REVIEW

The Effect of Canola Oil on Body Weight and Composition: A Systematic Review and Meta-Analysis of Randomized Controlled Clinical Trials

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ABSTRACT

A number of clinical trials have examined the effect of canola oil (CO) on body composition in recent years; however, the results have been inconsistent. The present investigation aims to examine the effect of CO on body weight (BW) and body composition using a systematic review and meta-analysis of controlled clinical trials. Online databases including PubMed, Scopus, and Google Scholar were searched up to February, 2018 for randomized controlled clinical trials that examined the effect of CO on anthropometric measures and body composition indexes in adults. The Cochrane Collaboration's tool was used to assess the risk of bias in individual studies. A random-effects model was used to evaluate the effect of CO consumption on several outcomes: BW, body mass index, waist circumference, hip circumference, waist-to-hip ratio, android-to-gynoid ratio, and body lean and fat mass. In total, 25 studies were included in the systematic review. The meta-analysis revealed that CO consumption reduces BW [weighted mean difference (WMD) = −0.30 kg; 95% CI: −0.52, −0.08 kg, $P = 0.007$; $n = 23$ effect sizes], particularly in participants with type 2 diabetes (WMD = −0.63 kg; 95% CI: −1.09, −0.17 kg, $P = 0.007$), in studies with a parallel design (WMD = −0.49 kg; 95% CI: −0.85, −0.14 kg, $P = 0.006$), in nonfeeding trials (WMD = −0.32 kg; 95% CI: −0.55, −0.09 kg, $P = 0.006$), and when compared with saturated fat (WMD = −0.40 kg; 95% CI: −0.74, −0.06 kg, $P = 0.019$). CO consumption did not significantly affect any other anthropometric measures or body fat markers ($P > 0.05$). Although CO consumption results in a modest decrease in BW, no significant effect was observed on other adiposity indexes. Further well-constructed clinical trials that target BW and body composition as their primary outcomes are needed. *Adv Nutr* 2019;10:419–432.

Keywords: canola oil, rapeseed oil, body weight, obesity, body mass index, systematic review, meta-analysis

Introduction

Obesity is now regarded as a major health concern, worldwide (1); in 2015, 603.7 million adults were obese and the overall prevalence of adulthood obesity was ∼12% (2). In addition, in 2016, 39% of men and women aged ≥18 y were overweight (3). Obesity increases the risk of several chronic diseases and disabilities such as insulin resistance, hypertension, dyslipidemia, type 2 diabetes (T2DM), cardiovascular disease morbidity and mortality (4–6), and several types of cancer (7–9). The subsequent complications of obesity impose an additional economic burden on health care systems (10–12). A decline in body weight (BW) of ∼5–10% weight may lead to a decrease in hypertension, elevated glycemic markers, abnormal blood lipids, and uric acid concentration (13–16).

Lifestyle change, of which diet is a major component, is regarded as the most important strategy for weight management (17). Several dietary components, such as protein, carbohydrate, and fiber, have been shown to be associated with BW and body composition (18–21). It has also been suggested that dietary fatty acid intake is associated with adiposity (22). For example, a large body of research has shown an inverse association between omega-3 PUFAs

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HR-D and MA contributed equally to this work.
Address correspondence to AS-A (e-mail: abargouei@ssu.ac.ir; abargouei@gmail.com).
Abbreviations used: ALA, α-linolenic acid; A:G, android-to-gynoid ratio; BW, body weight; CO, canola oil; HC, hip circumference; RCT, randomized controlled trial; T2DM, type 2 diabetes; WC, waist circumference; WHR, waist-to-hip ratio; WMD, weighted mean difference.

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and weight gain (22–24). This association may be driven by n–3 PUFAs' effects on fat oxidation (25) and on postprandial satiety in overweight and obese participants during weight loss (26).

Canola oil (CO) is a good source of oleic acid and α-linolenic acid (ALA) which can be converted to EPA and DHA in the human body (27). Furthermore, CO has reasonable ω-6-to-ω-3 fatty acid (2:1) and unsaturated-to-saturated fatty acid (15:1) ratios, which makes it a favorable dietary oil (28, 29). CO is one of the most widely consumed vegetable oils in the world which the universal trend toward replacing dietary oils with this oil is also increasing (30). A recent well-designed multicenter clinical trial done by Liu et al. (31), in which the effect of canola oil on anthropometric measurements was specifically investigated, reported a significant reduction in fat mass ($\sim$3.1 kg) after CO consumption compared with a high-PUFA dietary oil (a blend of flaxseed oil and safflower oil), $P < 0.05$. However, other randomized controlled trials (RCTs) reported inconsistent results in this regard. Some RCTs demonstrated a slight, but nonsignificant, reduction in BW, BMI, and body fat in participants who consumed CO (32–36) as well as nonsignificant reductions in waist circumference (WC) and waist-to-hip ratio (WHR), $P > 0.05$ (32–34). In contrast, several studies demonstrated a positive but nonsignificant relation between CO consumption and BMI (37), BW (31, 37), WC (37, 38), and WHR (39).

A narrative review that examined the effect of CO on different aspects of health (40) also examined the effect of CO consumption on weight loss. However, the review only included a limited number of studies on weight loss. Therefore, we aimed to perform a systematic review to summarize the randomized controlled clinical trials that examined the effect of CO consumption on BW and other anthropometric indexes compared with other sources of dietary fats. We also performed a meta-analysis to quantify the overall effects and to identify potential sources of heterogeneity across studies.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was used as a framework for reporting the current systematic review and meta-analysis (41). The study protocol was also registered in the International Prospective Register of Systematic Reviews (PROSPERO) database in February, 2017 (http://www.crd.york.ac.uk/PROSPERO) as CRD42017057100 (42).

Search strategy

A systematic literature search was conducted in PubMed and Scopus up to February, 2018 (the initial search was conducted on 28 April, 2016 and the updates were checked up to February, 2018) by using the following Medical Subject Headings (MeSH) and non-MeSH keywords: *1*) canola, colza, rapeseed, brassica rapa, oilseed rape, brassica napus, brassica juncea; *2*) Intervention Studies, intervention, controlled trial, randomized, randomised, random, randomly, placebo, assignment, clinical trial, and trial. Furthermore, the reference lists of included studies were checked to find additional related articles. The search strategy used for the online databases is provided in **Supplemental Table 1**. We also searched Google Scholar to find related articles not indexed in PubMed or Scopus.

Eligibility criteria

Published original articles with the following characteristics were included in the present study: *1*) randomized controlled clinical trial designs (RCTs); *2*) conducted on adults ($\geq$18 y of age); and *3*) reported the effect of oral ingestion of pure or conventional CO on BW or other anthropometric indexes related to body compositions. Studies were excluded if *1*) they were conducted in children or adolescents; *2*) the intervention period was $<$2 wk; *3*) they used enriched or modified CO; or *4*) CO consumption was lower than the amounts defined as reasonable based on previous investigations (43) ($<$10 g/d; previous studies examining the effect of CO used $\geq$10 g/d). Two researchers (HR-D and MA) independently screened the titles and abstracts to find the relevant articles based on the inclusion and exclusion criteria. Disagreements were resolved by discussion with the senior author (AS-A).

Data extraction

Eligible RCTs were reviewed and the following data were extracted independently by 2 investigators (HR-D and MA): publication details (first author's full name, publication year, and country in which the study was conducted); subjects' characteristics (age, health status, and gender); study characteristics [number of participants, type of control treatment, duration of the intervention, study design, method of treatments (feeding or nonfeeding trial), amount of CO and control oil used]; and outcomes {mean and SD for baseline, change and postintervention values for the outcomes of interest [BW, BMI, hip circumference (HC), WC, WHR, android-to-gynoid ratio (A:G), and lean and fat mass]} by treatment arm. Possible conflicts were resolved by discussion with the senior author (AS-A).

Quality assessment

The Cochrane Collaboration's tool for the assessment of the risk of bias was used to assess the quality of the studies included in this systematic review and meta-analysis (44). All 5 domains of the tool, including selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete data outcome), and reporting bias (selective outcome reporting), were evaluated. The articles were categorized as Yes (low risk of bias), No (high risk of bias), or Unclear for each domain. Finally, the overall quality of the studies was categorized into weak, fair, or good, if $<$3, 3, or $\geq$4 domains were rated as low risk, respectively.

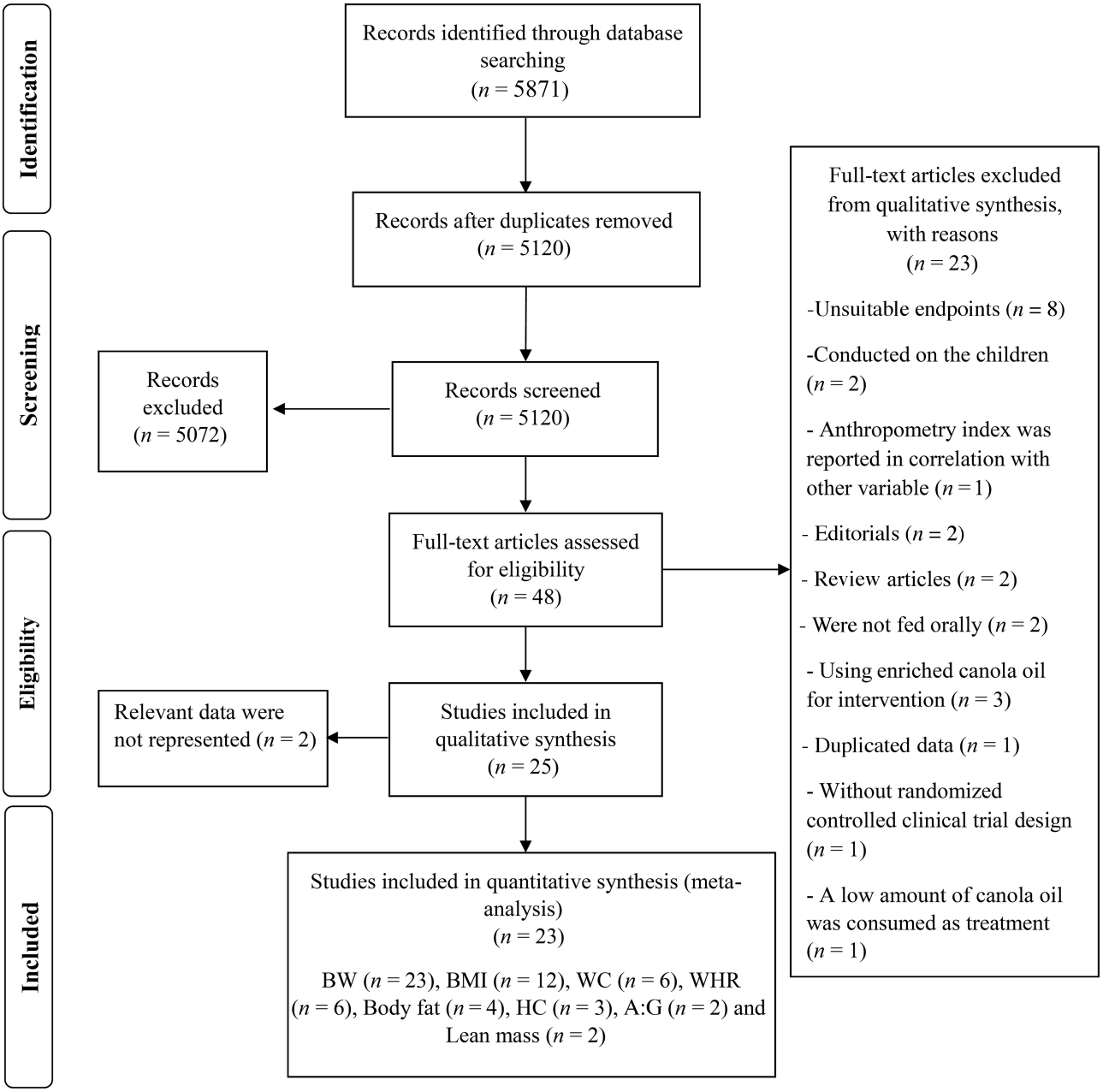

FIGURE 1 The study selection process. In total, 25 and 23 studies were included in the qualitative and quantitative syntheses, respectively. Twenty-three effect sizes on BW, 12 on BMI, 6 on WC, 6 on WHR, 4 on body fat, 3 on HC, 2 on A:G, and 2 on lean mass. A:G, android-to-gynoid fat ratio; BW, body weight; HC, hip circumference; WC, waist circumference; WHR, waist-to-hip ratio.

Statistical analysis

The change in mean BW, BMI, WC, HC, body fat percentage, WHR, A:G, and lean mass and the corresponding SDs were extracted from each study arm (CO and control) in order to calculate the mean difference and SE for inclusion in the meta-analysis. A number of studies reported the change values for BW (45, 33, 36, 38, 46, 47), BMI (45, 33), body fat (45, 33), lean mass (33), WC (33, 38), and WHR (45). However, the remaining studies did not provide data on changes in anthropometric indexes. Therefore, this statistic was calculated by using 0.5 as the correlation coefficient between baseline and after-treatment values. To ensure the meta-analysis was not sensitive to the selected correlation coefficient (r = 0.5), all analyses were repeated using correlation coefficients of 0.2 and 0.8.

The weighted mean differences (WMDs) and corresponding 95% CIs were calculated using the DerSimonian and Laird random-effects model (48) because it takes the between-study heterogeneity into account. The heterogeneity between studies was examined using Cochran's Q test and

the I-squared statistic (I^2) (49). Several subgroup analyses based on sex (male, female, and both), study duration ($\leq$4 wk, 5–8 wk, 12–16 wk, and $\geq$24 wk), feeding procedure (feeding, nonfeeding trial), control treatment (olive oil, sunflower oil, safflower oil, a blend of corn and safflower oils, a blend of flax and safflower oils, fish oil, rice bran oil, control diet, saturated fat, nuts, whole wheat), study design (parallel, crossover), and subjects' characteristics (hyperlipidemia, T2DM, obesity, other diseases, healthy) were conducted to check for potential sources of heterogeneity. Sensitivity analyses were conducted to determine whether the overall effects were dependent on a specific study (50). Publication bias was assessed using Begg's funnel plots and statistical asymmetry tests (Egger's test and Begg's test) (51). All analyses were conducted using STATA, version 11.2 (Stata Corp) and $P \leq 0.05$ was considered as statistically significant.

Results

Literature search

A total of 5871 citations were obtained from the initial database search. After the removal of duplicates, 5120 articles remained for screening of the titles and abstracts, from which 47 full-text articles underwent further assessment (**Figure 1**). Twenty-two studies (40, 52–72) were excluded from the systematic review for the following reasons: 8 studies did not report the relevant endpoints (52–59); enriched CO was used in 3 studies (68–70); 2 studies enrolled children or adolescents (60, 61); 2 studies did not provide CO orally (66, 67); 4 manuscripts were review articles (40, 63) or editorials (64, 65); 1 did not report the direct effect of CO on BMI (62); 1 study was a duplicate of a study already included in the systematic review (71); 1 trial used a very low amount of CO (4 g/d) as a placebo for conjugated linoleic acid (72). In total, 25 clinical trials were included in the systematic review (45, 31–39, 46, 47, 73–85). However, 2 of the included studies (76, 85) did not report the data required for meta-analysis. We contacted the authors of these 2 studies twice, but did not receive any response. These 2 studies were therefore excluded, leaving 23 studies for inclusion in the meta-analysis (45, 31–39, 46, 47, 73–75, 77–84) (Figure 1).

Study characteristics

The included studies were published from 1991 to 2017 and included a total of 1280 participants (**Table 1**). The duration of the interventions ranged from 3 to 28 wk (33, 34).

CO was provided to participants using different methods: using a vehicle like foods (38, 47, 73, 74, 81) or high-CO diets (31, 34, 39, 46, 77–80, 82–85). The edible oils used for the control groups and periods also varied: isocaloric diets based on SFAs (79, 82, 83, 85), olive oil (46, 77, 78), sunflower oil (39, 80), dairy fats (34), a blend of corn and safflower oil (31), and safflower (84). Some studies used diets supplemented with a specific amount of CO for the intervention group (45, 32, 33, 35–37, 75, 76), while the control groups consumed the same diets supplemented with an equivalent amount of sunflower oil (32, 36), olive oil (45, 33, 35, 76), or fish oil (75) or simply consumed a baseline diet (37). The trial design, location, and feeding or nonfeeding design, as well as other study characteristics, are presented in Table 1.

Assessment of risk of bias

Among 25 studies included in the systematic review, 8 were categorized as good quality (31, 35, 36, 38, 73, 75, 77, 84), 6 were fair quality (45, 32, 47, 79, 82, 83), and 11 were low quality (33, 34, 37, 39, 46, 74, 76, 78, 80, 81, 85). The details of the risk of bias in individual studies according to the domains used by the Cochrane Collaboration's tool are provided in **Table 2**. A summary of the risk of bias assessment is also provided in **Supplemental Figure 1**.

Findings from the meta-analysis

BW.

In total, 23 effect sizes from 22 studies studies (45, 31–39, 46, 47, 73–75, 77–80, 82–84) with 1078 participants examined the effect of CO consumption on BW. Overall, CO consumption significantly reduced BW by 0.3 kg compared with controls (P = 0.007) (**Figure 2**). The between-study heterogeneity was nonsignificant ($P > 0.05$, I^2 = 0%). The results of the overall meta-analysis, as well as subgroup analyses and the heterogeneity tests, are presented in **Table 3**.

Subgroup analysis based on gender revealed that the effect was significant in studies which provided the effect for both genders ($P = 0.005$) as well as female participants ($P = 0.033$); however, the test for between-group differences was nonsignificant (P = 0.08). Furthermore, CO intake significantly reduced BW in nonfeeding trials, in the trials using a parallel design, in participants with hyperlipidemia, and in those with T2DM; and also CO reduced BW when compared with SFAs and rice bran oil as the control treatments ($P < 0.05$) (Table 3). The between-group heterogeneity was nonsignificant for all subgroup analyses ($P > 0.05$).

BMI.

Twelve studies (n = 577) were included in the meta-analysis (45, 32–35, 37, 39, 62, 74, 78–80). The analysis revealed that CO consumption did not significantly affect BMI in adults (P = 0.46). The effect was also nonsignificant in different subgroups (**Table 4**).

WC.

Six studies with 481 participants were included in the meta-analysis (32, 33, 35, 37, 38, 80). **Supplemental Table 2** shows the overall effect of CO consumption on WC and by several subgroups. The overall effect was nonsignificant (P = 0.2). However, the subgroup analysis showed that CO intake reduces WC when compared with the usual diet and in trials with follow-up duration $\leq$4 wk ($P < 0.001$). The between-group heterogeneity was significant for subgroup analyses based on duration, control group, and subjects' characteristics ($P < 0.05$).

TABLE 1 Characteristics of studies reporting the effect of canola oil intake on body weight and other anthropometric indexes included in the systematic review[1]

	Trial characteristics			Intervention characteristics			Participants			
Authors (ref)	Design	Location	Feeding trial	Duration (wk)	Int treatment/period	Cn treatment/period	Characteristics	Int/Cn number	Overall (*n*)	Outcome
Salar et al. (36)	P	Iran	No	8	Balance diet[2] + 30 g CO/d	Balance diet[2] + 30 g SO/d	Type 2 diabetes mellitus	24/48	72	Secondary: BW
Kruse et al. (45)	P	Germany	No	4	50 g CO/d	50 g OO/d	Moderate obesity	9/9	18	Secondary: BW, BMI, body fat, WHR
Nigam et al. (35)	P	India	No	6	Standard diet[2] + ≤20 g CO/d	Two groups: *1*) Standard diet[2] + ≤20 g OO/d *2*) Standard diet[2] + ≤20 g soybean and safflower oils/d	Nonalcoholic fatty liver disease	33/60	93	Secondary: BW, BMI, WC
Baxheinrich et al. (33)	P	Germany	No	28	Hypoenergetic diet + 30 g CO/d	Hypoenergetic diet + 30 g OO/d	Metabolic syndrome	41/40	81	Primary: BW, BMI, WC, body fat, lean mass
Azemati et al. (32)	P	Iran	No	12	Normal diet + 40 g CO/d	Normal diet + 40 g SO/d	Postmenopausal women with osteoporosis	20/20	40	Secondary: BW, BMI, WC, HC, WHR
Iggman et al. (34)	C	Sweden	Yes	3	Isocaloric diet based on CO	Isocaloric diet based on dairy fat (SFAs)	Hyperlipidemia	20/20	20	Secondary: BW, BMI
Liu et al. (31)	C	Multicenter	Yes	4	Weight-maintaining diet based on CO (18% of total calories)	Two groups: *1*) Weight-maintaining diet based on corn and safflower oils (18% of total calories) *2*) Weight-maintaining diet based on flax and safflower oils (18% of total calories)	Subjects with central obesity	101/101	101	Primary: BW, fat mass, lean mass, A:G
Saedi et al. (80)	P	Iran	No	24	CO as regular consumption	SO as regular consumption	Hyperlipidemia	52/44	96	Primary: BW, BMI, WC, HC
Seppanen-Laakso et al. (81)	P	Finland	No	6	CO as water-oil emulsion (17 g/d)	Two groups: *1*) OO as water-oil emulsion (19 g/d) *2*) Breads containing margarine + butter	Hyperlipidemia	23/34	57	Secondary: BMI
Albert et al. (73)	C	Australia	No	8	1000 mg CO as a capsule	Krill and salmon oil as a capsule	Overweight	47/47	47	Secondary: BW, fat mass, A:G
Junker et al. (46)	P	Germany	Yes	4	High-fat diet containing CO + CO-enriched bread	Two groups: *1*) High-fat diet containing OO + OO-enriched bread *2*) High-fat diet containing SO + SO-enriched bread	Healthy	18/40	58	Secondary: BW
Uusitupa et al. (83)	C	Finland	No	3	Diet based on CO	Diet based on butter (SFAs) + small amount of CO	Healthy	10/10	10	Secondary: BW
McKenney et al. (47)	C	United States	No	6	Low-fat diet + oatmeal raisin cookies made from CO (3 pieces)	Low-fat diet + oatmeal raisin cookies made from coconut oil (3 pieces)	Hyperlipidemia	11/11	11	Secondary: BW
Öhrvall et al. (79)	C	Sweden	No	3	Isocaloric diet based on CO	Isocaloric diet based on SFAs	Healthy	20/20	20	Secondary: BW, BMI, WHR

(*Continued*)

TABLE 1 (*Continued*)

	Trial characteristics			Intervention characteristics			Participants			
Authors (ref)	Design	Location	Feeding trial	Duration (wk)	Int treatment/period	Cn treatment/period	Characteristics	Int/Cn number	Overall (*n*)	Outcome
Karvonen et al. (76)	C	Finland	No	4	Cheese based on RO	Cheese based on milk fat	Hyperlipidemia	31/31	31	Secondary: BW
Warensjö et al. (85)	C	Sweden	No	3	Diet based on CO	Diet based on SFAs	With overweight and moderate hyperlipidemia	20/20	20	Secondary: BW
Jenkins et al. (38)	P	Canada	No	12	CO-enriched bread (4.5 slices: 31 g CO/d or 14% of total calories)	Whole-wheat bread without CO (7.5 slices/d)	Type 2 diabetes mellitus	70/71	141	Secondary: BW, WC
Södergren et al. (82)	C	Sweden	No	4	Diet based on CO	Diet based on SFAs	Hyperlipidemia	10/9	19	Secondary: BW
Kratz et al. (77)	P	Germany	Yes	4	Diet based on CO	Two groups: *1*) Diet based on SO *2*) Diet based on OO	Healthy	17/38	55	Secondary: BW
Nydahl et al. (78)	C	Sweden	Yes	3.5	Diet based on CO (32.9 ± 14.2 g CO/d)	Diet based on OO (32.9 ± 14.2 g OO/d)	Hyperlipidemia	22/22	22	Secondary: BW, BMI
Chisholm et al. (74)	C	New Zealand	No	6	Low-fat diet + cereal containing 15 g CO/d	Low-fat diet + 30 g nuts/d	Healthy	28/28	28	Secondary: BW, BMI, WHR
Noroozi et al. (37)	P	Iran	No	4	Low-calorie diet + 30 g CO/d	Low-calorie diet	Hyperlipidemia	30/30	60	Secondary: BW, BMI, WC, HC, WHR
Gustafsson et al. (39)	P	Sweden	Yes	3	Diet based on CO (≤30% of total calories)	Diet based on SO (≤30% of total calories)	Hyperlipidemia	46/49	95	Secondary: BW, BMI, WHR
Wardlaw et al. (84)	P	United States	Yes	8	Diet based on CO (39 ± 1% of total calories)	Diet based on safflower oil (39 ± 1% of total calories)	Healthy	16/16	32	Secondary: BW
Herrmann et al. (75)	P	Germany	No	4	Regular diet + 12 g CO/d	Regular diet + 12 g fish oil	Coronary artery disease	18/35	53	Secondary: BW

[1] Feeding trials were defined as those trials in which the study team provided all food items (canola oil and other food items) for the participants. If food items were not fully provided by the research team, the study was categorized as a nonfeeding trial. A:G, android-to-gynoid fat ratio; BW, body weight; C, crossover; Cn, control; CO, canola oil; HC, hip circumference; Int, intervention; OO, olive oil; P, parallel; RO, rapeseed oil; SO, sesame oil; WC, waist circumference; WHR, waist-to-hip ratio.
[2] Balance diet: a diet with 55% carbohydrate, 18% protein, and 27% fat; standard diet: a diet with 15–21% protein (1–1.5 g/kg of desirable BW), 55–70% carbohydrate, and 20% fat.

TABLE 2 Study quality and risk of bias assessment using the Cochrane Collaboration's tool[1]

Study	Sequence generation	Allocation concealment	Blinding of participants or personnel	Blinding of outcome assessment	Incomplete outcome data	Selective outcome reporting	Score	Quality
Jenkins et al. (38)	✓	?	?	✓	✓	✓	4	Good
Södergren et al. (82)	?	?	✓	?	✓	✓	3	Fair
Kratz et al. (77)	✓	✓	✓	?	✓	✓	5	Good
Nydahl et al. (78)	?	?	?	?	✓	✓	2	Low
Chisholm et al. (74)	?	?	?	?	✓	✓	2	Low
Noroozi et al. (37)	?	?	7	?	✓	✓	2	Low
Gustafsson et al. (39)	?	?	?	?	✓	✓	2	Low
Wardlaw et al. (84)	?	?	✓	✓	✓	✓	4	Good
Herrmann et al. (75)	?	✓	✓	?	✓	✓	4	Good
Salar et al. (36)	✓	?	✓	✓	✓	✓	5	Good
Kruse et al. (45)	✓	?	?	?	✓	✓	3	Fair
Nigam et al. (35)	✓	?	?	✓	✓	✓	4	Good
Iggman et al. (34)	?	?	7	7	✓	✓	2	Low
Baxheinrich et al. (33)	?	?	?	?	?	✓	1	Low
Azemati et al. (32)	?	?	✓	?	✓	✓	3	Fair
Saedi et al. (80)	?	?	?	?	✓	✓	2	Low
Seppanen-Laakso et al. (81)	?	?	?	?	✓	✓	2	Low
Liu et al. (31)	✓	✓	✓	?	✓	✓	5	Good
Albert et al. (73)	✓	✓	✓	✓	✓	✓	6	Good
Junker et al. (46)	?	?	?	?	✓	✓	2	Low
Uusitupa et al. (83)	?	?	?	✓	✓	✓	3	Fair
McKenney et al. (47)	?	?	✓	?	✓	✓	3	Fair
Öhrvall et al. (79)	?	?	✓	?	✓	✓	3	Fair
Karvonen et al. (76)	?	?	✓	?	7	7	1	Low
Warensjö et al. (85)	?	?	?	?	7	7	0	Low

[1] ✓, low risk of bias; 7, high risk of bias; ?, unclear risk of bias.

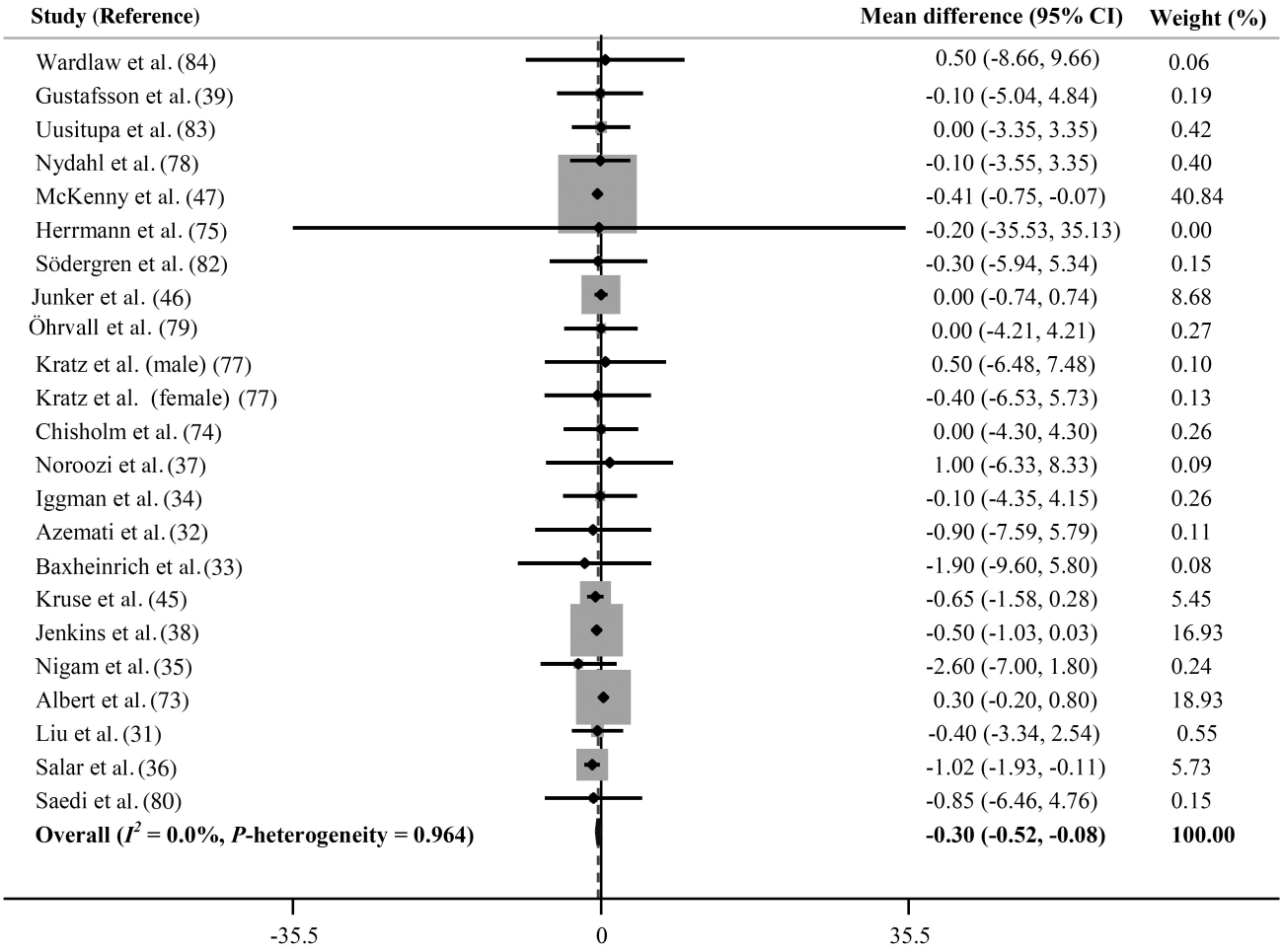

FIGURE 2 Forest plot of the effect of canola oil consumption on body weight using a random-effects model.

Body fat.

The effect of CO consumption on body fat was considered in 4 clinical trials (45, 31, 33, 73) (n = 247). CO did not significantly affect body fat (P = 0.564). The effect was also nonsignificant in different subgroups. The results for the overall and subgroup analyses are reported in **Supplemental Table 3**.

WHR.

Six studies (45, 32, 37, 39, 74, 79) with 261 participants were included in this meta-analysis. The overall analysis illustrated a nonsignificant effect of CO on WHR in adults (P = 0.968). The effect was also nonsignificant in different subgroups (**Supplemental Table 4**).

HC, lean body mass, and A:G.

These analyses revealed that CO ingestion does not significantly affect HC (WMD = −0.24 cm; 95% CI: −3.01, 2.54 cm, P = 0.867) (32, 37, 80), lean body mass (WMD = 0.01; 95% CI: −0.16, 0.19, P = 0.874) (31, 33), or A:G ratio (WMD = −0.01; 95% CI: −0.03, 0.01, P = 0.271) (31, 73). No evidence of heterogeneity was seen between the included studies ($P > 0.05$, I^2 = 0.0%).

Sensitivity analysis and publication bias

The sensitivity analysis, in which 1 study at a time was omitted, demonstrated that with the removal of the study by McKenney et al. (47) the effect of CO on BW became nonsignificant (WMD = −0.08 kg; 95% CI: −0.30, 0.14 kg, P = 0.467). The removal of the remaining studies, one by one, did not substantially change the effect of CO consumption on BMI, WC, body fat, or WHR. Changing the correction coefficient, using 0.2 and 0.8, also did not alter the outcomes.

Although slight asymmetries were seen when considering the various funnel plots, no significant publication bias was identified for the meta-analyses of BW (Begg's test, P = 0.635; Egger's test, P = 0.755), BMI (Begg's test, P = 0.451; Egger's test, P = 0.204), WC (Begg's test, P = 0.06; Egger's test, P = 0.52), or WHR (Begg's test, P = 1; Egger's test, P = 0.861). However, significant asymmetry was noted in the meta-analysis of CO on body fat (Begg's test, P = 0.086; Egger's test: P = 0.033), but the overall effect remained unchanged after the trim and fill analysis.

TABLE 3 The effect of canola oil intake on body weight in adults, overall and by subgroups, using a random-effects model[1]

Study group	Trials/participants, *n/n*	Meta-analysis		Heterogeneity			
		Weighted mean difference (95% CI)	*P*-effect	*Q* statistic	*P*-within group	I^2 (%)	*P*-between group
Sex	—	—		—	—	—	0.083
Female	5/166	−0.91 (−1.75, −0.07)	0.033	0.44	0.979	0.0	—
Male	6/230	0.06 (−0.37, 0.49)	0.788	4.56	0.472	0.0	—
Both	14/785	−0.37 (−0.64, −0.11)	0.005	1.67	1.000	0.0	—
Duration	—	—		—	—	—	0.836
≤4 wk	13/492	−0.23 (−0.76, 0.30)	0.402	1.36	1.000	0.0	—
5–8 wk	6/228	−0.31 (−0.85, 0.23)	0.259	9.37	0.095	46.6	—
12–16 wk	2/181	−0.50 (−1.03, 0.02)	0.22	0.01	0.907	0.0	—
24 wk	2/177	−1.21 (−5.75, 3.32)	0.60	0.05	0.829	0.0	—
Feeding status	—	—		—	—	—	0.999
Fed	8/344	−0.03 (−0.7, 0.65)	0.938	0.12	1.000	0.0	—
Unfed	15/734	−0.32 (−0.55, −0.09)	0.006	10.07	0.757	0.0	—
Control group	—	—		—	—	—	0.22
Olive oil	7/258	−0.23 (−0.79, 0.33)	0.426	1.66	0.948	0.0	—
Sunflower oil	7/352	−0.40 (−0.96, 0.16)	0.158	3.04	0.804	0.0	—
Safflower oil	2/95	−2.02 (−5.99, 1.95)	0.318	0.36	0.550	0.0	—
Corn and safflower oils	1/101	−0.40 (−3.34, 2.54)	0.79	0	—	—	—
Flax and safflower oils	1/101	−0.70 (−3.67, 2.27)	0.644	0	—	—	—
Control diet	1/60	1.00 (−6.33, 8.33)	0.789	0	—	—	—
Saturated fat	5/80	−0.40 (−0.74, −0.06)	0.019	0.11	0.998	—	—
Fish oil	2/100	0.30 (−0.20, 0.80)	0.24	0	0.978	0.0	—
Nut	1/28	0.00 (−4.30, 4.30)	1.000	0	—	—	—
Rice bran	1/49	−1.22 (−1.98, −0.46)	0.002	0	—	—	—
Whole wheat	1/141	−0.50 (−1.03, 0.03)	0.064	0	—	—	—
Design	—	—		—	—	—	0.560
Parallel	14/800	−0.49 (−0.85, −0.14)	0.006	4.46	0.985	0.0	—
Crossover	9/278	−0.18 (−0.46, 0.09)	0.193	5.34	0.721	0.0	—
Subjects' characteristics	—	—		—	—	—	0.134
Hyperlipidemia	7/323	−0.40 (−0.74, −0.07)	0.019	0.23	1.000	0.0	—
T2DM	2/188	−0.63 (−1.09, −0.17)	0.007	0.94	0.333	0.0	—
Obesity	5/202	0.08 (−0.36, 0.51)	0.731	3.24	0.519	0.0	—
Healthy	5/128	0.00 (−0.70, 0.70)	0.993	0.01	1.000	0.0	—
Other	4/237	−2.04 (−5.34, 1.27)	0.227	0.19	0.980	0.0	—
Overall	23/1078	−0.30 (−0.52, −0.08)	0.007	11.64	0.964	0.0	—

[1]T2DM, type 2 diabetes mellitus.

Discussion

This systematic review and meta-analysis of controlled clinical trials revealed that CO intake significantly decreases BW; however, CO intake did not significantly affect BMI, WC, body fat, WHR, HC, lean body mass, or A:G. Subgroup analyses affirmed that CO intake might decrease BW in female participants but not male subjects; also its reducing effect was observed in nonfeeding trials, studies with a parallel design, studies which compared CO with SFAs, and those subjects with hyperlipidemia or T2DM. Furthermore, subgroup analysis showed that WC was reduced when CO was compared with the usual diet and in studies that lasted for ≤4 wk.

Canola oil is the third-largest source of edible plant oil after soybean and palm oil (30). It is rich in both PUFAs and MUFAs (28, 86). ALA is the major PUFA of CO. This fatty acid is an essential fatty acid, which can be metabolized to EPA and DHA (87, 88). In addition, the beneficial effects of CO may be due to the high content of MUFAs (64.4%), a favorable ratio of unsaturated to saturated fatty acids (15:1), and a favorable ratio of ω-6 to ω-3 fatty acids (2:1) (28).

The evidence has shown that the storage and oxidization properties of fatty acids are involved in BW control. SFAs are stored in adipose tissue rather than being oxidized (89, 90); however, PUFAs (91) and MUFAs (91, 92) are oxidized. High-MUFA diets may increase thermogenesis, which stimulates the sympathetic nervous system (93–95). Based on prospective studies, high MUFA intake from olive oil (96) or from a Mediterranean diet (97) does not cause weight gain or obesity. Several studies have also revealed that ω-3 fatty acids can be helpful in obesity treatment (98–100). ω-3 PUFAs regulate proliferation, differentiation, and apoptosis of adipocytes (101). Results from a review study showed that increasing the intake of long-chain ω-3 PUFAs reduces BW and body fat in individuals who are either overweight or obese, by altering the expression of genes that increase fat oxidation in adipose, liver, and other tissues, and by reducing the fat deposition in adipose tissue (98). In addition, fats play an important role in hunger by eliciting satiety signals in the gastrointestinal tract (102). An inverse association was demonstrated between fatty acid chain length and hunger (103) in a randomized crossover study of CO and safflower oil, which significantly increased the feeling

TABLE 4 The effect of canola oil intake on BMI in adults, overall and by subgroups, using a random-effects model

Study group	Trials/participants, *n/n*	Meta-analysis		Heterogeneity			
		Weighted mean difference (95% CI)	*P*-effect	*Q* statistic	*P*-within group	I^2 (%)	*P*-between group
Sex	—	—	—	—	—	—	0.576
Female	1/40	−0.30 (−2.23, 1.63)	0.761	0	—	—	—
Male	2/81	−0.27 (−0.70, 0.16)	0.216	0.05	0.817	0.0	—
Both	9/456	−0.02 (−0.24, 0.20)	0.873	0.55	1.000	0.0	—
Duration	—	—	—	—	—	—	0.95
≤4 wk	6/235	−0.06 (−0.26, 0.15)	0.571	1.11	0.953	0.0	—
5–8 wk	3/125	−0.16 (−1.11, 0.78)	0.734	0.19	0.908	0.0	—
12–16 wk	1/40	−0.30 (−2.23, 1.63)	0.761	0	—	—	—
24 wk	2/177	−0.40 (−1.68, 0.89)	0.545	0.06	0.814	0.0	—
Feeding status	—	—	—	—	—	—	0.608
Fed	3/139	−0.04 (−0.64, 0.55)	0.895	0.03	0.987	0.0	—
Unfed	9/438	−0.06 (−0.27, 0.15)	0.580	3.11	0.928	0.0	—
Control group	—	—	—	—	—	—	0.999
Olive oil	5/230	−0.19 (−0.56, 0.19)	0.329	2.24	0.691	0.0	—
Sunflower oil	3/231	−0.12 (−0.92, 0.68)	0.767	0.12	0.941	0.0	—
Safflower oil	1/63	−0.50 (−2.48, 1.48)	0.621	0	—	—	—
Control diet	1/60	0.30 (−2.36, 2.96)	0.825	0	—	—	—
Saturated fat	2/40	0.00 (−0.25, 0.25)	1.000	0	1.000	0.0	—
Nut	1/28	0.00 (−1.21, 1.21)	1.000	0	—	—	—
Margarine	1/34	−0.30 (−2.62, 2.02)	0.8	0	—	—	—
Design	—	—	—	—	—	—	0.594
Parallel	8/487	−0.24 (−0.60, 0.13)	0.198	0.55	0.999	0.0	—
Crossover	4/90	−0.01 (−0.24, 0.23)	0.959	0.04	0.998	0.0	—
Subjects' characteristics	—	—	—	—	—	—	0.896
Hyperlipidemia	6/327	−0.07 (−0.60, 0.47)	0.806	0.21	0.999	0.0	—
Obesity	1/18	−0.26 (−0.70, 0.18)	0.247	0	—	—	—
Healthy	2/48	0.00 (−0.25, 0.25)	1.000	0	1.000	0.0	—
Other	3/184	−0.46 (−1.62, 0.70)	0.439	0.04	0.978	0.0	—
Overall	12/577	−0.07 (−0.27, 0.12)	0.460	1.71	0.999	0.0	—

of fullness and decreased the sensation of hunger. It has been shown that cholecystokinin secretion increases with CO intake, which in turn has a satiating effect in the ileum (104). In addition, CO contains lower proportions of SFAs (6.9%) in comparison to corn (13.8%), olive (15.2%), rice bran (20.6%), and soybean (15.1%) oils, and it is a rich source of unsaturated fatty acids (28). A higher ratio of PUFAs to SFAs in the diet, defined as the P/S index (∼3.2–4.1 for CO) (28, 105), may alter the nutrients' metabolism, decrease deposition of fats (106), and affect utilization of fatty acids (107, 108), which subsequently affects BW.

In the current study, CO consumption did not affect other anthropometric variables. A European prospective study of cancer and nutrition (109), as well as other studies (110, 111), did not demonstrate an association between types of fat and obesity. Among plant oils, flaxseed oil shares some similar features with CO, including a high content of unsaturated fatty acids (especially linoleic acid and ALA content) and low saturated fats (112). Flaxseed oil contains much more ALA than CO (54.2% for flaxseed oil compared with 8.3% for CO), whereas CO has a larger proportion of MUFAs (64.4% for CO compared with 22% for flaxseed oil) (105). However, a recent meta-analysis of clinical trials did not demonstrate a significant effect of flaxseed oil on adiposity indexes (113).

To the best of our knowledge, this is the first systematic review and meta-analysis examining the effect of CO on BW and other body fat indexes. We are aware of only a narrative review done by Lin et al. (40) which concerned different outcomes including effects of CO consumption on blood lipid profile and peroxidation, inflammation, insulin sensitivity and glucose tolerance, energy metabolism, and risk of cancers. Lin et al. (40) also briefly examined CO utilization and weight loss; however, the review of this outcome was limited.

There are a number of limitations to our review that should be noted. We found that CO consumption significantly reduced BW, but this effect was not seen for BMI or other markers of body composition. This is somewhat surprising with respect to BMI, because the height of the study participants would not change during the trial. This may be due to the difference in the number of studies included in the meta-analysis for BW and BMI. We tested this hypothesis by restricting the BW meta-analysis to those studies which also provided data for BMI. The analysis showed that the effect of CO on BW in this subset of studies became nonsignificant (WMD = −0.49 kg; 95% CI: −1.28, 0.30 kg, P = 0.222). This suggests that the inconsistency of the effect of CO on BMI and BW may be because the studies which were included in these 2 analyses were different.

In addition, we did not include 2 eligible studies in the meta-analysis (76, 85). Their results were inconsistent with the meta-analysis results. In a 4-wk crossover study done

by Karvonen et al. (76) in 31 patients with hyperlipidemia, the replacement of ordinary cheese with 65 g of CO-based cheese did not significantly affect BW. In addition, Warensjö et al. (85) indicated no difference in BW from consuming CO compared with SFA in a 3-wk crossover trial in overweight participants.

It is also important to note that the anthropometric measurements used in this review and meta-analysis were not the primary outcomes in the majority of the trials included in the present review (Table 1). These studies were likely underpowered to detect differences in secondary outcomes like BW and adiposity indexes. Furthermore, the duration may not have been long enough to see any effects on adiposity markers. In addition, only 32% of the included studies were categorized as high-quality articles. The studies also did not adjust for potential confounders related to lifestyle, such as physical activity, but the majority of studies advised their participants to maintain their physical activity or lifestyle during the study period (45, 31, 32, 34, 37–39, 46, 73, 77, 79, 80, 82, 85) and a number of studies excluded participants with significant lifestyle changes during the treatment period (31, 33, 35, 38, 46). It should be also considered that methods, reported outcomes, and the quality of individual studies might affect the meta-analyses (44). For example, in studies that accurately describe their methods, fewer assumptions need to be made regarding data extraction and analysis. In the current meta-analysis a number of studies (31, 32, 34, 35, 37, 39, 73–75, 77–80, 82–84) did not report the change values for different anthropometric indexes; therefore, the analyses were performed using a correlation coefficient of 0.5. However, we checked the effect of this correlation coefficient on our results by replicating all analyses using 0.2 and 0.8 as the correlation coefficients and found the results remained unchanged.

Publication bias is another concern in meta-analyses. Despite extensive literature searches, a systematic review can only include studies that are actually published; studies with negative or null findings may not be published. However, because BW and body composition indexes were frequently reported as secondary outcomes, the present review may be less prone to this type of bias. Indeed, both visual inspection of funnel plots and formal testing of asymmetry provided no evidence of publication bias.

In conclusion, the current systematic review and meta-analysis demonstrated that CO consumption leads to a modest but significant reduction in BW, particularly when compared with SFAs. However, no significant effect was seen on the other body composition indexes. Additional, well-designed clinical trials of the effect of CO consumption on BW and body composition are still required to confirm these results.

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