

## Original Article



# The Association of Dietary Phytochemical Index with Metabolic Syndrome in Adults

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## ABSTRACT

In this study, we assessed the association between the dietary phytochemical index (DPI) and metabolic syndrome (MetS) among adults in a cross-sectional study. We enrolled 850 adult men and women aged 18–65 years who had been referred to health centers in Tehran, Iran. The DPI was calculated based on 8 components including fruits, vegetables, legumes, whole grains, soy products, nuts, seeds, olive, and olive oil. The odds ratio (OR) and 95% confidence interval (CI) of the MetS across quartiles of the DPI were calculated using the logistic regression analysis, adjusting for age, energy intake, marital status, education status, occupation, smoking status, physical activity, and body mass index. The mean age of participants was  $44.7 \pm 10.7$ , of whom 69% were women. The prevalence of MetS was 30.5%. The mean score of DPI in women and men was  $36.2 \pm 26.8$  and  $33.7 \pm 24.7$ , respectively. There was no significant association between DPI and odds of MetS in men ( $OR_{\text{fourth vs. first quartile}}, 1.57$ ; 95% CI, 0.64–3.84) and women ( $OR_{\text{fourth vs. first quartile}}, 0.86$ ; 95% CI, 0.50–1.49) in the fully adjusted model. There was an inverse association between DPI and increased risk of central obesity in women ( $OR_{\text{fourth vs. first quartile}}, 0.54$ ; 95% CI, 0.29–1.00;  $p$  trend = 0.03). There was no significant association between DPI and other components of the MetS in men and women. Finally, we observed no significant association between the DPI and the odds of MetS. However, the finding suggests that having a phytochemical-rich diet can be inversely associated with abdominal obesity.

**Keywords:** Metabolic syndrome; Phytochemicals; index; Diet; Adults; Iran

## INTRODUCTION

Metabolic syndrome (MetS) is a complex health condition consisting of a series of risk factors that raise the risk of cardiovascular disease (CVD), type 2 diabetes (T2D), and all-cause of mortality [1,2]. Several metabolic disorders contribute to the development of MetS, such as glucose intolerance, insulin resistance, lipid disorders, abdominal obesity, and elevated blood pressure [3]. MetS is highly prevalent in developed countries and around the world [4]. The prevalence of MetS is 30% in Iran, with a significantly higher prevalence in women (35%) than in men (26%) [5].

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#### Conflict of Interest

The authors declare that they have no competing interests.

As a multifactorial phenomenon, MetS is a consequence of intricate interaction among genetic, lifestyle, and environmental factors [6]. Among these factors, diet as a modifiable component of lifestyle has been demonstrated to play a crucial role in the prevention of MetS [7,8]. Some observational studies have suggested that higher intake of plant-based foods and food groups such as fruit and vegetables, dietary fiber, and whole grains, or higher adherence to dietary patterns rich in plant-based foods, may be associated with a lower risk of developing MetS and its components [9-13]. Plant-based foods are rich in dietary phytochemicals and it is proposed that part of the inverse association found between these foods and MetS may be mediated by dietary phytochemicals [14].

Dietary phytochemicals are a large class of natural non-nutritious bioactive compounds including phenolic compounds (flavonoids, phenolic acids, hydroxycinnamic acids, lignans, tyrosol esters, and stilbenoids), isoprenoids, and organosulfur compounds (allyl sulfors and isothiocyanate) [15-17]. Several studies have indicated the beneficial effects of a specific subclass of phytochemicals such as flavonoids or phenolic acid for the prevention or treatment of MetS [18,19].

To capture the phytochemical properties of the diet and to present a dietary index reflecting the entire dietary phytochemical content, McCarty [20] introduced a dietary phytochemical index (DPI). This index is defined as the percentage of daily energy intake derived from phytochemical-rich foods. Previous studies showed inverse associations between higher DPI score and chronic disease risks such as MetS, obesity, T2D, cancers, and CVD risk factors [21-25].

However, to the best of our knowledge, no research has studied the association of the DPI with MetS and its components in the Middle East. So, this study was designed to examine the association between DPI and the likelihood of MetS and its components in Iranian adults.

## MATERIALS AND METHODS

### Participants

In this cross-sectional study, 850 adult men and women were recruited from health care centers in 5 parts (North, East, West, South, and center) of Tehran, capital of Iran, from 2018 to 2019. First, a list of all health centers in each region was prepared, and then eight health centers were randomly selected from 5 different areas throughout Tehran. Next, according to the inclusion criteria, participants were selected from each health center by a simple random sampling method. To find the number of participants in each health center, we divided the total sample size (850) by the number of health centers (40). Qualified subjects to include in our study were seemingly healthy adults 18 to 65 years old, residing in Tehran, who were willing to participate in the study. Individuals with at least one incomplete variable were excluded from the study and thus, 844 individuals were included in the conclusive analyses.

### Ethical approval

Before participating in the study, written information about the background and processes of the study was provided to the subjects, and then, written informed consent was obtained from participants. This study was performed in accordance with the Declaration of Helsinki and approved by the ethical committee of the Tehran University of Medical Sciences (Ethics No. IR.TUMS.VCR.REC.1397.157).

### Demographic factors

In this cross-sectional study, information about age, sex, education (under university/university graduated), marriage (single, married), smoking status (nonsmoker/former smoker/current smoker), and occupation (employee, housekeeper, retired, unemployed) were collected by demographic questionnaire.

### Physical activity

Participants' physical activity was assessed using a validated International Physical Activity Questionnaire [26]. Participants were divided into 2 groups according to their metabolic equivalents (METs) [27] including no or low (< 600 MET-minutes per week), and moderate and high physical activity (> 600 MET-minutes per week).

### Anthropometric and blood pressure assessments

Height was measured using a stadiometer with a sensitivity of 0.1 cm (Seca, Hamburg, Germany) in the standing position and without shoes when the shoulders were relaxed. The weight of participants was measured in light clothing without wearing shoes using a digital scale (808Seca; Seca), with an accuracy of 0.1 kg. Waist circumference (WC) was measured in the middle between the iliac crest and the lower rib margin, using a flexible anthropometric tape. Body mass index (BMI) was obtained by dividing weight by height ( $\text{kg}/\text{m}^2$ ). Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured twice on the right arm, by a digital sphygmomanometer (BC 08; Beurer, Ulm, Germany) after at least 10–15 minutes of rest and sitting. The average of the 2 measurements was reported as blood pressure per person.

### Measurement of biochemical parameters

After 12 hours of overnight fasting, blood samples were collected and measured to quantify serum levels of fasting plasma glucose (FPG), triglycerides (TG), and high-density lipoprotein (HDL) cholesterol. Blood samples were measured by standard methods at the Nutrition and Biochemistry Laboratory of the School of Nutritional Sciences and Dietetics at Tehran University of Medical Sciences.

### Dietary assessment

A validated and reliable semi-quantitative food frequency questionnaire with 168 items was used to assess the dietary intake of participants [28]. A trained nutritionist filled the information of questionnaires through face-to-face interviews. By using household measures, portion sizes of the consumed foods were converted to grams per day [29]. The intake of energy and nutrient content of foods was estimated by using Nutritionist IV software based on the Iranian foods-modified US Department of Agriculture food composition [30].

### Calculating the DPI

The DPI was calculated according to the method developed by McCarty [20]. The index consists of eight components including fruits, vegetables, legumes, whole grains, soy products, nuts, seeds, olive, and olive oil. We first calculated the ratio of energy obtained from the aforementioned eight foods or food groups (kcal) to total daily energy intake and then multiplied by 100 to calculate the DPI. Because of their high phytochemical content, natural fruit juices were categorized into the fruit group, and vegetable juices and tomato sauces were categorized into the vegetable group. Potatoes, pickled and powdered vegetables were excluded as they do not consider a rich source of phytochemicals.

### Definition of MetS

According to the criteria of the National Cholesterol Education Program Adult Treatment Panel III, the definition of MetS is to have 3 or more of the following criteria: 1) abdominal obesity (WC  $\geq$  88 cm for women and 102 cm for men); 2) high serum TG (TG  $\geq$  150 mg/dL); 3) low serum HDL cholesterol concentration ( $<$  50 mg/dL for women and  $<$  40 mg/dL for men); 4) hyperglycemia (FPG  $\geq$  100 mg/dL); and 5) hypertension (SBP  $\geq$  130 mmHg and/or DBP  $\geq$  85 mmHg) [31].

### Statistical methods

By using the Statistical Package for the Social Sciences (SPSS version 26; SPSS Inc., Chicago, IL, USA), all statistical analyses were performed. The  $p < 0.05$  was considered as a significant level. To compare the frequency of classified variables among the DPI quartiles, a chi-square test was used. A one-way analysis of variance test was used to compare the means of quantitative variables across DPI quartiles. Analysis of covariance (ANCOVA) was applied to assess the means of biochemical parameters across quartiles of the DPI score adjusting for age, sex, marital status, occupation, education status, smoking status, physical activity, energy intake, and BMI. We also used ANCOVA to evaluate the means of dietary intake across quartiles of the DPI controlling for age, gender, physical activity, and energy intake. To assess the relationship between DPI and odds of MetS in the crude and adjusted models, binary logistic regression analysis was used. In model 1, we adjusted for age, sex, and energy intake. In model 2, more control was done for education (under university, university graduated), marriage (single, married), smoking (nonsmoker/former, smoker/current smoker), occupation (employee, housekeeper, retired, unemployed), and physical activity (no physical activity, moderate or heavy physical activity). The first quartile of the DPI was the reference group.

## RESULTS

The general characteristics and anthropometric measures of the participants across quartiles of the DPI are shown in **Table 1**. The mean age of subjects was  $44.7 \pm 10.7$  years, 68.7% of whom were women. The prevalence of MetS was 30.5%. The mean and standard deviation of the score of DPI in women and men were  $36.2 \pm 26.8$  and  $33.7 \pm 24.7$ , respectively. The proportion of women increased significantly along with the increase in the DPI score. No other significant difference was observed in the general characteristics across quartiles of the DPI.

The values of laboratory tests of participants across quartiles of the DPI are presented in **Table 2**. Subjects in the top quartile of the DPI tend to have lower levels of FPG, SBP, DBP, TG,

**Table 1.** Sociodemographic characteristics of the study participants across quartiles of the DPI

Characteristics	Q1 (n = 211)	Q2 (n = 211)	Q3 (n = 211)	Q4 (n = 211)	p value*
DPI score	$< 17.2$	17.2–28.8	28.8–45.0	$> 45.0$	
Age (yr)	$44.9 \pm 10.5$	$44.3 \pm 11.0$	$45.1 \pm 10.1$	$44.7 \pm 11.2$	0.98
Weight (kg)	$74.3 \pm 12.8$	$74.1 \pm 15.7$	$72.4 \pm 12.5$	$73.0 \pm 12.9$	0.17
Gender (% men)	37.4	31.3	24.6	31.8	<b>0.04</b> <sup>†</sup>
Marital status (% married)	82.9	82.0	82.5	76.8	0.33
Smoking status (% current)	4.7	4.7	6.2	5.2	0.90
Occupation (% employed)	31.8	25.1	24.6	20.9	0.28
Physical activity (% moderate or heavy)	38.4	38.4	36.5	33.2	0.60
Education (% university graduated)	38.4	35.1	31.8	31.3	0.38

Values are mean  $\pm$  standard deviation for continuous variables and percent for categorical variables.

DPI, dietary phytochemical index; Q, quartile.

\*The p values resulted from the analysis of one-way analysis of variance for continuous variables and  $\chi^2$  test for categorical variables. <sup>†</sup>The p < 0.05 is significant.

**Table 2.** Values of cardiometabolic risk factors of the study participants across quartiles of the dietary phytochemical index

Variables	Q1 (n = 211)	Q2 (n = 211)	Q3 (n = 211)	Q4 (n = 211)	p value*
SBP (mm Hg)	120.0 ± 1.4	120.0 ± 1.4	119.0 ± 1.4	119.0 ± 1.4	0.90
DBP (mm Hg)	78.9 ± 0.9	79.0 ± 0.9	77.4 ± 0.9	77.8 ± 0.9	0.69
FPG (mg/dL)	108.0 ± 3.1	109.0 ± 3.0	108 ± 3.0	107.0 ± 3.1	0.96
TG (mg/dL)	146.1 ± 5.8	148.9 ± 5.6	144.2 ± 5.6	141.4 ± 5.7	0.76
HDL (mg/dL)	49.4 ± 0.7	49.1 ± 0.7	50.6 ± 0.7	50.1 ± 0.7	0.40
WC (cm)	93.7 ± 11.6	92.2 ± 13.3	91.6 ± 11.4	91.2 ± 13.4	0.55
BMI (kg/m <sup>2</sup> )	28.5 ± 7.8	27.9 ± 5.0	27.6 ± 4.3	27.5 ± 4.7	0.42 <sup>†</sup>

Values are mean ± standard deviation.

SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TG, triglyceride; HDL, high-density lipoprotein; WC, waist circumference; BMI, body mass index; Q, quartile.

\*Obtained by ANCOVA, adjusted for age, gender, education status, Occupation status, marital status, physical activity, smoking status, energy intake, and BMI;

<sup>†</sup>Put out the BMI from the analysis as confounder.

WC, and BMI and a higher level of HDL cholesterol, but the variations across quartiles of the DPI were not significant.

Dietary intakes of the study participants across the quartile of the DPI are presented in **Table 3**. Subjects in the highest quartile had a lower intake of energy, protein, carbohydrate, and total, saturated, unsaturated fats, and cholesterol. Also, compared with the participants in the first quartile of the DPI, those in the top quartile had a higher intake of fruit, vegetables, nuts, legumes, whole grains, seeds, olive oil, and soy products.

Crude and multivariable-adjusted odds ratios (ORs); 95% confidence intervals (CIs) of MetS and its components among quartiles of the DPI score in women and men are indicated, respectively, in **Tables 4** and **5**. No significant association was observed between DPI and odds of MetS in men and women neither in the crude nor in adjusted models. The DPI was not associated with components of the MetS in men and women. The exception was central adiposity in women, where a higher DPI score was associated with a lower likelihood of having central obesity either in the crude (OR, 0.58; 95% CI, 0.36–0.94; p trend = 0.02) or in the fully adjusted model (OR, 0.54; 95% CI, 0.29–1.00; p trend = 0.03).

**Table 3.** Dietary intake of the study participants across quartiles of the dietary phytochemical index

Variables	Q1 (n = 211)	Q2 (n = 211)	Q3 (n = 211)	Q4 (n = 211)	p value*
Energy (kcal/day)	3,563 ± 3,572	2,210 ± 796	2,346 ± 873	2,019 ± 859	< 0.001 <sup>†</sup>
Protein (g/day)	111 ± 72.8	87.3 ± 34.0	82.2 ± 33.3	69.5 ± 28.6	< 0.001
Carbohydrate (g/day)	545 ± 888	369 ± 130	350 ± 144	299 ± 120	< 0.001
Fat (g/day)	109 ± 71.3	82.4 ± 35.7	76.9 ± 37.9	66.0 ± 42.7	< 0.001
SFA (g/day)	32.7 ± 22.8	24.9 ± 13.0	23.0 ± 12.6	20.1 ± 16.4	< 0.001
PUFA (g/day)	22.1 ± 18.4	17.3 ± 10.4	16.3 ± 9.45	13.8 ± 9.60	< 0.001
MUFA (g/day)	33.6 ± 27.3	25.2 ± 12.3	22.8 ± 13.7	20.1 ± 12.9	< 0.001
Cholesterol (mg/day)	280 ± 202	236 ± 172	212 ± 113	192 ± 126	0.002
Fruit (g/day)	153 ± 102	250 ± 170	375 ± 270	602 ± 459	< 0.001
Vegetable (g/day)	145 ± 119	156 ± 90.6	217 ± 155	276 ± 202	< 0.001
Nuts (g/day)	6.58 ± 8.86	9.53 ± 10.3	11.9 ± 13.7	29.2 ± 38.3	< 0.001
Legumes (g/day)	34.7 ± 27.7	49.6 ± 42.2	56.0 ± 42.6	83.9 ± 107	< 0.001
Whole grains (g/day)	26.3 ± 29.5	36.2 ± 42.8	52.2 ± 57.5	85.4 ± 97.0	< 0.001
Seeds (g/day)	0.88 ± 2.37	1.19 ± 2.38	1.87 ± 5.11	4.18 ± 9.79	< 0.001
Olive oil (g/day)	1.10 ± 3.13	1.51 ± 3.11	3.03 ± 7.37	8.09 ± 30.9	< 0.001
Soy sources (g/day)	11.1 ± 12.5	15.4 ± 15.1	24.8 ± 38.8	22.6 ± 36.0	< 0.001

Data are expressed as mean ± standard deviation.

SFA, saturated fatty acids; PUFA, poly unsaturated fatty acids; MUFA, mono unsaturated fatty acids; Q, quartile.

\*Using analysis of covariance, adjusted for age, gender, physical activity, and energy intake. The p < 0.05 is significant; <sup>†</sup>Put out the energy intake from the analysis as confounder.

**Table 4.** Odds ratios (95% confidence interval) of metabolic syndrome and its components across quartiles of the dietary phytochemical index in women

Variable	Q1 (n = 132)	Q2 (n = 145)	Q3 (n = 159)	Q4 (n = 144)	p trend*
MetS (No.)	59	72	59	59	
Crude	1.00	1.22 (0.76–1.95)	0.73 (0.45–1.16)	0.85 (0.53–1.8)	0.18
Model 1	1.00	1.30 (0.79–2.15)	0.76 (0.46–1.56)	0.92 (0.55–1.57)	0.30
Model 2	1.00	1.32 (0.78–2.20)	0.73 (0.43–1.21)	0.86 (0.50–1.49)	0.17
Low HDL					
Crude	1.00	1.08 (0.67–1.74)	0.81 (0.51–1.30)	0.87 (0.54–1.41)	0.36
Model 1	1.00	0.99 (0.60–1.63)	0.75 (0.46–1.22)	0.77 (0.46–1.30)	0.19
Model 2	1.00	0.97 (0.58–1.60)	0.73 (0.45–1.20)	0.76 (0.44–1.29)	0.17
Central obesity					
Crude	1.00	0.80 (0.49–1.31)	0.70 (0.43–1.13)	0.58 (0.36–0.94)	0.02
Model 1	1.00	0.80 (0.46–1.40)	0.69 (0.40–1.19)	0.57 (0.31–1.02)	0.04
Model 2	1.00	0.76 (0.43–1.35)	0.63 (0.36–1.11)	0.54 (0.29–1.00)	0.03
Hyperglycemia					
Crude	1.00	0.85 (0.53–1.37)	0.76 (0.48–1.21)	0.84 (0.52–1.35)	0.41
Model 1	1.00	0.84 (0.52–1.37)	0.75 (0.49–1.21)	0.83 (0.50–1.36)	0.40
Model 2	1.00	0.88 (0.53–1.46)	0.71 (0.43–1.18)	0.76 (0.45–1.28)	0.22
Hypertriglyceridemia					
Crude	1.00	0.91 (0.56–1.48)	0.91 (0.56–1.46)	0.89 (0.55–1.46)	0.68
Model 1	1.00	0.99 (0.59–1.64)	0.99 (0.60–1.63)	1.0 (0.59–1.71)	0.97
Model 2	1.00	1.00 (0.59–1.67)	0.93 (0.56–1.54)	0.95 (0.55–1.63)	0.78
Hypertension					
Crude	1.00	1.56 (0.95–2.57)	0.93 (0.56–1.53)	1.29 (0.78–2.13)	0.82
Model 1	1.00	1.96 (1.09–3.51)	1.04 (0.58–1.86)	1.54 (0.84–2.81)	0.61
Model 2	1.00	1.92 (1.06–3.49)	0.99 (0.55–1.79)	1.51 (0.81–2.81)	0.70

MetS, metabolic syndrome; HDL, high-density lipoprotein; Q, quartile.

\*Obtained by logistic regression analysis. Model 1: Adjusted for age and energy intake. Model 2: Additionally adjusted for marital status, education status, occupation, physical activity, and smoking status.

**Table 5.** Odds ratios (95% confidence interval) of metabolic syndrome and its components across quartiles of the dietary phytochemical index in men

Variable	Q1 (n = 79)	Q2 (n = 66)	Q3 (n = 52)	Q4 (n = 67)	p trend*
MetS (No.)	14	18	7	16	
Crude	1.00	1.74 (0.78–3.84)	0.72 (0.27–1.93)	1.48 (0.66–3.32)	0.69
Model 1	1.00	2.0 (0.83–4.56)	0.79 (0.28–2.21)	1.76 (0.74–4.19)	0.48
Model 2	1.00	2.13 (0.91–4.97)	0.72 (0.25–2.07)	1.57 (0.64–3.84)	0.71
Low HDL					
Crude	1.00	1.81 (0.77–4.29)	0.80 (0.27–2.33)	1.34 (0.55–3.29)	0.86
Model 1	1.00	1.90 (0.78–4.60)	0.88 (0.29–2.63)	1.47 (0.57–3.79)	0.73
Model 2	1.00	1.99 (0.79–4.96)	0.86 (0.27–2.67)	1.25 (0.47–3.36)	0.99
Central obesity					
Crude	1.00	0.89 (0.42–1.88)	1.61 (0.76–3.40)	0.95 (0.45–1.97)	0.74
Model 1	1.00	1.12 (0.51–2.42)	1.99 (0.90–4.42)	1.27 (0.57–2.80)	0.33
Model 2	1.00	1.15 (0.52–2.53)	1.98 (0.87–4.47)	1.21 (0.54–2.73)	0.41
Hyperglycemia					
Crude	1.00	1.15 (0.59–2.23)	1.16 (0.57–2.36)	1.19 (0.61–2.30)	0.60
Model 1	1.00	1.06 (0.53–2.09)	1.06 (0.50–2.21)	1.05 (0.52–2.21)	0.89
Model 2	1.00	1.10 (0.54–2.21)	1.09 (0.51–2.34)	1.02 (0.49–2.11)	0.96
Hypertriglyceridemia					
Crude	1.00	0.82 (0.42–1.60)	0.48 (0.23–1.02)	0.71 (0.36–1.38)	0.16
Model 1	1.00	0.78 (0.39–1.55)	0.48 (0.22–1.05)	0.68 (0.33–1.39)	0.18
Model 2	1.00	0.78 (0.39–1.55)	0.49 (0.22–1.07)	0.66 (0.32–1.36)	0.16
Hypertension					
Crude	1.00	0.82 (0.42–1.63)	0.82 (0.39–1.69)	0.72 (0.36–1.43)	0.36
Model 1	1.00	1.0 (0.47–2.10)	0.79 (0.35–2.77)	0.84 (0.38–1.82)	0.56
Model 2	1.00	0.98 (0.46–2.09)	0.74 (0.32–1.72)	0.78 (0.35–1.72)	0.45

MetS, metabolic syndrome; HDL, high-density lipoprotein; Q, quartile.

\*Obtained by logistic regression analysis. Model 1: Adjusted for age and energy intake. Model 2: Additionally adjusted for marital status, education status, occupation, physical activity, and smoking status.



## DISCUSSION

Findings of the present cross-sectional study showed that the DPI was not associated with the likelihood of having MetS in men and women. We found a significant negative association between greater DPI score and abdominal obesity in women. However, among men, no association was found between DPI and abdominal obesity. No significant association was detected for other components of the MetS. To the best of our awareness, this is the first study that assessed the association of DPI score with MetS and its components in the Middle East.

In this study, we used the DPI to capture the phytochemical content of the diet. Several studies have presented that higher consumption of plant-based foods can increase serum phytochemical levels. One study indicated that consumption of whole plant foods (whole grains, vegetables, fruit, legumes, nuts, and seeds) was associated with serum carotenoids levels [32]. Another research demonstrated that plant-based foods were related to circulatory polyphenols and indicated that the consumption of phytochemical-rich foods can increase plasma phytochemicals [33].

In our study, no significant association was found between higher DPI score and odds of MetS. In line with our findings, a population-based study in South Korea showed that higher adherence to a diet with high amounts of whole grains, fruit, vegetables, nuts, legumes, tea, and coffee was not associated with MetS [34]. A nationwide cross-sectional investigation on 5,690 Polish adults showed that there was no significant association between higher dietary polyphenol intake and odd of MetS [35]. A cross-sectional study involving 2,000 Chinese adults indicated that a higher intake of dietary carotenoids was not associated with MetS [36]. Other cross-sectional research also showed no significant association between high intakes of total polyphenols and flavonoids and odds of MetS [37]. In contrast, a large cross-sectional study on 31,000 Korean adults found an inverse significant association between DPI and MetS and its components [23]. The inconsistency in the results may be due to the difference in eating habits and culture, sample size, study design, tools used for assessment of dietary intake, and the various metrics which were utilized to define MetS.

Our findings showed that higher consumption phytochemical-rich foods were inversely associated with abdominal adiposity in women. A randomized controlled trial found that increasing the consumption of whole grains, vegetables and fruits can decrease WC [38]. Previous studies showed that a higher intake of vegetables, fruits, and legumes was associated with smaller WC [38-40]. A systematic review and meta-analysis including 58 trials showed that intake of flavanols could decrease BMI and WC [41]. A cross-sectional study on Korean adults indicated a negative association between DPI and abdominal obesity, especially in women [42]. In contrast, a cross-sectional study on Iranian women showed that adherence to a diet with a high amount of whole grains, fruit, vegetables, nuts, legumes, tea, and coffee had no significant association with abdominal obesity [43]. Contradictory findings from different studies may be due to differences in sample size, study design, tools used to evaluate dietary intake, number of men and women in the study, and genetic characteristics of participants. Further research is required to examine the association between DPI and MetS and its components.

We did not find any significant relationship between the DPI and blood lipid profile. In line with our results, a longitudinal study on Iranian adults indicated that there was no significant association between DPI and 3 years changes of lipid and lipoprotein levels in men and women [44]. A meta-analyses study found that the plant-based diets were related to a lower

total cholesterol, low-density lipoprotein, and HDL, but not with serum TG [45]. In contrast, a cross-sectional study on Iranian adults observed that higher intakes of phytochemical-rich foods were associated with a lower risk of hypertriglyceridemia [46].

Based on previous studies, a higher intake of dietary phytochemicals, particularly polyphenols and flavonoids, can improve insulin resistance and blood pressure and regulate fat metabolism [16,47,48]. Especially, polyphenols can inhibit the proliferation of adipocytes and stimulate lipolysis and fatty acid oxidation in the mitochondria and peroxisomes by activating transcription of genes involved in fatty acid transport and  $\beta$ -oxidation [16,46,48]. In addition, polyphenols can normalize the production and secretion of insulin [47]. Also, some flavonoid subclasses such as quercetin and genistein may play a role in the reduction of BMI, visceral fat, and total body fat [49].

In our study, we found no significant association between higher DPI score and the odds of MetS. However, we observed a significant association between a higher DPI with abdominal obesity in women, but not in men. This sex difference may be due to the interaction between phytochemical intake and the multiple effects of sex hormones [50]. Special types of phytochemicals like isoflavones have a similar structure to estrogens and as a result, they are thought to emulate the role of estrogen in the body [38,50,51]. Consumption of phytoestrogens can have a positive influence on estrogen deficiency-related diseases [51]. Therefore, it is possible that consumption of foods rich in phytochemicals, through interaction with regulatory hormones, has a helpful influence against chronic diseases such as MetS and central obesity.

The strength of our study is the relatively large sample size and using a new index that presents the whole dietary phytochemical content. In addition, all information was evaluated with validated questionnaires and was collected by trained nutritionists. However, this study has some limitations. The cross-sectional study design cannot demonstrate causality between DPI and abdominal obesity. Some foods with a high phytochemical amount that do not have energy such as green and black tea were not considered because DPI was developed based on the amount of energy supplied by phytochemicals-rich foods. We did not consider phytochemical subclasses that individuals consumed and therefore, the quality of dietary phytochemicals may be different among participants with similar DPI scores. As a result, it can have different effects on preventing MetS. Despite adjusting for several confounders in our study, the possible effects of residual confounding should be considered.

## CONCLUSION

Overall, no significant association was observed between DPI score and odds of MetS in the present study. However, a significant inverse association was found between the consumption of foods rich in phytochemicals and central adiposity in women. There was no significant association between higher DPI score and other components of the MetS. More research, in particular those with prospective nature, is needed to approve the present findings.

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