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Fruit and vegetable intake modifies the association between ultra-processed food and metabolic syndrome

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Abstract

Background This prospective cohort study aimed to investigate the association between ultra-processed food (UPF) and the risk of metabolic syndrome (MetS), as well as to assess whether fruit and vegetable intake and weight change modify this association.

Methods We included 1915 healthy participants who participated in the Tehran Lipid and Glucose Study (TLGS), all of whom had complete demographic, anthropometric, and dietary measurements. A validated food frequency questionnaire was used to assess UPF consumption based on the NOVA classification system. MetS was defined according to the Joint Interim Statement. Multivariable adjusted Cox regression was used to estimate hazard ratios (HRs) for MetS events across tertiles of UPF. The effect of fruit and vegetable consumption and weight change on this association was assessed using joint classification by Cox regression.

Results UFP consumption showed no association with MetS risk after adjusting for confounders. However, after adjustment for dietary fiber, fruits, and vegetables, the highest tertile of UPF consumption was positively linked to MetS risk, compared to the lowest tertile. There was a significant interaction between fruit, vegetable, and dietary fiber intake and UPF consumption concerning the risk of MetS (All P values < 0.05). Among individuals consuming less than 248 g/day of fruit, the risk of MetS increased by 54% (confidence interval: 1.13–2.10) in the highest UPF tertile. Consuming vegetables and dietary fiber below the median (258 g/day and 42.2 g/day, respectively) increased the risk of MetS in the third tertile of UPF. However, consuming vegetables and fiber ≥ median intake, reduced the risk of MetS among those with the lowest UPF consumption. Furthermore, the risk of MetS was observed in the third tertile of UPF consumption among individuals with fruit and vegetable consumption < 537 g/day. UPF consumption was not associated with the risk of MetS in different weight change statuses.

Conclusions Consuming more fruits and vegetables mitigated the adverse effect of UPF on the risk of developing MetS.

Keywords Ultra-processed foods, Metabolic syndrome, Fruit and vegetable consumption, Weight change

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Introduction

Metabolic syndrome (MetS) is defined as a constellation of cardiovascular risk factors, including abdominal obesity, insulin resistance, atherogenic dyslipidemia, and hypertension. This condition increases the risk of type 2 diabetes by fivefold and the risk of cardiovascular disease by twofold [1, 2]. The prevalence of MetS has risen globally in recent decades [3, 4], with an estimated 12.5–31.4% of the global adult population, affected based on various diagnostic criteria [5]. In Iran, a nationwide study of metabolic syndrome prevalence revealed that the prevalence of MetS has increased over the last three decades. According to ATP III criteria, approximately 38.3% of Iranians have MetS [6]. A poor-quality diet is a recognized risk factor for MetS. Ultra-processed food (UPF), characterized by heavy processing and minimal whole-food ingredients, is high in calories and lacking in nutrients. Due to their high levels of calories, sodium, unhealthy fats, and sugars, and low levels of micronutrients, fiber, and proteins, UPF is linked to several chronic diseases such as type 2 diabetes, MetS, hypertension, and all-cause mortality [1, 7–10].

UPF is considered to contribute to obesity. A cross-sectional study across nineteen European countries observed that for every percentage point increase in UPF availability in households, there was a 0·25% point rise in obesity prevalence [11]. However, it remains uncertain whether UPF directly increases the risk of chronic diseases through obesity [10, 12]. Additionally, dietary inequality and inadequate consumption of healthy foods like fruits and vegetables have been reported among individuals with higher UPF intake [13–16]. Previous studies have adjusted for fruit and vegetable consumption as a confounding factor when examining the relationship between UPF and MetS, type 2 diabetes, and hypertension [10, 17, 18], although not all studies have done so [9, 19–21]. Nonetheless, in studies where adjustment for fruit and vegetable intake was made, the association between higher UPF consumption and increased MetS risk remained unchanged, suggesting that the adverse effects of UPF are independent of diet quality [22]. It is worth noting that inadequate consumption of healthy foods such as fruits and vegetables among individuals with higher UPF intake [13], and the lack of variation in fruit and vegetable intake across UPF quartiles [18] may have influenced the finding that adjusting for healthy food intake does not affect the association between UPF consumption and chronic diseases. To the best of our knowledge, there have been no studies investigating the modifying effect of fruits and vegetables on the association between UPF and the risk of MetS. Moreover, the majority of studies have been conducted in European countries [9, 15–18, 21], and Brazil [10, 13, 19], revealing a wide variation in UPF consumption, from 17% [17] to over 50% [10, 14, 19, 20] of the total calorie intake in these studies. By conducting the present study in the Middle East and North Africa (MENA) region, which exhibits different dietary habits compared to Western and European countries, we can expand our knowledge of the correlation between UPF consumption and chronic diseases.

Therefore, to address the aforementioned gap, in this population-based prospective cohort study, we aimed to (1) investigate the association between UPF consumption and MetS risk and (2) assess whether this association is influenced by fruit and vegetable consumption and weight change among adults.

Materials and methods

Study design and participants

We conducted this prospective population-based study within the framework of the Tehran Lipid and Glucose Study (TLGS), which is an ongoing prospective study to prevent non-communicable diseases. The details of this study have been provided elsewhere [23]. The study, initiated in March 1999 (Phase I), enrolled over 15,000 individuals aged≥3 years from District 13 of Tehran, the capital of Iran, using multistage stratified cluster random sampling. This district represents the urban population of Tehran. Since 1999, TLGS participants underwent assessments for various factors every three years, including sociodemographic factors, lifestyle, medication use, socioeconomic status, anthropometric indices, and medical history of cardiovascular risk factors. Phases II, III, IV, V, and VI were conducted during 2002–2004, 2005–2008, 2008–2011, 2012–2015, and 2016–2018, respectively. For this study, we utilized baseline examination data from Phase III (2005–2008) and followed the participants up to Phase VI (2016–2018) in an 8.91-year follow-up (interquartile range (IQR):7.98–9.69). During the third survey of TLGS (2005–2008), medical history and physical examination were collected for 12,523 participants, after which a representative sample of 4920 participants was randomly selected based on their age and gender to complete further dietary assessment. Of these, 3462 completed a food frequency questionnaire (FFQ). The characteristics of these participants were similar to those of the total population in Phase III of TLGS. From the 3462 participants, 3265 adults aged 19–74 years with complete information were selected from Phase III of TLGS (2005–2008). The following samples were excluded: (1) individuals with MetS at baseline (n=879); (2) pregnant or lactating women at baseline or follow-up (n=28); (3) subjects with daily energy intake<500 and >4000 kcal per day (n=115) [24]; (4) subjects with any specific diets due to hyperlipidemia, hypertension, and hyperglycemia (n=26); and (5) subjects with missing laboratory or anthropometric data related to the diagnosis of MetS during the follow-up (n=309). The final analysis was conducted on 1915 participants until 2018, with a response rate of 66% during an 8.9-year follow-up period (IQR: 7.98–9.69).

The study protocol was approved by the Ethics Committee of the Research Institute for Endocrine Sciences (RIES) of Shahid Beheshti University of Medical Sciences, Tehran, Iran. Written informed consent was also obtained from all participants.

Anthropometric measurements

Weight was measured using a digital scale (Seca 707; range: 0–150 kg; Seca GmbH, Germany), in the fasted state, with minimal clothing, without shoes, and recorded to the nearest 100 g. Height was also measured in a standing position, with shoulders in neutral alignment without shoes, using a stadiometer (Seca 225; Seca GmbH, Germany), and recorded to the nearest 0.5 cm. The body mass index (BMI) was calculated by dividing weight in kilograms by height in meters squared. The participants' waist circumference was measured in a standing position at the end of exhalation. The measurement was taken midway between the iliac crest and lowest rib using an unstretched tape measure with 0.5 cm accuracy [25]. After a 15-minute rest, blood pressure was measured using a standardized mercury sphygmomanometer (calibrated by the Iranian Institute of Standards and Industrial Research) on the right arm twice, at least 30 s apart. The average of the two measurements was reported as the subject's blood pressure.

Assessment of other variables

The participants' general characteristics, such as demographic details (age, sex), lifestyle factors (smoking status and physical activity), socioeconomic status (education and employment), medication regimen (e.g., antihypertensive, lipid-lowering, and anti-diabetes drugs), and medical history, were initially gathered by trained researchers using a standardized questionnaire. Subjects with a university degree were classified as highly educated individuals, while those with a degree below a diploma were categorized as less educated individuals. Additionally, physical activity was evaluated through the Modifiable Activity Questionnaire (MAQ), capturing the frequency and duration of weekly physical activity over the last year [26]. These activity levels were quantified as metabolic-equivalent (MET) hours per week (MET-h/week) [27]. The reliability and convergent validity of the Persian version of MAQ have been documented elsewhere [28].

Dietary assessment

Dietary intake was evaluated using a self-administered 168-item semiquantitative food-frequency questionnaire (FFQ) that had been validated in Iran [29]. The FFQ included a list of foods with standard serving sizes commonly consumed by Iranians. Trained dietitians, each with a minimum of 5 years experience in the TLGS survey, conducted face-to-face interviews and guided participants to report their frequency of consuming each food item over the previous year, based on a daily (e.g., bread), weekly (e.g., meat), or monthly (e.g., fish) basis. The reported frequency for each food item was converted to a daily intake. The consumed food's portion sizes were subsequently converted to grams using household measurements. The Iranian food composition Table (FCT) was utilized to determine the macro- and micronutrient content [30].

Out of 1915 participants at baseline, 592 completed all four FFQs, 804 completed three, 316 completed two, and 203 refused to complete any FFQs during the follow-up. The last observation carried forward method was employed to fill in the missing values [31]. In this study, given the significant impact of recent dietary intakes on the relationship between diet and chronic disease, we utilized an alternative approach based on the Hu et al. formula [31]. This approach gives greater emphasis to recent dietary assessments, intending to reduce within-subject variability and provide a more concise evaluation of long-term diet.

In the current study, UPF is defined based on the NOVA food group classification system, which categorizes foods according to the extent and purpose of food processing [32]. UPF included hydrogenated fat, mayonnaise, margarine, potato chips, Puffs, hamburger, sausage, pizza, sugar-sweetened beverages, biscuits, cakes, candies, chocolates, ice cream, cocoa milk, crackers, Iranian confectionery (gaz, Sohan, halvah), and pastries (non-crème and creamy). The consumption of UPF, as well as fruit, vegetables, and fiber, was assessed by adjusting the total energy intake using the residual model [24].

For UPF, a good correlation coefficient existed between FFQ and multiple 24 recalls and between two FFQs [33]. Moreover, the dietary patterns' reliability, validity, and stability were reasonable based on the data collected from the FFQ over eight years [34].

Biochemical assessment

For biochemical measurements, venous blood samples were collected in vacutainer tubes after 12–14 h of overnight fasting and centrifuged within 30–45 min of collection for all subjects. The fasting plasma glucose (FPG), high-density lipoprotein-cholesterol (HDL-C), and triglyceride (TG) levels were measured in the TLGS research laboratory on the day of sample collection using a Selectra 2 autoanalyzer (Vital Scientific, Spankeren, the Netherlands) and commercial kits (Pars Azmoon Inc., Tehran, Iran). FPG level was measured using an enzymatic colorimetric method with the glucose oxidase technique. The inter- and intra-assay coefficients of variation (CV) at baseline and after follow-up were both below 2.3%. TG was also assayed using an enzymatic colorimetric method with glycerol phosphate oxidase, while HDL-C was measured after the precipitation of apolipoprotein B-containing lipoproteins with phosphotungstic acid. In all baseline and follow-up assays, intra- and inter-assay CVs were below 2.1% and 3.0% for TG and HDL-C. All samples were analyzed when the internal quality control met the acceptable criteria.

Definition of MetS

According to the Joint Interim Statement, diagnosis of MetS requires the presence of three or more of the following criteria [35]: (1) elevated glucose concentration (FPG ≥ 100 mg/dL) or treatment with anti-hyperglycemic medications; (2) elevated serum TG concentration (≥ 150 mg/dL) or treatment with anti-hypertriglyceridemia medications; (3) reduced serum HDL-C concentration (< 50 mg/dL in women and < 40 mg/dL in men); (4) elevated blood pressure (≥ 130/85 mmHg) or treatment with anti-hypertensive medications; and (5) enlarged abdominal circumference (≥ 95 cm according to the population- and country-specific cut-off points for Iranian adults of both genders) [36].

Definition of weight change

Weight change was calculated by subtracting the baseline weight from the follow-up one (phase IV) and multiplying it by 100. Participants were categorized as those who lost weight (> 3%), those with weight stability (± 3%), and those who gained weight (> 3%) [37].

Statistical analysis

UPF consumption was adjusted for energy by the residual method [38] and was modeled as tertiles. The normality of the distribution of variables was assessed by the Histogram and the Kolmogorov-Smirnov test. Characteristics of participants were expressed as mean ± standard deviation (SD) for continuous variables and percentages for categorical variables. Cox proportional-hazards regression models were used to estimate the hazard ratio (HR) (95% confidence interval) for MetS risk across the tertiles of UPF. Five models were fit. The first model was crude. The second model was adjusted for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, and weight change. The third model additionally adjusted for fiber intake. The fourth model included the same variables as the second model, along with vegetable intake, the fifth model included the second model with the addition of fruit intake, and the sixth model included the second model with the addition of fruit and vegetable intake. In the multivariable model, significant interactions were observed between UPF consumption and fiber, fruit, and vegetable intake (all *P* values < 0.05), whereas no significant interaction was found between weight change and UPF (*P* interaction = 0.063). Therefore, we evaluated the effect of weight change, fruit, and vegetables on the association between ultra-processed foods and MetS risk. All statistical analyses were performed in SPSS version 15.0 (SPSS Inc., Chicago, IL, USA), and *P*-values less than 0.05 were considered statistically significant.

Results

The study included 1915 participants, with 1140 being female (59.5%) and a mean (SD) age and BMI of 36.5 years (13.3) and 25.6 (4.5) kg/m^2, respectively. The majority of participants had lower education levels ($n = 1418$, 74.0%), were non-smokers ($n = 1499$, 78.3%) and were not employed ($n = 1089$, 56.9%). The median UPF intake was 11.9% (IQR: 8.2 to 16.8) of total energy intake. The most common UPFs were hydrogenated vegetable oil (24.9%), biscuits (9.8%), cakes (9.3%), ice creams (9.0%), potato chips (8.3%), and mayonnaise (3.6%). The baseline participant's characteristics across tertiles of dietary UFPs are shown in Table 1. Participants in the lowest UPF tertile tended to be younger, current smokers, have higher BMI, and consume more energy, carbohydrates, protein, fat, saturated fatty acids (SFA), mono-unsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), cholesterol, red meat, processed meat, eggs, and refined grains. However, their intake of fiber, fruit, vegetables, nuts, dairy products, and whole grains decreased across the UFP tertiles.

During a median follow-up of 8.9 years, 591 new cases of MetS were documented. Table 2 presents a multivariable-adjusted hazard ratio (95% confidence interval) for MetS risk across UFP tertiles. Consumption of UPF was not associated with MetS risk in the crude model (model 1). This association remained non-significant even after adjustment for age, sex, smoking status, physical activity, family history of diabetes, dietary cholesterol, and weight change (Model 2), as well as additional adjustment for dietary fiber intake (model 3). Adjustment for vegetables (model 4), fruit (model 5), and fruit and vegetable intake (Model 6) revealed a positive association between higher UPF consumption and MetS risk (1.30, 1.05–1.61 in model 4; 1.31, 1.05–1.63 in model 5; 1.30, 1.04–1.63 in model 6, respectively).

A significant interaction was found between UFP consumption and dietary fiber ($P = 0.043$), fruit ($P = 0.029$), vegetables ($P = 0.017$), and fruit and vegetable intake (0.031) in relation to MetS risk. Subjects who consumed less than 248 g/day of fruit intake were found to have an increased risk of MetS in the third tertile of UPF consumption. Similarly, individuals with vegetable and dietary fiber intake < median exhibited an increased risk

Table 1 Baseline characteristics of participants across tertiles of Ultra-processed Food

	Ultra-Processed Food				
	Total population	**T1**	**T2**	**T3**	***P* value**
Participants (n/N)	591/1915	175/638	193/639	223/638	
Range of intake (% of total energy)	0.3–53.1	≤ 9.5	9.6–15.1	≥ 15.2	
Median intake (% of total energy)	11.9	6.8	11.9	18.9	
Age (y)	36.5 ± 13.3	41.2 ± 13.5	35.7 ± 12.9	32.6 ± 11.9	< 0.001
Women, n (%)	1140 (59.5)	383 (33.6)	359 (31.5)	398 (34.9)	0.082
Physical activity level, n (%)					
Low	966 (50.5)	330 (51.7)	312 (48.0)	324 (51.7)	0.506
Medium	489 (25.5)	162 (25.4)	167 (25.7)	160 (25.5)	
High	460 (24.1)	146 (22.9)	171 (26.3)	143 (22.8)	
Smoker, n (%)	416 (21.7)	110 (26.4)	142 (34.1)	164 (39.4)	0.001
Highly educated individuals, n (%)	497 (26.0)	178 (35.8)	171 (34.4)	148 (29.8)	0.138
Occupation (employee), n (%)	826 (43.1)	267 (32.3)	295 (35.7)	264 (32.0)	0.151
Family history of diabetes, yes	620 (32.4)	228 (36.8)	202 (32.6)	190 (30.6)	0.117
BMI (kg/m^2)	25.6 ± 4.5	26.1 ± 4.3	25.4 ± 4.3	25.2 ± 4.4	0.001
Dietary variables					
Total energy (kcal/d)	2332 ± 907	2277 ± 690	2332 ± 709	2487 ± 711	0.046
Carbohydrate (% of total energy)	61.3 ± 12.0	58.1 ± 11.8	62.0 ± 11.7	63.8 ± 11.8	< 0.001
Protein (% of total energy)	14.7 ± 2.1	13.7 ± 2.6	14.6 ± 2.1	15.7 ± 2.8	< 0.001
Fat (% of total energy)	30.1 ± 5.2	27.2 ± 4.5	29.6 ± 4.2	33.3 ± 5.0	< 0.001
SFA (% of total energy)	9.9 ± 2.5	9.3 ± 2.8	9.7 ± 2.1	10.5 ± 2.3	< 0.001
MUFA (% of total energy)	10.2 ± 2.7	9.2 ± 3.2	9.9 ± 2.1	11.5 ± 2.2	< 0.001
PUFA (% of total energy)	6.1 ± 1.9	5.3 ± 2.1	5.9 ± 1.3	7.1 ± 1.8	< 0.001
Total fiber (g/d)	42.2 ± 18.2	44.1 ± 19.6	43.8 ± 18.2	38.6 ± 16.0	< 0.001
Cholesterol (g/d)	232 ± 110	225 ± 103	274 ± 108	337 ± 120	0.003
Vegetables (g/d)	288 ± 157	305 ± 159	298 ± 175	261 ± 132	< 0.001
Fruit (g/d)	383 ± 130	418 ± 133	402 ± 131	330 ± 133	< 0.001
Red Meat, and processed meat (g/d)	28.0 ± 21.5	23.3 ± 20.2	27.9 ± 17.5	32.8 ± 25.2	< 0.001
Poultry and fish (g/d)	45.1 ± 31.1	39.7 ± 32.0	40.9 ± 31.7	54.9 ± 34.1	0.423
Eggs (g/d)	18.7 ± 5.8	17.0 ± 6.4	16.3 ± 5.2	20.0 ± 4.1	0.015
Whole grain (g/d)	141 ± 94	157 ± 104	146 ± 91	121.9 ± 82	< 0.001
Refined grain (g/day)	332 ± 163	339 ± 148	314 ± 158	353 ± 159	0.003
Nuts (g/week)	17.3 ± 8.4	24.3 ± 9.9	14.6 ± 8.8	9.3 ± 6.6	0.003
Legumes (g/d)	37.0 ± 28.7	34.8 ± 27.8	38.4 ± 28.5	37.7 ± 29.6	0.061
Dairy products (g/d)	390 ± 130	400 ± 136	401 ± 142	368 ± 110	0.014
Ultra-processed food (g/d)	105.3 ± 85	51 ± 29	98 ± 53	166 ± 106	< 0.001

n/N, number of metabolic syndrome events/Number of participants; MET, metabolic equivalent; BMI, body mass index; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids

Values are mean ± SD and number (%)

of MetS in the third tertile of UPF consumption. Subjects in the lowest tertile of UPF consumption, with the intake of fiber and vegetables ≥ median, had a lower risk of MetS. Furthermore, the risk of MetS was observed in the third tertile of UPF consumption among individuals with fruit and vegetable consumption < 537 g/day (Fig. 1).

Figure 2 presents HRs (95% CI) for MetS based on combined categories of UPF consumption and different weight change statuses. There was no association between UPF consumption and the risk of MetS in various weight change statuses.

We also conducted model runs using dietary data in Phase III. The results, as displayed in Supplementary Tables 1–2 and Supplementary Figs. 1–2, were generally consistent with those of models employing an alternative approach.

Discussion

In this 8.9-year follow-up study, UPF consumption was not associated with MetS risk in adults. However, after adjustment of fruit and vegetable intake, UPF consumption was found to increase the risk of MetS. We observed that the association between UPF consumption and MetS risk was modified by fruit and vegetable intake. Specifically, UFP consumption increased the risk of MetS only in individuals consuming < 250 g/day of fruits and

Table 2 Multivariable adjusted hazard ratio (95% confidence interval) for metabolic syndrome across tertiles of ultra-processed foods: Tehranlipidd andglucoseestudyy

Variable	Tertiles of intakes			
	T1	T2	T3	P_{trend}
Ultra-processed food (% of calorie)				
Participants (n/N)	175/638	193/639	223/638	
Range of intake	≤ 9.5	9.6–15.1	≥ 15.2	
Median intake	6.8	11.9	18.9	
Model 1	1	1.10 (0.90–1.35)	1.19 (0.97–1.45)	0.239
Model 2	1	1.18 (0.96–1.44)	1.24 (1.01–1.51)	0.093
Model 3	1	1.19 (0.97–1.46)	1.26 (1.03–1.56)	0.067
Model 4	1	1.10 (0.89–1.36)	1.30 (1.05–1.61)	0.047
Model 5	1	1.07 (0.86–1.33)	1.31 (1.05–1.63)	0.041
Model 6	1	1.06 (0.85–1.32)	1.30 (1.04–1.63)	0.039

n/N, number of metabolic syndrome events/Number of participants

Model 1 was crude.

Model 2 age, sex, smoking status, physical activity, family history of diabetes, cholesterol, and weight change

Model 3 was adjusted for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, weight change, and fiber intake

Model 4 was adjusted for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, weight change, and vegetable

Model 5 was adjusted for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, weight change, and fruit

Model 6 was adjusted for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, weight change, and fruit and vegetable

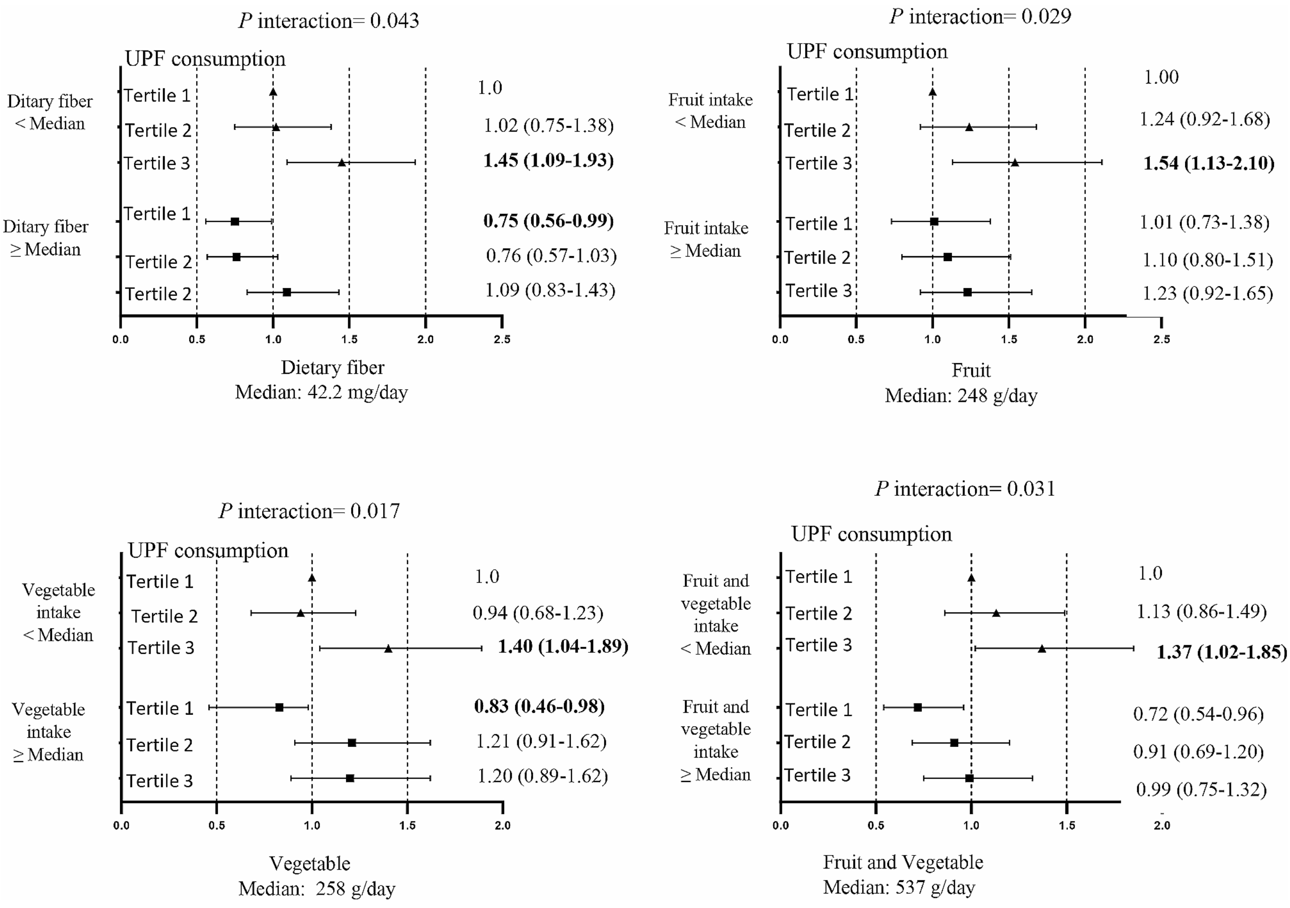

Fig. 1 Hazard ratios of the combined effect of ultra-processed foods and dietary fiber, fruit,vegetable intake (lower or higher than the median intake) on metabolic syndrome risk after adjustment for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, and weight change

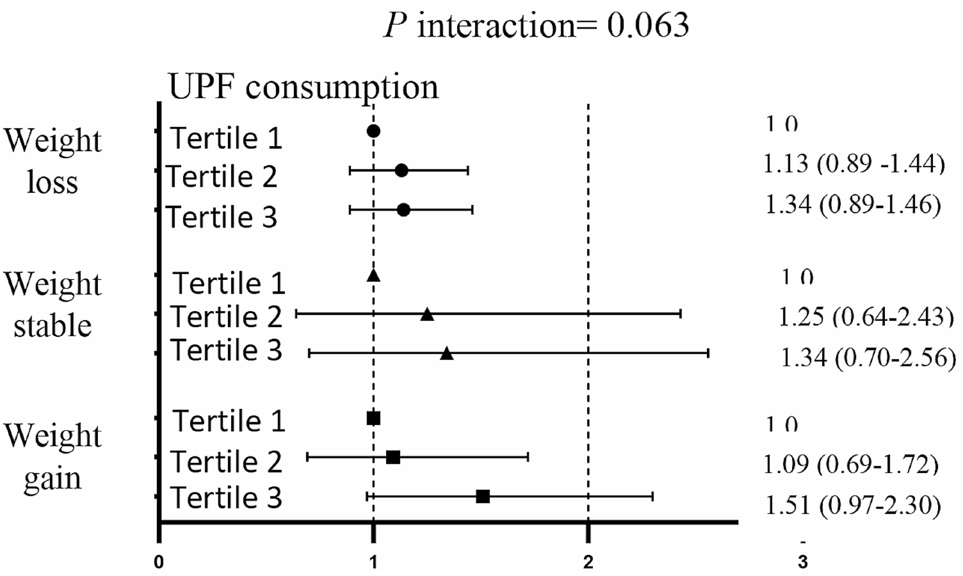

Fig. 2 Hazard ratios of the combined effect of ultra-processed foods and weight change status (triangle, weight loss > 3% weight loss; square, weight stable (±3%); and circle, > 3% weight gain) on metabolic syndrome risk after adjustment for age, sex, smoking status, physical activity, family history of diabetes, cholesterol, fiber, fruit, and vegetable intake

vegetables. Moreover, consuming < 540 g/day of fruits and vegetables increased the risk of MetS in those with higher UPF intake. This association disappeared when the intake was ≥540 g/day. Furthermore, the association between UPF and MetS risk was influenced by changes in weight status.

Increased consumption of UPF leads to a higher risk of MetS, as demonstrated in previous cross-sectional and prospective studies. Research conducted in various countries such as Brazil, Canada, Iran, and the United States consistently shows that higher UPF consumption is linked to an elevated MetS [14, 19, 20, 39]. For instance, Brazilian adults with a median UPF consumption of 366 g/day had a higher MetS risk after an 8-year follow-up [10]. Similarly, in the Chinese population, UPF consumption at a median intake of 16.3 g/day was associated with a reduced risk of MetS after 6.0 years of follow-up [40]. These findings are supported by intervention studies indicating that reducing UPF consumption can prevent and manage MetS [41]. In contrast to previous studies, our current study found no association between UFP consumption and MetS risk. This discrepancy could be because in previous studies [10, 14, 19, 20, 39, 40], UPF accounted for over 50% of the total calorie intake, which was approximately higher than in our study. The lower UPF consumption in the current study compared to previous ones may explain why we did not observe an association between UPF consumption and MetS risk, even after adjusting for various confounders such as age, sex, smoking status, physical activity, family history of diabetes, calorie intake, cholesterol, weight change, and dietary fiber intake. Our findings align with previous cross-sectional studies involving Brazilian women [42] and Lebanese adults [43], where UPF constituted a median of 30–40% of total calorie intake.

UPF is known to contribute to obesity [11]. The mechanisms by which UPF can increase the risk of obesity include higher energy intake due to increased sugar consumption, lower fiber intake, and lower protein density [44]. A recent systematic review reported that the link between UPF, chronic diseases such as type 2 diabetes, and MetS was not dependent on BMI [12]. In line with previous studies [10, 17], this current study found no significant association between UPF consumption and MetS after adjusting for weight change. We also found no interaction between UPF and weight status on the risk of MetS; increased UPF consumption was not associated with the risk of MetS across different weight change statuses. These results suggest that UPF products might contribute to the risk of MetS through mechanisms beyond weight change and BMI. Our findings along with an 8-year follow-up study indicated an interaction between UPF consumption and MetS risk, where consuming 150 g of UPF daily was associated with an increased risk of MetS in both non-obese and obese individuals [10].

We found that the observed associations became significant once we adjusted for vegetable and fruit consumption, indicating that the intake of fruits and vegetables may modify this association. Studies have reported diet inequality and inadequate intake of fruits and vegetables among individuals with higher UPF consumption [13–16]. Fruits and vegetables have been found to have a negative association with the risk of MetS [45, 46]. In most studies, the association between UPF and MetS, as well as its components such as type 2 diabetes and hypertension, has been adjusted for fruit and vegetable consumption as a confounding factor [10, 17, 18], although not in all of them [9, 19–21]. However, adjusting for fruit and vegetable intake in these studies did not change this association. This aligns with a review of prospective studies suggesting that the detrimental effects of UPF are not influenced by the quality of the diet [22]. Nevertheless, our study revealed that consuming a minimum of 250 g/day of fruits and vegetables counteracted the harmful impact of UPF consumption in increasing the risk of MetS. These findings are consistent with a recent meta-analysis of prospective studies demonstrating a 10% decrease in the risk of type 2 diabetes with an increase in fruit or vegetable intake up to 300 g/day [47]. Furthermore, we observed that dietary fiber modifies the association between UPF consumption and the risk of MetS. A high fiber intake can offset the adverse effects of UPF consumption on the development of MetS. Therefore, to prevent MetS, it is recommended to have a diet rich in fruits and vegetables while restricting the intake of UPF.

The present study has several strengths, including its population-based prospective design, long follow-up duration, utilization of validated FFQ, using alternative approaches for dietary intake assessment, and exploration of the influence of fruit and vegetable consumption as well as weight changes on the relationship between UPF and the risk of MetS over an 8.9-year follow-up. By conducting this study in the Middle East and North Africa region with different dietary habits compared to Western and Eastern countries, we can expand our understanding of this association. However, caution must be taken when extrapolating our findings to other populations due to varying levels of UPF consumption in different countries. Moreover, UPF consumption was assessed using a validated and reliable FFQ, which is considered a gold standard tool for assessing habitual dietary intake. Nevertheless, the FFQ was not specifically designed to collect data on UPF. This limitation could lead to misclassification, resulting in an underestimation of the dietary impact of UPF and biasing the association between UPF consumption and MetS toward the null findings. Another limitation is the possibility of residual or unmeasured confounders influencing the results. Additionally, as our study is observational, we cannot establish causality. Lastly, the conclusions drawn in the current study were based on an 8.9-year follow-up. Prospective studies with longer follow-up durations are necessary to further support our conclusions.

Conclusions

Our findings suggest that higher consumption of fruit and vegetable intake may offset the detrimental effect of UPF consumption on MetS risk.

Abbreviations

MetS	Metabolic syndrome
UPF	Ultra-processed foods
TLGS	Tehran Lipid and Glucose Study
FFQ	Food frequency questionnaire
BMI	Body mass index
WC	Waist circumference
MAQ	Modifiable Activity Questionnaire
MET	Metabolic-equivalent
MET-h/week	Metabolic-equivalent hours per week
FCT	Iranian food composition table
FPG	Fasting plasma glucose
HDL-C	High-density lipoprotein-cholesterol
TG	Triglyceride
CV	Coefficients of variation
SE	Standard error
HR	Hazard ratio
SFA	Saturated fatty acids
MUFA	Mono-unsaturated fatty acids
PUFA	Poly-unsaturated fatty acids

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Author contributions

S.H.N. conceptualized and designed the study. S.HN, H.M, and M.H analyzed and interpreted the data; S.HN, M.S, P.M, and F.A drafted the initial manuscript; PM and S.HN supervised the project; all authors read and approved the final version of the manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available due institution's policy but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the ethics committee of the Research Institute for Endocrine Sciences (RIES), Shahid Beheshti University of Medical Sciences, and written informed consent was acquired from participants before their inclusion in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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