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A cross-sectional study of the association between plant-based diet indices and kidney stones among Iranian adults

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There are limited studies on the relationship between plant-based diet indices (PDIs) including plant-based diet index (PDI), healthful plant-based diet index (hPDI) and unhealthful plant-based diet index (uPDI) and kidney stones (KS), especially in Middle Eastern populations. We aimed to investigate the relationship between these plant-based diet indices (PDI, hPDI, and uPDI) and KS in a large group of Iranian adults. This cross-sectional study was carried out on 9,839 adult participants aged 35–70 years. Dietary data were collected using a validated semi-quantitative 118-item food frequency questionnaire. The scoring method suggested by Satija et al. was applied to examine the adherence to the PDIs including PDI, hPDI, and uPDI. These indices are grounded in evidence linking plant-based foods to health outcomes such as obesity, diabetes, cancer, and cardiovascular disease. The history of KS was identified based on self-reported information provided by the participants. Approximately 16.4% (*n* = 1638) of study participants were found to have KS. After adjustment for a wide range of confounding variables, a significant positive association was observed between PDI and KS (OR: 1.17; 95% CI: 1.01–1.37). In the case of hPDI, we found no significant association between hPDI scores and risk of KS after adjustment for potential confounders (OR: 1.16; 95% CI: 0.98–1.38). Non-significant association was also observed for uPDI and risk of KS in the fully adjusted model (OR: 1.14; 95% CI: 0.95–1.35). In conclusion, findings of the present study showed that higher PDI score was positively associated with the risk of KS, whereas the hPDI and uPDI scores were not associated with the risk of KS. Further prospective studies are needed to establish causal relationships.

Keywords Cross-sectional, Kidney stones, Nutrition, Plant-based diet index

Abbreviations

KS	Kidney stones
NHANES	National Health and Nutrition Evaluation Survey
PDIs	Plant-based diet indices
PDI	Plant-based diet index
TCS	Tabari cohort study
PERSIAN	Prospective Epidemiological Research Studies in IrAN
FFQ	Food frequency questionnaire
USDA-FCT	USDA food composition tables
hPDI	Healthful plant-based diet index
uPDI	Unhealthful plant-based diet index

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SSBs	Sugar-sweetened beverages
SES	Socio economic status
PCA	Principal component analysis
MET	Metabolic equivalents
BMI	Body mass index
ORs	Odds ratios
CIs	Confidence intervals
HTN	Hypertension
CVD	Cardiovascular diseases
PUFA	Polyunsaturated fatty acids
SFA	Saturated fatty acids
MUFA	Monounsaturated fatty acids
EPIC	European Prospective Investigation into Cancer and Nutrition

Kidney stones (KS) are a common medical condition, with increasing rate in recent decades especially in mid adults[1,2]. It can be associated with a wide range of comorbidities such as metabolic syndrome[3], diabetes mellitus[4], cardiovascular events and vascular calcification[5,6], bone fracture[7] as well as chronic kidney diseases[8]. The prevalence of KS is increasing in both developed and developing countries[9]. The National Health and Nutrition Evaluation Survey (NHANES) reported an incidence of 11% of KS in United State people, during 2015 to 2018[10]. The overall prevalence of KS was 17.6% in Iranian adults in 2022[11].

Nowadays, various risk factors have been related to KS. Genetic predisposition, climate changes, age, existence of other disease such as hypertension, diabetes and gout, and a poor diet are the most well-known risk factors for developing KS[12–14]. There are strong evidences that nutritional exposure play a key role in developing of stones[12]. Low fluid, fruit and calcium intakes as well as high dietary consumption of sodium, oxalate and meat could properly predispose KS[15–17]. Current guidelines on preventing KS emphasize on balance intake of calcium, reduced intake of animal proteins and higher consumption of fiber[18]. It is important to note that evaluating overall dietary patterns, rather than focusing on a single food group or nutrient, provides a better representation of the actual dietary intakes of population. Plant-based diet index (PDI) is a good recommendation, as it emphasizes plant foods—the primary sources of dietary fiber—while discouraging meat consumption. Additionally, two indices—the healthful plant-based diet index (hPDI) and the unhealthful plant-based diet index (uPDI)—have been developed to evaluate the quality of plant-based dietary patterns. The healthful PDI prioritizes healthy plant foods such as whole grains, fruits and vegetables, while the uPDI emphasizes less healthy plant foods such as refined grains, potatoes and sweets and desserts[19]. Plant-based diet indices (PDIs) may influence the risk of KS through their impact on urinary composition, such as oxalate, calcium, and citrate levels[20]. PDI is increasingly becoming recognized as a healthy diet and its positive effects are being shown in various diseases[21–23]. A growing body of evidence has emerged on effect of PDI in chronic kidney disease as well as nephrolithiasis[24–26], but the results are still controversial. A diet with low intake of animal protein can alkalize the urine and therefore can reduce the risk of stones[27]. However, some plant foods, including whole grains or green leafy vegetables such as spinach, are associated with an increased likelihood of KS due to the presence of oxalate[28]. In this regard, in a large study of 83,922 postmenopausal women, greater consumption of fruit, vegetable and dietary fiber was associated with a 6–26% decreased risk of KS[29]. However another cohort study failed to reach any significant association between dietary plant protein intake and risk of KS[30]. In addition, an increased incidence of KS was observed by high consuming of fruits and vegetables in NHANES database[28].

Studies on the relationship between diet and KS are very limited in Middle Eastern countries which have different food culture than other worldwide countries[24,31]. To the best of our knowledge, no study has examined the linkage between PDI and KS in the Middle East so far. This study uniquely contributes to the global literature by examining the association between PDIs and KS among Iranian adults, a population with distinct dietary habits and a high prevalence of KS. Considering above, we aimed to investigate the relationship between three PDIs including PDI, hPDI, and uPDI and KS in a large group of Iranian adults.

Methods

Study participants. The cross-sectional study used the baseline information from the Tabari cohort study (TCS), which is a part of the Prospective Epidemiological Research Studies in IrAN (PERSIAN) cohort study. This cohort was initiated in 2014 across 18 regions of Iran to investigate the factors linked to non-communicable diseases. The word Tabari is derived from the name Tabaristan (another name of Mazandaran province) which is located in the north of Iran. The TCS had earlier been described in detail[32]. Briefly, during the enrollment phase of TCS, 10,255 individuals aged between 35 and 70 years were enlisted from rural and urban areas of Sari, Mazandaran province, Iran, with 7,012 being urban residents and 3,243 rural residents. The study's participants were chosen from a population census. From health records in health centers, a list of eligible individuals for the urban and rural areas was created. The criteria for eligibility included being Iranian, residing in the defined regions, and having no physical or mental impairments that would prevent participation. All those who met these criteria were invited to attend the cohort centers. In the current analysis, participants with total daily energy intake outside the range of 800–5,000 kcal/day were excluded. These ranges are considered reasonable for capturing typical energy intake in adult populations while excluding extreme outliers that could distort the analysis. Similar cutoffs have been applied in other epidemiological studies, such as the Tehran Lipid and Glucose Study (TLGS)[33] and the Isfahan Cohort Study[34]. Pregnant women were also excluded from the analysis. These exclusions left 9,839 individuals for the present analysis on KS. After providing a detailed explanation of the study's goals and design, a written informed consent was obtained from all subjects upon arrival at the cohort center. This study was approved by the ethics committee of Mazandaran University of Medical Sciences, Sari, Iran. All methods were carried out in accordance with the relevant guidelines and regulations.

Dietary intakes assessment. Usual dietary intakes of participants were assessed using a validated semi-quantitative 118-item food frequency questionnaire (FFQ), which was administered by a qualified interviewer[35]. The FFQ used in this study was validated within the context of the PERSIAN Cohort, which includes the Tabari cohort. The validation study assessed the validity of FFQ by comparing it to 24-hour dietary recalls (24 h). The results showed a good correlation between the dietary intakes determined by the FFQ and those from 24 h. The de-attenuated energy-adjusted Spearman correlation coefficients (DEA-SCC) for tea, sugars, whole grains, refined grains, oils, vegetables, fruits, and meats were 0.69, 0.70, 0.68, 0.65, 0.65, 0.55, 0.56, and 0.23, respectively. Further details on the validation process and results can be found in the previous publication[35].

Participants were asked about their typical consumption of each food item in the year leading up to the interview. They provided information on how often they consumed each item, whether it was daily, weekly, monthly or yearly, and the amount they consumed each time based on standard portion sizes. To ensure accuracy, various utensils and portion size models were used to estimate the exact portion size. A collection of 64 pictures showing standard portions for certain items was also available for reference when needed[36].The frequency of consumption for each food item in the FFQ was converted to daily intake. Then, the weight of the portion size consumed each time in grams was multiplied with the daily intake to get the total grams consumed per day. The USDA food composition tables (USDA-FCT) data were used to calculate the daily nutrient intakes of participants[37].

Construction of Plant-based Diet Indices (PDIs). Based on epidemiological knowledge of the relationship between certain plant foods and chronic (type 2 diabetes, cardiovascular disease, and certain cancers) and intermediate (obesity, hypertension or inflammation) conditions, we divided plant foods into healthy and less healthy categories. In the present study 18 food groups (belonged to the whole collection of animal foods, healthy and less healthy plant foods) were created based on nutrient and culinary standards. The total number of servings for entire foods in each of the 18 food groups was calculated by considering the daily values for each food item. According the method developed by Satija et al.[19] we constructed a plant-based diet index (PDI) and two versions of a healthful plant-based diet index (hPDI) and unhealthful plant-based diet index (uPDI) plant-based diet index. Healthy plant foods included whole grains, fruit, vegetables, nuts, legumes, vegetable oils, and tea/coffee, while less healthy plant foods included fruit juices, refined grains, potatoes, sugar-sweetened beverages (SSBs), and sweets/desserts. Animal food groups covered a broad spectrum of animal fats, dairy, eggs, fish/seafood, meat (poultry and red meat), and miscellaneous animal-based foods. For each 18 food groups, the cut-off values for the quintiles were determined by assigning a score ranging from 1 to 5 to each quintile. In terms of PDI, a rating of 5 was assigned to plant food groups that were consumed the most (highest quintile), while a score of 4 was given to those consumed between the second-highest and highest quintile. This pattern continued, with a score of 1 given to plant food groups consumed the least (lowest quintile). On the other hand, animal food groups that were consumed above the highest quintile were given a score of 1. For animal food groups consumed between the highest and second highest quintiles, a score of 2 was assigned. This pattern continued until a score of 5 was given for consumption under the lowest quintile. The hPDI was determined by assigning a score of 5 to individuals who consumed the highest amount of healthy plant foods, while those who consumed the least amount were given a score of 1. On the other hand, a score of 1 was given to those who consumed the highest amount of unhealthy plant foods and animal food items, while a score of 5 was given to those who consumed the least amount. The uPDI was determined by assigning scores ranging from 5 to 1 to individuals based on their consumption of unhealthy plant foods, with those consuming the most receiving a score of 5 and those consuming the least receiving a score of 1. Additionally, scores ranging from 1 to 5 were assigned to individuals based on their consumption of animal foods and healthy plant foods, with those consuming the most receiving a score of 1 and those consuming the least receiving a score of 5. The total score for each participant was obtained by adding up the scores for all 18 food groups, with a possible range of 18 to 90. It is important to note that a higher score on all indices indicates a lower intake of animal foods (Table 1).

Kidney stones (KS). The history of KS was identified based on self-reported information provided by the participants. The physicians in the cohort team reviewed and verified all the medical records (including ultrasound images, photographs and surgery documents) for accuracy.

Other variables. General information of participants including age (year), sex (male/female), level of education (university graduated/non-university education), socio economic status (SES) (very low/low/medium/high/very high), marital status (married/unmarried), place of residence (urban/rural), history of diseases (yes/no), smoking (yes/no), and alcohol consumption (yes/no) was collected through validated demographic and medical history questionnaires during face-to-face interviews by trained interviewers. SES was calculated using 13 variables related to participants' assets and by the method of principal component analysis (PCA) and then classified into five levels. To determine physical activity level of participants, the standard questionnaire of physical activity of PERSIAN cohort study was used. The intensity of physical activity was expressed in metabolic equivalents (MET), with one MET being equivalent to 1 kcal/kg/h. Anthropometric indices including height and weight were measured by trained staff in accordance with standard protocols. The height of participants was measured in a standing position without shoes using a SECA 226 stadiometer (SECA, Hamburg, Germany) while ensuring their shoulders were in normal alignment, back straight, and looking straight forward. The weight was measured using a mechanical SECA 755 column scale (SECA, Hamburg, Germany) while individuals were minimally clothed. Body mass index (BMI) was then calculated by dividing the weight in kilograms by the square of height in meters.

Statistical analysis. Participants were classified according to quartiles of energy-adjusted PDI, hPDI and uPDI score. To investigate differences in general characteristics of individuals across quartiles we used one-way ANOVA for continuous variables and chi-square tests for categorical variables. One-way ANOVA was also used

Food group	Specific items	Scoring criteria		
		PDI	hPDI	uPDI
Healthy plant foods				
Whole grains	Barbari, Sangak, barley bread, other grains (wheat/oats/barley)	Positive scores[a]	Positive scores	Reverse scores[b]
Fruits	Cantaloupe, melon, honeydew melon, watermelon, apricot, sweet/sour cherries, nectarines/peaches, prunus, mulberries, strawberries, plums, fresh figs, grapes, pears, apples, kiwi, citrus fruit, pomegranate, banana, persimmon, dates, raisins	Positive scores	Positive scores	Reverse scores
Vegetables	Lettuce, cabbage, cauliflower, broccoli, tomato, cucumber, greens, eggplant, celery, beets, turnips, carrot, garlic, onion, bell pepper, mushroom, corn, green peas, green beans, zucchini, green peppers	Positive scores	Positive scores	Reverse scores
Nuts	Walnuts, peanut, other nuts (almonds/cashew/pistachios/hazelnuts), seeds (pumpkin/watermelon/sunflower)	Positive scores	Positive scores	Reverse scores
Legumes	Beans, chickpeas, mung beans/lentils, split peas, lima beans	Positive scores	Positive scores	Reverse scores
Vegetable oil	Olive oil, other plant oils	Positive scores	Positive scores	Reverse scores
Tea and coffee	Tea, coffee	Positive scores	Positive scores	Reverse scores
Less healthy plant foods				
Fruit juices	Fruit juices	Positive scores	Reverse scores	Positive scores
Refined grains	Baguette, Lavash bread, white rice, pasta/noodle, crackers/wafers/biscuits	Positive scores	Reverse scores	Positive scores
Potatoes	Potatoes	Positive scores	Reverse scores	Positive scores
Sugar-sweetened beverages	Soda drinks, non-carbonated fruit drinks with sugar	Positive scores	Reverse scores	Positive scores
Sweets and desserts	Cookies, pastries (home-made and ready-made), candy, chocolate, jams, honey, tahini halva, sugar cubes, sugar	Positive scores	Reverse scores	Positive scores
Animal foods				
Animal fat	Animal fats, butter	Reverse scores	Reverse scores	Reverse scores
Dairy	Milk, yogurt, cheese, Doogh, curd, ice cream, cream	Reverse scores	Reverse scores	Reverse scores
Eggs	Eggs	Reverse scores	Reverse scores	Reverse scores
Seafood	Fish, canned tuna	Reverse scores	Reverse scores	Reverse scores
Meat	Beef and lamb variety meats, meats, chicken, chicken giblets, processed meats, hamburger	Reverse scores	Reverse scores	Reverse scores
Miscellaneous animal-based foods	Pizza, mayonnaise or other creamy salad dressing	Reverse scores	Reverse scores	Reverse scores

Table 1. Food items and criteria for scoring PDI, hPDI, and uPDI. [a]Positive scores: higher consumption receives higher scores (5 for top quintile, 1 for bottom quintile). [b]Reverse scores: lower consumption receives higher scores (5 for bottom quintile, 1 for top quintile). PDI plant-based diet index, hPDI healthful plant-based diet index, uPDI unhealthful plant-based diet index.

to compare participants' energy-adjusted dietary intakes across PDI, hPDI and uPDI quartiles. Binary logistic regression tests were performed to estimate the odds ratios (ORs) and 95% confidence intervals (CIs) of KS across quartiles of PDI, hPDI and uPDI in crude and multivariable-adjusted models with potential confounders including age, sex, place of residence, SES, marital status, education, smoking, alcohol, physical activity, energy, salt intake, water intake, diabetes, high blood pressure, cardiovascular diseases, cancer and BMI. These variables were selected based on their established relevance to the KS, as supported by prior literature, and their potential to act as confounders[38–40]. *P* for trends was determined by considering quartiles of PDI, hPDI and uPDI scores as ordinal variables in the logistic regression analysis. All analyses were carried out with the SPSS software (version 20; SPSS Inc.), and *p*-values less than 0.05 were considered statistically significant.

Results

General characteristics of study participants according to quartiles of plant-based diet index (PDI), healthful plant-based diet index (hPDI), and unhealthful plant-based diet index (uPDI) scores are shown in Table 2. Compared to those with the lowest adherence, participants with the highest adherence to the PDI were more likely to be urban residents, older, have a higher BMI, and a greater prevalence of hypertension (HTN). These participants were also less likely to be female, university graduated, of very low socio economic status (SES), and alcohol user and had lower physical activity and lower prevalence of diabetes. Regarding the hPDI, participants with higher scores were older and more likely to be female and of very low SES, and had higher BMI and greater prevalence of HTN, cardiovascular diseases (CVD) and diabetes. Additionally they were less likely to be married, university graduated, smoker and alcohol user. In terms of uPDI, a greater percentage of subjects in the highest category of uPDI had higher physical activity and were more likely to be of very low SES and smoker than those in the lowest category. Participants with the highest uPDI score also had lower BMI and lower prevalence of diabetes and HTN, and were less likely to be female, urban residents, university graduated and alcohol user.

Daily dietary intakes of study participants across quartiles of PDI, hPDI and uPDI scores are shown in Supplementary Tables 1–3.

Crude and multivariable ORs and 95% CIs of Kidney stones (KS) across quartile categories of PDI, hPDI and uPDI scores are illustrated in Tables 3, 4 and 5, respectively. Comparing the highest with the lowest quartiles of PDI scores, a significant positive association was observed between PDI and KS, after controlling for a wide range

	Quartiles of PDI				
	Q1 (*n* = 2625)	Q2 (*n* = 2492)	Q3 (*n* = 2021)	Q4 (*n* = 2701)	*P*[*]
Age (year)	49.72 ± 9.61	50.40 ± 9.46	50.56 ± 9.39	50.32 ± 8.91	0.009
BMI (kg/m2)	28.18 ± 4.86	28.55 ± 4.95	28.53 ± 4.82	28.42 ± 4.79	0.03
Physical activity (MET-h/day)	43.86 ± 9.87	43.10 ± 9.37	42.52 ± 8.81	42.69 ± 8.95	< 0.001
Female (%)	58.3%	60.4%	62.0%	57.5%	0.007
Married (%)	91.7%	91.5%	91.6%	92.6%	0.43
Urban (%)	61.4%	68.5%	70.3%	72.9%	< 0.001
SES (%)					
Very low	20.8%	18.7%	20.5%	19.8%	< 0.001
Low	20.8%	19.9%	19.4%	20.3%	
Medium	18.2%	19.1%	20.5%	22.1%	
High	18.7%	20.9%	21.2%	20.4%	
Very high	21.4%	21.4%	18.4%	17.4%	
Education (university graduated) (%)	25.4%	24.4%	22.3%	20.6%	< 0.001
Diabetes (%)	18.5%	18.6%	16.9%	14.7%	< 0.001
High blood pressure (%)	18.9%	24.6%	23.7%	22.3%	< 0.001
Cardiovascular diseases (%)	8.2%	9.2%	9.9%	9.4%	0.22
Cancer (%)	1.5%	1.6%	2.1%	2.0%	0.27
Smoker (%)	10.0%	8.3%	8.4%	9.4%	0.09
Alcohol use (%)	9.2%	8.0%	7.1%	6.5%	0.002
	Quartiles of hPDI				
	Q1 (*n* = 2508)	Q2 (*n* = 2329)	Q3 (*n* = 2624)	Q4 (*n* = 2378)	*P*[*]
Age (year)	47.64 ± 9.16	50.06 ± 9.38	50.93 ± 9.26	52.36 ± 8.94	< 0.001
BMI (kg/m2)	27.93 ± 4.79	28.42 ± 4.88	28.51 ± 4.85	28.80 ± 4.86	< 0.001
Physical activity (MET-h/day)	42.98 ± 9.14	42.99 ± 9.29	43.02 ± 9.24	43.29 ± 9.53	0.60
Female (%)	55.2%	59.0%	62.3%	60.9%	< 0.001
Married (%)	92.8%	92.4%	90.5%	91.9%	0.01
Urban (%)	68.4%	68.3%	68.7%	67.3%	0.74
SES (%)					
Very low	17.0%	19.3%	21.4%	22.0%	< 0.001
Low	19.4%	20.1%	20.0%	21.1%	
Medium	19.3%	21.0%	20.7%	19.0%	
High	23.5%	20.7%	18.7%	18.1%	
Very high	20.8%	19.0%	19.2%	19.8%	
Education (university graduated) (%)	27.3%	22.6%	21.5%	21.4%	< 0.001
Diabetes (%)	9.2%	14.8%	19.4%	25.4%	< 0.001
High blood pressure (%)	15.8%	20.9%	24.4%	28.0%	< 0.001
Cardiovascular diseases (%)	5.9%	9.4%	9.3%	11.9%	< 0.001
Cancer (%)	1.2%	1.8%	2.0%	2.1%	0.11
Smoker (%)	12.7%	9.4%	7.7%	6.3%	< 0.001
	Quartiles of uPDI				
	Q1 (*n* = 2368)	Q2 (*n* = 2252)	Q3 (*n* = 2899)	Q4 (*n* = 2320)	*P*[*]
Age (year)	50.34 ± 9.22	50.06 ± 9.19	50.42 ± 9.59	50.03 ± 9.31	0.34
BMI (kg/m2)	29.33 ± 4.89	28.90 ± 4.86	28.15 ± 4.77	27.32 ± 4.70	< 0.001
Physical activity (MET-h/day)	40.19 ± 6.98	41.75 ± 8.53	43.68 ± 9.77	46.53 ± 10.21	< 0.001
Female (%)	66.8%	61.5%	58.0%	51.6%	< 0.001
Married (%)	91.6%	91.5%	92.0%	92.4%	0.64
Urban (%)	89.2%	76.1%	62.8%	45.7%	< 0.001
SES (%)					
Very low	6.4%	14.9%	23.4%	34.3%	< 0.001
Low	14.7%	20.1%	23.0%	22.2%	
Medium	21.6%	19.6%	19.8%	18.9%	
High	24.2%	22.5%	18.9%	15.6%	
Very high	33.1%	23.0%	14.8%	9.0%	
Education (university graduated) (%)	34.2%	26.8%	19.0%	13.7%	< 0.001
Diabetes (%)	26.4%	18.4%	15.0%	9.3%	< 0.001
Continued					

	Quartiles of uPDI				
	Q1 (*n* = 2368)	Q2 (*n* = 2252)	Q3 (*n* = 2899)	Q4 (*n* = 2320)	*P*[*]
High blood pressure (%)	25.7%	24.4%	21.3%	17.8%	< 0.001
Cardiovascular diseases (%)	9.8%	9.5%	8.8%	8.3%	0.25
Cancer (%)	1.5%	1.7%	1.8%	2.0%	0.60
Smoker (%)	6.0%	7.5%	8.8%	14.1%	< 0.001
Alcohol use (%)	10.5%	7.7%	6.8%	6.2%	< 0.001

Table 2. Characteristics of study participants by quartile categories of PDI, hPDI, and uPDI scores. All values are mean ± SD, unless indicated; [*]ANOVA for continuous variables and Chi-squared test for categorical variables. PDI plant-based diet index, hPDI healthful plant-based diet index, uPDI unhealthful plant-based diet index, BMI body mass index, MET metabolic equivalents, SES social economic status.

	Quartiles of PDI				
	Q1 (*n* = 2625)	Q2 (*n* = 2492)	Q3 (*n* = 2021)	Q4 (*n* = 2701)	*p* trend
Kidney stone (n)	399	384	354	476	
Crude	1.00	1.01 (0.87–1.18)	1.18 (1.01–1.38)	1.19 (1.03–1.38)	0.005
Model 1[a]	1.00	1.01 (0.87–1.18)	1.19 (1.02–1.40)	1.17 (1.01–1.36)	0.007
Model 2[b]	1.00	0.99 (0.85–1.16)	1.19 (1.01–1.40)	1.18 (1.01–1.37)	0.007
Model 3[c]	1.00	0.99 (0.85–1.16)	1.19 (1.01–1.40)	1.17 (1.01–1.37)	0.008

Table 3. Multivariable-adjusted odds ratios (95% CIs) for kidney stone across quartile categories of PDI score. [a]Model 1: adjusted for age and sex. [b]Model 2: further adjusted for place of residence, SES, marital status, education, smoking, alcohol, physical activity, energy, salt intake, water intake, diabetes, high blood pressure, cardiovascular diseases, cancer. [c]Model 3: further adjusted for BMI. PDI plant-based diet index.

	Quartiles of hPDI				
	Q1 (*n* = 2508)	Q2 (*n* = 2329)	Q3 (*n* = 2624)	Q4 (*n* = 2378)	*p* trend
Kidney stone (n)	344	367	479	423	
Crude	1.00	1.17 (1.00-1.38)	1.40 (1.20–1.63)	1.36 (1.16–1.58)	< 0.001
Model 1[a]	1.00	1.15 (0.98–1.35)	1.39 (1.19–1.62)	1.30 (1.11–1.52)	< 0.001
Model 2[b]	1.00	1.12 (0.95–1.31)	1.31 (1.12–1.53)	1.17 (0.99–1.38)	0.01
Model 3[c]	1.00	1.11 (0.94–1.31)	1.31 (1.12–1.53)	1.16 (0.98–1.38)	0.01

Table 4. Multivariable-adjusted odds ratios (95% CIs) for kidney stone across quartile categories of hPDI score. [a]Model 1: adjusted for age and sex. [b]Model 2: further adjusted for place of residence, SES, marital status, education, smoking, alcohol, physical activity, energy, salt intake, water intake, diabetes, high blood pressure, cardiovascular diseases, cancer. [c]Model 3: further adjusted for BMI. hPDI healthful plant-based diet index.

	Quartiles of uPDI				
	Q1 (*n* = 2368)	Q2 (*n* = 2252)	Q3 (*n* = 2899)	Q4 (*n* = 2320)	*p* trend
Kidney stone (n)	391	366	463	393	
Crude	1.00	0.98 (0.84–1.14)	0.96 (0.83–1.11)	1.03 (0.88–1.20)	0.79
Model 1[a]	1.00	0.95 (0.81–1.11)	0.90 (0.77–1.04)	0.94 (0.80–1.10)	0.33
Model 2[b]	1.00	1.03 (0.87–1.21)	1.02 (0.87–1.20)	1.13 (0.95–1.35)	0.21
Model 3[c]	1.00	1.03 (0.87–1.21)	1.03 (0.88–1.20)	1.14 (0.95–1.35)	0.18

Table 5. Multivariable-adjusted odds ratios (95% CIs) for kidney stone across quartile categories of uPDI score. [a]Model 1: adjusted for age and sex. [b]Model 2: further adjusted for place of residence, SES, marital status, education, smoking, alcohol, physical activity, energy, salt intake, water intake, diabetes, high blood pressure, cardiovascular diseases, cancer. [c]Model 3: further adjusted for BMI. uPDI unhealthful plant-based diet index.

of confounding variables including age, sex, place of residence, SES, marital status, education, smoking, alcohol, physical activity, energy, salt intake, water intake, diabetes, high blood pressure, cardiovascular diseases, cancer and BMI (OR: 1.17; 95% CI: 1.01–1.37) (Table 3). Regarding hPDI, in the crude model, we found that individuals with the highest hPDI scores had significantly greater odds of KS compared to those with the lowest scores (OR: 1.36; 95% CI: 1.16–1.58); however, after adjustment for potential confounders this association became non-significant (OR: 1.16; 95% CI: 0.98–1.38) (Table 4). Regarding uPDI, we did not observe any significant association between uPDI and KS in the fully adjusted model (OR: 1.14; 95% CI: 0.95–1.35) (Table 5).

Discussion

In this cross-sectional study, we examined the association between adherence to the Plant-based diet indices (PDIs) and risk of Kidney stones (KS). We found a significant positive association between plant-based diet index (PDI) and risk of KS. However, no significant association was observed between healthful plant-based diet index (hPDI) and unhealthful plant-based diet index (uPDI) and risk of KS.

Kidney stones are a common medical condition influenced by multiple factors, including dietary intakes[39]. Since dietary factors play an important role in the genesis and recurrence of KS, dietary modifications are a fundamental tool for the prevention and management of KS. As part of nutritional recommendations, individuals with nephrolithiasis are commonly advised to follow a diet that is low in animal protein and high in fruits and vegetables[41–45], which can be mostly found in a plant-based diet.

The results of the present study suggested a positive association between the PDI and the risk of KS, while hPDI and uPDI were not associated with the risk of KS. Prior research on fruit, vegetable and dietary fiber consumption, as the major components of plant-based diets, has yielded varied results. Hiatt et al. performed a randomized controlled trial and investigated the potential protective benefits of a diet low in animal protein and high in fiber. Their findings indicated that this regimen did not offer greater advantages compared to the basic recommendation to increase fluid intake[46]. Another randomized trial conducted by Dussol et al. demonstrated that neither a low animal protein diet nor a high-fiber diet administered over 4 years, did not protect against stone recurrence in 175 idiopathic calcium stone formers[47]. On the other hand, an analysis of the Oxford cohort of the European Prospective Investigation into Cancer and Nutrition (EPIC) showed that vegetarians have a lower risk of developing KS compared with those who eat a high meat diet[48]. Moreover, in a large prospective study of postmenopausal women, greater consumption of fruit, vegetable and dietary fiber was associated with decreased risk of KS[29]. To the best of our knowledge, only one prospective cohort study has examined the associations between a posteriori dietary patterns and a priori plant-based dietary patterns (including PDI, hPDI, and uPDI) and the risk of incident nephrolithiasis, among 26,490 Chinese participants. The authors found that a posteriori balanced dietary pattern characterized by a higher intake of vegetables, eggs, grains, legumes, legume products, and meat was associated with a lower risk of nephrolithiasis. In addition, contrary to the results of our study—which showed null findings for hPDI and uPDI and positive findings for PDI—they observed that adherence to the uPDI increased the risk of incident nephrolithiasis by 46%, while other plant-based diet indices, including PDI and hPDI, were not associated with the risk of incident nephrolithiasis[24]. Some discrepancies in results might be explained by different study designs, sample sizes, participants' characteristics, and potential covariates adjusted for in the analysis. Overall, before having a recommendation on plant-based dietary patterns to prevent KS, further studies are required.

We found a significant positive association between the PDI and the risk of KS. This result might be in part due to high oxalate and low calcium intakes associated with adhering to an unbalanced plant-based diet in the present study[39]. Although diets high in fruits, vegetables and fiber may be protective against the risk of KS[29,48], these diets can also be rich in oxalate[20]. It has been suggested that high intakes of oxalate without adequate intake of calcium can lead to an increased risk of KS formation[20]. Beyond dietary oxalate, differences in hydration habits among those with the greater adherence to PDI may explain the increased risk of KS. While water intake was adjusted for in our analyses, subtle hydration variations or reliance on water-rich foods (such as fruits and vegetables) may lead to suboptimal fluid intake, consequently reducing urine volume and increasing lithogenic substance concentration[49]. This highlights the need for future studies to assess 24-hour urine volume and hydration biomarkers. Moreover, it must be kept in mind that the cross-sectional nature of the current study restricts the ability to establish a causal relationship between PDI and KS.

The possible reason for the observed discrepancy in outcomes between PDI and hPDI, may stem from the inclusion of less healthy plant foods, specifically sweets and desserts and SSBs, in the PDI. These foods, often high in added sugars, are linked to increased urinary calcium and calcium oxalate supersaturation[50], raising the risk of KS[51]. Regarding the uPDI, the observed differences in results may be attributed not only to variations in oxalate content but also to the presence of fructose in fruits, which are a component of the PDI. Fructose has been independently associated with a higher risk of KS[52], which could contribute to the contrasting outcomes between these two dietary patterns.

Several strengths of this study include large sample size, adjustment for a wide range of potential confounders in the analysis and being the first study in the Middle East region in this regard. In addition, we used energy-adjusted amounts of all food groups for constructing plant-based diet indices. However, some limitations also need to be considered. The present study was carried out in a cross-sectional design, which would not allow us to infer causality between exposure and outcome. The exploratory nature of our findings serves as a foundation for future research, but longitudinal or experimental studies are needed to establish causality between PDIs and KS. As in any epidemiological study, the application of FFQ might result in recall bias and misclassification of participants in terms of dietary intakes. Despite adjustment for a wide range of potential confounders, the possibility of residual confounding, such as genetic predisposition, specific medication use, or other lifestyle variables, which may influence the observed associations between PDIs and KS cannot be ignored. In addition, we did not collect information on different types of KS and 24-h urine composition. Studying the association between dietary factors and different types of KS could result in more accurate and precise findings. In conclusion, the findings of this study revealed that, after adjusting for a wide range of potential confounders, a higher PDI was positively associated with the risk of KS, while the hPDI and uPDI showed no significant association. These results have important implications for public health strategies in the Middle East, where dietary patterns are evolving. Public health initiatives should prioritize promoting balanced plant-based diets that include calcium-rich foods, adequate hydration, and limited consumption of processed plant foods to reduce the risk of KS. Further prospective studies incorporating biochemical analyses and detailed stone characterization are essential to confirm these findings and establish evidence-based dietary guidelines for the prevention of KS.

Data availability

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

Received: 30 June 2024; Accepted: 10 April 2025
Published online: 18 April 2025

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Acknowledgements
We wish to thank all individuals who kindly participated in Tabari cohort study.

Author contributions
MG, MM, AH and SS contributed to the conception and design of the study, data collection, analyses and interpretation of data; MG, ASM, AA, and SS drafted the manuscript; FG, MA, AH, and SS edited and revised the manuscript. All authors have read and approved the final version of the manuscript for publication. SS has primary responsibility for final content.

Funding
The financial support for this study comes from the Mazandaran University of Medical Sciences (Grant no. 2524).

Declarations

Competing interests
The authors declare no competing interests.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-98370-9.

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