Original Article

The Relationship between Plant-Based Diet Index and Semen Parameters of Men with Infertility: A Cross-Sectional Study

Mehran Nouri, Ph.D.[1, 2#], Nooshin Abdollahi, M.Sc.[3, 4#], Kimia Leilami, B.Sc.[5], Masha Shirani, M.Sc.[6, 7*]

1. Students' Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran
2. Department of Community Nutrition, School of Nutrition and Food Science, Shiraz University of Medical Sciences, Shiraz, Iran
3. Nutrition and Food Security Research Center, Department of Nutrition, Health Faculty, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
4. Department of Nutrition, Health Faculty, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
5. Nutrition Research Center, Shiraz University of Medical Sciences, Shiraz, Iran
6. Students' Research Committee, Isfahan University of Medical Sciences, Isfahan, Iran
7. Department of Community Nutrition, School of Nutrition and Food Science, Food Security Research Center, Isfahan University of Medical Sciences, Isfahan, Iran

Abstract

Background: Infertility is a major clinical problem that affects people psychologically and medically. For the past 40 years, studies have linked nearly 50% of childlessness to male infertility. It is worth noting that unlike other factors contributing to infertility, diet is a tunable factor and can be applied in counseling infertile men. The goal of this study was to determine the relationship between plant diet index (PDI) and semen parameters in Iranian infertile men.

Materials and Methods: In this cross-sectional study, dietary intake was determined by a valid 168-item questionnaire (FFQ). In this study, four dependent semen parameters, including total sperm motility (TSM), sperm concentration (SC), normal sperm morphology (NSM), and semen volume (SV) were measured.

Results: Results of this study stated that greater adherence to the healthful plant-based diet index (hPDI), can significantly increase sperm density and motility in men, as well as greater adherence to the PDI dietary pattern is related to a lower risk of sperm volume deficiency, and ultimately more adherence to the unhealthful plant-based diet index (uPDI), can reduce the risk of sperm motility.

Conclusion: In this study, for the first time, the relationship between PDI, hPDI, uPDI and male infertility was evaluated. Altogether, this study demonstrated that nutrition has an impact on semen quality and fertility of men.

Keywords: Healthy Diet, Infertility, Plant-Based Diet, Sperm, Unhealthy

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Introduction

The psychological impact of infertility has been debated for years as one major clinical problem. According to the World Health Organization (WHO), infertility is a disease determined by failure to become pregnant after 12 months of unprotected and ordered intercourse (1). Nearly 15% of couples worldwide face this problem and male infertility is responsible for not less than 50% of the occasions (2). While for many years women were considered the main issue causing infertility for couples, many recent studies have related nearly 50% of childlessness to male reproduction system problems (3, 4). So, considering the reproductive science progression in the female reproduction system, male infertility needs to be studied very well as it could result in many problems in pregnancy and embryo development (5).

Many physiological, environmental, and genetic factors could be respected in the pathogenesis of male infertility and sperm dysfunction (6). Disorders such as industrial chemicals exposures, alcohol consumption and smoking, infections, varicocele, stress, depression, nutritional deficiencies, and genetic disorders have been identified as factors that have negative impacts on semen quality (7). According to recent studies, lifestyle and nutritional factors play a key role in the functioning of the reproductive system (8, 9). Moreover, new researches showed that nutritional factors such as folate, omega-3 fats, saturated fats, soy, soy isoflavones, zinc, and antioxidants could affect semen quality (10). Spanish researchers introduced a positive relationship between sperm quality and consumption of folate-rich food sources, such as fruits and vegetables (11). Vujkovic et al. (12) reported

#These authors equally contributed to this work.
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*Corresponding Address: P.O.Box: 81745, Department of Community Nutrition, School of Nutrition and Food Science, Isfahan University of Medical Sciences, Isfahan, Iran
Email: mahsa.shirani1373@yahoo.com

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a better quality of sperm DNA for men with a "health-conscious" diet (high intake of fruits, vegetables, fish, and whole grains). Another study by Jurewicz et al. (13) of dietary patterns also showed a diet rich in vegetables, fruits, fish, poultry, and whole grains could correlate positively with the percentage of motile sperm. Diet is a complex variable, and traditional analyzes in nutritional epidemiology often examine the association between a disease and a nutrient, or a small number of them. People eat a variety of nutritious foods daily that contain complex nutrient compositions. Therefore, dietary pattern analysis is a method that can determine the relationship between diet and disease (14).

Today, researchers have developed new indices to assess the quality of a diet that measures adherence to a predominantly plant-based diet (15). Plant-based diet index (PDI), healthful plant-based diet index (hPDI), and unhealthful plant-based diet index (uPDI) evaluated the consumption of animal foods and plant foods according to the health of plant foods (16). Considering many studies in the field of male infertility, the relationship between PDI and male infertility has not yet been studied. Therefore, more research is needed. It is worth noting that unlike other factors contributing to infertility, diet is a tunable factor and can be applied in counseling infertile men. The goal of this study was to determine the relationship between PDI and sperm quality in Iranian infertile men.

Materials and Methods

This cross-sectional study was performed in a major infertility clinic in Isfahan province in 2018. 270 infertile adult men aged 18-55 years who met the inclusion criteria were selected. Before entering the study, participants signed an informed consent form. Subjects with the following criteria were not included in the study: (history of testicular atrophy, urinary tract infection, azoospermia, testicular torsion, genital surgery, and other genital diseases, endocrine, anatomical disorders), metabolic diseases (cardiovascular disease, cancer, diabetes, kidney disease or osteoporosis), psychiatric and physiological disorders such as depression, alcohol and drug abuse, supplement use, previous hormone therapy, anticoagulants, anti-androgens, androgens, cytotoxic drugs or immunosuppressants (17). Ten participants were excluded from the study due to calorie consumption of more than 4200 or less than 800 kcal per day or lack of basic information. Finally, 260 data were used for the final analysis Ethics Committee of Isfahan University of Medical Sciences (IUMS), Isfahan (IR.MUI.RESEARCH.REC.1397.232).

Assessment of semen parameters

Semen samples were taken from the participant after 3 days of abstinence and collected in sterile containers and half an hour before analysis was liquefied at 37°C. The 5th edition of the World Health Organization (WHO) laboratory manual was used to assess semen. Accordingly, sperm motility was expressed as A to D. A+B is defined as total progressive motility, C is defined as non-progressive motility, A+B+C is defined as total motility, and D is defined as immotile sperm. In this study, four dependent semen parameters, including total sperm motility (TSM), sperm concentration (SC), normal sperm morphology (NSM), and sperm volume were measured for evaluation (18).

Assessment of dietary intakes

Dietary intake was determined by a valid 168-item questionnaire (FFQ). FFQ validation is confirmed in Iran (19). This questionnaire contains common dietary guidelines in the country and can be used for adults. Participants specified their average frequency of consumption over the past 12 months (number of daily, weekly, monthly and annual) in this form. Specific groups were categorized as follows: 6 times or more a day, 3–5 times a day, 2-3 times a day, every day (once daily), 5-6 times /week, 2-4 times /week, once a week, 1-3 times a month and less than once a month. Finally, the frequency category chosen for each food item was converted into a daily intake for evaluation. Data extracted from the FFQ questionnaire were calculated by modified Nutritionist IV software for Iranian food.

Plant Diet Index

To create three versions of plant based diets PDI, hPDI, and uPDI, we use the Satije et al. method (20). All foods were grouped into 18 food groups in three main classes. According to food groups, hPDI included whole grains, fruits, vegetables, nuts, legumes, vegetable oils, and tea/coffee, uPDI included fruit juices, sugar-sweetened beverages, refined grains, potatoes, and sweets/desserts, and animal food included animal fat, dairy, egg, fish/seafood, meat, and miscellaneous animal-based foods. In each group, food items were altered to deciles and received 1-10 score according to the lowest and highest intake in each group. In PDI and hPDI index, the highest intake gets a 10 score and the lowest intake get a 1 score. In uPDI, scored 1 for highest intake and 10 for lowest intake of animal food intake by participants. Scores were summed up to get a score ranging from 18 to 180 for each PDI, hPDI, and uPDI index. A higher total score for every index showed higher conformity to that pattern.

Assessment of other variables

All participants were interviewed face-to-face and the height (in centimeters) and weight (in kilograms) of the subjects were measured by standard methods for calculating body mass index (BMI) in kilograms per square meter.

Statistical analysis

Participants were classified based on tertiles of PDI, hPDI, and uPDI. To compare continuous variables across tertiles of PDI, hPDI and uPDI, we use One-way analysis of variance (ANOVA) and chi-squared test used to compare the categorical variables across the tertiles of each pattern score. To determine the relation between plant-based diet scores and odds of sperm parameters, multivariable logistic regression was used in different models. This relation was observed in both crude and adjusted models. In the first model, we adjusted age and energy intake. In the second model, additional controls for BMI, physical activity, marriage time, educational status, smoking, and alcohol history were done. Statistical analyses were conducted using SPSS for Windows software (version 20.0), SPSS Inc., and Chicago IL. P<0.05 was considered statistically significant.

Results

Baseline characteristics of participants according to tertiles of PDI, hPDI, and uPDI are shown in Table 1. The mean age, body mass index, waist circumference, and physical activity of infertile men were 31.24 years, 26.94 kg/m^2, 94.51 cm, and 29.27 Met/day, respectively. BMI and waist circumference were higher in the last tertile of hPDI and waist circumference was higher in the first tertile of uPDI scores. Furthermore, there was a significant change between tertiles of uPDI with alcohol history and supplement use.

The energy-adjusted dietary nutrients and food items intakes of participants through tertiles of PDI, hPDI, and uPDI are shown in Table 2. Participants in the last tertile of PDI had a higher intake of fiber, vitamin E, B9, C, whole grains, fruits, legumes, vegetable oils, tea/coffee, and sugar sweetened beverages, but lower intake of carbohydrate, protein, SFA, cholesterol, B12, calcium, dairy, eggs and fish/seafood compared to lowest tertile.

Moreover, in the highest tertile of hPDI, participants consumed higher amounts of energy, carbohydrate, protein, fat, fiber, vitamin E, B9, magnesium, iron, whole grains, fruits, vegetables, legumes, vegetable oil, and tea/coffee, but lower intake of SFA, cholesterol, B12, refined grains, potatoes, sugar sweetened beverage, sweets desserts, animal fat, dairy, eggs, fish/seafood, and meats compared to the first tertile.

Furthermore, higher intake of refined grains and sugar sweetened beverages, but a lower intake of protein, cholesterol, vitamin A, B6, B12, and C, as well as fruits, vegetables, nuts, legumes, vegetable oil, animal fat, dairy, eggs, fish/seafood, and meats, as well as fruits, vegetables, nuts, legumes, vegetable oil, animal fat, dairy, eggs, fish/seafood and meats were observed in the highest uPDI tertile in comparison with those the lowest tertile.

The mean and standard deviation (SD) of sperm parameters in crude and adjusted models across tertile of PDI, hPDI, and uPDI are shown in Table 3. For the hPDI score, participants in the highest tertile had a higher mean of sperm density compared with those in the lowest tertile in the crude model. Also, after adjustment for potential covariates, the difference was significant. In addition, the mean of sperm motility in the third tertile of uPDI was higher than those in the first tertile in crude and adjusted models.

Table 1: Basic characteristics of participants across the tertiles of PDI, hPDI, and uPDI scores

Variable	PDI				hPDI				uPDI			
	T1 (n=96)	T2 (n=76)	T3 (n=82)	P	T1 (n=85)	T2 (n=89)	T3 (n=80)	P	T1 (n=90)	T2 (n=83)	T3 (n=81)	P
Age (Y)	30.94 ± 3.73	31.94 ± 4.88	31.12 ± 4.40	0.70	30.75 ± 3.69	31.26 ± 4.85	31.48 ± 4.29	0.53	30.98 ± 4.15	31.40 ± 4.05	31.12 ± 4.75	0.81
Body mass index (kg/m^2)	26.68 ± 27.43	27.43 ± 4.35	26.82 ± 3.88	0.46	26.67 ± 4.02	26.38 ± 3.76	27.88 ± 4.47	0.04*	27.49 ± 4.08	27.23 ± 4.28	26.07 ± 3.89	0.06
Waist (cm)	94.47 ± 10.11	95.01 ± 10.23	94.65 ± 10.88	0.94	94.66 ± 9.63	92.99 ± 9.52	96.61 ± 11.72	0.07	95.29 ± 10.92	95.11 ± 10.33	93.59 ± 9.78	0.51
Marriage time (Y)	5.66 ± 3.17	5.38 ± 2.71	5.43 ± 3.20	0.80	5.37 ± 2.40	5.33 ± 3.02	5.84 ± 3.62	0.49	5.86 ± 3.23	5.71 ± 2.96	4.89 ± 2.84	0.08
Physical activity (Met/day)	29.51 ± 2.15	29.11 ± 2.20	29.08 ± 1.99	0.45	29.35 ± 2.10	29.30 ± 1.97	29.09 ± 2.34	0.78	29.20 ± 2.14	29.20 ± 2.25	29.44 ± 1.96	0.79
Smoking history				0.85				0.08				0.95
Yes	35 (36.45)	30 (39.47)	29 (35.36)		37 (43.53)	35 (39.33)	22 (27.50)		33 (36.67)	30 (36.15)	31 (38.30)	
No	61 (63.55)	46 (60.53)	53 (64.64)		48 (56.47)	54 (60.67)	58 (62.50)		57 (63.33)	53 (63.85)	50 (61.70)	
Alcohol history				0.22	19 (22.35)			0.46				0.01*
Yes	17 (17.70)	21 (27.63)	15 (18.30)		66 (77.65)	21 (23.60)	13 (16.25)		28 (31.11)	12 (14.46)	13 (16.05)	
No	79 (82.30)	55 (72.37)	67 (81.70)			68 (76.40)	67 (83.75)		62 (68.89)	71 (85.54)	68 (83.95)	
Supplement use				0.94	32 (37.65)			0.24				0.03*
Yes	30 (31.25)	25 (32.89)	25 (30.49)		53 (62.35)	23 (25.85)	25 (31.25)		37 (41.11)	19 (22.90)	24 (29.63)	
No	66 (68.75)	51 (67.11)	57 (69.51)			66 (74.15)	55 (68.75)		53 (58.89)	64 (77.10)	57 (70.37)	
Education status				0.29				0.14				0.63
Less than high school	16 (16.66)	17 (22.37)	23 (28.05)		14 (16.47)	17 (19.10)	25 (31.25)		18 (20.00)	18 (21.70)	20 (24.70)	
High school diploma	28 (29.17)	23 (30.26)	27 (32.93)		25 (29.41)	30 (33.70)	23 (28.75)		33 (36.66)	23 (27.70)	22 (27.16)	
Bachelor degree or higher	52 (54.17)	36 (47.37)	32 (39.02)		46 (54.12)	42 (47.20)	32 (40.00)		39 (43.34)	42 (50.60)	39 (48.14)	

Values are mean (SD) for continuous and percentage for categorical variables. Using one-way ANOVA for continuous and Chi-square test for categorical variables. PDI; Plant-base diet index, hPDI; Healthful plant-base diet index, uPDI; Unhealthful plant-base diet index, T1; First tertile, T2; Second tertile, T3; Third tertile, P; P value, and *; P<0.05 was considered as significant (more explanation are reported in result section).

Table 2: Dietary intakes of participants across the tertiles of PDI, hPDI, and uPDI scores

Variable	PDI				hPDI				uPDI			
	T1 (n=96)	T2 (n=76)	T3 (n=82)	P value	T1 (n=85)	T2 (n=89)	T3 (n=80)	P value	T1 (n=90)	T2 (n=83)	T3 (n=81)	P value
Nutrient items												
Energy (kcal/d)	2640.21 ± 751.37	2465.46 ± 632.88	2427.66 ± 661.09	0.08	2413.03 ± 635.32	2410.82 ± 611.83	2752.91 ± 780.83	0.001*	2523.91 ± 552.97	2523.86 ± 840.85	2509.51 ± 672.53	0.98
Carbohydrate (g/d)	364.83 ± 113.98	360.26 ± 96.95	357.55 ± 103.55	0.003*	331.48 ± 87.00	345.99 ± 92.27	409.41 ± 120.31	<0.001*	354.53 ± 88.74	364.30 ± 121.50	365.14 ± 105.63	0.19
Protein (g/d)	105.00 ± 27.24	92.02 ± 24.38	84.44 ± 25.16	<0.001*	95.38 ± 24.41	89.79 ± 25.37	98.74 ± 30.92	0.004*	98.39 ± 24.23	93.77 ± 31.30	90.86 ± 25.16	0.009*
Fat (g/d)	95.44 ± 45.20	81.98 ± 31.06	81.95 ± 28.41	0.15	86.49 ± 35.15	82.63 ± 29.04	92.58 ± 45.06	0.01*	88.43 ± 27.52	88.70 ± 47.20	83.84 ± 33.79	0.31
Dietary fiber (g/d)	38.79 ± 16.61	41.22 ± 14.64	42.26 ± 18.03	0.009*	32.54 ± 11.05	40.61 ± 13.59	49.27 ± 19.86	<0.001*	41.95 ± 16.40	39.48 ± 14.57	40.37 ± 18.57	0.51
SFA (g/d)	31.98 ± 13.18	25.77 ± 9.80	24.49 ± 8.89	<0.001*	28.92 ± 11.63	26.30 ± 9.26	27.97 ± 13.21	<0.001*	28.36 ± 9.31	27.97 ± 14.00	26.70 ± 10.64	0.37
MUFA (g/d)	30.11 ± 15.16	26.99 ± 11.68	27.85 ± 10.60	0.55	27.51 ± 11.78	27.38 ± 10.94	30.62 ± 15.46	0.28	29.35 ± 9.92	28.58 ± 16.30	27.30 ± 11.68	0.33
PUFA (g/d)	17.87 ± 10.13	15.79 ± 6.89	16.99 ± 7.02	0.28	15.50 ± 7.56	16.98 ± 7.72	18.50 ± 9.45	0.20	17.69 ± 5.88	17.23 ± 10.69	15.88 ± 7.80	0.17
Cholesterol (mg/d)	390.35 ± 246.70	303.54 ± 204.51	238.87 ± 102.62	<0.001*	369.87 ± 198.90	293.31 ± 231.29	282.33 ± 173.86	<0.001*	345.37 ± 210.16	317.91 ± 228.66	279.75 ± 173.18	0.07
Vitamin A (RAE/d)	844.51 ± 428.17	818.43 ± 439.16	752.68 ± 348.31	0.62	780.59 ± 382.89	745.43 ± 357.69	903.76 ± 468.98	0.51	919.07 ± 447.39	802.77 ± 398.12	687.01 ± 335.16	<0.001*
Vitamin E (mg/d)	12.80 ± 5.99	13.46 ± 7.87	14.51 ± 6.17	0.001*	11.57 ± 5.44	14.01 ± 7.62	15.14 ± 6.28	0.009*	13.83 ± 5.36	13.86 ± 8.43	12.92 ± 5.95	0.51
Vitamin B6 (mg/d)	2.27 ± 0.57	2.22 ± 0.61	2.06 ± 0.60	0.05	2.05 ± 0.54	2.12 ± 0.58	2.40 ± 0.62	0.10	2.29 ± 0.59	2.14 ± 0.57	2.12 ± 0.62	0.004*
Vitamin B9 (μg/d)	552.80 ± 141.71	555.77 ± 139.59	560.61 ± 161.81	0.02*	502.36 ± 114.18	551.46 ± 121.72	618.71 ± 179.05	<0.001*	559.11 ± 134.36	544.48 ± 149.54	656.01 ± 159.44	0.37
Vitamin B12 (μg/d)	7.22 ± 3.68	5.96 ± 3.08	5.00 ± 2.68	<0.001*	7.16 ± 3.82	5.64 ± 2.98	5.56±2.89	<0.001*	6.90 ± 3.49	5.98 ± 3.41	5.41 ± 2.89	0.004*
Vitamin C (mg/d)	233.35 ± 121.22	264.20 ± 142.11	233.87 ± 117.18	0.02*	219.51 ± 113.90	226.49 ± 118.10	285.53 ± 139.62	0.79	269.05 ± 125.80	247.20 ± 128.30	208.95 ± 120.31	0.002*
Calcium (mg/d)	1362.73 ± 435.79	1183.35 ± 405.30	1076.67 ± 389.21	<0.001*	1178.37 ± 422.94	1176.70 ± 385.98	1301.70 ± 469.14	0.89	1262.96 ± 423.62	1213.67 ± 436.52	1168.42±436.52	0.18
Magnesium (mg/d)	477.22 ± 156.36	438.89 ± 114.41	436.31 ± 148.21	0.77	405.38 ± 102.31	439.90±133.43	516.72 ± 166.84	<0.001*	458.62 ± 118.24	455.64 ± 164.39	442.63 ± 146.01	0.54
Selenium (mg/d)	124.95 ± 51.89	109.91 ± 36.21	110.70 ± 43.85	0.31	104.26 ± 27.39	115.66±45.36	128.37 ± 56.77	0.06	111.53 ± 31.04	115.56 ± 52.62	120.95 ± 50.75	0.18
Zinc (mg/d)	15.88 ± 4.67	13.85 ± 4.37	12.76 ± 4.08	<0.001*	14.17 ± 4.17	13.77 ± 4.56	14.92 ± 4.97	0.10	14.71 ± 4.08	14.14 ± 5.21	13.90 ± 4.42	0.22
Iron (mg/d)	18.07 ± 5.89	17.62 ± 4.82	17.79 ± 5.56	0.05	16.01 ± 3.83	17.52 ± 4.95	20.17 ± 6.60	<0.001*	17.90 ± 4.46	17.72 ± 6.32	17.92 ± 5.60	0.84
Food items												
Whole grains (g/d)	43.47 ± 64.81	65.20 ± 65.23	74.40 ± 93.48	0.01*	34.50 ± 41.11	54.32 ± 59.54	93.28 ± 104.89	<0.001*	71.08 ± 85.03	54.80 ± 66.84	52.88 ± 74.50	0.22
Fruits (g/d)	408.90 ± 175.35	490.74 ± 177.37	599.12 ± 354.15	<0.001*	424.43 ± 158.97	471.87 ± 171.17	595.07 ± 374.31	<0.001*	582.62 ± 338.87	477.76 ± 191.76	414.47 ± 179.17	<0.001*
Vegetables (g/d)	327.70 ± 198.10	367.37 ± 169.88	373.79±165.95	0.17	311.90 ± 179.31	362.13 ± 175.42	391.12 ± 180.01	0.01*	414.36 ± 167.57	334.12 ± 182.14	308.72 ± 176.40	<0.001*

Table 2: Continued

Variable	PDI				hPDI				uPDI			
	T1 (n=96)	T2 (n=76)	T3 (n=82)	P value	T1 (n=85)	T2 (n=89)	T3 (n=80)	P value	T1 (n=90)	T2 (n=83)	T3 (n=81)	P value
Nuts (g/d)	18.71 ± 22.75	15.95 ± 12.17	17.65 ± 13.00	0.57	17.57 ± 14.96	18.21 ± 20.43	16.77 ± 15.38	0.85	23.46 ± 18.68	15.96 ± 16.86	12.58 ± 13.50	<0.001*
Legumes (g/d)	30.17 ± 23.82	31.15 ± 17.57	38.14 ± 17.51	0.02*	28.46 ± 16.49	37.53 ± 24.50	32.89 ± 18.09	0.01*	40.66 ± 21.15	32.63 ± 19.54	24.98 ± 17.13	<0.001*
Vegetable oil (g/d)	9.86 ± 7.32	14.11 ± 9.42	21.01 ± 11.47	<0.001*	12.35 ± 8.91	14.85 ± 9.78	17.13 ± 12.28	0.01*	18.03 ± 11.95	13.45 ± 9.14	12.38 ± 9.22	0.001*
Tea and coffee (g/d)	274.75 ± 247.36	361.96 ± 256.35	462.37 ± 257.30	<0.001*	286.73 ± 216.92	375.55 ± 237.01	425.04 ± 317.20	0.002	384.94 ± 242.90	374.56 ± 270.01	321.81 ± 279.28	0.25
Fruit juice (g/d)	28.81 ± 42.38	48.55 ± 81.39	47.57 ± 62.35	0.05	53.93 ± 49.01	32.35 ± 48.00	36.16 ± 85.48	0.05	36.82 ± 62.48	38.96 ± 55.76	47.01 ± 70.47	0.54
Refined grains (g/d)	278.82 ± 143.28	292.02 ± 131.91	325.65 ± 124.46	0.06	295.28 ± 115.53	323.18 ± 132.79	272.53 ± 152.15	0.04	262.57 ± 122.06	292.23 ± 113.01	342.93 ± 156.46	<0.001*
Potatoes (g/d)	25.48 ± 29.19	25.82 ± 22.77	29.20 ± 17.14	0.53	36.97 ± 29.17	24.06 ± 18.70	18.99 ± 18.75	<0.001*	27.72 ± 23.53	24.88 ± 25.03	27.70 ± 23.26	0.67
Sugar sweetened beverage (g/d)	34.94 ± 46.91	51.12 ± 60.96	77.79 ± 84.47	<0.001*	63.91 ± 70.90	60.58 ± 72.13	34.92 ± 53.52	0.008*	37.09 ± 45.25	45.75 ± 45.31	80.04 ± 94.26	<0.001*
Sweets desserts (g/d)	41.38 ± 43.31	35.68 ± 25.13	47.93 ± 24.66	0.06	56.92 ± 36.58	41.34 ± 31.02	26.21 ± 23.81	<0.001*	40.59 ± 34.34	40.13 ± 30.47	44.82 ± 35.10	0.61
Animal fat (g/d)	8.37 ± 12.93	5.93 ± 10.17	4.96 ± 5.87	0.06	8.26 ± 8.19	7.19 ± 11.71	3.98 ± 10.35	0.01*	9.04 ± 13.15	5.65 ± 7.64	4.67 ± 8.59	0.01*
Dairy (g/d)	527.79 ± 243.42	463.57 ± 225.46	386.20 ± 170.12	<0.001*	535.87 ± 231.23	442.53 ± 199.84	407.92 ± 223.18	<0.001*	505.34 ± 203.11	485.93 ± 216.57	392.04 ± 238.28	0.002*
Eggs (g/d)	23.24 ± 20.88	18.67 ± 14.09	15.72 ± 11.24	0.008*	24.40 ± 19.82	17.39 ± 12.69	16.47 ± 15.40	0.003*	23.14 ± 17.39	20.04 ± 12.87	14.74 ± 17.86	0.004*
Fish and seafood (g/d)	27.83 ± 23.27	21.08 ± 22.70	14.29 ± 10.75	<0.001*	30.69 ± 22.67	17.85 ± 16.33	15.61 ± 19.41	<0.001*	26.59 ± 23.29	19.12 ± 17.57	18.10 ± 19.43	0.01*
Meats (g/d)	70.71 ± 39.39	68.72 ± 50.87	57.04 ± 34.86	0.07	82.13 ± 36.32	62.50 ± 41.23	51.80 ± 43.51	<0.001*	75.01 ± 45.88	58.91 ± 35.79	62.32 ± 42.48	0.02*
Miscellaneous animal based foods (g/d)	25.25 ± 26.26	24.19 ± 32.35	18.18 ± 11.66	0.13	24.76 ± 18.52	25.45 ± 26.42	17.29 ± 28.44	0.05	24.15 ± 22.79	25.25 ± 33.61	18.32 ± 14.29	0.16

Values are mean ± SE. All values are adjusted for energy intake using ANCOVA. SFA; Saturated fatty acid, PUFA; Polyunsaturated fatty acid, MUFA; Monounsaturated fatty acid, T1; First tertile, T2; Second tertile, T3; Third tertile, and *; P<0.05 was considered as significant (more explanation are reported in result section).

Table 3: Mean sperm parameters across tertiles of PDI, hPDI, and uPDI scores

Variable	PDI				hPDI				uPDI			
	T1 (n=96)	T2 (n=76)	T3 (n=82)	P value	T1 (n=85)	T2 (n=89)	T3 (n=80)	P value	T1 (n=90)	T2 (n=83)	T3 (n=81)	P value
Volume (ml)												
Model I[a]	4.19 ± 2.23[d]	3.97 ± 1.92	4.31 ± 2.04	0.57	4.17 ± 2.18	3.82 ± 1.65	4.54 ± 2.33	0.07	4.21 ± 2.05	4.13 ± 1.80	4.14 ± 2.37	0.96
Model II[b]	4.19 ± 2.23	3.97 ± 1.92	4.31 ± 2.04	0.56	4.17 ± 2.18	3.82 ± 1.65	4.54 ± 2.33	0.14	4.21 ± 2.05	4.13 ± 1.80	4.14 ± 2.37	0.96
Model III[c]	4.19 ± 2.23	3.97 ± 1.92	4.31 ± 2.04	0.59	4.17 ± 2.18	3.82 ± 1.65	4.54 ± 2.33	0.13	4.21 ± 2.05	4.13 ± 1.80	4.14 ± 2.37	0.93
Density ($\times 10^6$/ml)												
Model I[a]	10.83 ± 10.75	15.54 ± 17.51	13.32 ± 18.55	0.14	9.35 ± 6.93	15.58 ± 19.22	14.15 ± 17.59	0.02*	11.96 ± 13.18	13.36 ± 15.24	13.93 ± 18.75	0.70
Model II[b]	10.83 ± 10.75	15.54 ± 17.51	13.32 ± 18.55	0.11	9.35 ± 6.93	15.58 ± 19.22	14.15 ± 17.59	0.02*	11.96 ± 13.18	13.36 ± 15.24	13.93 ± 18.75	0.69
Model III[c]	10.83 ± 10.75	15.54 ± 17.51	13.32 ± 18.55	0.07	9.35 ± 6.93	15.58 ± 19.22	14.15 ± 17.59	0.03*	11.96 ± 13.18	13.36 ± 15.24	13.93 ± 18.75	0.93
Total motility (%)												
Model I[a]	28.38 ± 17.99	31.68 ± 18.91	28.51 ± 17.52	0.43	26.60 ± 16.22	31.74 ± 19.72	29.81 ± 17.97	0.16	25.65 ± 16.74	28.09 ± 19.33	34.94 ± 17.14	0.002*
Model II[b]	28.38 ± 17.99	31.68 ± 18.91	28.51 ± 17.52	0.43	26.60 ± 16.22	31.74 ± 19.72	29.81 ± 17.97	0.19	25.65 ± 16.74	28.09 ± 19.33	34.94 ± 17.14	0.002*
Model III[c]	28.38 ± 17.99	31.68 ± 18.91	28.51 ± 17.52	0.36	26.60 ± 16.22	31.74 ± 19.72	29.81 ± 17.97	0.19	25.65 ± 16.74	28.09 ± 19.33	34.94 ± 17.14	0.009*
Normal morphology (%)												
Model I[a]	3.47 ± 8.29	4.67 ± 11.54	4.14 ± 10.65	0.74	3.85 ± 9.98	4.24 ± 9.92	4.03 ± 10.52	0.96	4.27 ± 10.64	3.34 ± 7.40	4.51 ± 11.80	0.73
Model II[b]	3.47 ± 8.29	4.67 ± 11.54	4.14 ± 10.65	0.87	3.85 ± 9.98	4.24 ± 9.92	4.03 ± 10.52	0.98	4.27 ± 10.64	3.34 ± 7.40	4.51 ± 11.80	0.67
Model III[c]	3.47 ± 8.29	4.67 ± 11.54	4.14 ± 10.65	0.91	3.85 ± 9.98	4.24 ± 9.92	4.03 ± 10.52	0.96	4.27 ± 10.64	3.34 ± 7.40	4.51 ± 11.80	0.67

Data are presented as mean ± SE. [a]; Crude, [b]; Adjusted for age and energy intake, [c]; Additionally adjusted for BMI, physical activity, marriage time, educational status, smoking and alcohol history, [d]; These values are mean (SE), T1; First tertile, T2; Second tertile, T3; Third tertile, and *; $P<0.05$ was considered as significant (more explanation are reported in result section).

Table 4: Crude and multivariable-adjusted odds ratios and 95% CIs for sperm parameters rs across tertiles of PDI, hPDI, and uPDI scores

Variable	PDI				hPDI				uPDI			
	T1 (n=96)	T2 (n=76)	T3 (n=82)	P value	T1 (n=85)	T2 (n=89)	T3 (n=80)	P value	T1 (n=90)	T2 (n=83)	T3 (n=81)	P-value
Volume (ml)												
Model Ia	1.00	1.11 (0.59, 2.08) [d]	0.53 (0.27, 1.05)	0.08	1.00	1.48 (0.78, 2.79)	0.80 (0.40, 1.59)	0.56	1.00	0.85 (0.44, 1.63)	0.99 (0.52, 1.89)	0.97
Model IIb	1.00	1.05 (0.55, 1.99)	0.49 (0.25, 0.98)	0.05	1.00	1.48 (0.78, 2.80)	0.86 (0.42, 1.74)	0.75	1.00	0.84 (0.44, 1.62)	0.98 (0.51, 1.88)	0.95
Model IIIc	1.00	0.92 (0.47, 1.78)	0.43 (0.21, 0.87)	0.02*	1.00	1.47 (0.77, 2.81)	0.84 (0.40, 1.75)	0.72	1.00	0.85 (0.43, 1.68)	0.99 (0.50, 1.96)	0.90
Density (×106/ml)												
Model Ia	1.00	0.60 (0.31, 1.18)	0.97 (0.49, 1.94)	0.89	1.00	0.46 (0.23, 0.93)	0.70 (0.33, 1.45)	0.34	1.00	0.89 9 0.45, 1.75)	0.86 (0.44, 1.70)	0.67
Model IIb	1.00	0.59 (0.30, 1.17)	0.98 (0.49, 1.97)	0.91	1.00	0.45 (0.22, 0.91)	0.66 (0.31, 1.40)	0.26	1.00	0.88 (0.44, 1.73)	0.86 (0.43, 1.70)	0.66
Model IIIc	1.00	0.52 (0.26, 1.07)	1.02 (0.50, 2.11)	0.97	1.00	0.44 (0.21, 0.89)	0.71 (0.33, 1.56)	0.36	1.00	0.97 (0.48, 1.96)	0.92 (0.45, 1.89)	0.84
Total motility (%)												
Model Ia	1.00	0.72 (0.37, 1.41)	1.18 (0.59, 2.38)	0.68	1.00	0.69 (0.35, 1.38)	0.80 (0.39, 1.65)	0.55	1.00	0.45 (0.21, 0.95)	0.34 (0.16, 0.72)	0.005*
Model IIb	1.00	0.69 (0.35, 1.37)	1.13 (0.56, 2.30)	0.77	1.00	0.69 (0.35, 1.39)	0.87 (0.42, 1.81)	0.70	1.00	0.45 (0.21, 0.95)	0.34 (0.16, 0.72)	0.005*
Model IIIc	1.00	0.66 (0.32, 1.33)	1.17 (0.56, 2.42)	0.75	1.00	0.68 (0.34, 1.38)	0.88 (0.41, 1.88)	0.66	1.00	0.49 (0.23, 1.06)	0.39 (0.18, 0.85)	0.01*
Normal morphology (%)												
Model Ia	1.00	0.65 (0.21, 2.04)	0.84 (0.26, 2.72)	0.76	1.00	1.05 (0.29, 3.76)	0.49 (0.15, 1.54)	0.20	1.00	1.52 (0.47, 4.85)	1.22 (0.40, 3.67)	0.70
Model IIb	1.00	0.73 (0.23, 2.30)	0.93 (0.28, 3.06)	0.90	1.00	1.10 (0.30, 4.01)	0.43 (0.13, 1.39)	0.14	1.00	1.64 (0.50, 5.31)	1.28 (0.42, 3.91)	0.63
Model IIIc	1.00	0.71 (0.21, 2.30)	0.86 (0.25, 2.96)	0.82	1.00	1.01 (0.27, 3.78)	0.35 (0.10, 1.21)	0.09	1.00	2.08 (0.61, 7.09)	1.72 (0.51, 5.73)	0.42

[a]; Crude, [b]; Adjusted for age and energy intake, [c]; Additionally adjusted for BMI, physical activity, marriage time, educational status, smoking and alcohol history, [d]; These values are odd ratio (95% CIs), e ; Obtained from logistic regression, T1; First tertile, T2; Second tertile, T3; Third tertile, BMI; Body mass index, CI; Confidence interval, and * ; P<0.05 was considered as significant (more explanation are reported in result section).

Multivariable-adjusted odds ratio (OR) and 95% confidence intervals (CIs) for sperm parameters across tertiles of PDI, hPDI, and uPDI are indicated in Table 4. Although there was no significant association between volume and PDI in the crude model (OR=0.53, 95% CI: 0.27, 1.05, P=0.08), which became significant in the fully-adjusted model and participants in the highest PDI tertile had a lower risk of volume deficiency (OR=0.43, 95% CI: 0.21, 0.87, P=0.02). In the crude model, there was a significant association between total motility and uPDI, and participants in the highest uPDI tertile had a lower risk of sperm motility (OR=0.34, 95% CI: 0.16, 0.72, P=0.005). After adjustment for potential confounders including age, energy intake, BMI, physical activity, marriage time, educational status, smoking, and alcohol history, the association was significant and participants in the highest uPDI tertile had a lower risk (OR=0.34, 95% CI: 0.16, 0.72, P=0.005 and OR=0.39, 95% CI: 0.18, 0.85, P=0.01).

Discussion

In this study, for the first time, the relationship between PDI, hPDI, uPDI and male infertility was studied and the results of this investigation revealed that greater adherence to the hPDI dietary pattern could significantly increase sperm concentration and motility in men. Greater adherence to the PDI dietary pattern also could associate with a lower risk of sperm volume deficiency, and ultimately more adherence to the uPDI dietary pattern could reduce the risk of sperm motility.

We create three different plant food patterns to be able that compare them more easily and even distinguished between healthy and unhealthy plant food according to their effect on various diseases such as type 2 diabetes mellitus, cancers, cardiovascular disease, and also some hazardous conditions (hypertension, hyperlipidemia, obesity, and inflammation). Previous studies have applied this type and category of dietary patterns (20, 21), but the association of it with infertility in men, has not been evaluated, yet.

Participants who have a higher hPDI score and consumption more amount of energy, carbohydrate, protein, fat, fiber, vitamin E, B9, magnesium, iron, whole grains, fruits, vegetables, legumes, vegetable oil, and tea/coffee, have a higher mean of sperm density and motility. These findings can partly confirm the results of one study that reported diet rich in vegetables, fruits, whole grains, fish and chicken can be a suitable way to improve semen quality (12). Joanna Jurewicz et al. (13) also conducted one important study to evaluate the association between dietary patterns and male infertility. The results indicated that men who consumed more fruits, cruciferous, vegetables, tomatoes, leafy green vegetables, whole grains, legumes, fish, and chicken had higher sperm concentration and testosterone levels. Besides, in a specific evaluation of the effect of extra virgin olive oil (vegetable oil) consumption on male fertility was found that extra virgin olive oil, due to changes in plasma lipid profile, affects the activity of several peptidases in the testes. In addition, with changes in angiotensinase activity in the testis, it is able to modulate the renin-angiotensin system and its functions in male fertility (22).

The suggested mechanism that a healthy diet is correlated with better semen quality maybe is related to a high amount of fiber sources such as fruits, vegetables, and whole-grain can bind to estrogen and reduce its level in the blood (23, 24). Also, a healthy dietary pattern is associated with more consumption of antioxidants, and several studies showed that more intake of an antioxidant such as carotenoids, vitamin E, and vitamin C can affect semen quality and especially enhance sperm motility (25, 26). Because one of the main reasons for male infertility is direct damage to the DNA of sperm cells and peroxidation of their membranes by reactive oxygen species (ROS) (22).

Even a review article that is about the effect of antioxidants and phytocompounds on seminal oxidative stress concludes that plant foods not only can reduce oxidative stress, but also can improve male reproductive functions (3). Recent studies conducted in the Iranian male population have also shown that there is a positive relationship between healthy dietary patterns and improvement of sperm indices, even following a healthy and traditional dietary pattern has been introduced as a protective factor against male infertility and western and fat-based dietary pattern as a risk factor (27, 28).

Our study also shows that men who follow most of the PDI dietary patterns with lower intake of carbohydrates, protein, SFA, cholesterol, B12, calcium, dairy, eggs, and fish, had a lower risk of volume deficiency. In the same way, Attaman et al in their study about dietary fat and semen quality have reported that high consumption of saturated fat can diminish sperm concentration (29).

In both PDI and hPDI patterns, men in the highest tertile with better semen quality had a lower intake of vitamin B12 and it is in contrast with many previous investigations that said vitamin B12 and folate are important for DNA methylation and improve sperm motility and concentration (30, 31). That may be this role can be more associated with folate compare to vitamin B12. Also in Vujkovic et al. (12) study, there is a positive association between traditional Dutch dietary patterns and seminal vitamin B12 concentration, which maybe is related to the high consumption of meat in this dietary Patten.

Also, the results of this study demonstrate that participants in the highest tertile of uPDI that have a higher intake of refined grains and sugar sweetened beverages were at lower risk of abnormal sperm motility. That could be because a high intake of simple sugar causes insulin resistance and oxidative stress that can affect sperm motility (32, 33). However, excessive fats and carbohydrates have always been the cause of obesity, but today it has been found that more complex relationships of macronutrients or even micronutrient deficiency in unhealthy dietary patterns can be involved in this case and consequently its relationship with infertility in men (34).

Some of the straight points of the current study are that this topic is new and we had innovation for choose of it, also an appropriate sample population of infertile men was available who were accurately evaluated for inclusion and exclusion criteria and also were relatively homogenous in age, ethnicity and anthropometric indexes, that reduces the chance of finding results be related to peripheral and uncontrolled factors. Additionally, to minimize errors in the results of this study after evaluating the cured model in another model adjusted in terms of BMI, physical activity, age, energy intake, BMI, marriage time, educational status, smoking, and alcohol history conducted that cause results become more valid and reliable.

In the present study for evaluating male infertility, semen samples were applied in a standard situation and taking into account all of the WHO criteria, but we have access only to one sample of each man, similar to other epidemiological studies, whereas it can be better to have several semen samples collected over 1-2 weeks (35). In this investigation, we use the dietary pattern method which is considered a complex of food consumption and different connections between food compounds, since dietary intake is a multidimensional variable and people do not consume food individually, using this dietary pattern method has more potential to be associated with health outcomes and provide a basis for dietary recommendations (36, 37).

In this study, 168-item FFQ was used for collecting nutritional data. This tool has adequate validity and reproducibility (19), However, there is likely to have some measurement error, which can usually cause errors in dietary classifications and reduce associations of interest in all observational studies (38, 39). But so far, it is the only tool available and suitable tool. There were not numerous limitations in this study, just because it was observational cross-sectional we cannot prove causality between diet and semen quality parameters.

Conclusion

In this study, for the first time, the relationship between plant PDI, hPDI, uPDI and male infertility were evaluated and demonstrated very important results, including that greater conformity to the hPDI dietary pattern could significantly increase sperm density and motility in men, as well as greater adherence to the PDI dietary pattern is associated with a lower risk of sperm volume deficiency, and ultimately more adherence to the uPDI dietary pattern, can reduce the risk of low sperm motility. Altogether, this cross-sectional study demonstrated that nutrition has an impact on semen quality and fertility of men.

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Authors' Contributions

M.Sh.; Participated in study design, data collection and evaluation. M.N.; Participated in data collection and evaluation. N.A.; Participated in statistical analysis of data and interpretation of data. K.L.; Participated in statistical analysis of data and editing the manuscript. All authors read and approved the final manuscript.

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