Sex as a biological determinant in the anthropometric, biochemical, and dietary changes during Ramadan fasting in healthy people: A systematic review of observational studies

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Systematic Review

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Abstract

Methods

A systematic search was conducted on Scopus and PubMed for experimental and observational studies tackling Ramadan fasting, dietary, anthropometric, and biochemical outcomes in both women and men. Data were extracted using a standardized data-collection form by two independent reviewers.

Results

From about 3870 studies, sex-based differences were reported in 29 studies, which included 3167 healthy people, of which 1558 (40.3%) were women. Most of the differences between men and women were reported both in the baseline period before Ramadan and during Ramadan. Sex differences were examined in a total of 69 outcomes of observing RDIF and included different nutrition and health-related aspects such as dietary and nutrition-related factors (17 outcomes), anthropometrics (13 outcomes), and biochemical (39 outcomes), with the latter including metabolic, hormonal, regulatory, inflammatory and diet-related biochemical markers.

Conclusion

A growing attention has been directed toward the sex differences concerning dietary and lifestyle modifications such as RDIF. Clear differences were observed in the tested dietary, anthropometric, and biochemical outcomes induced by RDIF. More attention has to be directed toward the inclusion of both sexes in studying the impact of observing RDIF and differentiating the outcomes based on the sex differences.

Introduction

Biological determinants can be all the characteristics of an individual that has a biological background, such as sex, age, family predisposition, genetics, and ethnicity [1]. These biological determinants may influence the patterns of how different lifestyle intervention interacts with other factors on multiple levels[1–4].

Sex is one of these determinant factors that affect human health and disease and human lifespan and mortality [5, 6]. Pervasive sex differences are existing in biological, behavioral, physical, and psychological aspects between males and females [7]. Underlying biological factors include sex-linked traits are among the featured differences between males and females that explain the reasons behind the variable sex differences in response to various lifestyle interventions [7, 8]. Considering the significance of the biological determinant in any biomedical research, integrating sex in such kind of research becomes a requirement by the international funding bodies [9].

Because of the role of biological determinants such as sex in determining the extent of changes produced when investigating dietary modifications and nutritional interventions [2, 3], it becomes pivotal to consider sex as one of the most powerful biological determinants in any adopted nutritional interventions. Intermittent fasting is one of the newly adopted dietary modifications that are looked at as a safe and effective modification intended for reducing body weight and improving glucose homeostasis and cardiometabolic risk factors and even extending human longevity [10–12]. Different forms of intermittent fasting have been evolved, including time-restricted eating, periodic fasting, 2:5 day fasting, alternate-day fasting, and religious forms of IF such as Ramada intermittent fasting [10]. Nonetheless, it is important to understand the major differences between the Ramadan fasting and other intermittent fasting regimens: that is the diurnal nature of Ramadan fasting, hence described as Ramadan diurnal intermittent fasting (RDIF) in comparison with the nocturnal nature of other IF regimens; second, being dry, not wet, fasting where all types of fluids and drinks, including water, are not allowed. Thus, RDIF is very different compared to other forms of IF.

Ramadan fasting is one of the most extensively studied religious forms of IF, with massive literature has been released over seven decades (around 1920 articles in the medical field according to Scopus database, Unpublished data). Among these, sex differences have been repeatedly reported in several systematic reviews and meta-analyses on the effect of Ramadan intermittent fasting, where sex was tested using sub-group analysis, with variable significant and non-significant effects being reported for sex as one of the main moderators [13–18].

During Ramadan, the ninth month of the lunar calendar, adult healthy Muslims are mandated to abstain from all foods and drinks, along with smoking and sexual activities, from dawn to sunset, with daytime that ranges from 12 to 18 daytime hours depending on the geographical location and the solar season. Patients, unable elderly, lactating and pregnant women, and children before puberty are all exempted from observing the ritual of fasting during Ramadan. Adult females are exempted from fasting during their menstrual cycle, which makes the total fasting days 5–7 less than males who observe the complete month of 29–30 days. Although adult females observe fewer days of RDIF, some reports indicate the lack of significant difference between males and females at the end of the month concerning the variable health and metabolic outcomes.

To the best of our knowledge, there is a scarcity of published works that examine the effect of sex on the impacts of RDIF among adult healthy people. Based on our understanding of and the existing knowledge regarding the sex differences in the variable dietary, metabolic and anthropometric aspects of human health, we hypothesized that obvious differences will be existing between males and females after observing the month of Ramadan. Therefore, this systematic review was designed and implemented, aiming to qualitatively examine the impact of the biological sex on the variable anthropometric, metabolic and biochemical as well as dietary outcomes of observing RDIF among healthy adult males and females. Being representing about 25% of the world population (about 2 billion Muslims out of the 8 billion world population) and about 1,5 billion Muslims observing RDIF each year [19], this work gains considerable importance in reflecting the role of biological sex in shaping the responses to a different lifestyle and dietary changes.

Materials And Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as a guideline for reporting the findings [20].

Database searches

Four authors (DA, RR, MK, NA, and MF) conducted an electronic search of the CINAHL, Cochrane, EBSCOhost, Google Scholar, ProQuest Medical, PubMed/MEDLINE, ScienceDirect, Scopus, and Web of Science databases for relevant studies published from 1950 to December 2021. The search strategy included the keywords: “Ramadan fasting” OR “Ramadan diurnal fasting” OR “Ramadan intermittent fasting” OR “Ramadan model of intermittent fasting” OR “Ramadan fast” OR “intermittent prolonged fasting during Ramadan” AND “Sex” OR “Gender” OR “Males” OR “Females” OR “Women” OR “Men”. Reference lists of identified studies were searched to find additional articles and reviews to ensure that all relevant publications were included in this review.

Inclusion criteria

We included observational and interventional studies that examined the sex-specific effect on RDIF. Specific inclusion criteria for study selection were: 1) publication date between 1950 and December 2021; 2) original research articles published in the English language; 3) studies that reported numerical values (e.g., arithmetic mean with/without standard deviation); 4) studies that assessed the impact of RDIF on healthy people with all age groups as the target population in prospective observational studies, or on healthy controls in case-control, semi-experimental, and experimental/interventional studies. 5) Participants with normal, overweight, or obese body mass index without any complications or disease. 6) We focused on studies that examined the sex-specific effect on RDIF; therefore, we included studies that examined these components at least twice: pre-fasting as the baseline (e.g., a few days or 1–2 weeks before Ramadan month, or the first few days of Ramadan month), and post fasting (at least 2 weeks into Ramadan month or after completion of Ramadan month) and we include the studies that compare males and females after Ramadan. It should be noted that Islamic laws pertaining to fasting specify that premenopausal women are exempt from fasting during menstruation days; therefore, these women are not expected to complete fasting for the whole month of Ramadan. A similar exemption applies to elderly people who may find it hard to complete the whole Ramadan month and may miss some fasting days.

Exclusion criteria

Identified articles were assessed against specific exclusion criteria to eliminate potential methodological and quality issues: 1) studies involving pregnant or lactating women who observed Ramadan fasting; 2) studies that included patients with different diseases or conditions who observed RDIF; 3) studies on the impact of RDIF on Muslim athletes that observed Ramadan fasting; 4) studies with no available full-text, even after contacting the authors; 5) studies that reported post-Ramadan measurement after one or more months, as evidence suggests RDIF-induced biochemical variables disappear/return to pre-fasting levels after one month of Ramadan month cessation; 6) case reports, abstracts, review articles, editorials, and non-English-language articles; and 7) unpublished, non-peer-reviewed data. Articles that met any of these criteria were excluded from the present analysis (Fig. 1. Flowchart diagram).

Main outcomes and measures

The principal outcome of this review was to report the sex-specific effect on RDIF outcomes in three different groups of outcome variables: anthropometric measurements, biochemical tests, and dietary intakes,

Anthropometric outcomes

Body weight (BW), body mass index (BMI), body fat mass (BFM), body fat percent (BFP), fat-free mass (FFM), waist circumference (WC), hip circumference (HC), muscle mass (MM), total body water (TBW), waist to hip ratio (WHR), visceral fat area (VFA), lean mass index (LMI), fat mass (FM), skeletal muscle mass (SMM), and fat-free mass (FFMI).

Dietary and energetic outcomes

Intakes of total calories, protein, total carbohydrates, total sugars, dietary fibers, total fats, monounsaturated fatty acids (MUFA), polyunsaturated fats (PUFA), saturated fats, dietary cholesterol, calcium, thiamin, and riboflavin. Resting metabolic rate (RMR), basal metabolic rate (BMR), energy expenditure (EE), physical activity, eating behaviors, and feelings of hunger and thirst during Ramadan were assessed as well.

Biochemical outcomes

Blood pressure (blood pressure BP, intraocular pressure, heartbeat); lipid profile and atherogenic factors (total cholesterol TC, triglycerides TG), low-density lipoprotein LDL, high-density lipoprotein HDL, very low-density lipoprotein VLDL, HDL/TC ratio, LDL/HDL ratio, Apo-A1, Apo-B, Apo-A1/Apo-B ratio, Apo-B/LDL ratio, Apo A1/HDL ratio); glucose homeostasis (fasting blood glucose FBG, glycosylated hemoglobin HbA1c); inflammatory markers (tumor necrosis factor-α TNF-α, adiponectin, interleukin-8 IL-8, insulin growth factor-1 IGF-1); kidney function tests (blood urea nitrogen BUN, creatinine, uric acid, urea); liver function tests (total serum protein, albumin total bilirubin aspartate aminotransferase AST, alanine aminotransferase ALT); hormones (thyroxine T4, triiodothyronine T3, thyrotropin-stimulating hormone TSH, cortisol); blood nutrients (serum folate, B_{12}, and calcium), and others (hemoglobin, matrix metalloproteinase-9 (MMP-9), myoglobin).

Two authors (RR and DA) independently screened the titles and abstracts of identified studies to assess the studies for eligibility. The first step of screening was examining all titles and abstracts to exclude irrelevant publications. Two authors (xx and DA) performed this initial screening, which was validated by another author (NA). To standardize data extraction, the review team systematically collected and coded data for study characteristics (e.g., title, year of publication, year of conducting, country, city, study design, the average number of fasting hours, study population, total sample size, age, sex and proportion of males and females, and the main findings for all variables before and after RDIF and the description of significance.

Results

Twenty-nine studies with a total of 3,167 participants have been included in this systematic review. Details of the sample size, participants' sex and age, study design, country, and major findings related to parameters for the included studies are shown in Table 1. Some of the included studies used a pre-post design to report changes between men and women, while others compare men and women post, Ramadan. Approximately 48.30% of participants were male, and the mean age was 29.31 years (range 12.0–66.7 years) for males and 28.27 years (range 11.3–66.7 years) for females.

Dietary intakes

Variable differences in the assessed dietary intake parameters were reported among the male and female fasting people during Ramadan. While total caloric intake was increased in both males and females in two studies [21, 22], it was decreased in both sexes in other studies [23, 24], with one study reporting a lack of difference in both sexes [25] at the end of the fasting month when compared with the pre-fasting levels. While the lack of differences between males and females was reported in one study [26], another study reported a significant difference between males and females after RDIF [22].

Regarding total fats consumed, significant increases were reported in both sexes in one study [21]. Another study revealed a lack of significant changes in fat intake in both sexes after Ramadan compared to before [25]. Only one study examined the difference between males and females in this regard and reported a lack of difference [22]. Examining differences in the intakes of dietary cholesterol, PUFA, MUFA and saturated fats intakes between the two sexes revealed a lack of difference in a soles study [22]. Only two studies examined the difference in protein intakes between males and females, with both denying the presence of difference either between pre and post-RDIF [25] and between males and females at the end of RDIF when compared with the pre-fasting intakes [22].

While one study reported significant increases in total carbohydrates consumed in both sexes [21] at the end of RDIF in comparison with the pre-fasting intakes, two studies denied the presence of a significant difference between the two sexes for both total carbohydrates and total sugars [22], and between pre-and-post RDIF intakes in both sexes [25]. For the tested micronutrients (calcium, thiamin, and riboflavin), while intakes of the three micronutrients were significantly increased among males[21], females reported a significant increase in thiamin only, with no difference in calcium and riboflavin intakes among females[21] at the end of the fasting month in comparison with the pre-fasting intakes.

Feeling with thirst and hunger showed variable behavior among males and females, while females reported increased feelings of hunger than males during Ramadan, males reported a higher sense of thirst than females when compared to the pre-fasting levels [27].

No difference was reported between males and females in BMR, Energy intake, and eating behavior [28–31]. Only one study reported that males have significantly higher BMR than females during Ramadan between males and females [32].

Anthropometric measurements

Body weight change is one of the most common outcomes reported among fasting people during Ramadan. While several studies revealed a more pronounced change in BW among males than females during Ramadan [21, 28, 29, 32], fewer studies reported a lack of difference between both sexes during Ramadan in comparison with the pre-fasting levels [22, 33]. Further, while several studies reported a significant reduction in BW among males during Ramadan in comparison with the pre-fasting weights [23, 34–36], a fewer number of studies revealed a significant reduction in females' BW at the end of Ramadan when compared to the pre-Ramadan weights [34–36].

Consistent with BW, changes in BMI at the end of Ramadan and between male and female fasting people were also variable. While the majority of studies revealed a lack of difference in BMI between males and females during Ramadan [25, 28–30, 32, 33, 37–40], one study reported a more pronounced change in BMI among males than females at the end of the fasting month in comparison with the pre-fasting levels [41]. While many studies reported a significant change in the BMI among males [23, 34–36], a smaller number of studies reported such a significant change in BMI among females between pre-and post-Ramadan fasting [34–36].

Two studies reported significant reductions in WC among males and females during Ramadan in comparison with the pre-fasting levels [35, 42] while only one study did not report such significance [38]. Only one study showed a significant reduction of waist circumference (WC) only in females rather than in males during Ramadan in comparison with the pre-fasting stage [23].

For HC, Khattak, et al.[33] reported a lack of difference between males and females during Ramadan, while one study [35] reported significant reductions in HC in both sexes during Ramadan when compared with the pre-fasting stage.

Regarding the TBW and differences between males and females during the month of Ramadan, only one study showed no significant difference between males and females at the end of Ramadan [30], while two studies showed that males were having significantly higher TBW than females at the end of Ramadan [32]. One study found that females had a significant reduction in TBW while males didn't have [36], one study showed that there is no significant difference between males and females in the waist to hip ratio (WHR) [30], and one study showed no significant difference in WHR between pre and post-Ramadan measurements in both sexes [36].

Regarding the body fat percent (BFP), many studies showed no significant difference between pre and post-values in both sexes [25, 36, 38], and one study showed no significant difference between males and females at the end of Ramadan [30]. One study found a significant reduction in BFP in both sexes at the end of Ramadan[43], while one study found a significant reduction in BFP only in males [35], and two studies revealed that the females had significantly higher BFP than males at the end of the fasting month [32, 43].

In measuring the fat mass (FM), one study found a significant reduction in FM in both sexes[35], while one study showed no significant difference in FM between pre and post-Ramadan measurements in both sexes [38], and one study revealed that the females had significantly higher FM than males at the end of Ramadan [32].

For FFM, both of the references that we found had the same results that males have higher FFM than females at the end of Ramadan [32]. Yeoh et al., 2015 [25] showed that females had a significant reduction in visceral fat area (VFA) at the end of Ramadan, while males did not. Akın et al., 2020 [39] reported no significant difference between pre and post-values in FMI and FFMI in both sexes.

Biochemical parameters

Lipid profile is the major biochemical parameter that was measured in both sexes in many studies. Regarding the LDL, two studies reported a significant difference between pre and post LDL values in both sexes [23, 44], while one study reported a significant difference between pre and post LDL values in males only [42], and one study showed a significant difference between pre and post LDL value in females only [40]. Many studies found no significant difference between pre and post LDL values in both males and females [25, 34, 38, 45–47].

Regarding HDL, many studies showed a significant increase in HDL in post-Ramadan values in comparison with pre-Ramadan values in both sexes [23, 40, 44, 45]. One study reported a significant reduction of post HDL value in comparison to the pre-Ramadan value in males only [34], and one study showed a significant increase in HDL post value in comparison to the pre-Ramadan value in females only [46], while many studies found no significant difference between pre and post LDL value in both males and females [25, 38, 42, 47].

Furthermore, one study found a significant decrease in total cholesterol (TC) in post-Ramadan value in comparison with pre-Ramadan value in both sexes [23], and one study reported a significant reduction in post TC value in comparison to the pre-Ramadan value in males only [42]. Sülü et al., 2010 [40] study showed a significant increase in TC post value in comparison to the pre-Ramadan value in females only, while Yeoh et al., 2015 [25] study showed a significant decrease in TC post value in comparison to the pre-Ramadan value in females only, while many studies found no significant difference between pre and post LDL value in both males and females [22, 34, 38, 45–47].

For the triglyceride (TG) parameter, the majority of studies showed no significant difference between pre and post-TG values in both sexes [22, 38, 40, 42, 45, 46]. One study showed a significant reduction in post-TG post value in comparison to the pre-Ramadan value in both sexes [23], and only one study showed a significant increase in TG post value in comparison to the pre-Ramadan value in males only [34]. Only one study measured the effect of RDIF on the lipid profile in general and found no significant difference between males and females at the end of Ramadan [47].

Also, regarding VLDL, all of the studies showed no significant difference between pre and post-VLDL values in both sexes [34, 40, 42]. Only one study measured the difference in LDL/ HDL ratio between pre and post-Ramadan values and found a significant increase in both sexes at the end of Ramadan in comparison with the pre-Ramadan value [34]. Aksungar et al., 2007 [46] reported a significant decrease in both sexes in the post-Ramadan HDL risk factor in comparison to the pre-Ramadan value. In addition to that, Lamri-Senhadji et al., 2009 [22] reported no significant change between pre-RDIF and post RDIF values for uric acid, total blood protein, Apo-A, and Apo-B values in both sexes.

For the fasting blood glucose (FBG), while three studies showed a significant reduction in post value in comparison to the pre-Ramadan value in both sexes [23, 24, 34], only one study showed a significant increase in FBG post value in comparison to the pre-Ramadan value in both sexes [40], one study showed a significant increase in FBG post value in comparison to the pre-Ramadan value in females only [38], and the remaining two studies revealed that no significant between pre and post FBG value in both sexes [25, 42]. Yeoh et al., 2015 [25] showed that there is no significant difference between pre and post HbA1C values in both sexes.

Aksungar et al., 2005 [45] reported no significant change between pre and post-values in both sexes for serum protein, serum calcium, blood urea nitrogen (BUN), and creatinine. Also, Sülü et al., 2010 [40] showed no significant difference between pre and post creatinine values in both sexes.

Ahmadinejad et al., 2006 [48] reported a significant decrease in both sexes in the post-Ramadan T4 value in comparison to the pre-Ramadan value, while no significant change was reported between pre-and-post RDIF for T3 values in both sexes, while a significant increase in TSH was reported post-RDIF value in comparison to the pre-Ramadan value in males only.

Ziaee et al., 's [34] study shows a significant increase in LDL/HDL ratio between Pre and post-values in both sexes, while Akaberi et al., 2014 [47] show no significant change in LDL/HDL ratio in both sexes. Also Akaberi et al., 2014 [47] show no significant change in TG/HDL ratio between pre-RDIF and post RDIF in both sexes. Aksungar et al., 2007 [46] reported that there is a significant reduction in HDL risk factor parameter at the end of Ramadan when compared to pre-Ramadan values in both sexes.

There was a significant increase in botɑh sexes in the post-Ramadan blood folate (BF) and blood vitamin B_{12} values in comparison to the pre-Ramadan value.

Sülü et al., 2010 [40] showed a significant reduction of bilirubin post RDIF value in comparison to the pre-Ramadan value in males only. While a significant increase in the albumin post-RDIF value in comparison compared to the pre-Ramadan value was reported in both sexes, there was a significant increase of urea post RDIF value comparedmadan value in females only, with the lack of any significant differences in AST and ALT values.

Mushtaq et al., 2019 [41] studied the effect of RDIF on TNF-α and adiponectin and reported that at the end of Ramadan males had significantly higher TNF-α values, while females have significantly higher adiponectin values. Brini et al., 2021 [49] found that males have a significant reduction in their heartbeats at the end of Ramadan, while females do not have any significant difference in comparison with the pre-RDIF values.

Kamal et al., 2021 [50] reported that there was no significant difference between males and females in the intracellular pressure values at the end of Ramadan. All of the studies showed no significant change between pre and post-blood pressure (BP) values in both sexes [23, 38, 42]. And finally, Riat et al., 2021[37] were concerned about cortisol, BDNF, IL-8, IGF-1, MMP-9, and myoglobin variables. It was found that no significant difference was found between males and females in the cortisol value at the end of Ramadan, while there is a significant reduction in the cortisol value at the end of Ramadan in males only when compared to the pre-RDIF value [37].

Furthermore, It was found that males have significantly higher BDNF values than females at the end of Ramadan, while there was a significant reduction in the BDNF value at the end of Ramadan in males only when compared to the pre-RDIF value[37].

Also, it was found that males have significantly higher IL-8 values than females at the end of Ramadan, while there was a significant reduction in the IL-8 value at the end of Ramadan in males only, and a significant increase in females only when compared to the pre-RDIF value [37]. In addition, no significant difference was reported between males and females in the IGF-1 value at the end of Ramadan, while a significant reduction in the IGF-1 value was reported at the end of Ramadan in males only when compared to the pre-RDIF value [37].

Finally, it was found that males had significantly higher MMP-9 values than females at the end of Ramadan, while no such significance was reported in the MMP-9 value at the end of Ramadan in both sexes when compared to the pre-RDIF value [37]. Further, males reported significantly higher myoglobin values than females at the end of Ramadan than the pre-fasting levels [37].

Discussion

Recently, the impact of sex on the metabolomic profile has been a matter of extensive research. Several studies have reported that sex impacts metabolites such as lipids and lipid profile, keto acids, amino acids, sugars, and metabolic markers [2, 51–55]. Furthermore, the effect of the menstrual cycle on the metabolomic profile of adult women is obvious, and the sex differences in the response to dietary interventions are all integral parts of the future field of study of personalized or precision nutrition [2, 4].

Anthropometric measurements

The observed sex differences in body composition parameters such as body fat distribution in response to RDIF may have also influenced the results observed for insulin homeostasis presented here in the form of the changes in FBG and HbA1c, and adiponectin that is involved in body fat distribution and appetite [56]. Indeed, it is well established that men have higher waist circumference than women, and have more visceral and less subcutaneous fat than do women [57, 58]. This relative decrease in visceral fat in women has significant metabolic consequences such as improvements in insulin sensitivity and glucose homeostasis [59], a matter that explains in part the sex differences observed in the glucose response between males and females at the end of RDIF month.

For WC, the findings of the current review are in line with the previous findings showing that some sex differences could also have contributed to differences observed in changes in WC between men and women. Studies have shown that men are more likely than women to experience a preferential mobilization of abdominal fat in response to lifestyle changes. In addition, changes in eating behaviors observed in men can also have contributed to improving their anthropometric profile

[60, 61]. Further, previously reported documented that men had significantly higher values of VFA than women, and higher VF volume and VF area than women. These discrepancies between men and women concerning the VF suggest that men are at higher risk for having CVD than women, and may explain, in part, by the fact that premenstrual women can accumulate more body fat than men of the same age before reaching the amounts of VF found in men [60]. Finally, the noted differences in the fat mass and adipose tissue between the two sexes in response to the RDIF are not only presented in the amount and distribution of adipose tissue but also in differences in its metabolic capacity and functions between the sexes [58].

Biochemical tests

Sex differences in the response to dietary intervention have been examined in 2012 by Alexandra Be´dard and colleagues [51]. In their study on the response to a 4-week isoenergetic traditional Mediterranean diet (MD) and sex-related differences concerning changes in cardiometabolic risk factors on 38 men and 32 premenopausal women (aged 25–50 years) who had slightly elevated LDL concentrations or TC: HDL ratio, TC, and LDL. They found that consuming an MD led to significant changes in plasma lipid profile in both men and women, while only men had significant improvements in insulin homeostasis, suggesting that sex-related differences in response to diet should be considered to individualize dietary guidelines in the prevention of type 2 diabetes and cardiovascular disease [51]. Another study by Leblanc and colleagues also examined the sex differences in response to the MD regimen [3]. In their study, 64 men and 59 premenopausal women participated in an a12-week dietary intervention program promoting the adoption of the MD. They found that TC: HDL ratio, TG levels, and TG: HDL ratio were more pronounced in men than in women after the intervention as well as at follow-up [3].

In more recent work, the authors excitingly reported that the observed differences in the cardiometabolic risk factors between males and females, the same as the ones observed after the observance of RDIF, could be ascribed to the sex differences in diet patterns between males and females, also the same as shown in the current work. They ascribed such difference to the differences in the vasculature and body composition between sexes that may be mediated by dissimilarities in the adherence to nutrient metabolism and diet patterns [62]. Among the variabilities reported, breakdown and storage of lipids and salt sensitivity may account for some differences in CVD risk between men and women. Also, sex differences in odor perception, social norms, and cognitive processing may be affected by biological differences and contribute to differences in dietary patterns and hence, in CVD risk [62].

Dietary intakes

Differences between males and females in the food consumption patterns and energy and nutrient intakes upon dietary interventions are excessively reported in different parts of the globe. While a greater percentage of women report dieting compared to men, this is not reflected in observed dietary differences in food choice and macronutrient distribution in cross-sectional studies [62]. Several studies in Canada[3], the UK[63], and Kuwait[64] reported women had higher percent energy from complex carbohydrates, such as potatoes and cereals, than men and exceeded the recommendations for sugar consumption. While men consistently consume more calories [3, 65] and animal protein compared to women, the latter consistently consume a greater amount of fruits and vegetables compared to men in the U.S. and Canada [65, 66].

The noticed differences between males and females in their corresponding food intakes and dietary behaviors during RDIF could be further explained by the wealth of literature suggesting that sex-based differences in food intake and the related behaviors are controlled by the differences in the lateral and dorsolateral prefrontal cortex and parietal cortex between men and women [67]. Greater prefrontal neuronal responses to food cues in women may suggest increased cognitive processing related to executive function, such as planning, guidance, or evaluation of behavior [67].

Regarding the inflammatory markers, the variation in the response to RDIF on inflammatory and proinflammatory markers is consistent with the fact that males and females are different in their inflammatory states and their responses to external stimulatory factors. While CRP concentrations are higher in premenopausal women than in men, IL-6 and TNF-α concentrations have been reported to be lower in women than in men [68]. These sex differences in the inflammatory markers are explained in part by the differences between males and females in both subcutaneous adipose tissue and the visceral adipose tissue that participate in the secretion of these cytokines. While subcutaneous adiposity was the key correlate of CRP in women, CRP concentrations were largely influenced by visceral adiposity in men [68].

Conclusions

The current work revealed a more pronounced decrease in BMI, BW, and WC, body fat among males than females. Sex biological differences should be considered as a stable factor when executing and interpreting the results of dietary modification such as the observance of RDIF.

Tables

le 1. Characteristics of the included studies on the sex-specific effect of Ramadan diurnal intermittent fasting 1ealthy people.

Author ame, Year	Data Collection Year	Country/ city	Study Design	Study group	Examined marker	Total Sample Size	Male n (%)	Male Age (mean ± S.D.)	Female n (%)	Female Age (mean ± S.D.)
Poh et al., 1996 [21]	1995	Malaysia / Kuala Lumpur	Observational	Adolescents	Wt., dietary intake,	117	51 (43.59)	12.00 ± 0.40	66 (56.41)	11.30 ± 0.40
inch et al., 1998 [27]	1996	UK / Reading	Observational	healthy	Hunger & Thirst	41	15 (36.59)	35.30 ± 1.80	26 (63.41)	35.30 ± 1.80
araagaoglu et al 2000 [28]	1996	Turkey / Ankara	Observational	healthy adults	Wt., BMI, calorie expenditure	750	320 (42.67)	40.40 ± 14.90	430 (57.33)	40.80 ± 16.00
ujeq et al., 2002 [44]	2001	Iran / Babul	Observational	healthy adults	LDL, HDL	83	57 (68.67)	34.25 ± 9.81	26 (31.33)	34.58 ± 11.54
akhrzadeh et al., 2003 [23]	2000	Iran / Tehran	Observational	healthy adults	Wt., WC, BMI, LDL, HDL, TC, TG, BP, Kcal, FBG	91	50 (54.95)	19.90 ± 1.80	41 (45.05)	21.90 ± 3.90
Larijani et al., 2003 [24]	2000	Iran / Tehran	Observational	healthy adults	FBG, caloric intake	115	67 (58.26)	21.20 ± 4.30	48 (41.74)	21.20 ± 4.30
ksungar et al., 2005 [45]	2004	Turkey / Istanbul	Observational	healthy adults	LDL, HDL, TC, TG, albumin, Ca, total protein, BW, BUN, Creatinine	24	12 (50.0%)	31.0 ± 2.70	12 (50.0%)	29.00 ± 3.20
aleh et al., 2005 [42]	2003	Kuwait / Kuwait	Observational	healthy adults	LDL, HDL, TC, TG, VLDL, WC, BP, FBG	60	41 (68.33)	37.0 ± 8.60	19 (31.67)	27.70 ± 3.40
hmadinejad et al., 2006 [48]	2002	Iran / Tehran	Observational	healthy adults	T4, T3, TSH	81	41 (50.62)	22.70 ± 2.30	39 (48.15)	22.70 ± 2.30
iaee et al., 2006 [34]	2002	Iran / Tehran	Observational	healthy adults	Wt., FBG, BMI, LDL, HDL, TC, TG, VLDL, LDL/HDL ratio	81	41 (50.62)	22.70 ± 2.30	39 (48.15)	22.70 ± 2.30
ksungar et al., 2007 [46]	2005	Turkey / Istanbul	Observational	Healthy adults	LDL, HDL, TC, TG, HDL risk factor, vitamin B12, Folate	40	20 (50.00)	34.00 ± 3.20	20 (50.00)	31.00 ± 4.20
Erol et al., 2008 [29]	2005	Turkey / Eskisehir	Observational	Adolescents	Wt., BMI, fasting behavior	79	16 (20.25)	16.29 ± 0.80	63 (79.75)	16.31 ± 0.70
Lamri-enhadji et al., 2009 [22]	2008	Algeria / Oran	Observational	young adults	Total Kcal, Pro, fat, sat. Fat, MUFA, PUFA, CHO, Sugar, Cholesterol	46	22 (47.83)	24.00 ± 3.00	24 (52.17)	24.00 ± 3.00
ülü et al.,	2007	Turkey /	Observational	healthy	BMI, FBG,	45	23	30.50	22	26.90

2010 [40, 69]					TG, TC, LDL, HDL, VLDL, AST, ALT, Albumin, Urea, creatinine, bilirubin		(51.11)	± 7.10	(48.89)	± 3.80
Singh et al., 2011 [26]	2009	Malaysia / Bahasa	observational	athletes	Dietary Patterns	734	411 (55.99)	16.30 ± 2.60	323 (44.01)	16.30 ± 2.60
Khattak et al., 2012 [33]	2011	Malaysia / Pahang	Observational	healthy obese	BMI, FFM, BW, WHR, RMR, BFP	25	-	-	-	-
Saedeghi et al., 2012 [43]	2011	Malaysia / Selangor	Observational	adults	BFP	23	13 (56.52)	28.0 ± 4.00	10 (43.48)	27.00 ± 3.00
Norouzy et al., 2013 [35]	2008	Iran / Mashhad	Observational	healthy adults	BMI, FFM, BW, WC, HC, BFP	82	31 (37.80)	-	51 (62.20)	-
Akaberi et al., 2014 [47]	2013	Iran / sebzevar	Observational	healthy	LDL, HDL, TC, LDL/HDL ratio, TG/HDL ratio	43	22 (51.16)	29.40 ± 4.00	21 (48.84)	30.20 ± 5.20
Yeoh et al., 2015 [25]	2013	Singapore	Observational	healthy	HbA1C, BMI, LDL, HDL, TC, FBG, dietary intake, BP, BFM, VFA	29	15 (51.72)	61.00 ± 11.00	14 (48.28)	54.00 ± 10.00
Ongsara et al., 2017 [38]	2015	Thailand / Walailak	Observational	healthy	Wt., WC, BMI, BP, FM, FFM, FBG, TC, TG, LDL, HDL	65	21 (32.31)	20.86 ± 1.35	44 (67.69)	20.80 ± 1.05
Lessan et al., 2018 [31]	2015-2016	China / Beijing	observational	healthy non-obese	RMR	29	13 (44.83)	35.80 ± 7.10	16 (55.17)	31.40 ± 10.10
Mushtaq et al., 2019 [41]	2014	Iran / Karachi	Observational	healthy & obese	Adiponectin, TNF, BMI	110	55 (50.00)	30.24 ± 1.20	55 50.00	28.11 ± 1.01
Akın et al., 2020 [39]	2019	Turkey / Kayseri	Observational	older people	Wt., BMI, SMMI, FMI, FFMI,	30	15 (50.00)	66.70 ± 4.70	15 (50.00)	66.70 ± 4.70
Nugraha et al., 2020 [32]	2017	Germany / Hannover	observational	healthy	BW, BMI, SMM, FFM, BFP, BWM, BMR	34	19 (55.88)	24.80 ± 1.00	15 (44.12)	25.50 ± 1.20
Urooj et al., 2020 [36]	2019	India / Karnataka	Observational	healthy	Wt., WHR, BMI	52	25 (48.08)	37.80 ± 12.07	27 (51.92)	37.80 ± 12.07
Brini et al., 2021 [49]	2018	Tunisia / kef	experimental	basketball players	Heartbeat	24	12 (50.00)	-	12 (50.00)	-
amal et al., 2021 [50]	2020	Pakistan / Sahiwal	Observational	healthy	intraocular pressure	200	135 (67.50)	34.56 ± 12.52	65 (32.50)	34.56 ±12.52
Riat et al., 2021 [37]	2020	Germany / Hannover	Observational	healthy adults	BMI, Cortisol,	34	19 (55.88)	24.80 ± 1.00	15 (44.12)	25.50 ± 1.20

					BDNF, IL-8, IGF-1, MMP-9, Myoglobin					

Table 2. The sex-specific effects on dietary intakes during RDIF.

Variable	Author name, Year	Change in variables (dietary intake)
Total Kcal	Poh et al., 1996 [21]	Total Kcal [sig ↑ male, sig ↑ female]
	Fakhrzadeh et al., 2003 [23]	Total Kcal [sig ↓ male, sig ↓ female]
	Larijani et al., 2003 [24]	Total Kcal [sig ↓ male, sig ↓ female]
	Lamri-Senhadji et al., 2009 [22]	Total Kcal [male □ female (sig.)] Total Kcal [sig ↑ male, sig ↑ female]
	Singh, et al., 2011 [26]	Total Kcal [no diff↔ between male & female]
	Yeoh et al., 2015 [25]	Total Kcal [no diff↔ male, no diff↔ female]
Fats	Poh et al., 1996 [21]	Fat [sig ↑ male, sig ↑ female]
	Lamri-Senhadji et al., 2009 [22]	Fat intake [no diff↔ between male & female]
	Yeoh et al., 2015 [25]	Fat intake [no diff↔ male, no diff↔ female]
Protein	Lamri-Senhadji et al., 2009 [22]	Protein intake [no diff↔ between male & female]
	Yeoh et al., 2015 [25]	Protein intake [no diff↔ male, no diff↔ female]
Total carbohydrates	Poh et al., 1996 [21]	Total CHO [sig ↑ male, sig ↑ female]
	Lamri-Senhadji et al., 2009 [22]	CHO intake [no diff↔ between male & female]
	Yeoh et al., 2015 [25]	CHO intake [no diff↔ male, no diff↔ female]
Calcium	Poh et al., 1996 [21]	Ca [sig ↑ male, no diff↔ female]
Thiamine, B_1	Poh et al., 1996 [21]	Thiamin [sig ↑ male, sig ↑ female]
Riboflavin, B_2	Poh et al., 1996 [21]	Riboflavin [sig ↑ male, no diff↔ female]
MUFA	Lamri-Senhadji et al., 2009 [22]	MUFA intake [no diff↔ between male & female]
PUFA	Lamri-Senhadji et al., 2009 [22]	PUFA intake [no diff↔ between male & female]
Saturated fats	Lamri-Senhadji et al., 2009 [22]	Saturated fat intake [no diff↔ between male & female]
Total sugars	Lamri-Senhadji et al., 2009 [22]	Sugar intake [no diff↔ between male & female]
Cholesterol	Lamri-Senhadji et al., 2009 [22]	cholesterol intake [no diff↔ between male & female]
Hunger	Finch et al., 1998 [27]	Hunger [female □ male (sig.)]
Thirst	Finch et al., 1998 [27]	Thirst [male □ female (sig.)]
BMR	Khattak et al., 2012 [30]	BMR [no diff↔ between male & female]
	Lessan et al., 2018 [31]	BMR [no diff↔ between male & female]
	Nugraha et al., 2020 [32]	BMR [male □ female (sig.)]
Intake vs expenditure	Karaagaoglu et al 2000 [28]	Intake less than expenditure [no diff↔ between male & female]
Eating behaviors	Erol et al., 2008 [29]	Eating behaviors [no diff↔ between male & female]

Table 3. The sex-specific effects on anthropometric measurements during RDIF.

Variable	Author name, Year	Change in variables (Anthropometric)
BW	Poh et al., 1996 [21]	BW [male female (sig.)]
	Karaagaoglu et al 2000 [28]	BW [male female (sig.)]
	Fakhrzadeh et al., 2003 [23]	BW [sig ↓ male, no diff↔ female]
	Aksungar et al., 2005 [45]	BW [no diff↔ male, no diff↔ female]
	Ziaee et al., 2006 [34]	BW [sig ↓ male, sig ↓ female]
	Erol et al., 2008 [29]	BW [male female (sig.)]
	Lamri-Senhadji et al., 2009 [22]	BW [no diff↔ between male & female]
	Khattak et al., 2012 [30]	BW [no diff↔ between male & female]
	Norouzy et al., 2013 [35]	BW [sig ↓ male, sig ↓ female]
	Ongsara et al., 2017 [38]	BW [no diff↔ male, no diff↔ female]
	Akın et al., 2020 [39]	BW [no diff↔ male, no diff↔ female]
	Nugraha et al., 2020 [32]	BW [male female (sig.)]
	Urooj et al., 2020 [36]	BW [sig ↓ male, sig ↓ female]
BMI	Karaagaoglu et al 2000 [28]	BMI [no diff↔ between male & female]
	Fakhrzadeh et al., 2003 [23]	BMI [sig ↓ male, no diff↔ female]
	Ziaee et al., 2006 [34]	BMI [sig ↓ male, sig ↓ female]
	Erol et al., 2008 [29]	BMI [no diff↔ between male & female]
	Sülü et al., 2010 [40]	BMI [no diff↔ male, no diff↔ female]
	Khattak et al., 2012 [30]	BMI [no diff↔ between male & female]
	Norouzy et al., 2013 [35]	BMI [sig ↓ male, sig ↓ female]
	Yeoh et al., 2015 [25]	BMI [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	BMI [no diff↔ male, no diff↔ female]
	Mushtaq et al., 2019 [41]	BMI [male female (sig.)]
	Akın et al., 2020 [39]	BMI [no diff↔ male, no diff↔ female]
	Nugraha et al., 2020 [32]	BMI [no diff↔ between male & female]
	Urooj et al., 2020 [36]	BMI [sig ↓ male, sig ↓ female]
	Riat et al., 2021 [37]	BMI [no diff↔ between male & female]
WC	Fakhrzadeh et al., 2003 [23]	WC [no diff↔ male, sig ↓ female]
	Saleh et al., 2005 [42]	WC [sig ↓male, sig ↓ female]
	Norouzy et al., 2013 [35]	WC [sig ↓ male, sig ↓ female]
	Ongsara et al., 2017 [38]	WC [no diff↔ male, no diff↔ female]
HC	Khattak et al., 2012 [30]	HC [no diff↔ between male & female]
	Norouzy et al., 2013 [35]	HC [sig ↓ male, sig ↓ female]
TBW	Khattak et al., 2012 [30]	TBW [no diff↔ between male & female]
	Nugraha et al., 2020 [32]	TBW [male female (sig.)]
	Urooj et al., 2020 [36]	TBW [no diff↔ male, sig ↓ female]
WHR	Khattak et al., 2012 [30]	WHR [no diff↔ between male & female]
	Urooj et al., 2020 [36]	WHR [no diff↔ male, no diff↔ female]
BFP	Khattak et al., 2012 [30]	BFP [no diff↔ between male & female]
	Saedeghi et al., 2012 [43]	BFP [female male (sig.)] BFP [sig ↓ male, sig ↓ female]
	Norouzy et al., 2013 [35]	BFP [sig ↓ male, no diff↔ female]
	Yeoh et al., 2015 [25]	BFP [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	BFP [no diff↔ male, no diff↔ female]
	Nugraha et al., 2020 [32]	BFP [female male (sig.)]
	Urooj et al., 2020 [36]	BFP [no diff↔ male, no diff↔ female]
FM	Norouzy et al., 2013 [35]	FM [sig ↓ male, sig ↓ female]
	Ongsara et al., 2017 [38]	FM [no diff↔ male, no diff↔ female]
	Nugraha et al., 2020 [32]	FM [female male (sig.)]
VFA	Yeoh et al., 2015 [25]	VFA [no diff↔ male, sig ↓ female]
FFM	Nugraha et al., 2020 [32]	FFM [male female (sig.)]
MM	Akın et al., 2020 [39]	MM [no diff↔ male, no diff↔ female]
	Nugraha et al., 2020 [32]	MM [male female (sig.)]
FMI	Akın et al., 2020 [39]	FMI [no diff↔ male, no diff↔ female]
FFMI	Akın et al., 2020 [39]	FFMI [no diff↔ male, no diff↔ female]

BFM: Body fat mass; BMI: Body mass index; BMR: basal metabolic rate; BW: Body weight; EE: Energy expenditure; FFM: Fat-free mass; FFMI: Fat-free mass index; FMI: Fat mass index; HC: Hip circumference; LMI: Lan mass index; MM: Muscle mass; BFP: Body fat Percent; RMR: Resting metabolic rate; SMMI: Skeletal muscle mass index; TBW: Total body water; VFA: Visceral fat area; WC: Waist circumference; WHR: Waist to hip ratio

Table 4. The sex-specific effects on biochemical variables during RDIF.

Variable	Author name, Year	Change in variables (biochemical)
LDL	Qujeq et al., 2002 [44]	LDL [sig ↓ male, sig ↓ female]
	Fakhrzadeh et al., 2003 [23]	LDL [sig ↓ male, sig ↓ female]
	Aksungar et al., 2005 [45]	LDL [no diff↔ male, no diff↔ female]
	Saleh et al., 2005 [42]	LDL [sig ↓ male, no diff↔ female]
	Ziaee et al., 2006 [34]	LDL [no diff↔ male, no diff↔ female]
	Aksungar et al., 2007 [46]	LDL [no diff↔ male, no diff↔ female]
	Sülü et al., 2010 [40]	LDL [no diff↔ male, sig ↑ female]
	Yeoh et al., 2015 [25]	LDL [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	LDL [no diff↔ male, no diff↔ female]
	Akaberi et al., 2014 [47]	LDL [no diff↔ between male & female]
HDL	Qujeq et al., 2002 [44]	HDL [sig ↑ male, sig ↑ female]
	Fakhrzadeh et al., 2003 [23]	HDL [sig ↑ male, sig ↑ female]
	Aksungar et al., 2005 [45]	HDL [sig ↑ male, sig ↑ female]
	Saleh et al., 2005 [42]	HDL [no diff↔ male, no diff↔ female]
	Ziaee et al., 2006 [34]	HDL [sig ↓male, no diff↔ female]
	Aksungar et al., 2007 [46]	HDL [no diff↔ male, sig ↑ female]
	Sülü et al., 2010 [40]	HDL [sig ↑ male, sig ↑ female]
	Yeoh et al., 2015 [25]	HDL [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	HDL [no diff↔ male, no diff↔ female]
	Akaberi et al., 2014 [47]	HDL [no diff↔ between male & female]
TC	Fakhrzadeh et al., 2003 [23]	TC [sig ↓ male, sig ↓ female]
	Aksungar et al., 2005 [45]	TC [no diff↔ male, no diff↔ female]
	Saleh et al., 2005 [42]	TC [sig ↓ male, no diff↔ female]
	Ziaee et al., 2006 [34]	TC [no diff↔ male, no diff↔ female]
	Aksungar et al., 2007 [46]	TC [no diff↔ male, no diff↔ female]
	Lamri-Senhadji et al., 2009 [22]	TC [no diff↔ male, no diff↔ female]
	Sülü et al., 2010 [40]	TC [no diff↔ male, sig ↑ female]
	Yeoh et al., 2015 [25]	TC [no diff↔ male, sig ↓ female]
	Ongsara et al., 2017 [38]	TC [no diff↔ male, no diff↔ female]
	Akaberi et al., 2014 [47]	TC [no diff↔ between male & female]
TG	Fakhrzadeh et al., 2003 [23]	TG [sig ↓ male, sig ↓ female]
	Aksungar et al., 2005 [45]	TG [no diff↔ male, no diff↔ female]
	Saleh et al., 2005 [42]	TG [no diff↔ male, no diff↔ female]
	Ziaee et al., 2006 [34]	TG [sig ↑ male, no diff↔ female]
	Aksungar et al., 2007 [46]	TG [no diff↔ male, no diff↔ female]
	Lamri-Senhadji et al., 2009 [22]	TG [no diff↔ male, no diff↔ female]
	Sülü et al., 2010 [40]	TG [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	TG [no diff↔ male, no diff↔ female]
BP	Fakhrzadeh et al., 2003 [23]	BP [no diff↔ male, no diff↔ female]
	Saleh et al., 2005 [42]	BP [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	BP [no diff↔ male, no diff↔ female]
VLDL	Saleh et al., 2005 [42]	VLDL [no diff↔ male, no diff↔ female]
	Ziaee et al., 2006 [34]	VLDL [no diff↔ male, no diff↔ female]
	Sülü et al., 2010 [40]	VLDL [no diff↔ male, no diff↔ female]
FBG	Fakhrzadeh et al., 2003 [23]	FBG [sig ↓ male, sig ↓ female]
	Larijani et al., 2003 [24]	FBG [sig ↓ male, sig ↓ female]
	Saleh et al., 2005 [42]	FBG [no diff↔ male, no diff↔ female]
	Ziaee et al., 2006 [34]	FBG [sig ↓ male, sig ↓ female]
	Sülü et al., 2010 [40]	FBG [sig ↑ male, sig ↑ female]
	Yeoh et al., 2015 [25]	FBG [no diff↔ male, no diff↔ female]
	Ongsara et al., 2017 [38]	FBG [no diff↔ male, sig ↑ female]
Serum protein	Aksungar et al., 2005 [45]	Total protein [no diff↔ male, no diff↔ female]
Serum Ca	Aksungar et al., 2005 [45]	Serum Ca [no diff↔ male, no diff↔ female]
BUN	Aksungar et al., 2005 [45]	BUN [no diff↔ male, no diff↔ female]
Creatinine	Aksungar et al., 2005 [45]	Creatinine [no diff↔ male, no diff↔ female]
	Sülü et al., 2010 [40]	Creatinine [no diff↔ male, no diff↔ female]
T4	Ahmadinejad et al., 2006 [48]	T4 [sig ↓ male, sig ↓ female]
T3	Ahmadinejad et al., 2006 [48]	T3 [no diff↔ male, no diff↔ female]
TSH	Ahmadinejad et al., 2006 [48]	TSH [sig ↑ male, no diff↔ female]

LDL/HDL ratio	Ziaee et al., 2006 [34]	LDL/HDL ratio [sig ↑ male, sig ↑ female]
	Akaberi et al., 2014 [47]	LDL/HDL [no diff↔ between male & female]
TG/HDL ratio	Akaberi et al., 2014 [47]	TG/HDL [no diff↔ between male & female]
HDL risk factor	Aksungar et al., 2007 [46]	HDL risk factor [sig ↓ male, sig ↓ female]
Blood folate	Aksungar et al., 2007 [46]	Blood folate [sig ↑ male, sig ↑ female]
Blood vitamin B_{12}	Aksungar et al., 2007 [46]	Blood vitamin B12 [sig ↑ male, sig ↑ female]
Uric acid	Lamri-Senhadji et al., 2009 [22]	Uric acid [no diff↔ male, no diff↔ female]
Total serum protein	Lamri-Senhadji et al., 2009 [22]	Total protein [no diff↔ male, no diff↔ female]
Apo-A	Lamri-Senhadji et al., 2009 [22]	Apo-A [no diff↔ male, no diff↔ female]
Apo-B	Lamri-Senhadji et al., 2009 [22]	Apo-B [no diff↔ male, no diff↔ female]
Bilirubin	Sülü et al., 2010 [40]	Bilirubin [sig ↓ male, no diff↔ female]
Albumin	Sülü et al., 2010 [40]	Albumin [sig ↑ male, sig ↑ female]
Urea	Sülü et al., 2010 [40]	Urea [no diff↔ male, sig ↑ female]
AST	Sülü et al., 2010 [40]	AST [no diff↔ male, no diff↔ female]
ALT	Sülü et al., 2010 [40]	ALT [no diff↔ male, no diff↔ female]
HbA1c	Yeoh et al., 2015 [25]	HbA1C [no diff↔ male, no diff↔ female]
TNF-α	Mushtaq et al., 2019 [41]	TNF [male female (sig.)]
Adiponectin	Mushtaq et al., 2019 [41]	Adiponectin [female male (sig.)]
Heartbeat	Brini et al., 2021 [49]	Heartbeat [sig ↓male, no diff↔ female]
Intracellular pressure	Kamal et al., 2021 [50]	Intracellular pressure [no diff↔ between male & female]
Cortisol	Riat et al., 2021 [37]	Cortisol [no diff↔ between male & female] Cortisol [sig ↓male, no diff↔ female]
BDNF	Riat et al., 2021 [37]	BDNF [male female (sig.)] BDNF [sig ↓male, no diff↔ female]
IL-8	Riat et al., 2021 [37]	IL-8 [male female (sig.)] IL-8 [sig ↓male, sig ↑ female]
IGF-1	Riat et al., 2021 [37]	IGF-1 [no diff↔ between male & female] IGF-1 [sig ↑ male, no diff↔ female]
MMP-9	Riat et al., 2021 [37]	MMP-9 [male female (sig.)] MMP-9 [no diff↔ male, no diff↔ female]
Myoglobin	Riat et al., 2021 [37]	Myoglobin [male female (sig.)]

ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; BDNF: Brain-derived neurotrophic factor; BF: Blood folate; BMR: basal metabolic rate; BP: Blood pressure; BUN: Blood urea nitrogen; HDL: High-density lipoprotein; IGF-1: Insulin-like growth factor-1; IL-8: Interleukin-8; LDL: Low-density lipoprotein; MMP-9: Matrix metalloproteinase-9; T3: Triiodothyronine; T4: Thyroxine; TC: Total cholesterol; TG: Triglycerides; TNF-α: Tumor necrosis factor-α; TSH: Thyrotropin-stimulating hormone; VLDL: Very-low-density lipoprotein.

Abbreviations

ALT

Alanine aminotransferase

AST

Aspartate aminotransferase

BDNF

Brain-derived neurotrophic factor

BF

Blood folate

BFM

Body fat mass

BG

Blood glucose

BMI

Body mass index

BMR

basal metabolic rate
BP
Blood pressure
BUN
Blood urea nitrogen
BW
Body weight
Cr
Creatinine
EB
Eating behaviors,
EE
Energy expenditure
FFM
Fat-free mass
FFMI
Fat-free mass index
FMI
Fat mass index
HC
Hip circumference
HDL
High-density lipoprotein
IGF-1
Insulin-like growth factor-1
IL8
Interleukin 8 (IL8)
Kcal
Total calories
LDL
Low-density lipoprotein
LMI
Lan mass index
LP
Lipid profile
MM
Muscle mass
MMP-9
Matrix metalloproteinase-9
MUFA
Monounsaturated fatty acids
BFP
Percent body fat
PUFA
Polyunsaturated fatty acids
RMR
Resting metabolic rate

SMMI
Skeletal muscle mass index
T3
Triiodothyronine
T4
Thyroxine
TBW
Total body water
TC
Total cholesterol
TG
Triglycerides
TNF-α
Tumor necrosis factor-α
TSH
Thyrotropin-stimulating hormone
VFA
Visceral fat area
VLDL
Very-low-density lipoprotein
WC
Waist circumference
WHR
Waist to hip ratio

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Declarations

Competing interests: The authors declare no competing interests

Figures

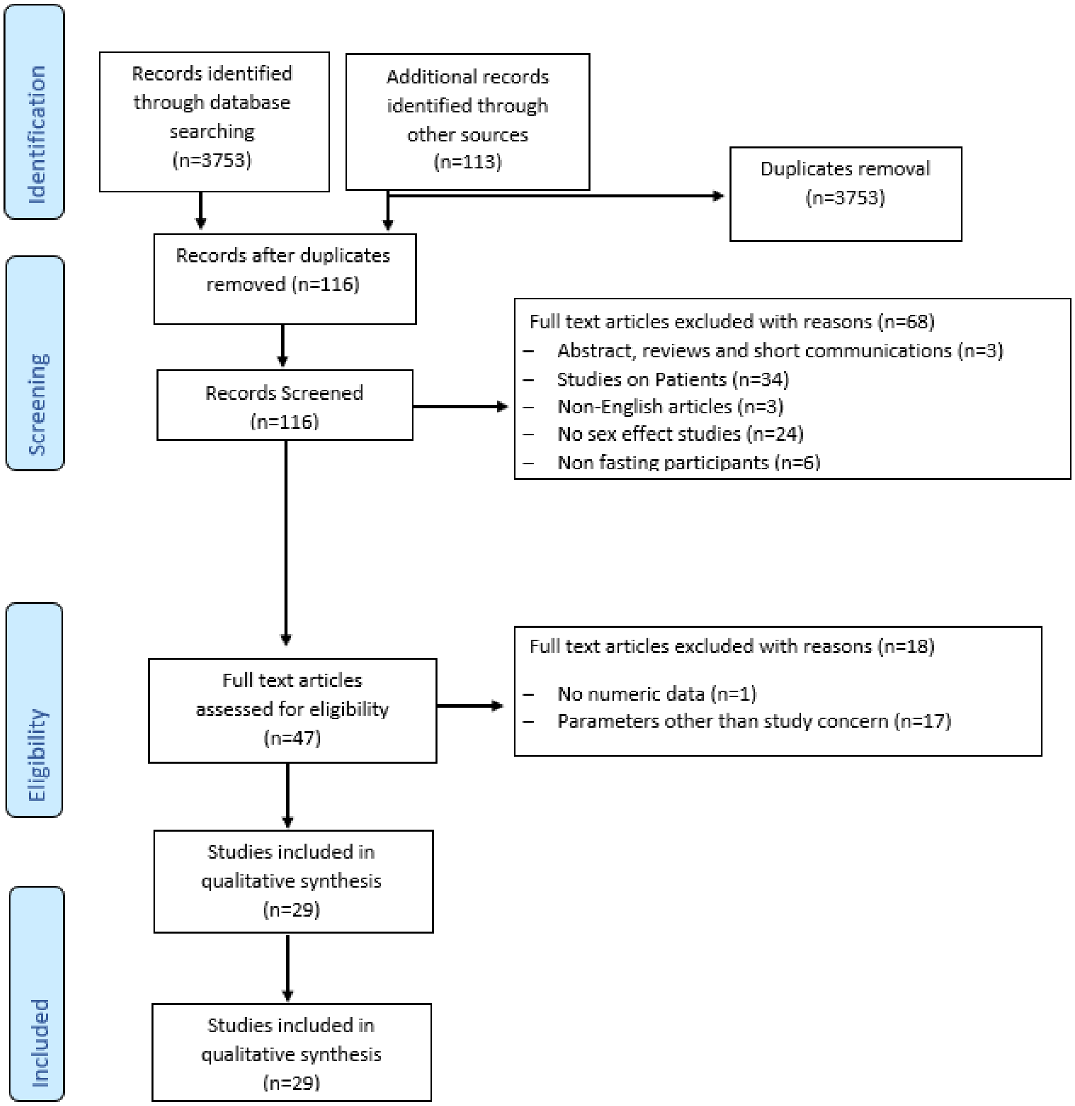

Figure 1

A PRISMA flowchart diagram of included and excluded studies.