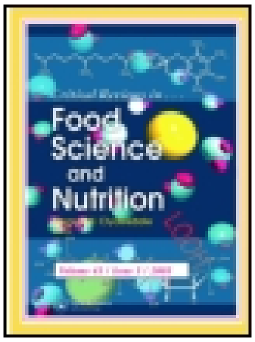


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# Effect of nuts on energy intake, hunger, and fullness, a systematic review and meta-analysis of randomized clinical trials

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REVIEW

# Effect of nuts on energy intake, hunger, and fullness, a systematic review and meta-analysis of randomized clinical trials

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**ABSTRACT**
Despite high energy content, nut consumption has not been associated with weight gain in epidemiological and clinical investigations. Since a satiety effect a decreased sense of hunger in the following meals has been proposed as the mechanism of nuts against obesity, the present meta-analysis was performed to examine how nut consumption affects “energy intake”, “hunger”, and “fullness”. “Weight” was not included among the search terms but weight data were extracted from the collected articles in order to help interpreting the results. A total of 1048 trials were found, of which 31 passed the eligibility process. Daily energy intake was mostly assessed by 3-day food records, and hunger and fullness were estimated by visual analog scale (VAS). Nut consumption was associated with increased energy intake (mean difference (MD) (nuts - control) = 76.3 kcal; 95% CI: 22.7, 130 kcal; $P = 0.005$). In contrast, hunger suppressed following nut consumption (MD = −6.54 mm VAS; 95% CI: −12.7, −0.42 mm VAS; $P = 0.03$). Nuts did not affect sense of fullness and weight in the overall estimate. Subgroup analysis based on participants’ BMI revealed that energy intake of overweight/obese individuals was increased following nut consumption while such effect was not observed in normal weight participants. In conclusion, pooled estimates of available clinical trials showed increased energy intake following nut consumption in overweight/obese individuals but not in persons with normal weight. Nut consumption was associated with decreased hunger but no effect was observed on fullness and weight.

**KEYWORDS**
Nuts; energy intake; hunger; satiety; fullness; weight; obesity

## Introduction

Nuts are highly nutritious, containing ample amounts of protein, unsaturated fatty acids, vitamins, minerals, and phytochemicals (Bolling, McKay, and Blumberg 2010). Thanks to this composition, nuts have health benefits for prevention of diseases, especially metabolic syndrome and cardiovascular diseases (Ros 2015). On the other hand, due to high fat content, nuts are energy-dense; and thus, assumed to increase the risk of weight gain and obesity. However, cross-sectional studies have shown an inverse association between nut consumption and the prevalence of general and abdominal obesity and metabolic syndrome (Ibarrola-Jurado et al. 2013). Likewise, prospective cohorts have found lower risk of weight gain and obesity in individuals with higher nut consumption (Bes-Rastrollo et al. 2009). A recent meta-analysis of prospective cohorts and clinical trials also showed decreased risk of overweight/obesity and lower measures of weight, body mass index, and waist circumference in higher nut consumptions (Li et al. 2018).

Based on evidence from epidemiological and interventional studies, a number of mechanisms have been suggested for the inverse association of nut consumption and body weight (Tan, Dhillon, and Mattes 2014). One of these mechanisms is a satiety effect which is proposed to occur following nut consumption and may extend until the next meal or meals (Tan, Dhillon, and Mattes 2014). According to this hypothesis, the satiety effect postpones the sense of hunger and enables the person to compensate for extra energy acquired from nuts by decreasing food ingestion over the next meals, something that is called energy compensation and may help in weight control (Tan and Mattes 2013).

Based on the aforementioned hypothesis, a number of clinical trials have examined the effect of nuts on hunger and satiety but the results are rather complex and contradictory (e.g., Tan and Mattes 2013; Hull et al. 2015; Kirkmeyer and Mattes 2000; Burton-Freeman 2005). Since there is no conclusive evidence on this subject, we performed a meta-analysis on available randomized clinical trials to see how nut consumption affects daily energy intake and hunger. Because previous meta-analyses have investigated weight effects of nuts (Li et al. 2018; Flores-Mateo et al. 2013) we did not include “weight” among our search terms but extracted weight data

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from the collected articles in order to help us better interpret the results.

## Methods

A systematic review and meta-analysis was conducted in accordance with the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses at all stages of design, implementation, and reporting (PRISMA-P Group 2015).

### Search

PubMed, Scopus, and EMBASE databases were searched from the earliest online available date through August 2018 to find randomized clinical trials examining the effect of nuts on daily energy intake, hunger, satiety, and fullness in adults aged >18 years. Search terms were nuts, walnut, almond, peanut, pecan, hazelnut, filbert, pistachio, macadamia, cashew, Brazil nut, pine nut, chestnut, energy, food intake, appetite, satiety, satiation, hunger, and fullness (search strings are provided as supplementary material). The search was performed by one investigator and screening titles and abstracts was performed by two independent investigators. Final decision was made through discussion with a third investigator. There was no restriction on language. The meta-analysis was not pre-registered in any database.

### Eligibility criteria

Randomized clinical trials, in either parallel or crossover design, investigating the effect of nuts on daily energy intake, hunger, and fullness were included. Trials on satiety were not included in this report because a few studies ($n = 5$) assessed the effect of nuts on satiety. Trials had to be randomized, but the blindness was not a requirement because in majority of the studies nuts were administered in their regular form. Trials were included if they provided similar conditions in the treatment and control groups except for nut consumption, executed control over diet and physical activity of participants, and administered certain amount of nuts to the treatment group. It is worth noting that, because of technical difficulty in preparation of an identical control food for nuts, administration of a control food/load to the control group was not necessary but the presence of the control group itself was. Studies were excluded: 1) if study participants were involved in pathologic conditions affecting either energy intake or appetite, such as malnutrition, type 2 diabetes, cancer, and organ failure; 2) if an isocaloric and nutritionally comparable control was not applied (Food and Drug Administration, XXXX). For instance, in some trials, different doses of nuts were administered in different arms but no control group (i.e. non-effective compound) was used. Also, in some studies regular nuts were compared with high-oleic nuts or in some trials shelled nuts were compared with in-shell nuts. Such studies were excluded; 3) if nuts and control strategies were not isocaloric; 4) if diets of control and nut groups were not controlled for dietary nut consumption; 5) if nuts were not given in similar quantities to all participants in nut-treated group; 6) if a suitable technique for evaluating hunger and fullness (e.g., measuring the amount of foods consumed or using a subjective tool, such as visual analog scale (VAS)) was not applied; 7) if nut ingredients, such as nut oil, were examined; 8) if specific types of nuts, for instance high oleic peanuts, was used; 9) if nuts were mixed with other foods, such as raisins, and so the observed effects could not be solely attributed to nuts; 10) in crossover designs, if a wash-out period was not established between the two sequences or if all subjects did not experience both control and nut conditions; 11) if sufficient information (i.e. the mean and standard deviation or error) for parameters of interest (daily energy intake, hunger, fullness, and weight) was not provided; 12) if baseline values were not reported; and 13) in repeated publications, where only one report with the most relevant design to the aims of this meta-analysis was used. Scores of the study quality (Jadad scale) were not reported because of difficulty in blindness of the studies.

### Risk of bias assessment

Risk of bias was determined according to a recent systematic review on appetite and energy intake (Halford et al. 2018). Risk of bias was rated as low or high for each of 4 issues: 1) power calculation and meeting the calculated sample size; 2) results reported from 100% sample size or the use of intention-to-treat analysis; 3) the percentage of dropouts; and 4) complete report of outcomes.

### Statistical analysis

Pooled effects were calculated by estimating mean difference (MD) and standard error of energy intake, hunger, fullness, and weight between control and nut-treated groups using the inverse-variance random-effect model. Heterogeneity was assessed by $I^2$ statistics (Higgins and Green, 2011). Subgroup analysis was performed for each of the investigated variables (energy, hunger, fullness, weight) based on subjects' weight status (normal ($BMI < 25\,kg/m^2$) *vs.* overweight/obese ($BMI \geq 25\,kg/m^2$)(. Subgroup analysis was also performed based on nut type (walnut, almond, hazelnut, and peanut) for energy intake, but due to insufficient number of trials this subgroup analysis was not performed for other parameters. STATA software version 12.0 (StataCorp, USA) was used for data analysis.

## Results

### Search results

After searching PubMed, Scopus, and EMBASE databases, 1048 articles were identified; 305 were duplicates and put aside, 672 were excluded following screening titles and abstracts, 71 were assessed for eligibility, and 31 trials were entered in the meta-analysis (Figure 1). Non-English articles entered the screening process through reading their English

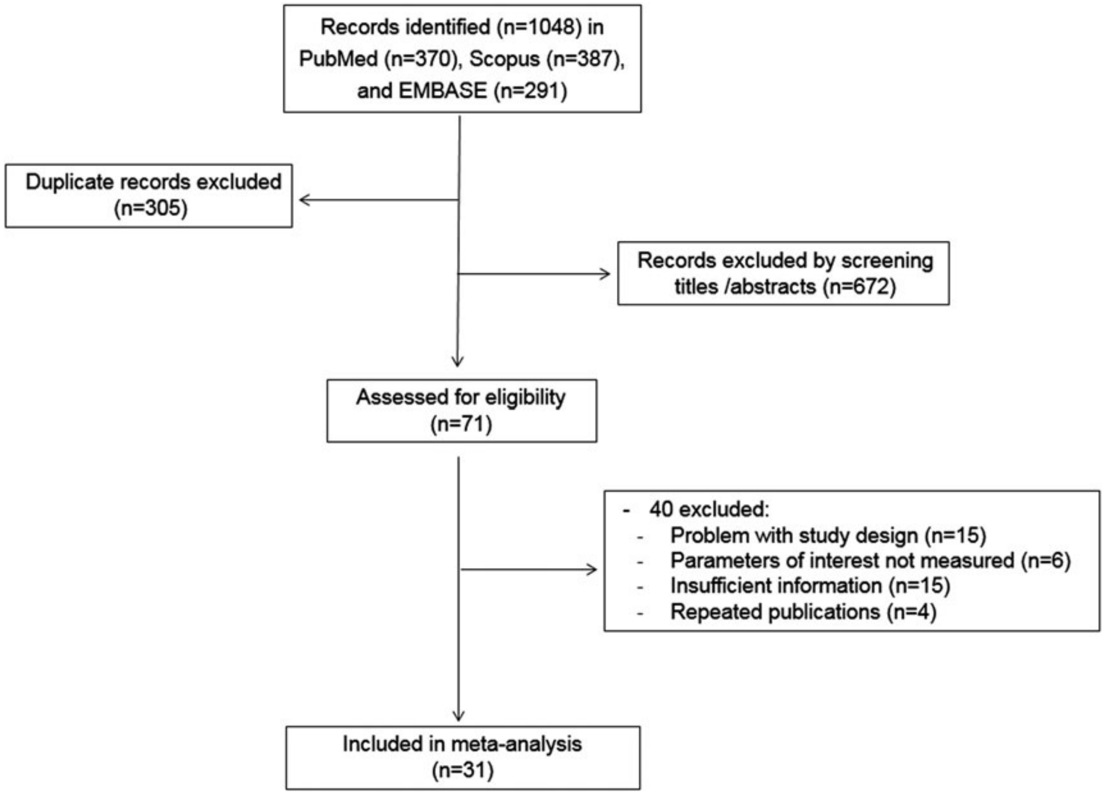


**Figure 1.** Summary of the screening and selection process of trials included in the meta-analysis of the effect of nuts on energy intake, hunger, and fullness.

abstract. None of the trials written in other languages passed the eligibility process.

Table 1 presents a summary of the included trials. Twenty three, 14, 10, and 15 trials assessed daily energy intake, hunger, fullness, and weight, respectively. Daily energy intake was mostly assessed by 3- to 7-day food records, and hunger and fullness were estimated by visual analog scale (expressed as mm). Three studies were cited twice because they had used different doses (Hull et al. 2015; Tey et al. 2013) or different types of nuts (Kirkmeyer and Mattes, 2000).

A total of 1467 participants were included in the meta-analysis. They were either healthy or with relatively mild medical conditions like overweight, obesity, hyperlipidemia, metabolic syndrome, and prediabetes. The participants had a wide variety of BMI, including normal ($<25\,kg/m^2$), overweight ($25–29.9\,kg/m^2$), and obese ($\geq 30\,kg/m^2$). Nuts included almond, walnut, peanut, hazelnut, and pecan in doses ranging from 20.0 g/day to 87.5 g/day. There was large variability in the type of control food, varying from no control food (i.e. control group just followed their usual diet instead of getting a control food plus usual diet) to receiving snacks, cereals, or fruits as the control food.

## *Effect of nuts on daily energy intake*

As stated, 23 trials investigated the effect of nuts on daily energy intake. An overall significant increasing effect of nuts on energy intake (MD (nuts - control) = 76.3 kcal; 95% CI: 22.7, 130 kcal; P = 0.005) was observed (Figure 2). Subgroup analysis based on participants' BMI showed significant increased energy intake following consumption of nuts in overweight/obese individuals (MD = 125 kcal; 95% CI: 70.8, 180 kcal; $P < 0.001$) but not in individuals with normal weight (MD = −27.5 kcal; 95% CI: −10.5, 50.5 kcal; $P = 0.49$) (Figure 2-A). Subgroup analysis of energy intake based on nuts type showed that walnut, almond, and hazelnut consumption was associated with higher energy intake although the association was statistically significant only for hazelnut (MD = 227 kcal; 95% CI: 25.6, 427.6 kcal; $P = 0.03$) (Figure 2-B). There was high level of heterogeneity in the overall effect ($I^2 = 82.1\%$) and walnut ($I^2 = 92.8\%$) and almond ($I^2 = 71.3\%$) subgroups.

## *Effect of nuts on hunger*

Pooled estimate of 14 trials showed suppressed sense of hunger following nut consumption (MD = −6.54 mm VAS; 95% CI: −12.7, −0.42 mm VAS; $P = 0.03$) (Figure 3). Subgroup analysis based on participants' BMI did not show a significant association between nut consumption and BMI. There was high heterogeneity in the overall effect and the BMI subgroups ($I^2 = 78.2\%–97.7\%$).

## *Effect of nuts on sense of fullness*

Ten studies reported the effect of nuts on sense of fullness (MD = 0.03 mm VAS; 95% CI: −12.2, 12.3 mm VAS; P = 1) (Figure 4). Nuts did not seem to affect fullness in the overall effect, but in subgroup analysis normal individuals showed

**Table 1.** Characteristics of the clinical trials included in the meta-analysis of the effect of nuts on energy intake, hunger, and satiety.

| First author, year (ref) | Subjects | Subjects number | Age Bolling, McKay, and Blumberg 2010 (y) | BMI Bolling, McKay, and Blumberg 2010 ($kg/m^2$) | Study design | Intervention | Nut dose | Control | Outcome |
|---|---|---|---|---|---|---|---|---|---|
| Chen et al. 2015 | Coronary artery disease | 45 | 61.8 ± 8.6 | 30.2 ± 5.1 | Crossover | Almond | 85 g | – | E |
| Dhillon, Tan, and Mattes 2016 | Overweight/obese | 50 | 34.3 ± 13.0 | 30.5 ± 3.5 | Parallel | Almond | 15% energy intake | – | E, H, F, W* |
| Hull et al. 2015 | Healthy | 32 | 48.4 ± 1.0 | 22.7 ± 0.26 | Crossover | Almond | 28 g | – | H*, F* |
| Hull et al. 2015 | Healthy | 32 | 48.4 ± 1.0 | 22.7 ± 0.26 | Crossover | Almond | 42 g | – | H*, F* |
| Jenkins et al. 2008 | Hyperlipidemic | 27 | 64.0 ± 9 | 25.5 ± 4 | Crossover | Almond | 73 g | Muffin | E, W |
| Jung et al. 2017 | Overweight | 84 | 52.4 ± 0.6 | 25.4 ± 0.22 | Crossover | Almond | 56 g | Cookie | E* |
| Kirkmeyer and Mattes, 2000 | Healthy | 24 | 22 ± 2.5 | Normal | Crossover | Almond | 80.4 | Chestnut | E*, H* |
| Liu et al. 2018 | Healthy | 85 | 26.55 ± 5.3 | 22.2 ± 3.12 | Parallel | Almond | 56 g | – | E, W* |
| Sayer et al. 2017 | Overweight/obese | 22 | 35.0 ± 3.0 | 30.0 ± 1.0 | Crossover | Almond | 28 g | Baked food | H*, F* |
| Tan and Mattes, 2013 | Overweight/obese | 55 | 30.8 ± 10.5 | 27.6 ± 4.6 | Parallel | Almond | 43 g | – | E*, H*, F*, W* |
| Wien et al. 2010 | Prediabetes | 65 | 53.5 ± 10.0 | 29.5 ± 5.0 | Parallel | Almond | 56 g | – | E, W* |
| Zaveri and Drummond, 2009 | Overweight/obese | 32 | 37.7 ± 6.6 | 30.1 ± 3.2 | Parallel | Almond | 56 g | Cereal bar | E*, H*, W* |
| Agebratt et al. 2016 | Healthy | 30 | 23.5 ± 3.7 | 22.3 ± 1.9 | Parallel | Walnut | 7 kcal/kg | Apple/pear | E*, W* |
| Burton-Freeman, 2005 | Healthy | 25 | 31.5 ± 3 | 23.0 ± 2 | Crossover | Walnut | 20 g | Strawberry shake | E*, H*, F* |
| Casas-Agustench et al. 2009 | Healthy | 29 | 22 ± 4.0 | 24.1 ± 4.5 | Crossover | Walnut | 54 g | Olive oil | H* |
| Holt et al. 2015 | Hypercholesterolemic | 30 | 60.0 ± 4.7 | 24.6 ± 3.4 | Parallel | Walnut | 35 g | – | E |
| Neale et al. 2017 | Overweight/obese | 170 | 43.0 ± 8.4 | 32.6 ± 4.3 | Parallel | Walnut | 30 g | – | E*, W* |
| Rock et al. 2017 | Overweight/obese | 100 | 52.8 ± 1.5 | 32.4 ± 0.4 | Parallel | Walnut | 15% energy intake | – | F*, W* |
| Morgan and Clayshulte, 2000 | Healthy | 19 | 41.0 ± 11.0 | 24.0 ± 4.5 | Parallel | Pecan | 68 g | – | E |
| Casas-Agustench et al. 2011 | Metabolic syndrome | 50 | 51.8 ± 8.4 | 30.8 ± 3.1 | Parallel | Walnut/ almond/ hazelnut | 30 g | – | E*, W* |
| Barbour et al. 2014 | Overweight/obese | 24 | 61 ± 1 | 30.5 ± 3 | Crossover | Peanut | 84 g males/ 56 g females | Potato crisp | H*, F* |
| Claesson et al. 2009 | Healthy | 25 | 23.4 ± 2.7 | 22.2 ± 1.7 | Parallel | Peanut | 20 kcal/kg | Candy | E*, W* |
| Alves et al. 2014 | Overweight/obese | 44 | 27.7 ± 2.2 | 29.6 ± 2.4 | Parallel | Peanut | 56 g | – | H, F, W* |
| Moreira Alves et al. 2014 | Overweight/obese | 44 | 27.7 ± 2.2 | 29.6 ± 2.4 | Parallel | Peanut | 56 g | – | E |
| Duarte Moreira Alves et al. 2014 | Overweight/obese | 47 | 27.1 ± 0.7 | 29.8 ± 2.4 | Parallel | Peanut | 56 g | Biscuit | H*, F* |
| Johnson et al. 2013 | Healthy | 44 | 40.5 ± 1.6 | 31.8 ± 0.9 | Parallel | Peanut | 23 g | Grains | E*, W* |
| Kirkmeyer and Mattes, 2000b | Healthy | 24 | 22 ± 2.5 | Normal | Crossover | Peanut | 87.5 | Chestnut | E*, H* |
| Reis et al. 2011 | Healthy | 13 | 28.5 ± 10.0 | 22.7 ± 2.5 | Crossover | Peanut | 63 g | Cheese sandwich | E* |
| Pearson et al. 2017 | Healthy | 52 | 38.6 ± 14.1 | 23.9 ± 3.1 | Parallel | Hazelnut | 42 g | Potato crisp | E* |
| Tey et al. 2013 | Overweight/obese | 70 | 42.5 ± 13.3 | 30.6 ± 4.6 | Parallel | Hazelnut | 30 g | – | E, W* |
| Tey et al. 2013 | Overweight/obese | 74 | 42.0 ± 11.9 | 30.7 ± 5.3 | Parallel | Hazelnut | 60 g | – | E, W* |

[1]Values are means ± SD.
*indicates that the variable was measured as the primary outcome in the corresponding study. Abbreviations: E, energy intake; F, fullness; H, hunger; W, weight.

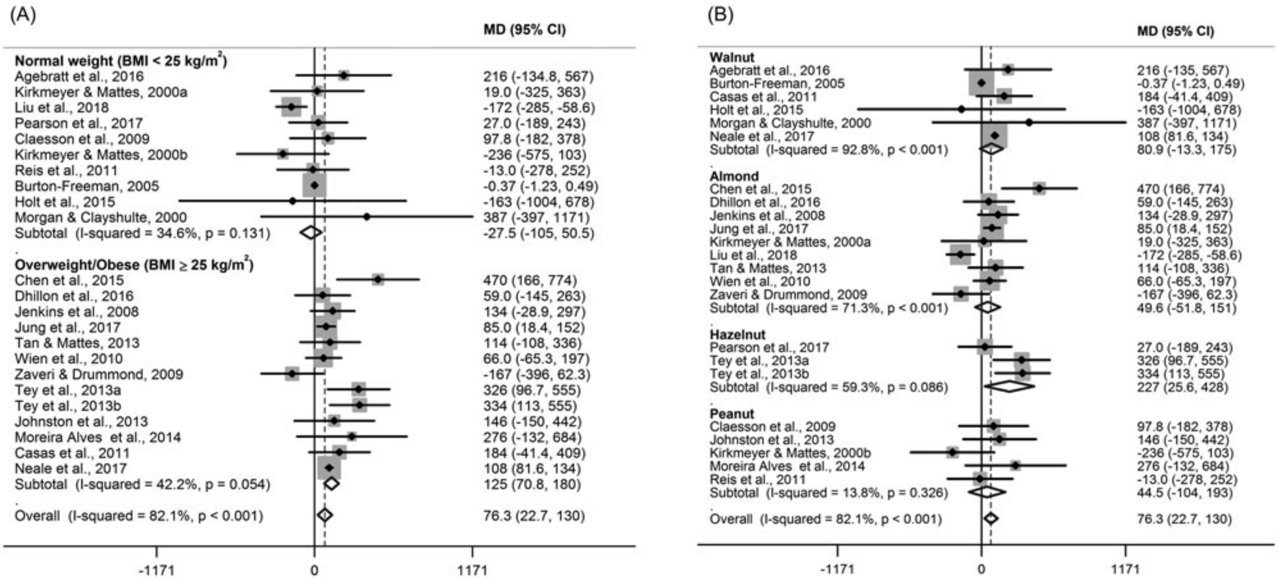


**Figure 2.** Forest plot of clinical trials examining the effect of nuts on energy intake with subgroup analysis based on: A) participants' BMI; B) nut type. Values are the mean difference (MD) between nuts and control groups with 95% CIs.

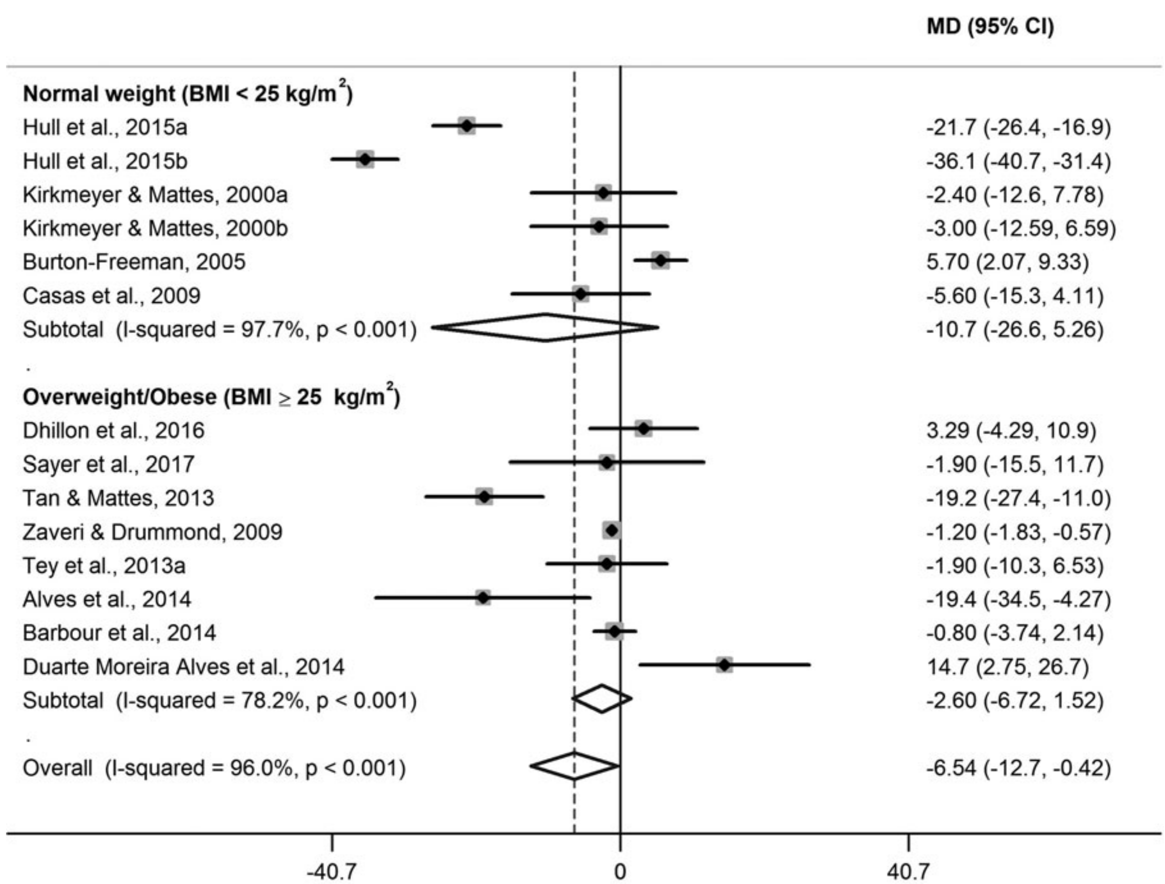


**Figure 3.** Forest plot of clinical trials examining the effect of nuts on hunger with subgroup analysis based on participants' BMI. Values are the mean difference (MD) between nuts and control groups with 95% CIs.

non-significant increased sense of fullness (MD = 17.9 mm VAS; 95% CI: −2.78, 38.6 mm VAS; $P = 0.09$) and overweight/obese individuals indicated non-significant decreased fullness (MD = −8.43 mm VAS; 95% CI: −18.8, 1.91 mm VAS; $P = 0.11$) following nut consumption. High heterogeneity was observed in the overall effect and the BMI subgroups ($I^2 = 85\%–99.7\%$).

### Effect of nuts on weight

Assessment of weight was not among the primary aims of this work. Therefore, weight was not included in the search terms, but it assessed in studies which were included in the analysis based on the main outcomes. Fifteen out of 31 trials reported weight. These trials did not show any effect from

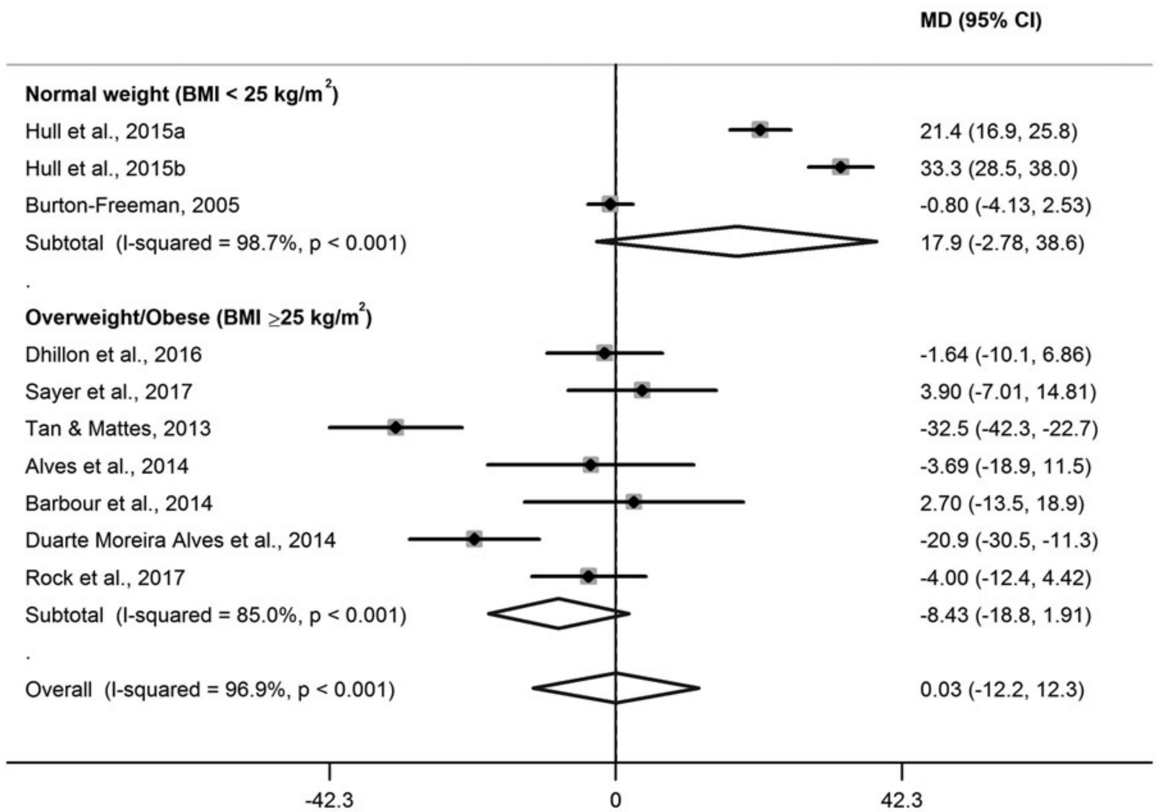


**Figure 4.** Forest plot of clinical trials examining the effect of nuts on sense of fullness with subgroup analysis based on participants' BMI. Values are the mean difference (MD) between nuts and control groups with 95% CIs.

nuts on weight (MD = −0.09 kg; 95% CI: −0.59, 0.41 kg; $P = 0.72$) (Figure 5). The overweight/obese subgroup indicated the same result as the overall effect but trials on normal weight individuals revealed a non-significant inverse association between nut consumption and weight (MD = −0.52 kg; 95% CI: −1.19, 0.15 kg; $P = 0.13$). Heterogeneity in normal weight subgroup was low ($I^2 = 0$) but a moderate heterogeneity was observed among the whole trials and in overweight/obese subgroup ($I^2 = 59.7\%–68.0\%$).

### *Risk of bias assessment*

Risk of bias assessment is reported in Supplementary Table 1. The most frequent risks of bias were due to absence/not reporting power calculation and analysis on less than 100% of sample size or absence of intention-to-treat analysis.

## Discussion

Concerning the current hypothesis on the beneficial effect of nuts on weight and their satiety effect as one of the mechanisms by which nuts exert such effect, we conducted this meta-analysis to investigate randomized clinical trials examining the effect of nuts on hunger, satiety, and energy intake. According to results of this meta-analysis, consumption of nuts increases daily energy intake and suppresses hunger but it has no effect on sense of fullness or weight. Subgroup analysis based on BMI suggested that weight status may influence the effect of nuts on energy intake and sense of fullness.

Nuts are classified as high energy density foods, producing >4 kcal energy per gram (Brufau, Boatella, and Rafecas 2006). This high energy density is due to nuts' high fat content (from about half to as much as 75% of weight). Despite high energy content, consumption of nuts has not been accompanied with obesity in epidemiological and clinical investigations (Ibarrola-Jurado et al. 2013; Li et al. 2018). The absence of congruence between energy content and weight effects of nuts has been proposed to be, at least partly, due to a satiety effect that is generated after nut consumption, extends for hours, and influences food consumption over the next meals (Tan, Dhillon, and Mattes 2014). This satiety effect is proposed to either decrease daily energy intake or at least keep it unchanged (Halford et al. 2018).

However, results of this meta-analysis showed a positive association between ingestion of nuts and energy intake; although the magnitude of the increased energy intake was lower than that obtained from the consumed nuts. The average nut consumption in trials of energy was 50.9 g/day. Based on food composition tables, this amount of nuts should provide about 300 kcal/day while the quantity of energy intake estimated from trials was 76.3 kcal/day. There may be several explanations for this inequality between calculated and acquired energy from nuts. One explanation is incomplete digestion of nuts in which a number of cell walls in nuts remain intact during digestion process and pass undigested through gastrointestinal tract (Mandalari et al. 2014). *In vitro* experiments showed that even prolonged

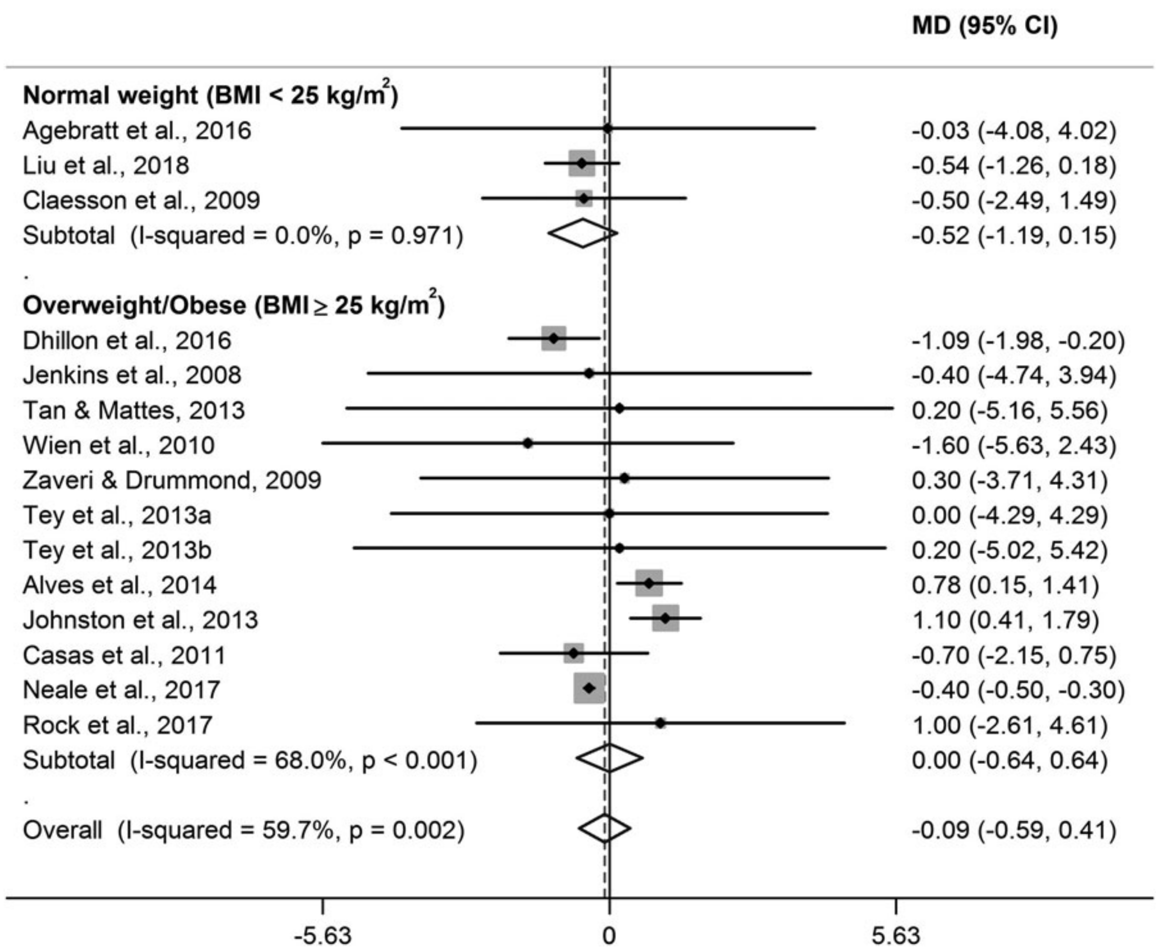


**Figure 5.** Forest plot of clinical trials examining the effect of nuts on weight with subgroup analysis based on participants' BMI. Values are the mean difference (MD) between nuts and control groups with 95% CIs.

digestion periods are unable to release encapsulated lipids from the intact cells (Grundy et al. 2016). In some cases, slow penetration of lipase into the cell walls may lead to the release of fat in the ileum or colon where sites of fat absorption have already passed (Grundy et al. 2015). Second explanation is that nuts may increase energy expenditure. Nuts, including peanuts (Alper and Mattes, 2002) and walnuts (Tapsell et al. 2009), have shown potential to increase resting energy expenditure (Alper and Mattes, 2002) and body fat oxidation (Tapsell et al. 2009). Mono- (Casas-Agustench et al. 2009) and poly- (Casas-Agustench et al. 2009; Piers et al. 2002) unsaturated fatty acids have shown to augment postprandial oxidation. In this regard, animal studies reported higher sympathetic activity following consumption of safflower oil in comparison with beef tallow diet (Matsuo et al. 1995). Also, safflower-enriched diets increased the expression of peroxisome proliferator-activated receptor-$\alpha$ gene (*PPARA*) which is involved in fatty acid oxidation (Zhang et al. 2010). In addition, polyunsaturated fatty acids are suggested to upregulate uncoupling protein genes, genes implicated in proton leak across mitochondrial inner membrane and dissipation of energy in the form of heat instead of ATP (Armstrong and Towle, 2001).

Due to paucity of data, we did not report data on satiety, but trials on hunger indicated an inverse association between nut consumption and sense of hunger. This finding is in line with previously proposed hypothesis on the satiety effect of nuts if we note that hunger is the opposite sense of satiety (de Graaf, 2011). Interestingly, nut consumption appeared to be ineffective on the sense of fullness in the overall effect estimate which could be because nuts are energy-dense, are ingested in small quantities, and thus do not occupy much of the stomach volume. Mechanisms of the satiety-promoting effect of nuts are not completely understood but it is suggested that specific hormones, such as cholecystokinin, peptide YY, and glucagon-like peptide 1, may be involved (Reis et al. 2013; Pasman et al. 2008). Fatty acid composition of nuts, in particular polyunsaturated fatty acids, may be effective in induction of nuts satiety effect through stimulation of satiety-related hormones (Stevenson, Clevenger, and Cooper 2015; Kozimor, Chang, and Cooper 2013; Maljaars et al. 2009).

Subgroup analysis revealed that weight status may influence the effect of nuts on the assessed variables. Compared to normal weight individuals, people with overweight/obese showed trends towards less suppressed hunger (MD = −2.60 *vs.* −10.66, mm VAS), less sense of fullness (MD = −8.43 *vs.* 17.9, mm VAS), higher weight (MD = 00 *vs.* −0.52, kg) and increased energy intake (MD = 125 *vs.* −27.5, kcal/day) after nut consumption. These weight-dependent effects of nuts may be explained by the fact that obese people have altered appetite sensitivity and regulation. Compared to people with normal weight, overweight/obese individuals have poorer ability to perceive signals of hunger and satiety (Herbert and Pollatos, 2014). Obese persons are more sensitive to appetitive stimulations of ghrelin (Druce et al. 2005). Additionally, a large cross-sectional study showed that genetic susceptibility to obesity is associated with reduced satiety responsiveness (Llewellyn et al. 2014). Unfortunately, no study has yet compared nut effect on satiety and weight in overweight/obese *vs.* normal weight individuals. Also, studies on the effect of nuts on hunger and satiety are limited and the findings are still inconclusive. More studies need to focus on these areas.

## Strengths and limitations

There were limitations with this work. We did not report data on satiety because few studies assessed it. Furthermore, methods of assessing energy intake, such as food record or recall, are not quite reliable, especially obese individuals may underreport their food intake. In addition, application of different methods of dietary assessment can increase risk of bias. Time of nut consumption might affect hunger, fullness, and energy intake, but subgroup analysis based on time was not possible because in some studies the time of nut administration was not specified and participants were free to eat nuts as a snack or with meals. However, this meta-analysis was the first that investigated the effect of nuts on energy intake, hunger, and fullness.

## Conclusions

In conclusion, pooled estimates of available clinical trials showed increased energy intake following nut consumption in overweight/obese individuals but not in normal weight ones. In the overall effect, nut consumption was associated with decreased hunger but no effect was observed on fullness and weight. Person's body weight may influence the effect of nuts on fullness and weight but results were not significant in this regard. More trials are needed to confirm these results.

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## Disclosure statement

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The authors received no funding for this study.

## Abbreviations

| | |
|---|---|
| BMI | body mass index |
| CI | confidence interval |
| MD | mean difference |
| VAS | visual analog scale |

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