffee-drinking could decrease the risk of symptomatic gallstones in women but not in men. Recommendations for the primary prevention of cholecystolithiasis include, among other things, moderate coffee consumption (Lammert & Matern, 2004).

Studies show that regular coffee-drinking may reduce the odds of having asthma symptoms (Schwartz & Weiss, 1992) and prevent clinical manifestations of bronchial asthma (Pagano *et al.* 1988). Coffee has also been suggested in the treatment of acute and chronic airflow obstruction in smokers (Santos & Lima, 1989).

Energy metabolism

Early studies from Naismith *et al.* (1970) reported that increased coffee consumption reduced plasma glucose level. In Japan, Isogawa *et al.* (2003), in a caffeine-controlled study, confirmed the inverse association of coffee-drinking with the prevalence of fasting hyperglycaemia, but no significant association of green (Japanese), black or oolong (Chinese) tea with fasting hyperglycaemia. Recent studies suggest that coffee consumption protects women from the development of diabetes (Rosengren *et al.* 2004), and Salazar-Martinez *et al.* (2004) have confirmed that long-term coffee consumption is associated with a statistically significant lower risk of type 2 diabetes.

In a Dutch study of 17 111 individuals, coffee consumption was associated with a substantially lower risk of clinical type 2 diabetes. Individuals who drank seven cups of paper-filtered coffee on a daily basis were half as likely to develop type 2 diabetes

as those individuals who drank two cups daily (van Dam & Feskens, 2002). Studies in Sweden showed that coffee consumption was related to improved insulin sensitivity in elderly, non-diabetic men (Arnlov *et al.* 2004) and a reduced risk of type 2 diabetes and impaired glucose tolerance in men and women drinking five or more cups of coffee per d (Agardh *et al.* 2004). Coffee-drinking has a graded inverse association with the risk of type 2 diabetes among middle-aged Finnish men and women (Tuomilehto *et al.* 2004). Such observations, however, were not recorded in Pima Indians (Saremi *et al.* 2003) and in unfiltered-coffee drinkers in Finland (Reunanen *et al.* 2003). Heredity and early childhood factors were taken into account in the study of twins by Carlsson *et al.* (2004). Analyses of discordant twin-pairs suggested a reduced risk of type 2 diabetes in twins with a moderate or high coffee intake compared with their low-coffee-consumption siblings. Recently, Richardson *et al.* (2004) showed that regular caffeine use (250 mg twice daily) might have the potential to reduce the risk of cardiovascular events in patients with long-standing type 1 diabetes.

Acheson *et al.* (1980) studied the effect of coffee-drinking (4 mg/kg caffeine) in obese and control subjects. The metabolic rate increased significantly in both groups, but significant increases in fat oxidation were observed only in the control group. Coffee consumption increases thermogenesis and lipid oxidation in lean women (Bracco *et al.* 1995). Increases in metabolic rate follow from the breakfast ingestion of caffeinated coffee (Zahorska-Markiewicz, 1980). Indeed, Tagliabue *et al.* (1994) also reported an increase in skin temperature and energy expenditure induced by coffee-drinking. Caffeine added to decaffeinated coffee in combination with red pepper reduced the cumulative *ad libitum* energy intake and also increased energy expenditure (Yoshioka *et al.* 2001). The combination of coffee and exercise elicited a higher lipolytic response than exercise alone (Mougios *et al.* 2003). A specific review of caffeine and sports activity by Nehlig & Debry (1994*b*) covers the methylxanthine effects at molecular and physiological levels.

Psychoactive and neurological effects

Recently, Dye & Blundell (2002) discussed the role of FF on psychological and behavioural functions, focusing on foods designed to optimise cognitive performance without compromising satiety. Their discussion centred on the main dietary components but not on coffee. The improvement of mood is among the effects attributed to caffeine in coffee-drinkers (Quinlan *et al.* 1997). Kawachi *et al.* (1996) studied registered female nurses (*n* 86 626) in relation to coffee and caffeine consumption and risk of suicide; the data suggested a strong inverse association between coffee intake and risk of suicide.

Tieges *et al.* (2004) suggested that the consumption of a few cups of coffee strengthened central information-processing, specifically the monitoring of ongoing cognitive processes for signs of erroneous outcomes. Mental workload increased catecholamine levels, and coffee-drinking seems to increase the concentrations of adrenaline and noradrenaline. Papadelis *et al.* (2003) reported an increase in urinary adrenaline with one cup of coffee and a statistically significant increase in urine noradrenaline. Indeed, caffeine added to coffee showed positive effects on the speed of encoding of new information (Smith *et al.* 2003). Gender differences in the cognitive response to coffee intake and cognitive function appear to exist. Lifetime and current exposure to caffeinated and decaffeinated coffee intake may be associated with a better cognitive performance among women, especially among those aged 80 or more years (Johnson-Kozlow *et al.* 2002). However, caffeine intake via coffee did not counteract age-related cognitive decline (Hameleers *et al.* 2000).

The effects of coffee consumption on the nervous system go beyond alertness and mood changes. There are several studies showing a positive effect of coffee consumption on neurological outcomes. The addition of coffee to anticonvulsant therapy suppressed sleep seizures beginning at night or during a siesta (Feijoo & Bilbao, 1992). Hyperactive children seem to benefit from coffee consumption (Harvey & Marsh, 1978). Studies show that coffee and caffeine intake is associated with a lower incidence of Parkinson's disease in Asian Americans (Abbott *et al.* 2003) and in the elderly populations of China (Tan *et al.* 2003), the USA (Ross *et al.* 2000; Ascherio *et al.* 2001) and Italy (Ragonese *et al.* 2003). Coffee (or caffeine from non-coffee sources), but not decaffeinated coffee, has been associated with a low relative risk of Parkinson's disease (Ascherio *et al.* 2001; Ross *et al.* 2000). However, this association is an inverse one for women using hormones (Ascherio *et al.* 2003). The meta-analysis of Hernan *et al.* (2002) concluded that there was strong epidemiological evidence that coffee-drinkers have a lower risk of Parkinson's disease. Coffee consumption was also associated with a reduced risk of Alzheimer's disease (Lindsay *et al.* 2002; Heuser, 2003).

Addictive substances and behaviour share a common mechanism in dopamine-based brain- reward physiology. Nestler & Malenka (2004) showed that addictive substances and behaviour cause the nucleus accubens to receive a flood of dopamine and dopamine-mimicking signals, thus indicating potentially more efficient ways for the socio-pharmocological treatment of addiction. Caffeine may improve the health of dopaminergic systems through its ability to increase the expression of neurotrophic factors known to promote the survival of dopaminergic neurones (Martyn & Gale, 2003). Wynne *et al.* (1987) reported that instant coffee contains substances with opiate antagonist activity, such as (iso)feruloylquinic acid lactones. Such coffee components may act on brain receptors. Thus, the use of coffee in treating alcoholism (Santos *et al*. 1991) and drug addiction (Santos *et al.* 1990) is currently under consideration (Flores *et al.* 2000). Furthermore, because caffeine affects clozapine metabolism through the enzyme cytochrome P4501A2, studies suggest that caffeinated coffee inhibits clozapine metabolism and increases serum clozapine concentrations. Although some individuals were more sensitive, the effect of drinking instant coffee on serum clozapine concentration was of minor clinical relevance in most of the patients (Raaska *et al.* 2004). Cappuccino coffee was used in the treatment of xerostomia in patients taking tricyclic antidepressants (Chodorowski 2002).

Concerns about coffee drinking

Coffee, tea and chocolate are largely consumed on a daily basis throughout the world. Coupled with this wide and long-term consumption, caffeine, the most active component found in these drinks, is also used in medications and other beverages. Therefore, there is legitimate concern about the potential adverse effects of an excessive use of caffeine in foods. In the medical literature, the main related topics reported include chemical and

metabolic tolerance, cardiovascular health and early human development. In addition, and further complicating studies of caffeine consumption, the adverse effects of caffeine are inextricably associated with coffee consumption due to a lack of specific markers of caffeinated-beverage consumption.

Rogers & Dernoncourt (1998) reviewed the adverse and beneficial effects of caffeine on mood and performance. They concluded that regular caffeine use is likely to substantially benefit drinkers, but one of the significant factors motivating caffeine consumption appears to be a 'withdrawal relief'. Indeed, experimental manipulations of caffeine concentration have shown that the lengthening of interval between cups consumed during the day was due to some factors other than caffeine level accumulation (Griffiths *et al.* 1986).

Habitual coffee-drinkers deprived of caffeinated beverages in the morning, even for short periods, can have noticeably unpleasant 'caffeine withdrawal' symptoms by midday (Lane, 1997). The subjective effects and headaches of both continuous and intermittent caffeine abstinence are transient. Hofer & Battig (1994) reported that these symptoms disappeared after a few days of abstinence and weakened over successive, separated abstinence periods. Also, it has been found that, in susceptible groups such as the elderly, the consumption of over six cups of coffee per d is among the factors associated with short sleep (Ohayon, 2004). In addition, coffee-drinking at a rate of more than six cups (642 mg caffeine) per d increases urine excretion, causing negative fluid balance (Neuhaser-Berthold *et al.* 1997).

A tolerance to the cardiovascular effects of caffeine may explain the apparent disparity between the acute effects of caffeine and the relative absence of deleterious consequences of heavy coffee-drinking (Robertson *et al.* 1981). In hypertensive subjects, the prolonged administration of caffeine was not associated with a significant elevation in blood pressure (Robertson *et al.* 1984). More recently, in a review of studies associating dietary caffeine with risk of cardiovascular health, it was concluded that the impact of dietary caffeine on population blood pressure levels is likely to be modest (James, 2004). Nevertheless, on a comprehensive basis, it was suggested that the blood pressure-elevating effects of dietary caffeine contribute appreciably to population levels of cardiovascular mortality and morbidity (James, 2004).

A relationship exists between moderate-to-high coffee consumption and increased inflammatory processes that could affect the cardiovascular system (Zampelas *et al.* 2004). Happonen *et al.*'s (2004) study showed that, after adjusting for age, smoking, exercise ischaemia, diabetes, income and serum insulin concentration, the rate ratios in non-drinkers, daily light (375 ml or less), intermediate and heavy (814 ml or more) drinkers were 0·84 (95 %CI 0·41, 1·72), 1·22 (95 %CI 0·90, 1·64), 1·00 (95 %CI) and 1·43 (95 % CI 1·06, 1·94), respectively. They concluded that heavy coffee consumption increased the short-term risk of acute myocardial infarction, or coronary death, in Finnish men.

However, associations between cardiovascular illnesses with diet vary among populations. The prevalence of hypertension in Western populations (Finland, Italy, The Netherlands, the UK and the USA) have shown that the population-attributable risk percentages vary with an inadequate intake of Ca (2–8 %), Mg (4–8 %), coffee (0–9 %) and fish fatty acids (3–16 %) (Geleijnse *et al.* 2004). Mukamal *et al.* (2004) studied the effect of coffee consumption on prognosis after acute myocardial infarction. They concluded that self-reported coffee consumption had no overall association with post-infarction mortality.

CHD is a leading cause of mortality in many parts of the industrialised world. As a result, great amounts of research into causes and preventive measures have been published. It is, however, not the objective of this structured review to explore this further. But it is important to mention that there are many stronger predictors of CHD, than coffee-drinking. These include exercise, cigarette-smoking and the consumption of vegetables, PUFA, salt, saturated fat and cholesterol, all of which are cited in the dietary guidelines of the American Heart Association (Krauss *et al.* 2000). It should be noted that coffee-drinking (or caffeine intake) is not mentioned.

Associations of coffee consumption with CHD are better understood when dietary components and lifestyle are taken into consideration. Fortes *et al.* (2000) compared associations of specific food groups to overall 5-year survival in elderly Italians. The relative risk (0·38 95 % CI) was higher when milk and yoghurt were consumed more than three times per week or once per week, than when drinking more than two cups of espresso (0·35 95% CI) per week. In general, studies suggest that there is no effect of coffee consumption on the risk of acute myocardial infarction. A recent study by Tavani *et al.* (2004) showed that the strongest risk factors for acute myocardial infarction were smoking (odds ratio 11·6 for 25 or more cigarettes per d), diabetes, hypertension, hyperlipidaemia and a family history of acute myocardial infarction. In the Italian women studied, heavy coffee-drinking had no significant association with acute myocardial infarction risk (odds ratio 1·4 for more than three cups per d).

In Narod *et al.*'s (1991) review, the studies in which coffee consumption was associated with spontaneous abortion and delayed time to conception were inconsistent, although it was suggested that the consumption of three or more cups of coffee per d had a modest effect on lowering infant birth weight. Recently, Parazzini *et al.* (2004) examined coffee-drinking before and during pregnancy, looking for associations between coffee-drinking and small-for-gestational age birth. In comparison with non-drinkers, odds ratios for small-for-gestational age birth were 1·3 (95 % CI 0·9, 1·9), 1·2 (95 % CI 0·8, 1·8), 1·2 (95 % CI 0·8, 1·8) and 0·9 (95 % CI 0·6, 1·4) for consumers of four or more cups of coffee per d before, and during the first, second and third trimesters of pregnancy, respectively. However, Lawson *et al.* (2004) showed that signals of early pregnancy included an aversion to coffee, in addition to nausea and vomiting. These resulted in decreased caffeine consumption. They concluded that a decrease in caffeine consumption could be a sign of pregnancy and that this could have acted as a confounder.

Considering the abundance of studies on coffee consumption, concerns about coffee-drinking can now be subjected to balanced consideration. Moderate coffee-drinking, defined as two to four (USA) cups per d, may no longer be met with physicians' warnings of alleged ill-effects (Anonymous, 2004).

Conclusion

Coffee-drinking is used for social engagement, leisure, enhancement of work performance and well-being. Epidemiological and experimental studies have shown positive effects of regular coffee-drinking on various aspects of health, such as psychoactive responses (alertness, mood change), neurological (infant hyperactivity, Parkinson's disease) and metabolic disorders (diabetes, gallstones), and gonad and liver function. Unlike other FF that act on a defined population with a special effect, the wide use of coffee-drinking impacts a broad demographic (from children

to the elderly), with a wide spectrum of health benefits. Many studies support the idea that coffee-drinking has health benefits. Thus, it is simple to conceptualise coffee as a FF.

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