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Review Article

Impact of green tea on obesity-related hormones in postmenopausal women: A systematic review and meta-analysis of randomized controlled trials

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Abstract

Objective: Menopause leads to hormonal changes that increase visceral fat, raising risks for metabolic disorders and breast cancer due to altered adipocytokine levels. Green tea (Camellia sinensis L.), containing catechins like EGCG (epigallocatechin gallate), may improve metabolic health in postmenopausal women. In this review we assessing the effects of green tea consumption on key obesity related hormones in postmenopausal women.

Materials and Methods: This study reviewed randomized controlled trials (RCTs) from PubMed, Science Direct, Cochrane Library, and Google Scholar up to March 2024, focusing on green tea's effects on leptin, adiponectin, ghrelin, and insulin. Eight RCTs with 632 participants were analyzed using standardized mean differences (SMDs) with 95% confidence intervals (CIs) in a random-effects model. Heterogeneity was measured with the I^2 statistic, and publication bias was assessed via Egger's test and funnel plots.

Results: Green tea significantly reduced ghrelin levels (SMD: -4.63, 95% CI: -8.44 to -0.82, p = 0.02, I^2 = 98.98%), particularly at doses >1000 mg/day and durations >8 weeks. No significant effects were observed for leptin (SMD: -0.33, 95% CI: -0.89 to 0.22, p = 0.24), adiponectin (SMD: -0.53, 95% CI: -1.44 to 0.39, p = 0.26), or insulin (SMD: -0.87, 95% CI: -4.31 to 2.58, p = 0.62). Subgroup analyses revealed significant reductions in leptin at doses >1000 mg/day, durations ≤8 weeks, and BMI <29 kg/m²; adiponectin at 400–1000 mg/day and insulin at durations ≤8 weeks and BMI <29 kg/m². High heterogeneity and some evidence of publication bias were noted.

Conclusion: Green tea notably reduced ghrelin, with context-specific effects on leptin, adiponectin, and insulin based on dose, duration, and body mass index (BMI), suggesting tailored benefits for postmenopausal women's metabolic health.

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Introduction

Menopause causes a redistribution of body fat with a significant augmentation in abdominal fat. This shift in fat distribution, beyond the decline in estrogen levels, is mainly due to visceral fat, which acts as an endocrine organ by secreting proinflammatory adipocytokines into the circulation system, raising the risk of metabolic disorders such as cardiovascular diseases and type 2 diabetes (Bacha et al. 2004; Barrea et al. 2021; Davis et al. 2012; Kapoor et al. 2019; Williams et al. 1996). Moreover, it has been shown that excess adiposity, particularly visceral adiposity, contributes to post-menopausal breast cancer (Vona-Davis et al. 2007).

Several hormonal changes during menopause are experienced by women, including reduced adiponectin levels, resulting in increased adipose tissue which may lead to insulin resistance (Goodarzi et al. 2007; Rolland et al. 2006). Therefore, post-menopausal decreased adiponectin levels can aggravate this lipid-induced metabolic dysregulation (Bajaj et al. 2004; Fruebis et al. 2001; Henneman et al. 2010; Kim et al. 2010; Zhao et al. 2014). Other adipokines such as leptin, and ghrelin have a pivotal role in modulating the development and proliferation of adipocytes, as well as angiogenesis, via the paracrine system, and as a result, adjusting fat mass. During menopause, there is a significant increase in leptin levels, while ghrelin levels decrease along with adiponectin (Olszanecka et al. 2010; Reaven et al. 2004; Waki and Tontonoz 2007). Ghrelin, often called the "hunger hormone", is produced mainly in the stomach and stimulates appetite (Rezaie et al. 2015). After menopause, estrogen levels decline, which can lead to an increase in ghrelin levels (Espinoza García et al. 2021). This increase in ghrelin can result in a heightened appetite, and weight gain, particularly visceral fat (Abdalla and Jegasothy 2020). Leptin is another adipokine that helps regulate energy balance by inhibiting hunger. Postmenopausal women often experience higher leptin levels due to increased fat mass, especially visceral fat, as it regulates fat storage and metabolism. However, despite higher leptin levels, many women still experience weight gain and metabolic issues, a condition known as leptin resistance. This resistance can lead to difficulties in managing body weight and an increased risk of obesity-related problems like insulin resistance, type 2 diabetes, and cardiovascular diseases (Gower et al. 2000; Jaballah et al. 2021; Kassab 2022; Picó et al. 2022). Apart from the adipocytokines mentioned above, other hormones such as reproductive hormones, corticosteroids, and insulin, can affect lipid metabolism and distribution (Liedtke et al. 2012; Rigato et al. 2020; Rolland et al. 2006; Saltiel and Kahn 2001; Wang et al. 2012).

Dietary phytochemical supplements and a low-calorie diet can mitigate adipose tissue dysfunction. Green tea extracts, which are rich in polyphenols such as catechins —including epigallocatechin-3-gallate (EGCG), a highly bioactive compound— are recognized for their metabolic properties (Khan and Mukhtar 2007; Rains et al. 2011; Ríos-Hoyo and Gutiérrez-Salmeán 2016; Wolfram et al. 2006).

The effects of green tea extract (GTE) on obesity-related hormones, anthropometrics, and glucose homeostasis in postmenopausal women have been under academic investigation. Research has shown that catechins, especially EGCG, are considered anti-obesity and antidiabetic compounds (Basu et al. 2010a; Zamora-Ros et al. 2014). Flavanolic substances of GTE reduce the Catechol-O-methyltransferase (COMT) enzyme activity *in vitro*. Through this mechanism, green tea intake can extend the duration of norepinephrine effects and, as a result, increase energy expenditure and lipid oxidation, which may influence body weight regulation and fat loss (Nagle et al. 2006; Wolfram et al. 2006). It has been shown that high-activity COMT decreases plasma adiponectin and increases insulin,

favoring emerging metabolic disorders (Dostal et al. 2016c). It has been demonstrated that adequate adiponectin concentration regulates insulin sensitivity of hepatocytes and is effective in energy homeostasis in mouse model research (Kubota et al. 2007). Furthermore, green tea catechins (GTC) increased adiponectin transcription in mouse pre-adipocytes (Cho et al. 2007). Moreover, GTE has reduced fasting insulin levels in experiments, indicating potential benefits for those with elevated insulin concentration exposed at risk of metabolic syndrome, and it lowers the chance of type 2 diabetes occurrence (Dostal et al. 2016c). However, its influences on adiposity-associated hormones have been controversial. Research that analyzed the body composition of followed GTE consumers showed modifications in the adipose distribution so that visceral adipose tissue (VAT) and fat mass significantly reduced without affecting fat-free mass (FFM)(Nagao et al. 2007). Studies that monitored obese women's treatment with EGCG showed elevated adiponectin levels and adiponectin/leptin ratio in the treated individuals (Chen et al. 2016).

Despite these findings, the effects of GTE on obesity-related hormones in postmenopausal women remain controversial. Some studies report significant improvements in adiponectin, insulin sensitivity, and fat distribution (Chen et al. 2016; Nagao et al. 2007), while others, such as Wu et al. (2012) and Dostal et al. (2015a, 2015b), found no consistent effects on adiponectin, leptin, or insulin levels, highlighting a lack of consensus (Dostal et al. 2016a; Dostal et al. 2016c; Wu et al. 2012). These contradictory results, combined with limited evidence on the comprehensive impact of GTE on the interplay of adipokines (such as adiponectin, leptin, and ghrelin) and other hormones (such as insulin) in postmenopausal women, underscore the need for a systematic evaluation.

The aim of this systematic review and meta-analysis of randomized controlled trials (RCTs) was to evaluate the effect of green tea consumption on hormones affecting energy balance and obesity in postmenopausal women.

Materials and Methods

Search strategy

The literature search was conducted in four databases, PubMed, Science Direct, Cochrane Library, and Google Scholar, until March 2024. Additionally, we searched the reference lists of the included studies and relevant reviews. The search strategy was developed using Medical Subject Headings (MeSH) terms, structured according to the PICO framework as follows: Population (P): Postmenopausal women, Intervention (I): Green tea or its derivatives, Comparison (C): All relevant RCTs with green tea as the primary intervention, with a control group., Outcome (O): Studies reporting baseline and post-intervention values, or mean changes, for at least one outcome, including leptin, adiponectin, ghrelin, and insulin. Further information is provided in the supplementary file.

Screening and data extraction

Studies were included if they met the following criteria: 1) The study design was a randomized clinical trial; 2) Participants in the intervention group were postmenopausal women, defined as having ≥12 months of amenorrhea or follicle-stimulating hormone (FSH) levels ≥25 IU/L; 3) The intervention consisted of green tea or green tea extracts (e.g. catechins, EGCG) as the primary treatment; 4) A control group was included (e.g. placebo, no treatment, or usual care); 5) The study reported baseline and post-intervention values, or mean changes, for at least one of the following obesity-related hormonal outcomes: leptin, adiponectin, ghrelin, or insulin; 6) Studies that are published until March 2024.

Studies were excluded if they were: 1) Review articles, case reports, abstracts, letters to editors, animal studies, or *in vitro* studies. 2) Studies in which the outcome data were not fully reported or were presented in a format that did not allow conversion into mean ± SD, thereby preventing inclusion in the quantitative synthesis.

Data extraction and quality evaluation

Data extraction was performed independently by two reviewers (S.Gh and H.H) using a standardized data extraction form. In the event of any controversy, the involvement of an independent third researcher (M.A) was sought. In summary, the following data were retrieved from each research to assess its quality: name of the first author, year of publication, sample size (number of participants in the intervention and control groups), study type, and mean and standard deviation (SD) or standard error (SE) for the following outcome measures: leptin, adiponectin, ghrelin, and insulin.

Risk of bias assessment

The appropriate Joanna Briggs Institute (JBI) critical appraisal checklist for study designs, specifically RCTs, was utilized to evaluate the articles. The JBI critical appraisal checklist for RCTs consists of 13 questions that assess various methodological aspects, including randomization, concealed allocation, blinding, follow-up, and analysis. All versions of the JBI checklist are available for reference (Amakye et al. 2024).

Statistical analysis

To ensure comparability of results, we calculated the Standardized Mean Differences (SMD) along with the 95% confidence intervals for both the intervention and control groups (Andrade 2020). Data analysis was performed using STATA, version 17.0 (Stata Corp LLC, College Station, TX, USA). The Cochrane Q test and the I^2 statistic were used to assess heterogeneity among the studies. The I^2 statistic, assesses the inconsistency of results across studies. When we identified heterogeneity—defined as I^2 values exceeding 50%—we employed a random-effects model(Higgins et al. 2003).

The results of the Q-test were considered statistically significant at a p-value threshold of 0.1. We performed subgroup analyses to establish the possible causes of heterogeneity between the studies on meta-analysis outcomes. Subgroup analyses were performed using the aforementioned moderator variables: the dose of each hormone (<400 mg/day, 400-1000 mg/day vs.>1000 mg/day), the BMI of participants (<29 Kg/m^2 vs.>29 Kg/m^2), and the duration of the study (>8 weeks vs. ≤8 weeks).

Additionally, to assess publication bias, both funnel plot asymmetry and Egger's regression test were employed, with statistical significance determined at a p-value of 0.05.

Results

Study selection

A total of 2862 articles related to the subject under study were identified in all the databases searched, with 99 articles remaining following the removal of duplicate records and those deleted for other reasons. In the following steps, we reviewed the titles and abstracts, leading to the exclusion of 59 articles. We then examined the full text of 40 articles, of which 36 were found to be unrelated and were excluded. Of the 36 articles assessed for eligibility, 23 were excluded due to irrelevant outcomes, and 6 were excluded for lacking an intervention. Ultimately, 8 articles were included in the study (Dostal et al. 2017; Dostal et al. 2016a; Dostal et al. 2016c; Hill et al. 2007; Mielgo-Ayuso et al. 2014; Rondanelli et al. 2022; Takahashi et al. 2014; Wu et al. 2012). The PRISMA flow diagram illustrates the study selection process (Figure 1). The table of demographic characteristics of included articles provides more information (Table 1).

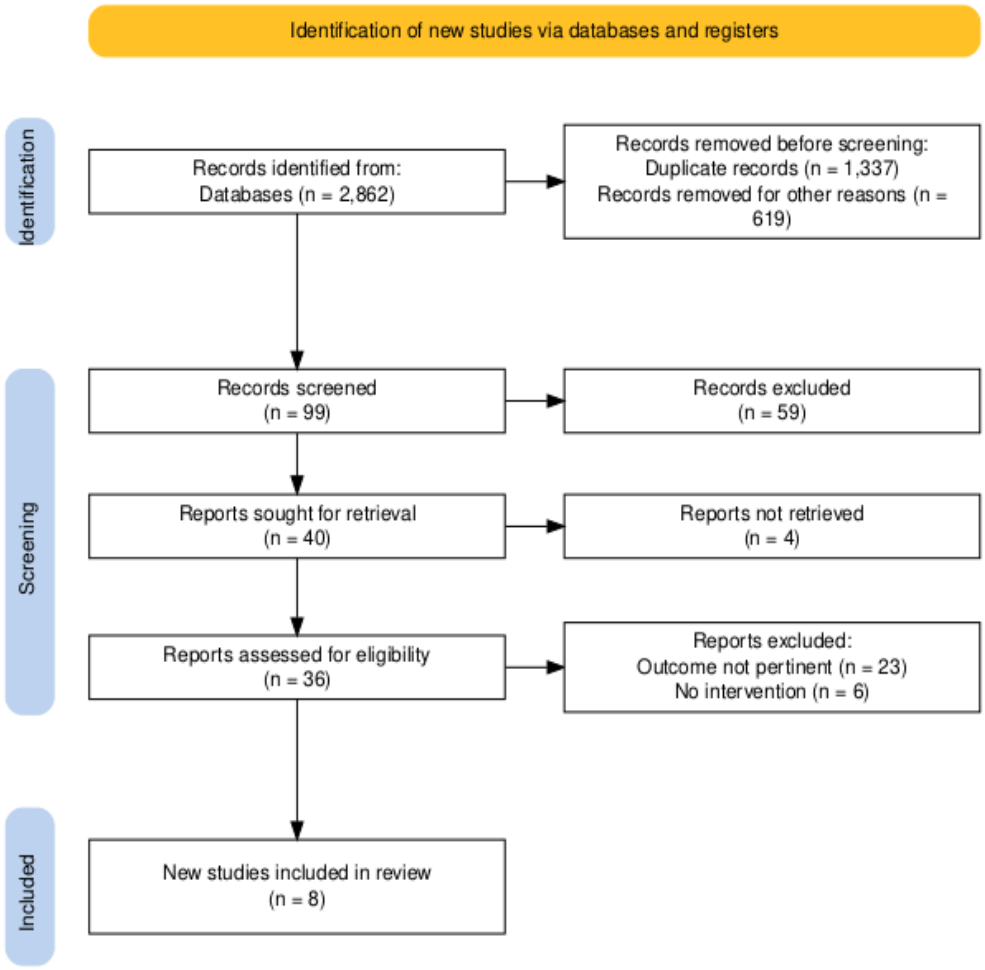

Figure 1. PRISMA flow chart to illustrate the article search and selection process

Table 1. Characteristics of the studies included in the systematic review and meta-analysis

Author	year	Design	Country	Gender	Dose (mg/day)	N. Intervention	N. Control	Follow-up (weeks)
Hill	2007	RCT	Australia	Women	300	19	19	12
Wu	2012	RCT	USA	Women	400 / 800	37 / 34	16	8
Mielgo-Ayuso	2013	RCT	Spain	Women	300	43	40	12
Takahashi	2014	RCT	Japan	Women	615	11	11	4
Dostal	2015	RCT	USA	Women	1315	117	120	12
Dostal	2015	RCT	USA	Women	1315	61	60	12
Dostal	2017	RCT	USA	Women	1315	30	30	12
Rondanelli	2022	RCT	Italy	Women	300	14	14	8

Abbreviation: RCT: Randomized clinical trial, USA: United States America.

Studies quality assessment

In meta-analyses, the inclusion of high-quality studies is essential for producing reliable and valid results. The results of our qualitative assessment regarding the critical appraisal and risk of bias of the included articles are presented in the following section. Publication bias rarely affected our included studies, according to Egger's regression test ($p > 0.05$). In order to examine for evidence of publication bias, funnel plots were developed. These plots showed a symmetrical distribution for most of our outcome analyses, indicating a low risk for publishing bias (supplementary file). Our results indicated a low risk of bias for all included studies based JBI critical appraisal checklist tool. The results of the quality assessment by the JBI checklist tool are presented in Figure 2.

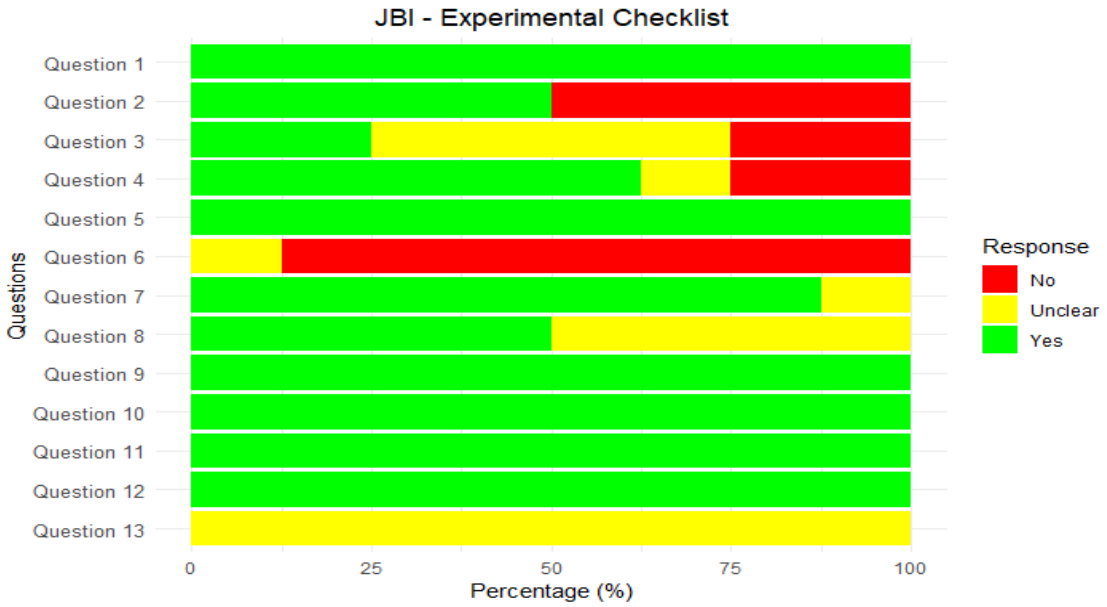

Figure 2. Quality assessment of experimental studies based on the JBI checklist, including criteria such as randomization, allocation concealment, baseline similarity, blinding of participants, personnel and outcome assessors, completeness of follow-up, intention-to-treat analysis, reliability of outcome measures, appropriate statistical analysis, clarity of trial design, group comparability, and ethical approval. An abbreviated checklist is provided in the supplementary file.

Results of meta-analyses

Leptin

A random-effects meta-analysis that included five trials with a total of 484 participants (241 cases and 243 controls) found no significant difference in leptin levels after consuming green tea (SMD: -0.33, 95% CI: [-0.89, 0.22], p = 0.24) (Figure 3 and Table 2). Furthermore, there was a high degree of heterogeneity among the studies ($p < 0.0001$; $I^2 = 86.48\%$). Egger's test indicated no significant evidence of publication bias (p = 0.51) (Table 3); however, some asymmetry was observed in the funnel plot, suggesting potential factors influencing the distribution of studies.

Subgroup analyses were performed based on green tea dosage, BMI, and intervention duration. Following subgrouping analysis, the results showed a significant effect on a dose of more than 1000 mg/day. Additionally, subgroup analyses based on intervention duration and BMI demonstrated a statistically significant reduction in leptin levels for less than 8 weeks and less than 29 kg/m², respectively (Table 4).

Adiponectin

A random-effects meta-analysis that included seven trials with a total of 587 participants (312 cases and 275 controls) found no significant difference in Adiponectin levels after consuming green tea (SMD: -0.53, 95% CI: [-1.44, 0.39], p = 0.26) (Figure 4 and Table 2). Furthermore, the studies had a high degree of heterogeneity ($p < 0.0001$; $I^2 = 95.88\%$). Egger's test indicated no significant evidence of publication bias (p = 0.19) (Table 3); however, some asymmetry was observed in the funnel plot, suggesting potential factors influencing the distribution of studies.

Results of subgroup analysis showed that duration of consumption and BMI have no significant influence on adiponectin levels. Nevertheless, a dose-based subgroup analysis revealed that adiponectin levels were significantly lower at 400–1000 mg dosages per day (Table 4)

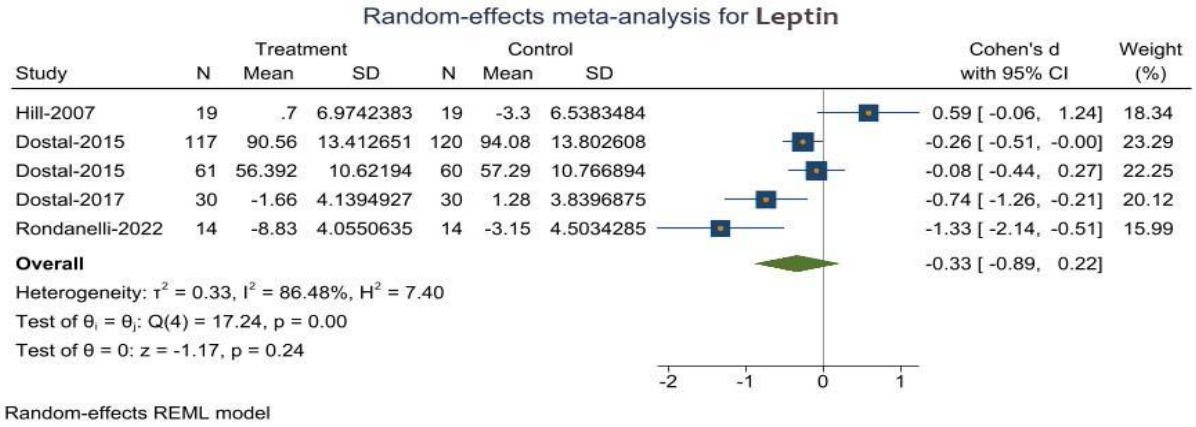

Figure 3. Forest plot for the effects of green tea on leptin levels in postmenopausal women.

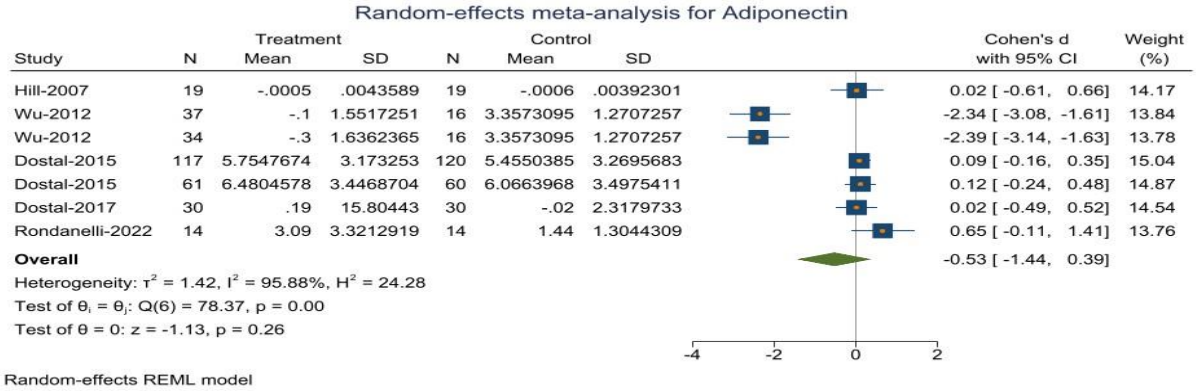

Figure 4. Forest plot for the effects of green tea on adiponectin levels in postmenopausal women.

Ghrelin

A random-effects meta-analysis that included three trials with a total of 418 participants (208 cases and 210 controls) found a significant difference in Ghrelin levels after consuming green tea (SMD: -4.63, 95% CI: [-8.44, -0.82], p = 0.02) (Figure 5 and Table 2). Furthermore, there was a high degree of heterogeneity among the studies (p < 0.0001; I^2 = 98.98%). Egger's test did not indicate significant evidence of publication bias (Table 3) (p = 0.19); however, some asymmetry was observed in the funnel plot, suggesting potential heterogeneity or small-study effects.

Results of subgroup analysis showed that duration of consumption and BMI have a significant influence on ghrelin levels at >8 weeks and <29 kg/m^2, respectively. Also, a dose-based subgroup analysis revealed that Adiponectin levels were significantly lower at >1000 mg per day (Table 4).

Insulin

A random-effects meta-analysis that included eight trials with a total of 632 participants (336 cases and 296 controls) found not significant difference in Insulin levels after consuming green tea (SMD: -0.87, 95% CI: [-4.31, 2.58], p = 0.62) (Figure 6 and Table 2). There was a high degree of heterogeneity among the studies (p < 0.0001; I^2 = 99.57%). Furthermore, Egger's test did not indicate significant evidence of publication bias (Table 3) (p = 0.60); however, some asymmetry was observed in the funnel plot, which may be due to heterogeneity or small-study effects.

Results of subgroup analysis showed that dosage of consumption did not have a significant influence on insulin levels. Nevertheless, the duration of green tea consumption and BMI subgroup analysis revealed that insulin was significantly reduced at less than or equal to 8 weeks group and less than 29 kg/m^2, respectively (Table 4).

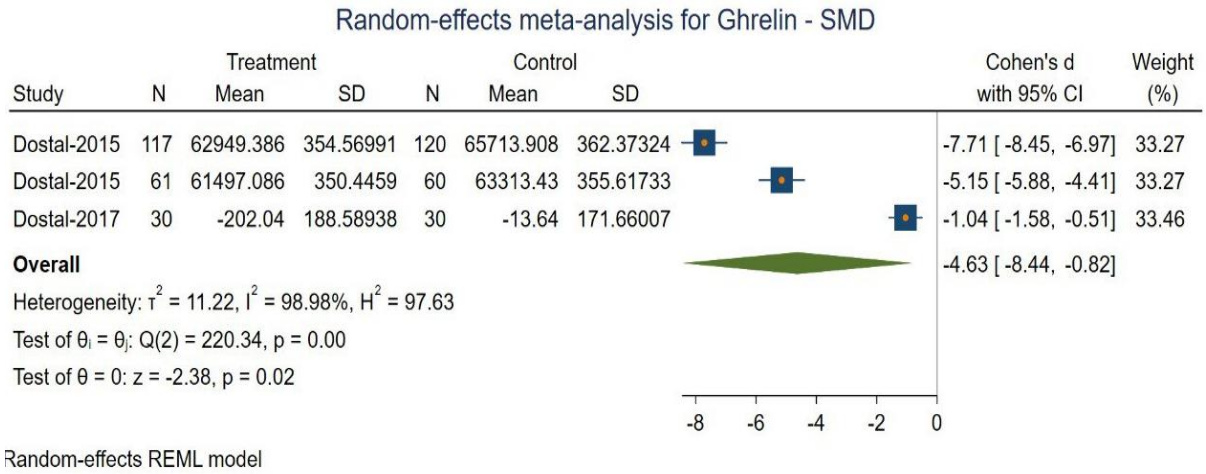

Figure 5. Forest plot for the effects of tea green on ghrelin levels in postmenopausal women.

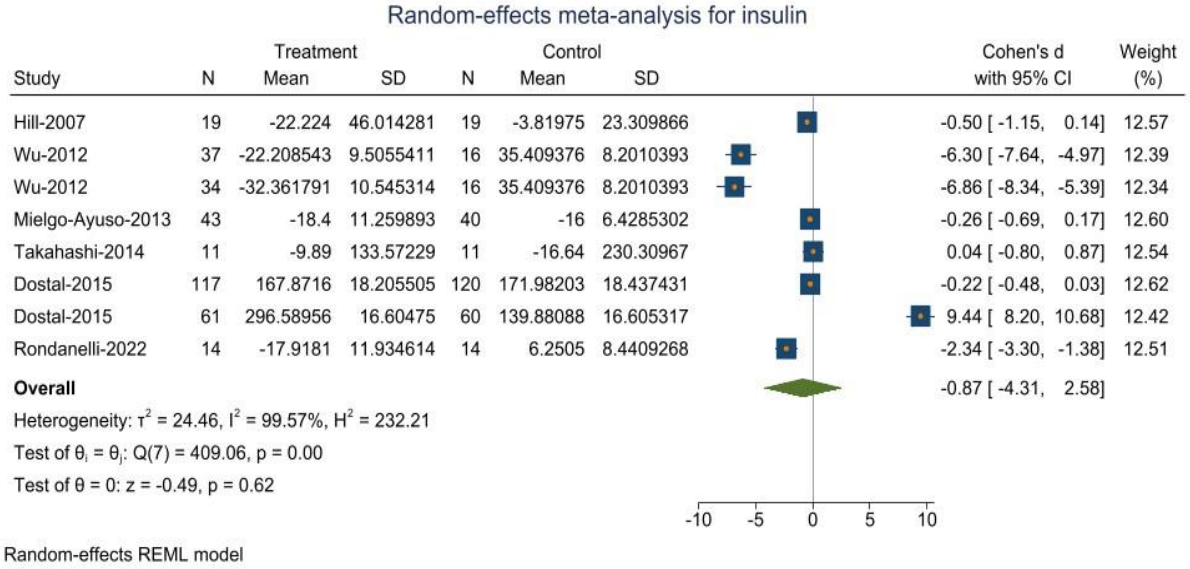

Figure 6. Forest plot for the effects of green tea on insulin levels in postmenopausal women.

Table 2. Overall standard mean difference (SMD) and I^2 statistics results for the effects of green tea consumption on hormones

Variables	SMD (95% CI)	p-value	I^2 %	No. of study in analysis
Leptin	-0.33 (-0.89, 0.22)	0.24	86.48	5
Adiponectin	-0.53 (-1.44, 0.39)	0.26	95.88	7
Ghrelin	-4.63 (-8.44, -0.82)	0.02	98.98	3
Insulin	-0.87 (-4.31, 2.58)	0.62	99.57	8

Table 3. Assessment of publication bias using Egger's regression test for green tea effects on hormones

Variable	Egger's regression intercept	95% CI	p value
Leptin	-2.03	(-5.15, 1.12)	0.51
Adipokine	-5.82	(-10.34, -1.30)	0.19
Ghrelin	-52.70	(-10.34, -1.30)	0.19
Insulin	-4.66	(-13.56, 4.24)	0.60

Table 4. Subgroup analysis of the effects of green tea consumption on hormones by dose, BMI, and duration.

Variable	No. of effect size	Mean difference	95% confidence interval	I^2	p heterogeneity between group
			Leptin		
Dose (mg/day)					
>1000	3	-0.30	-0.60, -0.01	50.60	0.96
< 400	2	-0.35	-2.33, 1.53	92.27	
BMI (Kg/m^2)					
>29	2	-0.337	-2.164, 1.491	91.89	0.002
<29	3	-0.3	-0.596, -0.005	49.95	
Duration (weeks)					
>8	4	-0.15	-0.61, 0.31	0.00	0.01
≤8	1	-1.33	-2.14, -0.51	79.98	
			Adiponectin		
Dose (mg/day)					
>1000	3	0.09	-0.10, 0.28	0.00	
400-1000	2	-2.37	-2.89, -1.84	0.00	0.00
< 400	2	0.30	-0.31, 0.92	35.52	
BMI (Kg/m^2)					
>29	4	-1.108	-2.717, 0.501	94.86	< 0.001
<29	3	-2.717	-0.104, 0.279	0	
Duration (weeks)					
>8	4	0.08	-0.10, 0.27	0.00	0.15
≤8	3	-1.36	-3.33, 0.61	95.16	
			Insulin		
Dose (mg/day)					
>1000	2	4.59	-4.88, 14.05	99.5	
400-1000	3	-0.97	-2.21, 0.26	90.70	0.17
< 400	3	-4.34	-8.71, 0.02	97.51	
BMI (Kg/m2)					
>29	4	-2.299	-4.248, -0.350	96.38	< 0.001
<29	3	3.022	-1.420,7.464	99.1	
Duration (weeks)					
>8	4	2.09	-2.67, 6.84	99.79	0.04
≤8	4	-3.83	-7.06, -0.60	97.09	
			Ghrelin		
Dose (mg/day)					
>1000	3	-4.63	-8.44	-0.82	0.00
BMI (Kg/m^2)					
<29	3	-4.63	-8.63	-0.59	0.00
Duration (weeks)					
>8	3	-4.63	-8.44	-0.82	0.00

Discussion

This meta-analysis examined the impact of green tea consumption on key metabolic hormones—leptin, adiponectin, ghrelin, and insulin—across multiple RCTs. The results presented a multifaceted picture: while overall effects are largely non-significant except for ghrelin, subgroup analyses reveal specific conditions under which green tea may modulate these hormones, suggesting context-dependent efficacy influenced by dosage, duration, and participant characteristics.

For leptin, the random-effects meta-analysis of five trials (484 participants) found no significant overall change following green tea consumption. The high heterogeneity indicates considerable variability, likely stemming from differences in study design, participant demographics (e.g. BMI, age, or sex), or intervention specifics (e.g. catechin content or administration frequency). Subgroup analyses provided critical insights, showing significant leptin reductions at doses exceeding 1000 mg/day, durations less than 8 weeks, and BMI below 29 kg/m^2. These findings resonate with Rondanelli et al. who conducted a 60-day green tea extract intervention (approximately 300 mg/day

catechins) in overweight postmenopausal women and observed improved adipose tissue function, potentially linked to leptin modulation (Rondanelli et al. 2022). Similarly, Mielgo-Ayuso et al. reported metabolic improvements in obese women supplemented with EGCG at 300 mg/day for 12 weeks, suggesting that higher doses or shorter durations may amplify leptin effects in specific populations (Mielgo-Ayuso et al. 2014). The absence of publication bias bolsters confidence in these results, though the asymmetrical funnel plot hints at possible underrepresentation of smaller studies with null or opposing outcomes. A concern was also noted by Basu et al. who found variable lipid and weight responses in obese subjects with metabolic syndrome (Basu et al. 2010b).

Adiponectin analysis, based on seven trials (587 participants), revealed no significant overall effect, with substantial heterogeneity. This variability could reflect differences in green tea formulations, participant health status (such as metabolic syndrome vs. healthy), or trial duration. Subgroup analysis identified a significant adiponectin reduction at doses of 400–1000 mg, but not with duration or BMI, suggesting a dose-specific mechanism possibly tied to catechin bioavailability or receptor interactions. Several factors may explain this dose-specific reduction in adiponectin levels. First, the bioactive compounds in green tea, particularly catechins such as EGCG, may exhibit a dose-dependent effect on adiponectin regulation. At moderate dosages (400–1,000 mg/day), EGCG and other polyphenols may interact with signaling pathways, such as AMP-activated protein kinase (AMPK) or Peroxisome proliferator-activated receptor (PPAR) pathways, in a manner that suppresses adiponectin production or secretion. This effect weakens at lower doses (<400 mg/day) due to insufficient active compounds or at higher doses (>1,000 mg/day) where pathways may become saturated or trigger compensatory responses. Second, the moderate dosage range may align with a threshold where catechins of green tea influence adipose tissue metabolism optimally. Adiponectin, secreted by adipocytes, could be reduced at these doses due to changes in inflammation or oxidative stress responses, altering adipocyte function. Third, the lack of significant effects in duration and BMI subgroups suggests that the dose-specific reduction is not strongly modulated by these factors. However, the observed effect at 400–1,000 mg/day may reflect study-specific protocols, such as the timing of green tea administration or differences in catechin bioavailability.

However, this contrasts with Wu et al. who administered 500 mg/day green tea extract for 2 months in healthy postmenopausal women and found no hormonal changes (Wu et al. 2012). Additionally, Dostal et al. (2016a), who observed no adiponectin shifts after 12 months of 1315 mg/day catechins in overweight/obese postmenopausal women (Dostal et al. 2016b). Dostal et al. (2016b) further noted that the catechol-O-methyltransferase (COMT) genotype might influence adiponectin responses, hinting at genetic factors not captured in the meta-analysis (Dostal et al. 2016d). The lack of publication bias supports the reliability of the findings, yet the asymmetrical funnel plot suggests potential selective reporting, possibly excluding smaller studies with positive effects.

Ghrelin levels, evaluated in three trials (418 participants), demonstrated a significant overall decrease with green tea consumption (SMD: -4.63, 95% CI: -8.44 to -0.82, $p = 0.02$), pointing to a potential appetite-suppressing role. This aligns with Hill et al. who tested 270 mg/day EGCG for 12 weeks in obese subjects and suggested that green tea fat-reducing effects might involve appetite regulation, possibly via ghrelin suppression (Hill et al. 2007). The effect size is striking, but the extremely high heterogeneity ($I^2 = 98.98\%$, $p <$

0.0001) and evidence of publication bias (Egger's test, $p = 0.19$) urge caution. The limited trial number and funnel plot asymmetry indicate that these results may overrepresent studies with positive outcomes, a concern compounded by the lack of ghrelin-specific data in many cited studies such as Wu et al and Takahashi et al.(Takahashi et al. 2014; Wu et al. 2012). Mechanistically, catechins might inhibit ghrelin secretion via gut-brain signaling, a hypothesis warranting further exploration given green tea known polyphenol content.

Insulin analysis across eight trials (632 participants) showed no significant overall difference, with extreme heterogeneity reflecting diverse study conditions. Subgroup analyses revealed significant insulin reductions at durations of 8 weeks or less and BMI below 29 kg/m², but not with dosage. Takahashi et al. found that acute catechin-rich green tea (627 mg catechins) ingestion improved postprandial glucose in postmenopausal women, supporting the short-term effect (Takahashi et al. 2014). Dostal et al. (2017) observed COMT genotype-modified insulin responses after 12 months of 1315 mg/day catechins in overweight/obese postmenopausal women (Dostal et al. 2017), while Basu et al. (2010) reported lipid and glucose benefits with 440 mg/day catechins over 8 weeks in metabolic syndrome patients, reinforcing the BMI-related finding (Basu et al. 2010b). Conversely, Dostal et al. (2016a) found no long-term insulin changes, suggesting that chronic exposure may diminish the acute benefits (Dostal et al. 2016b). The differences in dosage and duration likely reflect variations in study protocols, participant compliance, and the pharmacokinetic properties of active compounds of green tea. For instance, higher doses may saturate metabolic pathways, eliciting stronger responses, while duration influences whether effects are acute or sustained. These factors, combined with participant characteristics like BMI, explain much of the observed heterogeneity (I^2 ranging from 86.48% to 99.57%). Publication bias and funnel plot asymmetry indicate selective reporting, possibly favoring studies with larger effects in smaller samples.

In line with our findings, a recent systematic review and dose–response meta-analysis by Asbaghi et al. (2024) reported that green tea extract supplementation significantly reduced body mass, BMI, body fat percentage, and malondialdehyde (MDA), while increasing total antioxidant capacity (TAC) and adiponectin, but had no significant effects on fat mass, leptin, or ghrelin. Compared to their results in the general population, our meta-analysis focusing on postmenopausal women revealed a different pattern: we observed a significant reduction in ghrelin, whereas effects on leptin, adiponectin, and insulin were largely non-significant except under specific conditions of dose, duration, or BMI. These discrepancies may reflect differences in study populations, as hormonal changes during menopause and the unique metabolic profile of postmenopausal women could modulate the responsiveness to green tea supplementation. Collectively, the evidence suggests that while green tea extract exerts consistent benefits on oxidative stress and body composition in broader populations, its influence on obesity-related hormones may be context-dependent, highlighting the need for tailored interventions in postmenopausal women.

The differences in dosage and duration likely reflect variations in study protocols, participant compliance, and the pharmacokinetic properties of active compounds of green tea. For instance, higher doses may saturate metabolic pathways, eliciting stronger responses, while duration influences whether effects are acute or sustained. These factors, combined with participant characteristics like BMI, explain much of the observed heterogeneity (I^2 ranging from 86.48% to 99.57%). Publication bias and funnel plot

asymmetry indicate selective reporting, possibly favoring studies with larger effects in smaller samples(Asbaghi et al. 2024).

In a broader context, these results suggest that the metabolic effects of green tea are not universal but they depend on intervention parameters and participant profiles. The significant ghrelin reduction supports a role in appetite control, potentially mediated by the interaction of EGCG with gastrointestinal pathways, as speculated by Hill et al. (Hill et al. 2007). Leptin and insulin reductions in shorter interventions and lower-BMI groups such as studies of Rondanelli et al. (Rondanelli et al. 2022) and Basu et al. (Basu et al. 2010b) may reflect heightened sensitivity in less obese individuals or an early catechin-driven boost in insulin sensitivity, as seen in Takahashi et al. (Takahashi et al. 2014). Dose-dependent adiponectin decrease (400–1000 mg/day) is unclear, potentially indicating a suppressive effect at moderate doses not sustained at higher ones, contrasting with null findings in Wu et al. (Wu et al. 2012) and Dostal et al. (2016a(Dostal et al. 2016b), 2016b (Dostal et al. 2016d)). The pervasive heterogeneity likely stems from inconsistent catechin dosages, participant metabolic baselines, and trial durations, while bias signals a need for more transparent reporting.

Strengths and limitations

One of the strengths of this meta-analysis lies in its exclusive inclusion of RCTs, which bolsters the robustness and credibility of our findings. Moreover, this meta-analysis is underpinned by several methodological merits. By restricting our scope to RCTs, we ensured the incorporation of evidence reflecting the pinnacle of interventional research quality. A comprehensive search strategy, spanning multiple databases, was employed to achieve extensive coverage of the pertinent literature. Furthermore, our meticulous quality appraisal, conducted using the Joanna Briggs Institute (JBI) critical appraisal checklist, guaranteed that only studies of high methodological rigor were included.

Nevertheless, several limitations warrant consideration. The substantial heterogeneity observed across studies, as evidenced by I^2 values surpassing 85%, points to considerable variability in study designs, participant demographics, and intervention protocols. Additionally, while publication bias did not reach statistical significance, the asymmetry detected in funnel plots suggests a potential risk of selective reporting. A further constraint is the relatively limited number of studies included, which may curtail the broader applicability of our conclusions.

Future studies

Future studies should focus on conducting large-scale, standardized RCTs using uniform green tea formulations and extended follow-up durations to more clearly define dose-response relationships and therapeutic benefits. Thereby providing robust evidence to inform clinical guidelines for managing metabolic health in postmenopausal women. Green tea should be regarded as a supplemental rather than a stand-alone treatment. Since it shows no significant effects on insulin, adiponectin, or leptin, future research should focus on comprehensive approaches that combine dietary phytochemicals with lifestyle modifications such as exercise or calorie restriction to mitigate menopause-related metabolic disorders.

This meta-analysis provides the first comprehensive evaluation of the impact of green tea on obesity-related hormones in postmenopausal women. Our study highlights the significant effect of green tea on reducing ghrelin levels, which may help mitigate appetite increases and visceral fat accumulation during this life stage. While the overall effects on leptin, adiponectin, and insulin were not significant, subgroup analyses suggest that green tea efficacy depends on dosage, intervention duration, and BMI. These findings suggested the potential of green tea as a dietary

intervention for managing metabolic health in postmenopausal women.

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Conflicts of interest

The authors declare no conflict of interests.

Availability of data

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References

Abdalla MMI, Jegasothy R (2020) Role of Ghrelin in Postmenopausal obesity. Int J Womens Health Reprod Sci 8:119–124

JBI Critical Appraisal Tools | JBI (2024) https://jbi.global/critical-appraisal-tools.

Andrade C (2020) Mean Difference, Standardized Mean Difference (SMD), and Their Use in Meta-Analysis: As Simple as It Gets. J Clin Psychiatry 81(5) doi:10.4088/JCP.20f13681

Asbaghi O, Rezaei Kelishadi M, Larky DA, et al. (2024) The effects of green tea extract supplementation on body composition, obesity-related hormones and oxidative stress markers: a grade-assessed systematic review and dose-response meta-analysis of randomised controlled trials. Br J Nutr 131(7):1125–1157 doi:10.1017/s000711452300260x

Bacha F, Saad R, Gungor N, Arslanian SA (2004) Adiponectin in youth: relationship to visceral adiposity, insulin sensitivity, and β-cell function. Diabetes Care 27(2):547–552

Bajaj M, Suraamornkul S, Piper P, et al. (2004) Decreased plasma adiponectin concentrations are closely related to hepatic fat content and hepatic insulin resistance in pioglitazone-treated type 2 diabetic patients. The journal of clinical endocrinology & metabolism 89(1):200–206

Barrea L, Pugliese G, Laudisio D, Colao A, Savastano S, Muscogiuri G (2021) Mediterranean diet as medical prescription in menopausal women with obesity: a practical guide for nutritionists. Crit Rev Food Sci Nutr 61(7):1201–1211

Basu A, Sanchez K, Leyva MJ, et al. (2010a) Green tea supplementation affects body weight, lipids, and lipid peroxidation in obese subjects with metabolic syndrome. J Am Coll Nutr 29(1):31–40

Basu A, Sanchez K, Leyva MJ, et al. (2010b) Green tea supplementation affects body weight, lipids, and lipid peroxidation in obese subjects with metabolic syndrome. J Am Coll Nutr 29(1):31–40 doi:10.1080/07315724.2010.10719814

Chen I-J, Liu C-Y, Chiu J-P, Hsu C-H (2016) Therapeutic effect of high-dose green tea extract on weight reduction: A randomized, double-blind, placebo-controlled clinical trial. Clinical nutrition 35(3):592–599

Cho SY, Park PJ, Shin HJ, et al. (2007) (−)-Catechin suppresses expression of Kruppel-like factor 7 and increases expression and secretion of adiponectin protein in 3T3-L1 cells. American Journal of Physiology-Endocrinology and Metabolism 292(4):E1166–E1172

Davis SR, Castelo-Branco C, Chedraui P, et al. (2012) Understanding weight gain at menopause. Climacteric 15(5):419–429

Dostal AM, Arikawa A, Espejo L, Bedell S, Kurzer MS, Stendell-Hollis NR (2017) Green tea extract and catechol-O-methyltransferase genotype modify the post-prandial serum insulin response in a randomised trial of overweight and obese post-menopausal women. Journal of human nutrition and dietetics 30(2):166–176

Dostal AM, Arikawa A, Espejo L, Kurzer MS (2016a) Long-term supplementation of green tea extract does not modify adiposity or bone mineral density in a randomized trial of overweight and obese postmenopausal women. The Journal of nutrition 146(2):256–264

Dostal AM, Arikawa A, Espejo L, Kurzer MS (2016b) Long-Term Supplementation of Green Tea Extract Does Not Modify Adiposity or Bone Mineral Density in a Randomized Trial of Overweight and Obese Postmenopausal Women. J Nutr 146(2):256–64 doi:10.3945/jn.115.219238

Dostal AM, Samavat H, Espejo L, Arikawa AY, Stendell-Hollis NR, Kurzer MS (2016c) Green tea extract and catechol-O-methyltransferase genotype modify fasting serum insulin and plasma adiponectin concentrations in a randomized controlled trial of overweight and obese postmenopausal women. The journal of nutrition 146(1):38–45

Dostal AM, Samavat H, Espejo L, Arikawa AY, Stendell-Hollis NR, Kurzer MS (2016d) Green Tea Extract and Catechol-O-Methyltransferase Genotype Modify Fasting Serum Insulin and Plasma Adiponectin Concentrations in a Randomized Controlled Trial of Overweight and Obese Postmenopausal Women1234. The Journal of Nutrition 146(1):38–45 doi:https://doi.org/10.3945/jn.115.222414

Espinoza García AS, Martínez Moreno AG, Reyes Castillo Z (2021) The role of ghrelin and leptin in feeding behavior: Genetic and molecular evidence. Endocrinologia, diabetes y nutricion 68(9):654–663 doi:10.1016/j.endien.2020.10.009

Fruebis J, Tsao T-S, Javorschi S, et al. (2001) Proteolytic cleavage product of 30-kDa adipocyte complement-related protein increases fatty acid oxidation in muscle and causes weight loss in mice. Proceedings of the National Academy of Sciences 98(4):2005–2010

Goodarzi MT, Babaahmadi-Rezaei H, Kadkhodaei-Eliaderani M, Haddadinezhad S (2007) Relationship of serum adiponectin with blood lipids, HbA1c, and hs-CRP in type II diabetic postmenopausal women. J Clin Lab Anal 21(3):197–200

Gower B, Nagy T, Goran M, Smith A, Kent E (2000) Leptin in postmenopausal women: influence of hormone therapy, insulin, and fat distribution. The Journal of Clinical Endocrinology & Metabolism 85(5):1770–1775

Henneman P, Janssens AC, Zillikens MC, et al. (2010) Menopause impacts the relation of plasma adiponectin levels with the metabolic syndrome. J Intern Med 267(4):402–9 doi:10.1111/j.1365-2796.2009.02162.x

Higgins JP, Thompson SG, Deeks JJ, Altman DG (2003) Measuring inconsistency in meta-analyses. Bmj 327(7414):557–60 doi:10.1136/bmj.327.7414.557

Hill AM, Coates AM, Buckley JD, Ross R, Thielecke F, Howe PR (2007) Can EGCG reduce abdominal fat in obese subjects? Journal of the American College of Nutrition 26(4):396S–402S

Jaballah A, Soltani I, Bahia W, et al. (2021) The relationship between menopause and metabolic syndrome: experimental and bioinformatics analysis. Biochem Genet 59(6):1558–1581

Kapoor E, Faubion SS, Kling JM (2019) Obesity update in women. J Womens Health 28(12):1601–1605

Kassab HS (2022) Leptin as a Biomarker in Nutrition and Metabolism: Applications to Diabetes Biomarkers in Nutrition. Springer, p 1–16

Khan N, Mukhtar H (2007) Tea polyphenols for health promotion. Life Sci 81(7):519–533

Kim DH, Vanella L, Inoue K, et al. (2010) Epoxyeicosatrienoic acid agonist regulates human mesenchymal stem cell-derived adipocytes through activation of HO-1-pAKT signaling and a decrease in

PPARγ. Stem cells and development 19(12):1863–73 doi:10.1089/scd.2010.0098

Kubota N, Yano W, Kubota T, et al. (2007) Adiponectin stimulates AMP-activated protein kinase in the hypothalamus and increases food intake. Cell metabolism 6(1):55–68

Liedtke S, Schmidt ME, Vrieling A, et al. (2012) Postmenopausal sex hormones in relation to body fat distribution. Obesity 20(5):1088–1095

Mielgo-Ayuso J, Barrenechea L, Alcorta P, Larrarte E, Margareto J, Labayen I (2014) Effects of dietary supplementation with epigallocatechin-3-gallate on weight loss, energy homeostasis, cardiometabolic risk factors and liver function in obese women: randomised, double-blind, placebo-controlled clinical trial. British Journal of Nutrition 111(7):1263–1271

Nagao T, Hase T, Tokimitsu I (2007) A green tea extract high in catechins reduces body fat and cardiovascular risks in humans. Obesity 15(6):1473–1483

Nagle DG, Ferreira D, Zhou Y-D (2006) Epigallocatechin-3-gallate (EGCG): chemical and biomedical perspectives. Phytochemistry 67(17):1849–1855

Olszanecka A, Pośnik-Urbańska A, Kawecka-Jaszcz K, Czarnecka D, Fedak D (2010) Adipocytokines and blood pressure, lipids and glucose metabolism in hypertensive perimenopausal women. Kardiol Pol 68(7):753–60

Picó C, Palou M, Pomar CA, Rodríguez AM, Palou A (2022) Leptin as a key regulator of the adipose organ. Rev Endocr Metab Disord 23(1):13–30 doi:10.1007/s11154-021-09687-5

Rains TM, Agarwal S, Maki KC (2011) Antiobesity effects of green tea catechins: a mechanistic review. The Journal of nutritional biochemistry 22(1):1–7

Reaven G, Abbasi F, McLaughlin T (2004) Obesity, insulin resistance, and cardiovascular disease. Recent Prog Horm Res 59:207–23 doi:10.1210/rp.59.1.207

Rezaie P, Mazidi M, Nematy M (2015) Ghrelin, food intake, and botanical extracts: A Review. Avicenna J Phytomed 5(4):271–81

Rigato M, Avogaro A, Vigili de Kreutzenberg S, Fadini GP (2020) Effects of basal insulin on lipid profile compared to other classes of antihyperglycemic agents in type 2 diabetic patients. The Journal of Clinical Endocrinology & Metabolism 105(7):2464–2474

Ríos-Hoyo A, Gutiérrez-Salmeán G (2016) New dietary supplements for obesity: what we currently know. Current obesity reports 5:262–270

Rolland YM, Perry III HM, Patrick P, Banks WA, Morley JE (2006) Leptin and adiponectin levels in middle-aged postmenopausal women: associations with lifestyle habits, hormones, and inflammatory markers—a cross-sectional study. Metabolism 55(12):1630–1636

Rondanelli M, Gasparri C, Perna S, et al. (2022) A 60-day green tea extract supplementation counteracts the dysfunction of adipose tissue in overweight post-menopausal and class I obese women. Nutrients 14(24):5209

Saltiel AR, Kahn CR (2001) Insulin signalling and the regulation of glucose and lipid metabolism. Nature 414(6865):799–806

Takahashi M, Miyashita M, Suzuki K, et al. (2014) Acute ingestion of catechin-rich green tea improves postprandial glucose status and increases serum thioredoxin concentrations in postmenopausal women. British journal of nutrition 112(9):1542–1550

Vona-Davis L, Howard-McNatt M, Rose D (2007) Adiposity, type 2 diabetes and the metabolic syndrome in breast cancer. Obes Rev 8(5):395–408

Waki H, Tontonoz P (2007) Endocrine functions of adipose tissue. Annu Rev Pathol 2:31–56 doi:10.1146/annurev.pathol.2.010506.091859

Wang J-C, Gray NE, Kuo T, Harris CA (2012) Regulation of triglyceride metabolism by glucocorticoid receptor. Cell & bioscience 2:1–9

Williams M, Hunter G, Kekes-Szabo T, et al. (1996) Intra-abdominal adipose tissue cut-points related to elevated cardiovascular risk in women. International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity 20(7):613–617

Wolfram S, Wang Y, Thielecke F (2006) Anti-obesity effects of green tea: from bedside to bench. Molecular nutrition & food research 50(2):176–187

Wu AH, Spicer D, Stanczyk FZ, Tseng C-C, Yang CS, Pike MC (2012) Effect of 2-month controlled green tea intervention on lipoprotein cholesterol, glucose, and hormone levels in healthy postmenopausal women. Cancer Prevention Research 5(3):393–402

Zamora-Ros R, Forouhi NG, Sharp SJ, et al. (2014) Dietary intakes of individual flavanols and flavonols are inversely associated with incident type 2 diabetes in European populations. The Journal of nutrition 144(3):335–343

Zhao L, Fu Z, Liu Z (2014) Adiponectin and insulin cross talk: the microvascular connection. Trends Cardiovasc Med 24(8):319–24 doi:10.1016/j.tcm.2014.08.001