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# Effects of tea catechins and exercise training on body composition parameters

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## Abstract

The impact of phytochemicals, as tea catechins, on body composition measures has become a relevant topic as ongoing epidemiological evidence suggests a potential role in weight loss.

Despite catechins have been shown to modulate energy metabolism, the clinical effects of tea consumption still remain controversial, with most studies showing only modest decreases of body weight.

Given the role played by physical exercise in weight management, it is important to determine whether the combination of catechins and exercise provides an additive effect on energy expenditure, fat oxidation, and body composition measures. Some studies failed to demonstrate an ability of catechins in improving outcomes over those obtained with exercise alone. In contrary, other studies have reported further improvements in the exercise-induced changes of body composition following association of catechins and training.

This review evaluates the current scientific literature on the interplay between catechins and exercise in overweight and obese populations.



Key-words. Catechins, green tea, exercise, fat, weight loss.

## Introduction

Energy balance is the difference between energy intake and expenditure (EE).

Resting metabolic rate (RMR), thermic effect of feeding and energy expended through physical activity represent the three main components of EE.[1]

Excessive dietary energy intake in relation to EE is the leading cause of weight gain.

Although fasting and very low calorie diets are initially associated with a reduction in fat mass, they lead to a decrease in RMR because of the concomitant decline in free-fat mass (FFM), which represents a key determinant of RMR. This mechanism explains why the long-term effectiveness of weight-loss programs is difficult to achieve. [1]

Fat loss, while preserving FFM and RMR, is possible associating diet and physical exercise.[2]

Exercise acutely increases fat oxidation and regular training enhances the ability to oxidize fats and improves glucose metabolism, increasing insulin sensitivity.[3] Carbohydrates (CHOs) and fats are the principal sources of fuel used by working muscles. The type of substrate and the rate at which it is used during exercise are influenced by many variables, such as exercise intensity and duration, diet, and training status, with a role played also by individual variation, sex, hormonal influences, diet, and nutritional status.[3-8]

During physical exercise the sources of fat are mainly represented by lipid droplets in adipocytes, circulating lipoproteins and intramuscular triglycerides (IMTGs), whose contribution to energy production is greater in well-trained athletes compared with untrained subjects.[7]

Exercise intensity represents one of the most important regulators of substrate oxidation.[3,9] During low-intensity exercise the oxidation of plasma free fatty acids (FFAs) released from adipose tissue participates considerably in energy production, while the contribution of IMTGs and lipoprotein-derived TG is little. During moderate-intensity exercise fat reaches the highest rate of oxidation, with a greater contribution of IMTGs, which represent about half of all fat oxidized.[6] When exercise intensity further increases, there is a decrease in fat oxidation; the decline of plasma FFA, IMTG, and lipoprotein-derived TG use is associated with a shift in substrate utilization towards CHO oxidation, so that muscle glycogen becomes the main fuel source.[3-5,9]

Maximal rates of fat oxidation have been observed at intensities between 59% and 64% of maximal oxygen consumption ($VO_2$max) in trained subjects and between 47% and 52% $VO_2$max in the general population.[10] In moderately trained athletes it was calculated that the contribution of fat oxidation to EE became negligible above 89 +/- 3% $VO_2$max.[4] Compared with untrained subjects who exercised at the same absolute intensity, endurance trained individuals showed higher fat oxidation during low- and moderate-intensity exercise.[8] Exercise training is not only able to elicit high rates of fat oxidation, but also to significantly increase insulin sensitivity.[11]

Considering the effects of acute and chronic exercise on metabolism, behavioral interventions based on diet and training represent the key elements for weight management and for reducing the risk of metabolic and cardiovascular comorbidities in overweight and obese populations.[12] Modest weight loss, between 5 and 10% of initial body weight, may produce significant health benefits.[13]

Body mass index (BMI) and physical activity levels are characterized by an inverse association,[14] with a potential dose-response relationship.[15] The American College of Sport Medicine recommends that adults participate in at least 150 minutes $\cdot$ week$^{-1}$ of moderate-intensity PA to prevent significant weight gain and to produce favorable changes in chronic disease risk factors.[15] Moderate-intensity PA between 150 and 200 minutes $\cdot$ week$^{-1}$ is able to provide only modest weight-loss (about 2-3 kg). Doses of PA between 250 and 300 minutes $\cdot$ week$^{-1}$ of moderate-intensity PA are necessary to obtain both greater weight loss and enhanced prevention of weight regain.[15] Aerobic and resistance training are respectively recommended to reduce fat mass and increase lean mass.[12,15]

Several dietary supplements have been proposed as additional strategies to training, in order to increase EE and to counteract the decrease in RMR present during weight loss. In particular, catechins, contained in green tea (GT), have been widely studied.

Catechins are antioxidant molecules belonging to the chemical family of flavonoids, polyphenolic compounds widely present in the plant kingdom.[16,17]

Flavonoids are subdivided in the following subclasses: flavan-3-ols (also referred to as flavanols), flavonols (i.e. quercetin), anthocyanins, flavanones, flavones, and isoflavones. Flavanols include catechin, epicatechin-3-gallate, epigallocatechin, epigallocatechin-3-gallate (EGCG), proanthocyanidins, theaflavins, and thearubigins.[17,18] The pharmacokinetics and extent of absorption differ markedly among catechins.[18] In a study, which compared different molecules, epigallocatechin showed quick rise and short elimination half-life (1.7 hours). Epicatechin-3-gallate was intermediate in rise, but had the slowest decline, with an elimination half-life of 6.9 hours. EGCG was the slowest in rise, but intermediate in decline, with an elimination half-life of 3.9 hours. At 24 hours, epicatechin-3-gallate was still elevated, differently from the other two molecules.[19]

Regarding oral bioavailability, food intake is able to interfere with the systemic absorption of catechins.[20] Pure EGCG, taken in capsule form without food, has been associated with higher plasma levels compared to EGCG mixed with food. [20]

EGCG appears in plasma in large proportion in a free form, whereas the other catechins are highly conjugated with glucuronic acid and/or sulfate groups.[18] The gut microbiota-derived metabolites, valerolactones, appear later than catechins in plasma and have long half-lives.[18]

The thermogenic properties of GT have long been attributed to its ability to inhibit catechol-*O*-methyltransferase, enzyme that catalyzes the O-methylation, and thereby the degradation, of catecholamine neurotransmitters. Their reduced degradation and more prolonged life, and the adrenergic stimulation of lipolysis, have been proposed as mechanisms able to explain the enhancement of fat metabolism observed, after supplementation with GT, in some studies.[21-22] Nevertheless, no significant changes in plasma catecholamine concentrations two hours after acute intake of GT extract (GTE) or following chronic supplementation for 7 days have been demonstrated either at rest or during exercise.[23-24]

Recently the adrenergic stimulation has been questioned as main mechanism able to influence substrate utilization, and other mechanisms of action, such as reduced lipid absorption and inhibition of adipocyte proliferation and differentiation, have been postulated, without, however, reaching univocal findings.[25-27]

Epidemiological and interventional studies have found an inverse relationship between GT consumption and body weight, showing anti-inflammatory properties of GT with beneficial effects on lipid and glucose metabolism.[28-32]

Significant improvements in body composition measures, i.e. body weight, body fat percentage (BFP), and visceral fat area have been reported following GT supplementation associated with a supervised exercise training program in previously sedentary men and women. These benefits were evident in all participants who underwent physical training both with and without GT supplementation, but the extent in the exercise-induced changes of body composition parameters were higher following association of training with GT.[33-34] In contrast, other studies failed to demonstrate an ability of GT in improving outcomes over those obtained with exercise alone.[22,35]

Considering the conflicting findings, aim of the present review was to evaluate whether GT supplementation adds further benefits compared to physical exercise training alone, analyzing its effects on fat metabolism, EE, and body composition measures.

**Search strategy and inclusion criteria**

A literature search was conducted using PUBMED and Cochrane Library. Search terms were grouped as follows: population (i.e. humans, overweight, obese), compounds investigated (i.e. catechins, green tea, EGCG), terms related to exercise (i.e. intensity, endurance, resistance, training), and terms related to anthropometric and body composition parameters (i.e. waist circumference, fat mass, BFP). Titles and abstracts identified through the literature searches were screened. Studies included were limited to human participants and were written in English language. No limit was set for publication date.

**Effect of GT on EE, fat oxidation, and weight-loss**

Although claimed as a substance able to enhance thermogenesis, mixed findings on the effects of GT on fat oxidation[21-23,36-39] and EE[36,40-43] are reported. Many factors have to be considered, in particular the potentially confounding effect due to the concomitant presence of caffeine. In fact, along with catechins, GT also contains caffeine, which is able to enhance fat oxidation and to increase energy metabolism.[44]

Short-term (≤2 days) supplementations with caffeinated GT or decaffeinated products containing pure EGCG have been associated with enhanced fat oxidation at rest, during and after exercise.[21-22,36-37]

A study on obese men showed that pure EGCG in capsules (300 mg/day for two days) was effective in achieving significant enhancements in fat oxidation at rest, as assessed by lower respiratory quotient. However, EGCG was not able to exert significant changes in EE, compared to placebo.[36]

Enhanced exercise-induced fat oxidation has been shown in women, who ingested 3 grams of Matcha powder mixed with water the day before exercise and 1 gram two hours before exercise, which consisted in a 30-minute brisk walk. One gram of tea contained 143 mg of catechins and 30 mg of caffeine.[37]

Venables and colleagues calculated the extent to which GT supplementation (366 +/- 5 mg of EGCG), ingested in the 24-hour period before the experimental trial, enhanced fat oxidation. They observed that GTE was able to increase the contribution of fat oxidation to total EE and that average fat oxidation rates were 17% higher after ingestion of GTE than after ingestion of placebo.[45]

The aforementioned findings are consistent with those reported by Gahreman and collaborators on trained and untrained men, who ingested 3 capsules the day before exercise and 1 capsule 90 minutes before exercise. Each capsule of GT contained 125 mg of EGCG and 20 mg of caffeine. Exercise consisted in a 20-min sprint interval exercise protocol performed on a cycle-ergometer. An increase in fat oxidation was demonstrated both at rest and after exercise. Higher plasma glycerol and epinephrine levels during and after interval sprinting were observed.[22] Similar results were obtained by the same authors also in women.[21]

In healthy physically-active men, longer supplementation (7 days) with caffeinated GTE (1200 mg catechins, 240 mg caffeine/day) was associated with changes in the concentrations of parameters related to fat metabolism (3-β-hydroxybutyrate), lipolysis (glycerol), and tricarboxylic acid cycle (citrate) at rest and with reduced 3-β-hydroxybutyrate concentrations and increased pyruvate, lactate and alanine levels during moderate-intensity exercise, when compared to placebo ingestion.[23] However, when a similar study was carried out by the same researchers' group in healthy men who ingested decaffeinated GTE for 28 days, several metabolic effects found in the previous study with caffeinated GTE were not present. The only significant change was represented by an increase in 3-hydroxybutyrate levels measured on day 7 and 28 at rest; no significant effect was demonstrated during exercise.[38]

No significant differences in plasma FA concentrations and glycerol at rest and during exercise and no significant changes in fat oxidation rates during exercise were found between supplementation with placebo or decaffeinated GTE for 28 days in a cross-over placebo controlled study on healthy active men.[39]

However when supplementation with decaffeinated GTE (571 $mg \cdot day^{-1}$ providing 400 $mg \cdot day^{-1}$ of EGCG) was associated with exercise (cycling 3 times per week at 50%$VO_2$max for 1 hour) for 4 weeks, an increase in total fat oxidation rates by 24.9% was found in recreationally active men with mean body weight of 77.29±2.03 kg. Percentage contribution of fat to exercise EE increased from 32.61±3.53% to 41.45±1.31%.[46] The same author investigated the effects of 8-week supplementation with decaffeinated GTE, in overweight recreationally active women and men, who were engaged in about 150 minutes of moderate aerobic exercise per week. Maximal fat oxidation showed a non-significant increase after decaffeinated GT supplementation.[47]

When  additional antioxidant nutrients (quercetin and α-lipoic acid) were included in the supplement's formula, an increase in maximal fat oxidation rate from 154.4 ± 20.6 at baseline to 224.6 ± 23.2 $mg \cdot min^{-1}$ was observed over the intervention period. Also substrate utilization, during steady-state exercise, resulted enhanced, with a significant increase in the contribution of fat to EE.

The authors hypothesized that the better performance of decaffeinated GTE plus was a result of an enhanced EGCG bioavailability and mitochondria efficiency.[47]

Although GT has been claimed to have calorie-restriction-mimetic effects, its ability in reducing body weight remains controversial. Meta-analytical data, with inclusion of studies lasting at least 12 weeks, suggest that catechins have a small beneficial effect on weight loss and maintenance. It has been estimated that subjects, who received GTE, lost on average 1.31 kg more weight than participants, who did not receive the supplement. The average effect was non significantly larger in Caucasian than Asian people and in samples with a low- in comparison to a moderate-to-high regular caffeine intake, suggesting that habitual caffeine intake and ethnicity together may act as moderators able to influence the effects of GTE on body weight.[29]

In sub-studies of the Minnesota Green Tea Trial, a 12-month randomized, double-blind, placebo-controlled clinical trial involving healthy postmenopausal women, decaffeinated GTE (containing 843 mg of EGCG) was not associated with reductions in body weight, BMI, total fat mass, BFP, or waist circumference nor with changes in circulating obesity-associated hormones as leptin, ghrelin, adiponectin, or glucose concentrations. However, tissue and gynoid percentage of fat decreased in individuals with higher BMI.[48]

Reduced skinfold thickness, waist circumference and subcutaneous fat area, as obtained from computed tomography (CT) images, have been demonstrated after 12 weeks of daily consumption of tea containing high doses of catechins, compared to a control tea, in Japanese men, aged 24-46 years and whose BMI was normal to overweight.[49] The total catechin content was 689.9 mg/340 mL beverage in the high-catechin beverage and 21.8 mg/340 mL in the control beverage. The amount of caffeine was low in both beverages (22 and 23 mg/100 ml for the high-catechins beverage and control beverage, respectively) and during the trial the consumption of other dietary source of catechins or caffeine was not allowed. The high-catechins beverage produced a mild decrease in body weight equal to -2.4±0.5 kg, while in the control group the reduction was -1.3±0.3 kg.[49]

**Exercise training and GT supplementation**

Main findings of studies that have analyzed the effects of GT supplementation associated with exercise training are summarized in table 1 and shown in chronological order.[33-35,50-57] The studies' duration ranged between 8 and 22 weeks and studies' size ranged between 22 and 50 participants. Four studies included both women and men, six studies included only women and two studies included only men. Two studies were carried out in Australia, three in North-America, one in South-America, one in UK,  five in Asia.

An heterogeneity of type (beverages, capsules or tablets), dose, and duration of supplementation is evident from the data reported in table 1. Different doses and variations in chemical content of GT preparations represent important factors to evaluate. Moreover, in some studies participants received catechins alone,[33-35,50,53,55-57] whereas, in others, catechins were administered in association with substances as quercetin, lipoic acid, N-oleyl-phosphatidylethanolamine , vitamin E, taurine, guarana extract, glucuronolactone, and ginger extract.[47,51-52,54] Another important difference was represented by the use of caffeinated[33-34,50,53,55,57] or decaffeinated[47] GT supplements.

Most of the studies used dietary diaries or questionnaires to analyze participants' typical individual diet and to evaluate the presence of differences in energy, CHO, fat or protein intake between or within groups.[33-35,47,50-53,56-57]

Regarding caffeine intake, some studies excluded habitual coffee users,[34-35] others asked participants not to take coffee or tea during the study,[57] or allowed to consume no more than 2 caffeinated beverages per day (not including the study supplement), calculating and not finding differences in terms of caffeine intake between the study groups.[50]

Also exercise training protocols were heterogeneous, as reported in table 1. Physical activity type and intensity ranged from prescription of walking for 30 minutes 6 days a week[54] to individualized work out programs with endurance and resistance training supervised by specialists.[51]

**Effects on body composition parameters**

BMI is the most widely used method by which to determine the prevalence of overweight for population-based screening. However, measures of central obesity as waist circumference and quantification of visceral adipose tissue (VAT) mass, using imaging modalities such as abdominal CT or total body dual-energy x-ray absorptiometry (DXA), represent better predictors of increased risk of cardio-metabolic diseases associated to overweight.[58-59]

Anthropometric measures, as waist circumference, waist-to-hip ratio (WHR), and waist-to-height ratio, estimate abdominal obesity. The recommended site for waist circumference measurement vary. The World Health Organization (WHO) suggests that the measurement be made at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest.[60] The U.S. National Institute of Health recommends to measure waist just above the iliac crest.[61]

The effects of catechins and training on anthropometric parameters were investigated in several studies,[33,35,50,52-55] showing not univocal results. Moreover, information about the techniques used for the measurements were not always reported.

In a study by Cardoso, supplementation with GT alone was able to significantly reduce waist circumference; reduction was, however, more pronounced when GT was associated with physical exercise.[53] In contrast, in a study by Gahreman, GT alone did not produce a significant decrease in waist circumference, which resulted reduced only after exercise training with or without GT intake.[55] These data are in accordance with the observations reported by both Hill and Bagheri, who demonstrated an ability of training to affect anthropometric measures, reducing waist circumference and WHR, compared with baseline values.[33,35] Waist circumference in these studies was measured as recommended in the U.S. National Institute of Health Guidelines.[33,35] However, in the study by Hill, supplementation with GT, compared to placebo, did not further enhance exercise-induced changes of anthropometric parameters,[35] whereas data from Bagheri suggested a more pronounced reduction in WHR, when training was associated with GT.[33]

Narotzki observed a significant decrease of men's and women's waist circumferences (from 100.8 and 95.7 to 96.9 and 85.0 cm, respectively) after supplementation of GT and vitamin E in elderly engaged in 30 minutes of moderately intense walking 6 days a week. The decrease in waist circumference was associated with significantly lower fasting glucose levels and lower insulin concentrations. The improvement in insulin levels was attributable to exercise, being present also after training associated with placebo.[54]

The effects of catechins and training on total body and abdominal composition were evaluated by means of different methodologies; each of them has advantages and limitations.

Bioelectrical impedance analsysis (BIA) is a non-invasive method used to assess BFP and the amount of VAT. Compared with DXA, BIA significantly underestimated both total and central adiposity, in particular when it is high.[62] However, according to some scientific data, BIA seems to be more accurate, compared to waist circumference, in evaluating VAT and in predicting cardiovascular risk.[63,64]

DXA, being a two-dimensional imaging technique, is not able to directly differentiate visceral and subcutaneous adipose tissue, but, a good correlation between DXA-estimated VAT and CT- or magnetic resonance imaging (MRI)-measured VAT has been demonstrated.[65]

CT and MRI are considered the reference methods for abdominal obesity evaluation because they directly measure VAT area or volume. CT presents as a limit the exposure to radiations so that single-slice imagines are often used.[66] Despite being less accurate compared with total volume imaging, they represent a good compromise for reducing radiations.

As shown in table 1, several body composition parameters were investigated to evaluate the potential benefits following the association of supplementation with GT and exercise training.

Some studies did not find any significant changes in BFP.[35,47,51-52] In particular, BFP, assessed by means of BIA and skinfold measurements, as well as BMI, fat mass, and FFM were totally unaffected by supplementation with decaffeinated GTE (400 mg of EGCG daily) in men and women, whose amount of aerobic moderate-intensity exercise was in accordance with the guidelines set out by the American College of Sport Medicine.[47]

When a blend of EGCG, caffeine, taurine, guaranà, and ginger administered prior to exercise was associated with both endurance and resistance training, a significant increase in total muscle mass (MM), assessed by DXA, was demonstrated following a training program either with or without concomitant supplementation. However, the increase in MM was not associated with a significant reduction in fat mass and BFP.[51]

Decreased estimated BFP, using skinfold measurements and SIRI equation, reduced body weight and BMI, were observed following aerobic exercise training either with or without GT supplementation in overweight and obese sedentary women. Significant differences between training groups and control group were not associated with significant differences between the training groups, demonstrating the absence of further benefits from GT supplementation. The dose of GT administered was, however, low.[56] Following supplementation with higher doses, estimated BFP by skinfold measurements, was found reduced in another study after GT supplementation alone or training or training associated with GT. It was observed that post-intervention changes were more pronounced when training and GT were associated. GT groups received 3 tablets of GT daily; each table contained about 294 of EGCG and 58.1 mg of caffeine. In the GT group, BFT was reduced from 34.28±1.38% at baseline to

32.42±1.27% after intervention, while in the GT and training group, BFT resulted decreased from 34.12 ±1.80% to 27.12±1.45%.[57]

Statistically significant differences in BFP changes between supervised training alone and supervised training associated with GT supplementation (500 mg of caffeinated GTE daily) were also observed, when this parameter was assessed by means of BIA in overweight women. Although in both training groups BFP was significantly reduced, the magnitude of changes were higher if training was associated with GT. BFP was reduced by GT associated with training from 39.4±3.7% at baseline to 34.9 ±3.3% (-4.48%, 95%CI -4.98 to 3.98). Training alone reduced BFP from 37.1±5.5% at baseline to 34.4±5.3% (-2.73, 95% CI -2.98 to -2.48) [33]. Very similar results were obtained in overweight men.[34]

Data from scientific literature about effects of GT on abdominal fat appear heterogeneous. No significant effect on abdominal fat, measured by means of DXA, was observed, by Mangine, following low doses of EGCG (105 mg daily) and regular exercise in overweight men and women compared to placebo and exercise.[52]

Aerobic moderate-intensity training, with or without 300 mg of EGCG daily, significantly reduced abdominal fat, measured by means of DXA, and VAT, measured by means of CT, compared to baseline, in overweight and obese post-menopausal women.[35] However, exercise-induced changes in body composition were not further enhanced by EGCG supplementation, as demonstrated by the absence of significant differences between the treatment groups.

In overweight middle-aged men, visceral fat area, assessed by BIA, was reduced following exercise training.[34] Changes were greater when exercise was associated with GT supplementation (500 mg daily). The reduction in VFA was -4.2 $cm^2$ (95% CI -5.1 to 3.4) in the exercise and placebo group and -5.3 $cm^2$ (95% CI -6 to -4.3) in the exercise and GT group.[34]

High doses of catechins (625 mg/daily), associated to 39 mg of caffeine, produced significant benefits in body composition measures during exercise-induced weight-loss in a study by Maki and collaborators on sedentary men with waist circumference ≥ 90 cm and women with waist circumference ≥ 87 cm. [50] Caffeinated GT was compared to a placebo beverage, which contained the same dose of caffeine.

Aerobic exercise associated with catechins was able to elicit a greater reduction in total abdominal fat area and abdominal subcutaneous fat area (assessed by means of CT), when compared to exercise and placebo. In contrast, no significant differences in intra-abdominal fat area were found between the two training groups.[50]

Few studies have evaluated whether GT supplementation alone is able to produce effects comparable to training.  In a study by Cardoso 20 g of caffeinated GT daily either alone or associated with exercise reduced body fat mass and BFP, assessed by BIA.[53] However, exercise was necessary to implement lean mass, which resulted greater in participants who underwent exercise training associated with GT or placebo. GT alone did not produce favorable changes in lean mass as well as in  resting metabolic rate measured by indirect calorimetry. The exercise-induced increase in MM, being more metabolically active and requesting higher energy compared to fat mass, led to a concomitant increase in EE.

Gahreman observed favorable metabolic changes after GT consumption with higher fat oxidation at rest and in the post-exercise compared to placebo.[21-22] However, despite an increased fat utilization during submaximal exercise, long-term ingestion of GT alone did not result in a significant decrease in body or abdominal fat and the combination of 12 weeks of GT ingestion and exercise training was not associated with greater total and abdominal fat reduction compared to 12 weeks of ISE alone.[55]

**Effects on hormones, inflammatory markers, and lipids**

Increased levels of adiponectin have been demonstrated, by Bagheri and colleagues, after 8-week supplementation with GT associated with physical exercise both in men and women, who were sedentary and overweight.[33-34]

Adiponectin, hormone secreted from adipose tissue, is involved in the modulation of a number of metabolic processes; it is able to suppress hepatic gluconeogenesis, to enhance insulin sensitivity, and to promote glucose uptake and β-oxidation in skeletal muscle.[67] Obesity, being associated with a down-regulation of anti-inflammatory adipokines, such as adiponectin, and with an increase in pro-inflammatory adipokines, such as interleukin (IL)-1β, IL-6, tumor necrosis factor- α (TNF-α) and leptin, is characterized by a chronic state of low-grade inflammation, able to promote  the development of cardiovascular diseases and diabetes mellitus.[68-69] In contrast, an inverse relationship between inflammatory markers and PA levels has been demonstrated.[70]

Both studies of Bagheri did lack a group who underwent supplementation alone without training, so that it is not clear whether the improved levels of adiponectin are attributable only to training.[33-34] Significant changes in adiponectin concentrations were present both in the exercise and supplement group and in the exercise and placebo group. However, changes in adiponectin levels were greater in the exercise and GT group when compared with the exercise and placebo group or the placebo without exercise group.

Meta-analytical data from randomized controlled trials did not show significant effects of GT supplementation alone on serum adiponectin levels.[71]

In particular, 12-month supplementation with high doses of decaffeinated GT did not affect adiponectin concentrations in overweight and obese post-menopausal women.[48] In contrast, it has been demonstrated that low-carb diet and exercise are able to exert beneficial metabolic effects, increasing adiponectin and decreasing leptin.[72]

Regarding inflammatory markers, scientific literature appears conflicting. In some studies, no significant changes in high-sensitivity C reactive protein (hs-CRP)[50,53] were observed. Other data showed a significant reduction in both hs-CRP and IL-6, following exercise training either associated to GT or placebo.[33-34] No significant changes in TNF-α has been reported.[33-34]

Although the results were not univocal,[35] most studies reported favorable effects on plasma lipids following the association of GT and exercise.[50-51,53,57]

However, as previously reported for other parameters, it is often not clear whether the benefits are attributable to training or GT supplement.

In a 8-week study, low doses of GT associated with training did not show better results in TG and LDL reduction compared with training alone.[56]

A 10-week supplementation period with 500 mg of GT daily, either alone or associated with training, as well as training alone were able to improve lipid profile and to decrease fibrinogen levels in overweight women.[57] The association of training and GT led to the most favorable changes in terms of low-density lipoprotein (LDL), high-density lipoprotein (HDL), TG, and fibrinogen. Although GT alone produced a statistically significant decrease in LDL and TG, changes were lower compared to those observed after training associated with placebo or training associated to GT. Moreover, GT administration alone was not able to produce statistically significant changes in HDL levels. Only training associated with GT or placebo led to significant increases in HDL. [57]

Benefits on TG levels following the association of GT and exercise have also been reported.[50,53] In particular, in a 12-week study, TG concentrations were significantly lower after exercise intervention in participants who ingested a caffeinated beverage with high doses of catechins (~625 mg daily) compared with subjects who ingested a caffeinated control beverage. In contrast, no difference was found in total cholesterol, HDL and LDL concentrations between the two groups.[50]

## Conclusions

Analysis of scientific literature revealed inconsistencies on the real effectiveness of catechins. Differences in the study designs regarding dose and type of supplement, exercise training protocols, and techniques used for assessing parameters may in part explain the controversial data shown as to the impact of GT on body composition measures. From the data analyzed, GT alone is not able to produce the same benefits of exercise, which is necessary to enhance muscle mass and to increase EE. Most of the studies did not find that the association of exercise training and GT supplementation was able to elicit more favorable changes on body composition parameters compared to the association of exercise and placebo.

**Conflict of interest.** All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Table 1. Effects of tea catechins and exercise on body composition measures

| Author, year | Participants | Supplements | Training | Main findings |
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| Hill et al., 2007 [35] | 38 overweight/ obese post-menopausal women | 12-week trial<br><br>Participants randomly assigned to receive capsules containing 150 mg of EGCG or placebo twice daily. | All participants were instructed to maintain their habitual PA patterns and to complete their moderate-intensity exercise sessions 3 times per week (walking or running for 45 min at 75% of age-predicted maximum heart rate) | Significant decrease of waist circumference, WHR, total body fat mass, abdominal fat mass and visceral fat area in both groups, without significant differences between placebo and EGCG. Significant reduction in plasma glucose in subjects with impaired glucose tolerance following EGCG supplementation. No significant changes in total cholesterol, LDL, HDL, and TG in either groups. |
| Maki et al., 2009 [50] | 107 men and women overweight/ obese | 12-week trial<br>Participants randomly assigned to receive 500 mL/day of a beverage containing approximately 625 mg of catechins and 39 mg of caffeine or a control beverage (39 mg of caffeine, no catechins) | All participants were instructed to engage in ≥ 180 minutes/week of moderate-intensity physical activity, and to attend at least 3 supervised exercise sessions per week | No differences in the percentage changes in fat mass or intra-abdominal fat area between the catechin and control groups. Total abdominal fat area, subcutaneous abdominal fat area, and fasting serum TG decreased more in the catechin group compared to the control group.<br>No significant difference in the changes from baseline in total cholesterol, LDL, and HDL between catechin and control groups. |
| Smith et al., 2010 [51] | 27 overweight women | 10-week trial<br><br>Participants were randomly allocated in the following groups: EGCG and exercise, placebo and exercise, EGCG without exercise, placebo without exercise. | Participants assigned to the exercise groups underwent both endurance and resistance training. Endurance training protocol: exercise 3 days per week on cycle ergometer beginning at 15 to 20 min in duration at a % heart rate reserve of 40–50 at week 1 and progressing to 30–35 min | No group showed significant differences in fat mass and BFPt from pre-training to post-training.<br>Significant improvement in muscle mass and upper-body and lower-body strength in the exercise and supplement group and in the exercise and placebo group, without |

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| | | All participants consumed 1 drink per day. The supplement drink contained vitamins B6 and B12, and a blend of taurine, guarana extract, EGCG, caffeine, glucuronolactone, and ginger extract.<br><br>The placebo drink contained the same vitamin content without the active blend. | at 60%–70% heart rate reserve by week 10<br>Resistance training protocol: exercise 2 days per week, with at least 24 hours of recovery between exercise sessions. Resistance exercises: bench press, lat pulldown, seated military press, biceps curl, triceps pushdown, leg press, lying leg curl, low-back extension, and abdominal crunch<br>(8 to 12 repetitions per exercise until volitional fatigue). | significant differences between these two groups.<br>Changes in total cholesterol and LDL from pre- to post-training were significant only in the exercise and supplement group. LDL was significantly reduced both in the exercise and supplement group and in the supplement without exercise group. HDL showed no significant changes in any group. A main effect for treatment was found for TG, which resulted significantly higher from pre- to post-training in the exercise and supplement group, which showed at baseline the highest mean in TG concentrations. |
| Mangine et al., 2012<br>[52] | 50 overweight (BMI > 25 $m \cdot kg^2$) men and women | 8-week trial<br><br>Participants were randomly assigned to the supplement group or the placebo group. Supplement: 3 capsules/day. Each capsule contained: 35 mg of ECGC, 40 mg N-oleyl-phosphatidylethanolamine, and 25 mg of phospholipids. | All participants were invited to follow a low caloric diet and to exercise at least 3 times per week, 30 minutes per day at moderate intensity (between 60 and 75 of the maximum heart rate). | Changes in waist circumference, BFP, and abdominal fat were not significantly different between the supplement and placebo groups.<br><br>Higher compliance in maintaining a low caloric diet at week 4 in the supplement group. This difference was not still present at week 8. |
| Cardoso et al., 2013<br>[53] | 36 women with BMI between 25 and 35 | 8-week trial<br><br>After 4 weeks on an adaptive diet, participants were divided in four groups: GT group, placebo group, GT and resistance training group, placebo and resistance training group. Participants consumed 10 g of either GT or placebo twice daily. Supplement: powder of GT soluble | Training groups exercised with bench press, back pull down, leg press, side lateral raises, triceps pushdown, bicep curls with<br>the bar, leg curls, gluteus kickback, bent-knee calf raises,<br>and sit-ups. For the bench press, back pull down, and leg<br>press (45°), 70% of the 1RM was used. | Changes in the GT without training group: significant decrease in BMI, waist circumference, body fat mass and BFP. No significant change in lean body mass. Significant decrease in RMR.<br><br>Changes in the GT and training group: significant decrease in waist circumference, body fat mass, BFP, and TG levels. No significant change in BMI. |

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| | | in water, orange pulp, vitamin C, zinc, selenium, lemon flavor, chlorophyll dye, and sucralose. Each portion of GT (10 g) contained 20 mg of caffeine (40 mg of caffeine daily). Placebo: same ingredients of supplement with the exclusion of GT. Placebo did not contain caffeine. | Training protocol: 3 sets of 10 repetitions of each exercise, three times a week. | Significant increase in muscle strength, lean mass, and RMR (changes present also in the placebo and training group).<br>GT and training group was the only to show significant decrease in TG levels. |
| Narotzki et al., 2013 [54] | 22 elderly men and women | 22-week trial<br><br>Participants were randomly assigned to supplement or placebo group.<br><br>Supplement: 3 cups of GT (3x1.5 g of GT to be brewed in 240 mL of water) and 400 IU of vitamin E. | 30 minutes of moderately intense walking 6 d/wk. | Significant reduction in body weight and fasting insulin levels in both groups. Reduced waist circumferences, decreased fasting glucose levels, reduced plasma protein carbonyls, and increase in erythrocyte catalase activities in the exercise and GTE plus vitamin E group. |
| Gahreman et al., 2016 [55] | 48 overweight men | 12-week trial<br><br>Participants were randomly assigned to the following groups: ISE group, GT group, GT and ISE group, and control group.<br><br>The GT and control groups ingested 3 GTE or placebo capsules daily at breakfast, lunch, and dinner. On exercise days, the exercise and GT group ingested 1 capsule 1 hour before training and 1 capsule with lunch and dinner. | Training groups exercised 3 times per week.<br><br>Supervised ISE training protocol: 5-min warm-up, 20 min of ISE, and a 5-min cool-down. The main exercise session consisted of 60 bouts of 8 s of high-intensity cycling followed by 12 s of slow cycling recovery. ISE workload set at 85% to 90% of each participant’s maximum heart rate at a cadence between 100 and 120 revolutions per minute. | Significant reduction in BMI, waist circumference, total body fat mass, abdominal fat mass and increase in total lean mass in both training groups. No significant changes of the aforementioned parameters in the GT and control groups. Significant increase in fat oxidation during submaximal aerobic exercise in the GT group, in the GT and exercise group, and in the exercise group; no changes in the control group.<br><br>Significant decrease in total cholesterol in the GT and training group. |

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| | | The GTE capsule contained 250 mg of *Camellia sinensis* extract with 187.5 mg polyphenols, 125 mg EGCG, and 20 mg caffeine. | | Significant decrease in TG in the training group. |
| Amozadeh et al., 2018 [56] | 39 overweight and obese women sedentary | 8-week trial.<br><br>Participants were randomly assigned to 3 groups: GT and aerobic training group, aerobic training group, and control group.<br><br>GT and training group ingested 3 capsules of GT daily after the main meals. Each capsule contained 33 mg of GT.<br><br>Participants of the control group performed their daily physical activities, but did not exercise. | Training protocol: 80-90 minutes of aerobic exercise 3 times per week. Exercise intensity: beginning at 40% to 50% of target heart rate and reaching 70% to 80% of target heart rate | Decrease of body weight, BMI, BFP, TG, LDL in the training groups with and without GT supplementation. Post-training values of the aforementioned parameters were statistically different between training groups and control group, whose participants did not undergo exercise training. No significant differences were observed between the training group and the training and GT group. |
| Ghasemi et al., 2019 [57] | 30 young women with BMI ≥25 kg/m$^2$ | 10-week trial<br><br>Participants were randomly allocated in 3 groups: GT, high-intensity interval training and GT, and high-intensity interval training and placebo. The GT group did not practice sport activities.<br>Participants ingested 3 tablets of GT or placebo daily. Each 500 mg GT tablet contained ~ 294 mg of EGCG, 74 mg of EGC, 20.7 mg of EC, 51.2 mg of ECG, and 58.1 of caffeine. | Training protocol: 40 minutes of maximal shuttle run test 3 times per week. | Significant decrease in body weight, BFP, TG, LDL, and fibrinogen in all groups. Significant increase in HDL in the training and GT group and in the training and placebo group.<br><br>Changes in body weight, BFP, TG, LDL, and fibrinogen between pre- and post-intervention were higher in the training and GT group compared to the training and placebo group and the GT without training group. |

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| Bagheri et al., 2020 [33] | 30 overweight and sedentary women | 8-week trial<br><br>Participants were randomly assigned to 3 groups: training and placebo, training and GTE, no training and placebo.<br><br>The GTE and exercise group ingested 1 capsule of GTE (500 mg) daily. Each GTE capsule contained a minimum of 45% of EGCG and 15 mg of caffeine. | Training protocol: supervised exercise program which included aerobics, aerobic circuit training, and fast walking or jogging 3 times per week. Exercise intensity was between 40 and 49 heart rate reserve in weeks 1–4 and between 50 and 59 in weeks 5–8.<br><br>Circuit training consisted in five 3-minutes aerobic stations (fast walking or jogging on treadmill, rowing machine, bicycle ergometer, stair climber and elliptical). Resting period between the stations: 30 seconds. Circuit was repeated 3 times per training session. | Significant decrease in body weight, BMI, and BFP in the training groups. Changes in in the aforementioned parameters were more pronounced in the training and GT group compared to the training and placebo group and the control group. Increase in adiponectin and decrease in CRP, without any significant changes in irisin, IL-6 or TNF-α levels, in both training groups. |
| Bagheri et al., 2020 [34] | 45 overweight and sedentary men | 8-week trial<br><br>Participants were randomly assigned to 3 groups: exercise and placebo, exercise and GTE, no exercise and placebo.<br><br>The GTE and exercise group ingested 1 capsule of GTE (500 mg) daily. Each GTE capsule contained a minimum of 45% of EGCG and 15 mg of caffeine. | Training protocol: supervised exercise program which included circuit training, fast walking or jogging 3 times per week. Exercise intensity was between 40 and 49 heart rate reserve in weeks 1–4 and between 50 and 59 in weeks 5–8. Circuit training consisted in five 3-minutes aerobic stations (fast walking or jogging on treadmill, rowing machine, bicycle ergometer, stair climber and elliptical). Resting period between the stations: 30 seconds. Circuit was repeated 3 times per training session. | Significant reduction in body weight, BMI, BFP, and visceral fat area in both training groups. Changes in the aforementioned parameters were more pronounced in the training and GT group compared to the training and placebo group and the control group. Increase in adiponectin and decrease in IL-6 and CRP, without any significant changes in TNF-α, in both training groups. Irisin concentrations increased only in the exercise and GTE group. |
| Roberts et al., 2021 [47] | 27 overweight men and women | 8-week trial<br>Participants were randomly subdivided in 3 groups (placebo, GTE, GTE plus). | All participants were invited to engage in regular aerobic exercise ~150 minutes per week in 3–5 sessions at moderate intensity (~75–80%HRmax). | Significant increase in maximal fat oxidation in the GTE plus group. Improvements in substrate utilization during steady state exercise, with lower |

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| | | Participants ingested 2 capsules daily of placebo or decaffeinated GTE (580 mg·d$^{-1}$ decaffeinated GTE delivering 400 mg·d$^{-1}$ of EGCG), or decaffeinated GTE plus (580 mg·d$^{-1}$ decaffeinated GTE delivering 400 mg·d$^{-1}$ of EGCG,50 mg·d$^{-1}$ of quercetin, and 150 mg·d$^{-1}$ of lipoic acid. | | mean RER, improved relative fat oxidation and increase in the contribution of fat to total energy expenditure in the GTE plus group.<br>Non-significant changes in BMI, BFP, fat mass, fat-free mass, estimated visceral fat area in any group. |

Legend. BFP, body fat percentage; BMI, body mass index; CRP, C-reactive protein; EC, epicatechin; ECG, epicatechin-3-gallate; EGC, epigallocatechin; EGCG, epigallocatechin-3-gallate; GT, green tea; GTE, green tea extract; HDL, high-density lipoprotein; IL-6, interleukin 6; ISE, interval sprinting exercise; LDL, low-density lipoprotein; min, minute; PA, physical activity; RER, respiratory exchange ratio; RMR, resting metabolic rate; s, seconds; TG, triglyceride; TNF- α, tumor necrosis factor-α; WHR, waist-to-hip ratio.