

Article to the Special Issue

Health Potential for Functional Green Teas?

Niels Boon¹

¹ Unilever R&D Vlaardingen and the Lipton Institute of Tea, Vlaardingen; Vlaardingen, The Netherlands.
E-mail: niels.boon@unilever.com

Received for publication: January 27, 2009; Accepted for publication: March 17, 2009

Abstract. Obesity is a major health problem in the developed and developing world. Many “functional” foods and ingredients are advocated for their effects on body composition but few have consistent scientific support for their efficacy. However, an increasing amount of mechanistic and clinical evidence is building for green tea. The tea plant is naturally rich in a group of antioxidants known as catechins. Unlike black tea, green tea production involves little processing and fermentation and therefore, green tea brews are rich in catechins.

Green tea has been suggested to have a number of potential health benefits in areas such as cardiovascular disease, cancer prevention, glucose homeostasis and dental health. Although there is some promising evidence in all of these areas, more data from human intervention trials are needed.

A lot of attention has lately been focused on the beneficial effects of green tea on body composition and particularly visceral fat, which has been shown to have a strong link with different components of the metabolic syndrome such as cardiovascular disease and type 2 diabetes. Most, but not all, of the positive results come from a number Asian studies, in which overweight subjects (men and women) consumed green tea for approximately 12 weeks. Finally, green tea may also have measurable acute effects on energy metabolism and fat oxidation and in particular during physical activity, as evidenced by other studies specifically looking at these endpoints. Small cumulative effects on energy metabolism could also be responsible for the longer-term effects of green tea on body composition, and these long-term effects may also be most apparent in the context of moderate physical activity. However, more research is needed to further clarify the exact mechanisms of action and to extrapolate these findings to non-Asian populations.

Key words: Green tea, catechins, health benefits.

Introduction

Tea has been consumed for thousands of years in China and Japan and was first brought to Europe in the sixteenth century. Although now primarily considered as a refreshing beverage, tea may have originated as a medicinal herb. Tea, particularly green

tea (GT), is still associated with good health in China and Japan [1].

The potential health benefits of regular tea consumption have been increasingly investigated during the last twenty years, and a great deal has been learnt about the effects of tea and tea components in humans and experimental animals. In general, the scientific evidence supports the view that tea is in-

deed a 'healthy' beverage (for reviews see;[1;2]). Most of the earlier research focused on the role of antioxidant components of tea and their potential to reduce the risk of cardiovascular disease and cancer. There has also been interest in the possible beneficial effects of GT on glucose homeostasis and dental health. In addition, an increasing number of published reports have shown that consumption of GT may help control body weight and reduce body fat, particularly from abdominal fat depots around the abdomen. Although not conclusive, the evidence suggests that these effects of GT are due to its content of a particular group of antioxidant polyphenolic compounds, the catechins.

The chemistry of tea

To understand the particular significance of GT and its chemical difference from other types of tea it is necessary to briefly outline the processes of tea production. There are three kinds of tea: green, black and oolong, which are all derived from the leaves of the *Camellia Sinensis* plant. This is an evergreen shrub whose leaves contain high levels of catechins. These molecules are flavonoids that belong to a family of compounds known as polyphenols, and a mixture of catechins are found in fresh harvested tea leaves (figure 1). If tea leaves are not heat-treated to inactivate endogenous enzymes, the catechins are rapidly converted by oxidation to a complex mixture of other derivatives known as thearubigins and theaflavins. These components are responsible for the characteristic color of oolong and black tea. GT is produced by heat-treating leaves soon after harvest, thereby preserving the catechins from oxidation, whereas oolong and black teas are produced by allowing oxidation to proceed before heat treatment and drying. In black tea, the process of oxidation essentially goes to completion, whereas in oolong tea oxidation is stopped at an intermediate time point, resulting in a mixture of catechins, thearubigins and theaflavins.

The amount of catechins in a cup of GT is highly variable, depending on the type of tea, the ratio of dry tea to water and infusion time. An average serving of 250 ml of GT contains 50 to 100 mg of catechins. In addition, GT contains a variable amount of caffeine and a complex mix of other water soluble components [3].

General health benefits of green tea

GT has been suggested to have a number of potential health benefits in areas such as cardiovascular disease, cancer prevention, glucose homeostasis and dental health.

Many epidemiological studies have investigated the association between GT consumption and cardiovascular events as well as risk markers for cardiovascular disease. Most of these studies have been conducted among Asian populations and suggest a cardioprotective effect of GT consumption [4–6]. The mechanisms for these observations, however, remain uncertain. Several studies, mainly using *in vitro* and animal models, have looked into potential mechanisms including anti-hypertensive effects, prevention of LDL oxidation, anti-inflammatory/anti-thrombotic/antiproliferative effects, and lipid lowering effects. Although the results from animal and *in vitro* experiments were generally have been promising, the results from intervention trials are less consistent (see [4] for a review).

There are more consistent data from the area of endothelial function. Normal endothelial function regulates vasomotor tone, platelet activity, leukocyte adhesion and vascular smooth muscle cell proliferation via a release of several paracrine factors including nitric oxide (NO). Experimental studies have demonstrated that flavonoids can enhance the synthesis and release of endothelial-derived NO. The assessment of flow-mediated dilation of the brachial artery is currently widely used as a non-invasive method of determining changes in NO-regulated vascular tone and thus endothelial function. There is good evidence from human intervention trials that GT consumption can improve endothelial function. This has been observed in 3 human trials in healthy subjects after acute and chronic tea consumption [7–9]. A recent study by Widlansky et al [10] also shows that acute supplementation with epigallocatechin gallate (EGCG), the most abundant catechin in GT, improved endothelial function in humans with coronary artery disease. Part of the effects of GT may also be related to a flavanoid-mediated reduction in incorporation of cholesterol into mixed micelles [11].

There is also some observational evidence for beneficial effects of GT consumption with respect to cardiovascular disease. However, results of clinical trials on surrogate markers of cardiovascular disease are far from definitive. The only convincing evidence so far has been for the endothelial function improvement after GT consumption.

The role of GT in cancer prevention has been hypothesized from a large number of cell culture and animal models, the majority of which reported beneficial effects of GT and catechins [12]. GT has been shown to inhibit tumorigenesis in many animal models, including those for cancer of the skin, lung, oral cavity, oesophagus, stomach, small intestine, colon, liver, pancreas, bladder, and prostate [1].

A large number of epidemiological studies have also investigated the association between GT consumption and different types of cancer. The results of these studies are inconsistent and do not provide support for the idea that GT is protective against cancer [11–13]. Thus, the evidence so far is too contradictory to suggest a benefit of GT consumption on cancer prevention, despite promising work from experimental studies.

Epidemiological studies have suggested that GT consumption is associated with a decreased risk of diabetes [13–15] and a reduced level of fasting blood glucose in non-obese people [16]. Animal studies have also shown evidence for an improvement in glucose tolerance and insulin sensitivity with GT extract consumption [1;16]. Results from the few clinical studies conducted so far on this topic are however mixed [17–23] and further human studies are needed before drawing firmer conclusions on the effects of GT and its components on blood glucose control.

Finally, epidemiological studies reported that populations who drink tea on a regular basis have a reduced number of carious teeth [24;25]. In a limited body of human trials, tea (oolong and green) and catechins (without added sugar) have also been shown to inhibit plaque deposition [26], reduce plaque and gingival index [27;28] and inhibit acid production in dental plaque bacteria [29].

Tea is a rich natural source of fluoride in the diet [30], providing for example 85 % of the total fluoride intake in the UK [31]. While fluoride may have a beneficial effect on dental health [32], it is suggested that tea polyphenols, including GT flavonoids, rather than fluoride are responsible for the noted effects on oral health [33]. Several mechanisms have been proposed for the observed anticariogenic properties of tea and its polyphenols, including inhibitory effect on bacterial growth and bacterial viability, inhibition of glucosyl transferase, thus limiting the biosynthesis of sticky glucan, and inhibition of salivary α -amylase activities and the consequent inhibition of starch hydrolysis to sugars [33]. Moreover, tea components have been shown to increase acid resistance of tooth enamel [34].

Larger well-controlled studies are required to confirm the promising benefits of GT on oral health in humans.

Green tea, body weight and body fat

One of the anecdotal health benefits traditionally associated with drinking GT in China is reduction of body fat. However, scientific scrutiny of this claim has only begun relatively recently. An association between tea consumption, particularly GT, with a lower percentage body fat and a smaller waist circumference was found in a Taiwanese population [35] and furthermore a significantly smaller increase in BMI was observed in women with the highest intake of catechins in Dutch women aged 55–69y [36]. Much evidence shows that accumulation of adipose tissue in the abdominal region is a significant risk factor for development of ‘metabolic syndrome’ and associated morbidities.

Several placebo controlled intervention studies, in which subjects consumed one or two daily servings of GT or a catechin-rich GT extract (550–900 mg), for periods of 12–13 weeks, have reported beneficial effects on and body weight, body fat and abdominal fat in particular. The subjects were usually overweight, and instructed to follow their habitual patterns of food intake and exercise, so effects were measured against the background of habitual levels and variation in energy intake and energy expenditure. These experimental designs and the amounts, frequencies and beverage (or pill) forms of catechins consumed have typically reflected a realistic consumer situation. The majority of these studies were performed in Asian populations, but there is also evidence from Caucasian populations.

There is a strong body of evidence in particular from Japanese trials in particular [19;37–41]. These trials were all rather similar in design (i.e. they compared the effects of a placebo to 1–2 daily servings of a GT beverage containing 550–900 mg of catechins, the subjects in these experiments were overweight or obese, and the intervention period was around 12 weeks). The effects of GT supplementation on visceral adipose tissue and abdominal obesity in these trials have been particularly consistent. In addition to this, in a trial in 182 healthy, overweight Chinese subjects, consumption of two servings of an extra high-catechin GT (containing in total 886 mg of catechins per day) for 90 days led to improvements in body composition and a reduction in abdominal fatness [42].

Finally, although studies with a similar design observed significant improvements in body composition related parameters in different populations (i.e. obese Thai adults and Japanese children with higher levels of obesity [43;44]), Hsu et al. [45] did not observe any effects of supplementation with 492 mg of catechins per day in obese Taiwanese women. In contrast to these other studies, the subjects in the latter study were all women, and the average BMI ($\sim 31 \text{ kg/m}^2$ at baseline) in this study was also higher than in the other studies, which may have caused the difference in results.

So far, only five studies have been performed in Caucasian subjects, and the results from these studies are less consistent than those in Asian populations. Kovacs et al. [46] found no overall effect of a GT-caffeine mixture (104 mg/d caffeine, 573 mg/d catechins of which 323 mg/d EGCG) on weight regain following a period of weight loss on a very low energy diet. However, when the habitual caffeine intake of the subjects was taken into account in a separate analysis of the same data, Westerterp-Plantenga et al. [47] observed that subjects with a low habitual caffeine intake ($< 300 \text{ mg/day}$) who received the GT extract continued to lose body weight, waist circumference and body fat, compared with the low habitual caffeine group receiving placebo. In the high habitual caffeine consumers ($> 300 \text{ mg/day}$), no effects of the GT-caffeine mixture were observed. In a separate study [36] no effects of green tea supplementation on weight or fat loss were observed in subjects that followed an energy-restricted diet and whose caffeine intake was standardized at 300 mg per day. Thus, the green tea-caffeine mixtures may be more likely to improve weight maintenance in subjects who consume low amounts of caffeine and/or green tea effects may be limited to specific conditions, e.g. during weight loss. In addition to this, in a non-placebo controlled trial, Chantre and Lairon [48] observed that ingestion of GT (catechins: 375 mg/d) for 12 weeks led to a 4.6 % decrease in body weight and a 4.5 % decrease in waist circumference compared to baseline.

Recent studies have begun to explore whether the benefits of GT might be more readily apparent in active individuals. Hill et al. [49] observed no added benefit of the ingestion of 300 mg EGCG on top of a 12-week exercise program in overweight to obese Caucasian women, with regard to various measures of body composition. However, Maki et al. [50] more recently reported that consumption of 625 mg of GT catechins per day for 12 weeks enhanced the effects of an exercise intervention (180 min/week at a moderate

intensity) in an abdominally overweight Western population. Total abdominal fat area (7.6 % vs. -0.6 %, $p = 0.018$) and subcutaneous abdominal fat area (-6.1 % vs. 0.5 %, $p = 0.01$) were significantly reduced in the catechin group, compared with the placebo group (who also followed the exercise program but only received a control drink), at week 12.

There are several potential mechanisms of action for an effect of GT catechins on body composition. First, it has been demonstrated that short-term supplementation with GT [51;52] or catechins alone [23] at rest [51;52] and in combination with light to moderate physical activity [23] can increase fat oxidation.

In line with these observations, there is evidence for a chronic stimulating effect of high-catechin beverages on particular aspects of energy metabolism. For example, Harada et al. [53] reported both acute and chronic effects on postprandial metabolism and energy expenditure during exercise after 12-week consumption of a GT beverage with 592 mg of catechins and around 90 mg caffeine. Lastly, Ota et al [54] observed stimulating effects of catechin supplementation on fat metabolism during exercise, after daily consumption of a beverage containing 570 mg of catechins and 40 mg of caffeine for eight weeks.

Caffeine has been shown to inhibit the intracellular activity of phosphodiesterase (PDE), which decreases the breakdown of cAMP (1) and could also act on the sympathetic nervous system through an antagonism of the negative modulatory effect of adenosine on noradrenalin release [55], thus causing increased sympathetic nervous system activity. Interestingly, physical activity also causes an increase in sympathetic nervous system activity to respond adequately to the altered energy requirements by stimulating fat and carbohydrate oxidation [56].

Catechins in GT could act synergistically with either or both of these mechanisms because they may inhibit the activity of catechol-o-methyltransferase (COMT). This is an enzyme that catalyzes the breakdown of noradrenalin in the synapses in the nervous system, which could increase the wash-out time of noradrenalin [57]. An increased wash-out time of noradrenaline could cause a prolonged stimulation of the sympathetic nervous system, thus causing increased energy expenditure. Furthermore, green tea supplementation has also been shown to increase mRNA expression of enzymes related to β -oxidation in muscle and liver tissue in animal studies [34–37].

In support of this hypothesis, GT intervention studies in which a small to moderate amount of physical activity was incorporated into the design,

have consistently shown a decrease in visceral fat and/or other measures of body composition [50;58;59].

There are also some other potential mechanisms of action that could explain the effects of GT on body composition. *In vitro* studies have shown that GT catechins, and in particular EGCG can inhibit adipocyte proliferation and differentiation [60;61]. GT could also potentially slow or reduce carbohydrate and fat absorption by inhibition of various digestive enzymes. Although most of the evidence for decreased nutrient absorption comes from animal studies [62–64], there is also evidence from human studies [65]. Furthermore, Juhel et al. [66] showed that a GT extract containing 25 % catechins and rich in EGCG inhibits gastric lipase and pancreatic lipase *in vitro*, probably via altered lipid emulsification. Overall, the literature suggests several plausible mechanisms by which GT may induce modest but potentially persistent influences on energy balance and body composition. These may each be of a relatively small absolute magnitude in the short-term, but nevertheless relevant on the long-term. Recent evidence also indicates that these modest effects may be more pronounced in active individuals.

Conclusion

GT has been linked to a number of health benefits (for example cardiovascular health, cancer prevention, diabetes and improvements in oral health) in general and treatment of overweight and obesity in particular. The medical problems associated with obesity are an increasing challenge in developed and developing societies. The evidence reviewed here suggests that regular consumption of GT may be particularly beneficial in helping to reduce the risk excess fat accumulation, especially in the abdominal region. There is also some emerging evidence from Western and Asian populations indicating a possible synergy between GT and physical activity with respect to these beneficial effects on body composition. There are indications that this synergy could be mediated by effects on energy metabolism. Further studies are required to confirm this hypothesis. These studies need to be carried with more diverse populations, followed-up for longer periods of time, and plausible mechanism(s) of action need to be established. Nevertheless, it is an attractive possibility that a simple and enjoyable dietary addition – the regular consumption of GT, which is also naturally calorie free when consumed without sugar or milk – may have a beneficial effect on some of the most intractable of public health problems.

Acknowledgements

The author wishes to acknowledge John Fletcher, Mary Gilsean, Eva Kovacs, Dave Mela, Solene Naveos, Jane Rycroft and Paul Quinlan for their contribution to this article.

References

1. Cabrera, C., Artacho, R. and Gimenez, R. (2006) Beneficial effects of green tea—a review. *J Am Coll Nutr.* 25, 79–99.
2. Gardner, E.J., Ruxton, C.H. and Leeds, A.R. (2007) Black tea—helpful or harmful? A review of the evidence. *Eur J Clin Nutr.* 61, 3–18.
3. Astill, C., Birch, M.R., Dacombe, C., Humphrey, P.G. and Martin, P.T. (2001) Factors affecting the caffeine and polyphenol contents of black and green tea infusions. *J Agric Food Chem.* 49, 5340–5347.
4. Stangl, V., Lorenz, M. and Stangl, K. (2006) The role of tea and tea flavonoids in cardiovascular health. *Mol Nutr Food Res.* 50, 218–228.
5. Khan, N., Afaq, F., Saleem, M., Ahmad, N. and Mukhtar, H. (2006) Targeting multiple signaling pathways by green tea polyphenol (-)-epigallocatechin-3-gallate. *Cancer Res.* 66, 2500–2505.
6. Wolfram S. Effects of green tea and EGCG on cardiovascular and metabolic health. *J Am Coll Nutr.* 2007; 26: 373S-388S.
7. Alexopoulos, N., Vlachopoulos, C., Aznaouridis, K. et al. (2008) The acute effect of green tea consumption on endothelial function in healthy individuals. *Eur J Cardiovasc Prev Rehabil.* 15, 300–305.
8. Jochmann, N., Lorenz, M., Krosigk, A. et al. (2008) The efficacy of black tea in ameliorating endothelial function is equivalent to that of green tea. *Br J Nutr.* 99, 863–868.
9. Kim, W., Jeong, M.H., Cho, S.H. et al. (2006) Effect of green tea consumption on endothelial function and circulating endothelial progenitor cells in chronic smokers. *Circ J.* 70, 1052–1057.
10. Widlansky, M.E., Hamburg, N.M., Anter, E. et al. (2007) Acute EGCG Supplementation Reverses Endothelial Dysfunction in Patients with Coronary Artery Disease. *J Am Coll Nutr.* 26, 95–102.
11. Vermeer, M.A., Mulder, T.P. and Molhuizen, H.O. (2008) Theaflavins from black tea, especially theaflavin-3-gallate, reduce the incorporation of cholesterol into mixed micelles. *J Agric Food Chem.* 56, 12031–1206.
12. Yang, C.S., Lambert, J.D., Ju, J., Lu, G. and Sang, S. (2007) Tea and cancer prevention: molecular mechanisms and human relevance. *Toxicol Appl Pharmacol.* 224, 265–273.
13. US FDA. Letter responding to health claim petition dated January 27, 2004: Green tea and reduced risk of cancer health claim. 2004. Ref Type: Internet Communication
14. Song, Y., Manson, J.E., Buring, J.E., Sesso, H.D. and Liu, S. (2005) Associations of dietary flavonoids with risk of type 2 diabetes, and markers of insulin resistance

- and systemic inflammation in women: a prospective study and cross-sectional analysis. *J Am Coll Nutr.* 24, 376–384.
15. Iso, H., Date, C., Wakai, K., Fukui, M. and Tamakoshi, A. (2006) The relationship between green tea and total caffeine intake and risk for self-reported type 2 diabetes among Japanese adults. *Ann Intern Med.* 144, 554–562.
 16. Polychronopoulos, E., Zeimbekis, A., Kastorini, C.M. et al. (2008) Effects of black and green tea consumption on blood glucose levels in non-obese elderly men and women from Mediterranean Islands (MEDIS epidemiological study). *Eur J Nutr.* 47, 10–16.
 17. Fukino, Y., Shimbo, M., Aoki, N., Okubo, T. and Iso, H. (2005) Randomized controlled trial for an effect of green tea consumption on insulin resistance and inflammation markers. *J Nutr Sci Vitaminol (Tokyo).* 51, 335–342.
 18. Fukino, Y., Ikeda, A., Maruyama, K., Aoki, N., Okubo, T. and Iso, H. (2008) Randomized controlled trial for an effect of green tea-extract powder supplementation on glucose abnormalities. *Eur J Clin Nutr.* 62, 953–960.
 19. Hase, T., Komine, Y., Meguro, S. et al. (2001) Anti-obesity effects of tea catechins in humans. *J Oleo Sci.* 50, 599–605.
 20. Mackenzie, T., Leary, L. and Brooks, W.B. (2007) The effect of an extract of green and black tea on glucose control in adults with type 2 diabetes mellitus: double-blind randomized study. *Metabolism.* 56, 1340–1344.
 21. Ryu, O.H., Lee, J., Lee, K.W. et al. (2006) Effects of green tea consumption on inflammation, insulin resistance and pulse wave velocity in type 2 diabetes patients. *Diabetes Res Clin Pract.* 71, 356–358.
 22. Tsuneki, H., Ishizuka, M., Terasawa, M., Wu, J.B., Sasaoka, T. and Kimura, I. (2004) Effect of green tea on blood glucose levels and serum proteomic patterns in diabetic (db/db) mice and on glucose metabolism in healthy humans. *BMC Pharmacol.* 4, 18.
 23. Venables, M.C., Hulston, C.J., Cox, H.R. and Jeukendrup, A.E. (2008) Green tea extract ingestion, fat oxidation, and glucose tolerance in healthy humans. *Am J Clin Nutr.* 87, 778–784.
 24. Hamilton-Miller, J.M. (2001) Anti-cariogenic properties of tea (*Camellia sinensis*). *J Med Microbiol.* 50, 299–302.
 25. Jones, C., Woods, K., Whittle, G., Worthington, H. and Taylor, G. (1999) Sugar, drinks, deprivation and dental caries in 14-year-old children in the north west of England in 1995. *Community Dent Health.* 16, 68–71.
 26. Ooshima, T., Minami, T., Aono, W., Tamura, Y. and Hamada, S. (1994) Reduction of dental plaque deposition in humans by oolong tea extract. *Caries Res.* 28, 146–149.
 27. Liu, T., Chi, Y. (2000) [Experimental study on polyphenol anti-plaque effect in human]. *Zhonghua Kou Qiang Yi Xue Za Zhi.* 35, 383–384.
 28. You, S.Q. (1993) [Study on feasibility of Chinese green tea polyphenols (CTP) for preventing dental caries]. *Zhonghua Kou Qiang Yi Xue Za Zhi.* 28, 197–9, 254.
 29. Hirasawa, M., Takada, K. and Otake, S. (2006) Inhibition of acid production in dental plaque bacteria by green tea catechins. *Caries Res.* 40, 265–270.
 30. Wei, S.H., Hattab, F.N., Mellberg, J.R. (1989) Concentration of fluoride and selected other elements in teas. *Nutrition.* 5, 237–240.
 31. Food Standard Agency (2001). Committee on Toxicity of Chemicals in Food, Consumer. 2001. Ref Type: Report
 32. NHS CRD (2000). A systematic Review of Public Water Fluoridation (CRD Report No 18). NHS Centre for Review and Dissemination, University of York: York, UK. 2000. Ref Type: Report
 33. Wu, C.D., Wei, G.X. (2002) Tea as a functional food for oral health. *Nutrition.* 18, 443–444.
 34. Yu, H., Oho, T. and Xu, L.X. (1995) Effects of several tea components on acid resistance of human tooth enamel. *J Dent.* 23, 101–105.
 35. Wu, C.H., Lu, F.H., Chang, C.S., Chang, T.C., Wang, R.H. and Chang, C.J. (2003) Relationship among habitual tea consumption, percent body fat, and body fat distribution. *Obes Res.* 11, 1088–1095.
 36. Hughes, L.A., Arts, I.C., Ambergen, T. et al. (2008) Higher dietary flavone, flavonol, and catechin intakes are associated with less of an increase in BMI over time in women: a longitudinal analysis from the Netherlands Cohort Study. *Am J Clin Nutr.* 88, 1341–1352.
 37. Kajimoto, O., Kajimoto, Y., Yabune, M. and Nakamura, T. (2006) Tea catechins with a galloyl moiety reduce body weight and fat. *Journal of Health Science.* 2005;51(2): 161–71.
 38. Nagao, T., Meguro, S., Soga, S., Otsuka, A. and Tomonobu, K. (2001) Tea catechins suppress accumulation of body fat in humans. *J Oleo Sci.* 50, 717–728.
 39. Nagao, T., Komine, Y., Soga, S. et al. (2005) Ingestion of a tea rich in catechins leads to a reduction in body fat and malondialdehyde-modified LDL in men. *Am J Clin Nutr.* 81, 122–129.
 40. Nagao, T., Hase, T. and Tokimitsu, I. (2007) A green tea extract high in catechins reduces body fat and cardiovascular risks in humans. *Obesity (Silver Spring).* 15, 1473–1483.
 41. Tsuchida, T., Itakura, H. and Nakamura, H. (2002) Reduction of body fat in humans by long-term ingestion of catechins. *Progress in Medicine.* 22, 2189–2203.
 42. Wang, M., Wen, Y., Du, Y., Yan X., Wei Guo, H., Rycroft, J., Boon, N., Kovacs, E., and Mela, D. (2007) The effects of 90 days consumption of a high-catechin green tea beverage on body composition. The 4th Asia-Oceania conference on obesity. 115, Ref Type: Conference Proceeding
 43. Matsuyama, T., Tanaka, Y., Kamimaki, I., Nagao, T. and Tokimitsu, I. (2008) Catechin safely improved higher levels of fatness, blood pressure, and cholesterol in children. *Obesity (Silver Spring).* 16, 1338–1348.
 44. Auvichayapat, P., Prapochanung, M., Tunkamnerdthai, O. et al. (2008) Effectiveness of green tea on weight reduction in obese Thais: A randomized, controlled trial. *Physiol Behav.* 93, 486–491.
 45. Hsu, C.H., Tsai, T.H., Kao, Y.H., Hwang, K.C., Tseng, T.Y. and Chou, P. (2008) Effect of green tea extract on obese women: A randomized, double-blind, placebo-controlled clinical trial. *Clin Nutr.* 2008;27(3): 363–70.
 46. Kovacs, E.M., Lejeune, M.P., Nijs, I. and Westerterp-Plantenga, M.S. (2004) Effects of green tea on weight maintenance after body-weight loss. *Br J Nutr.* 91, 431–437.
 47. Westerterp-Plantenga, M.S., Lejeune, M.P. and Kovacs, E.M. (2005) Body weight loss and weight maintenance

- in relation to habitual caffeine intake and green tea supplementation. *Obes Res.* 13, 1195–1204.
48. Chantre, P. and Lairon, D. (2002) Recent findings of green tea extract AR25 (Exolise) and its activity for the treatment of obesity. *Phytomedicine.* 9, 3–8.
 49. Hill, A.M., Coates, A.M., Buckley, J.DI, Ross, R., Thielecke, F. and Howe, P.R. (2007) Can EGCG reduce abdominal fat in obese subjects? *J Am Coll Nutr.* 26, 396S–402S.
 50. Maki, K.C., Reeves, M.S., Farmer, M. et al. (2008) Green Tea Catechin Consumption Enhances Exercise-Induced Abdominal Fat Loss in Overweight and Obese Adults. *J Nutr.* 2009;139(2): 264–70.
 51. Dulloo, A.G., Duret, C., Rohrer, D. et al. (1999) Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans. *Am J Clin Nutr.* 70, 1040–1045.
 52. Rudelle, S., Ferruzzi, M.G., Cristiani, I. et al. (2007) Effect of a thermogenic beverage on 24-hour energy metabolism in humans. *Obesity (Silver Spring).* 15, 349–355.
 53. Harada, U., Chikama, A., Saito, S. and Takase, H. (2004) Effects of the long-term ingestion of tea catechins on energy expenditure and dietary fat oxidation in healthy subjects. *Journal of Health Science.* 51, 248–252.
 54. Ota. (2005) Fat utilization in sedentary and exercise after 8wk catechin treatment. *Journal of Health Science.* 51, 233–236.
 55. Dulloo, A.G., Seydoux, J. and Girardier, L. (1992) Potentiation of the thermogenic antiobesity effects of ephedrine by dietary methylxanthines: adenosine antagonism or phosphodiesterase inhibition? *Metabolism.* 41, 1233–1241.
 56. Saris, W.H. (1995) Effects of energy restriction and exercise on the sympathetic nervous system. *Int J Obes Relat Metab Disord.* 19 Suppl 7, S17–S23.
 57. Dulloo, A.G., Seydoux, J., Girardier, L., Chantre, P. and Vandermader, J. (2000) Green tea and thermogenesis: interactions between catechin-polyphenols, caffeine and sympathetic activity. *Int J Obes Relat Metab Disord.* 24, 252–258.
 58. Takashima, S. (2004) The long term intake of catechins improves lipid catabolism during exercise. *Progress in Medicine.* 24, 3371–3379.
 59. Kataoka, K. (2004) Body fat reduction by the long term intake of catechins and the effects of physical activity. *Progress in Medicine.* 24, 3358–3370.
 60. Kao, Y.H., Chang, H.H., Lee, M.J. and Chen, C.L. (2006) Tea, obesity, and diabetes. *Mol Nutr Food Res.* 50, 188–210.
 61. Moon, H.S., Lee, H.G., Choi, Y.J., Kim, T.G. and Cho, C.S. (2007) Proposed mechanisms of (-)-epigallocatechin-3-gallate for anti-obesity. *Chem Biol Interact.* 167, 85–98.
 62. Klaus, S., Pultz, S., Thone-Reineke, C. and Wolfram, S. (2005) Epigallocatechin gallate attenuates diet-induced obesity in mice by decreasing energy absorption and increasing fat oxidation. *Int J Obes (Lond).* 29, 615–623.
 63. Ikeda, I., Tsuda, K., Suzuki, Y. et al. (2005) Tea catechins with a galloyl moiety suppress postprandial hypertriglycerolemia by delaying lymphatic transport of dietary fat in rats. *J Nutr.* 135, 155–159.
 64. Raederstorff, D.G., Schlachter, M.F., Elste, V. and Weber, P. (2003) Effect of EGCG on lipid absorption and plasma lipid levels in rats. *J Nutr Biochem.* 14, 326–332.
 65. Hsu, T.F., Kusumoto, A., Abe, K. et al. (2006) Polyphenol-enriched oolong tea increases fecal lipid excretion. *Eur J Clin Nutr.* 60, 1330–1336.
 66. Juhel, C., Armand, M., Pafumi, Y., Rosier, C., Vandermader, J. and Lairon, D. (2000) Green tea extract (AR25) inhibits lipolysis of triglycerides in gastric and duodenal medium in vitro. *J Nutr Biochem.* 11, 45–51.

Niels Boon

Unilever R&D Vlaardingen
Vlaardingen, The Netherlands
E-mail: niels.boon@unilever.com

Appendix

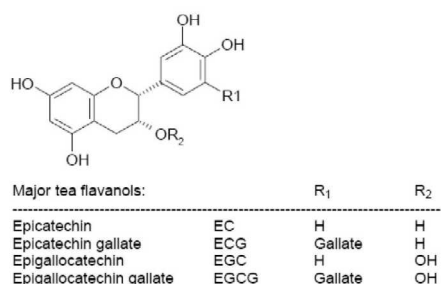


Figure 1: The basic catechin structures