Bazshahi *et al. BMC Nutrition* (2024) 10:139
https://doi.org/10.1186/s40795-024-00949-4

BMC Nutrition

RESEARCH

Open Access

Adherence to plant-based diet during pregnancy and risk of gestational diabetes: a prospective birth cohort study

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Abstract

Background Studies have shown that plant-based foods have a protective effect against gestational diabetes (GDM). We examined the association between plant-based dietary patterns and the risk of GDM in a sample of Iranian adults.

Methods We enrolled 635 pregnant women for the present study. Dietary intakes were evaluated by using a 90-item food frequency questionnaire during the first trimester of pregnancy. Three plant-based including plant-based (PDI), unhealthy (uPDI) and healthy (hPDI) were calculated. Cox proportional hazard model were fitted to estimate hazard ratio (HR) and 95% confidence interval (CI) of GDM across categories of the plan-based dietary indices, while controlling for age, educational level, physical activity, family income, prepregnancy body mass index, gestational weight gain, and total energy intake.

Results A total of 635 mothers were included, of whom 79 participants were diagnosed with GDM. Those in the third tertile of the PDI (HR: 0.55, 95% CI: 0.30, 0.98) and hPDI (HR: 0.43, 95% CI: 0.24, 0.78) had a lower risk of developing GDM during their current pregnancy as compared to the first tertile. There was no association between uPDI and risk of GDM.

Conclusions We found that higher adherence to a plant-based diet during early pregnancy may be associated with a lower GDM risk among Iranian women. Confirmation of this finding is necessary in larger cohort studies, taking into account other pregnancy outcomes such as birth weight.

Keywords Plant-based diet, Gestational diabetes, Pregnancy, Cohort

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Background

Pregnancy is one of the physiological conditions that may be associated with various complications. Gestational diabetes mellitus (GDM) is a common complication, affecting 1 to 30% of pregnancies worldwide [1]. The prevalence of GDM has increased steadily during the past decades, including 14% of pregnancies in the US, 5.7% of pregnancies in Australia and 5 to 10% of pregnancies in Asian countries [2, 3]. In Iran, the prevalence of GDM is estimated to be about 3.4% of total annual pregnancies [4]. The incidence of rising pregnant women of GDM across the world is partly due to the concurrent increases in well-known risk factors, including advanced maternal age [5], pre-pregnancy overweight or obesity [6], excessive gestational weight gain [7] and family history of diabetes are associated with an increased risk of developing GDM [8]. Women with GDM are at greater risks of several complications such as preeclampsia, shoulder dystocia, type 2 diabetes, high blood pressure, and cardiovascular disease (CVD) later in their life [9–11]. Also, children born to mothers with GDM are at greater risks for overweight/obesity, impaired glucose tolerance, and metabolic syndrome later in their life [12–14].

Cohort studies have greatly contributed to the evidence needed to identify disease risk factors and the cause of the disease. Birth cohort studies can explore the pattern of lifelong exposures and allow to investigate the potential association between these exposures and maternal and neonatal outcomes [15]. Several epidemiological studies have shown that adverse environmental and lifestyle factors during pregnancy play an important role in health status of infants and possibly contribute to the development of some chronic and degenerative diseases in later life of children [16, 17].

Epidemiological studies have shown that diet, as a modifiable key factor, plays a role in the development of GDM. Studies have shown that plant-based foods and nutrients such as cereals, fruits, legumes and dietary fibers have a protective effect against GDM [18–20]. However, a study of vegan diet reported a modest no significant association with GDM [21]. Previous studies about the health effects of maternal plant-based diets have mainly focused on vegetarian diets. In general, people adhering to vegetarian dietary patterns tend to avoid some or all of the major animal foods in their dietary choices. Therefore, the general Plant-based Diet Index (PDI) has been created to compensate for this limitation. PDI evaluates the degree of adherence to a diet rich in plant-based foods and food groups [22]. The PDI positively weights plant foods and negatively weights animal foods and measures the plant-based diet on a continuous scale. Prospective cohort studies have suggested that higher PDI score is associated with a reduced insulin resistance and a lower risk of developing prediabetes and type 2 diabetes [22–24].

However, there is limited evidence about the association between PDI and risk of GDM. Only one case-control study in Iran reported an inverse relationship between PDI and GDM risk [25]. Hence PDI is associated with a reduced risk of type 2 diabetes in the general population, we proposed the hypothesis that PDI may also be associated with a lower risk of GDM and its associated complications in pregnant women. Therefore, the purpose of this prospective cohort study was to evaluate the potential relationship between PDI and risk of GDM in a sample of Iranian women.

Methods

Participants

This prospective cohort study was conducted within the framework of the Persian (Prospective Epidemiological Research Studies in IRAN) Birth Cohort [26]. An ongoing prospective cohort study is being conducted in five districts of Iran nationwide as part of the Persian Birth Cohort to present scientific evidence and enhance knowledge for the development of national policies that are grounded in evidence on different aspects of the developmental origins of health and diseases [26]. This cohort study investigates the potential associations of lifestyle, environmental, and socioeconomic factors with pregnancy outcomes and mother-child mental and physical health and well-being. Pregnant women who lived in Semnan, a city situated in central Iran, were selected for the study. This prospective cohort study was open to pregnant women who were referred to healthcare centers in Semnan during 2018–2021. Additionally, we utilized advertisements on local and social media, as well as medical clinics in the city, to encourage women to take part in this prospective cohort study. Inclusion criteria were women of Iranian nationality who were within the first trimester of pregnancy, irrespective of gravidity, parity or use of fertility treatment, who have resided in Semnan for at least one year and plan to give birth in a hospital located in Semnan. All pregnancy outcomes, regardless of whether they resulted in a natural vaginal delivery or a caesarean section, were included. The criteria for excluding were twin gestations and hormone-related diseases or hormone therapy.

In all, 1024 women agreed to take part in the study. Of those, mothers who did not complete dietary questionnaires during the first trimester ($n=293$), those who did not continue the study until the end and had incomplete information about study outcomes ($n=45$), mothers with total energy intake outside the range of 800 to 4200 kcal/day ($n=18$), those who used cigarette smoking ($n=10$) and had a history of GDM ($n=23$) were excluded from the analyses, leaving 635 pregnant women for the present study. All participants were educated about the study protocol and signed the informed consent form. The protocol of the study was approved by the ethic committee of Semnan University of Medical Sciences (Ethic code: IR.SEMUMS.REC.1400.252).

Assessment of dietary intake

A 90-item food frequency questionnaire (FFQ) was used to evaluate the participants' dietary intake during the first trimester of pregnancy that was developed and validated for use in this prospective cohort study [26]. Trained interviewers conducted face-to-face interviews for dietary assessments. Mothers were asked to provide information on their frequency of consumption of food items in the FFQ, based on commonly used units or portions sizes, during their first trimester of pregnancy. The frequency response categories were nine multiple-choice categories varying from "never or less than once a month" to "6 or more times per day" depending on the nature of food items. The household measures were used to convert all reported consumption frequencies to grams per day. We used Nutritionist IV software (version 7.0; N-Squared Computing, Salem, OR), modified for Iranian foods, to calculate the total energy and nutrient intakes.

Calculation of plant-based-diet

We calculated PDI score using the method introduced by Martínez González et al. [27]. Three plant-based diet indices including PDI, unhealthy (uPDI) and healthy PDI (hPDI) were calculated. We classified foods into three food groups according to the characteristics of nutrients and foods, including healthy plant-based foods (fruits, vegetables, nuts, legumes, vegetable oils, tea and coffee), less healthy plant-based foods (fruit juices, refined grains, potatoes, sugar-sweetened beverages, sweets and desserts), and animal-based foods (animal fat, dairy, eggs, fish and seafood, meat, animal fat). We ranked food groups into deciles and gave positive or reverse scores to each food group. To calculate PDI, we classified plant-based food groups into deciles and assigned a score of 10 to the highest category and a score of 1 to the lowest category. An inverse scoring system was used for animal-based food groups. We summed the score of all food groups to calculate PDI.

To calculate hPDI, we assigned a score of 10 to those in the highest category of healthy plant-based food groups, while an inverse scoring system was used for unhealthy plant-based foods and animal based foods. To calculate uPDI, a score between 10 and 1 was given to the highest through the lowest consumption of unhealthy plant foods.

Participants with the highest to the lowest consumption of animal-based foods and healthy plant foods were given a score between 1 and 10. Scores were summed to obtain a score ranging from 18 to 180 for PDI, hPDI, and uPDI indexes.

Outcome assessment

Diagnosis of GDM was made using a computer questionnaire and during a structured interview with a pregnant mother. The pregnant mother was asked if the doctor has told her that she has GDM and whether she was treated or hospitalized for GDM or not. In the next stage, all tests and medical records of the mother (separately for the first, second and third trimesters) were taken from the mother at 38–39 weeks of pregnancy and scanned in the system. If the mother responded positively, the diagnosis of GDM was confirmed by examining the mother's medical records.

Criteria for diagnosing GDM was elevated blood glucose levels and symptoms of diabetes in a pregnant woman who has not previously been diagnosed with diabetes. Diagnosis of GDM was based on an oral glucose tolerance test. Having at least two of the following criteria was considered as a diagnosis of GDM: fasting plasma glucose higher than 95 mg/dL, one-hour plasma glucose higher than 180 mg/dL, two-hour plasma glucose higher than 155 mg/dL, plasma glucose three hours greater than 140 mg/dL and/or pharmacological treatment for GDM [28].

Assessment of other variables

Structured pre-tested questionnaires that were developed for Persian Birth Cohorts were used by trained interviewers to obtain information about the characteristics of the study participants [26]. Information about age, history of diseases, educational level, mother- and father's occupational status, and family income were recorded by trained interviewers.

Physical activity

We used the generally validated International Physical Activity Questionnaire (IPAQ) to evaluate physical activity levels [29]. Based on Metabolic Equivalents minutes per week (MET-min/week) [30], participants were grouped into two categories no or low physical activity (<3000 MET-minute/week) and moderate and high low physical activity (>3000 MET-minute/week).

Anthropometric measures

Weight and height were measured by a trained interviewer. Weight was measured at the study baseline using a digital scale to the nearest 0.5 kg with light clothes and without shoes. Weight measurement was repeated in the second and third trimesters. The final weight of the mothers was measured using the same protocol in the hospital before delivery. Weight gain was calculated by subtracting the first weight from the last weight. Height was measured in a standing position with a tab measured to the nearest 0.5 centimeter by asking the participants to stand without shoes and shoulders touching the wall. Body mass index (BMI) was calculated based on the weight in kilograms divided by height in meters squared.

Statistical analyses

Firstly, we classified study participants across tertiles of PDI, hPDI, and uPDI indexes. Secondly, we compared the characteristics of participants across categories of PDI, hPDI, and uPDI scores by performing ANOVA for continuous variables and $\chi2$ test for categorical variables. The hazard ratio (HR) and 95% confidence interval (CI) of GDM were calculated by utilizing both an ANOVA test and a Cox proportional hazard model for each category of the plan-based dietary indices. For multivariable analyses, we included age, educational levels (illiterate, under diploma, diploma, University graduate), physical activity (no or low/moderate to high), history of CVD, prepregnancy hypertension, hypothyroidism and hyperthyroidism, (yes/no), prepregnancy BMI, gestational weight gain, total energy intake and father income. All statistical analyses were carried out using SPSS (SPSS Inc., version 22). P values were considered significant at <0·05.

Results

General characteristics of the study participants across tertiles of PDI, hPDI, and uPDI scores are shown in Table 1. Subjects in the third tertile of PDI had a lower prepregnancy BMI as compared to those in the second and first tertiles ($P=0.004$). Comparing participants across tertiles of hPDI score, those in the highest tertile were more likely to be in their third or higher pregnancy order ($P=0.04$). Participants in the highest tertile of uPDI were also more likely to have nausea during their current pregnancy ($P=0.001$). No other significant differences were observed in terms of other general characteristics across tertiles of PDI, hPDI, and uPDI scores.

Table 2 presents the dietary intakes of the study participants across tertiles of PDI, hPDI, and uPDI scores. Subjects in the highest tertile of PDI had higher intakes of total energy, carbohydrate, fat, protein, saturated fat, polyunsaturated fatty acids, monounsaturated fatty acids, dietary fiber, and vitamin C ($P<0.001$ for all) as compared to those in the lowest tertile. In addition, these participants had significantly different intakes of fruits, vegetables, nuts, legumes, grains, potato, sweets, sugar-sweetened beverages ($P<0.001$ for all), tea ($P=0.03$), dairy ($P=0.04$), and fish and seafoods ($P=0.03$). Women with the greatest hPDI score had lower intakes of energy ($P<0.001$), carbohydrate ($P=0.001$), fat, protein, saturated fat, monounsaturated fatty acids, cholesterol ($P<0.001$ for all) and polyunsaturated fatty acids

Table 1 Characteristics of study participants across tertiles of plant-based diet scores

Variable	PDI				hPDI				uPDI			
	T1 (*n*=220)	T2 (*n*=204)	T3 (*n*=210)	P-value	T1 (*n*=213)	T2 (*n*=215)	T3 (*n*=206)	P-value	T1 (*n*=206)	T2 (*n*=230)	T3 (*n*=198)	P-value
Age (years)	28.7±5.2	28.9±4.9	28.6±5.0	0.86	28.5±5.2	28.7±4.9	28.9±4.9	0.76	28.8±4.8	28.9±5.2	28.5±5.1	0.62
Prepregnancy BMI (kg/m^2)	25.8±4.8	24.7±4.2	24.5±4.1	0.004	24.5±4.0	25.2±4.5	25.4±4.7	0.06	25.2±4.5	25.2±4.7	24.6±3.9	0.31
Weight gain during current pregnancy (kg)	13.3±5.3	13.5±4.9	13.7±4.8	0.70	14.0±5.1	13.5±4.7	12.9±5.1	0.09	13.1±4.9	13.8±5.1	13.6±4.9	0.27
Having job with income (%)	30.5	29.4	24.3	0.31	29.1	28.8	26.2	0.76	28.6	24.8	31.3	0.31
University graduate (%)	5.2	4.0	5.3	0.58	5.7	3.9	4.9	0.12	5.0	5.8	3.6	0.06
Physical activity (%)				0.86								0.20
Low	76.8	76.5	74.8		71.4	78.6	78.2	0.14	74.3	80	73.2	
Moderate	23.2	23.5	25.2		28.6	21.4	21.8		25.7	20	26.8	
History of CVD (%)	0.9	2.0	0.5	0.33	0.9	1.9	0.5	0.38	1.0	1.3	1.0	0.93
History of hypertension (%)	2.7	2.0	1.9	0.81	1.9	2.8	1.9	0.77	1.9	2.6	2.0	0.87
History of hypothyroidism (%)	16.8	18.1	17.6	0.93	18.3	16.7	17.5	0.91	16	19.6	16.7	0.58
History of hyperthyroidism (%)	0.5	0.5	2.4	0.09	0.9	0.9	1.5	0.84	1.0	1.3	1.0	0.93
Order of pregnancy (≥3, %)	20.9	17.6	19	0.69	17.8	15.3	24.8	0.04	19.4	17.8	20.7	0.75
Nausea during current pregnancy (%)	56.8	46.1	49.0	0.07	47.4	52.6	52.4	0.48	43.2	48.3	61.6	0.001
Multivitamin use during current pregnancy (%)	11.4	12.7	8.6	0.37	15.0	8.4	9.2	0.05	11.7	13.5	7.1	0.09

Abbreviations: CVD, cardiovascular diseases; PDI, overall plant-based diet index; hPDI, healthful plant-based diet index; uPDI, unhealthful plant-based diet index

($P=0.007$). Also, intakes of grains, sweets, sugar-sweetened beverages, animal fat, dairy, egg, red and processed meat, fish and seafood ($P<0.001$ for all) and tea ($P=0.006$) were significantly different among tertiles of hPDI. Participants with the highest score of uPDI had lower intakes of energy, carbohydrate, fat, protein, saturated fat, polyunsaturated fatty acids, monounsaturated fatty acids, cholesterol, dietary fiber and vitamin C ($P<0.001$ for all) compared to the participants with lowest score of uPDI.

Table 3 indicates the multivariable-adjusted HRs of GDM across tertiles of PDI, hPDI, and uPDI scores. We found no significant association between PDI score and risk of GDM in the crude model. After adjustment for multiple confounders, there was a significant association between PDI score and risk of GDM (HR $_{\text{third versus first tertile}}$: 0.55; 95% CIs: 0.30, 0.98, p-value=0.04). In addition, third compared to the first tertile of hPDI score was associated with a lower risk of GDM in both crude (HR: 0.49; 95% CIs: 0.27, 0.88, p-value=0.01) and multivariable adjusted models (HR: 0.43; 95% CIs: 0.24, 0.78, p-value<0.001). With regards to uPDI, there was a significant association between uPDI and risk of GDM in the crude model (HR $_{\text{third tertile}}$: 0.57; 95% CIs: 0.32, 0.98, p-value=0.04). However, this association became non-significant after adjustment for potential confounders (HR: 0.72; 95% CIs: 0.40, 1.30, p-value=0.27).

Discussion

In this prospective birth cohort study, we found that there was an inverse association between PDI and risk of GDM in Iranian women. We found that being in the third tertile of PDI was associated with a 45% lower risk of GDM. In addition, women who were in the third tertile of hPDI had a 57% decreased risk of GDM compared to those in the first tertile. There was no association between uPDI and risk of GDM. To the best of our knowledge, this is the first prospective cohort study to evaluate the association between maternal plant-based diet indices during pregnancy and GDM risk in Iranian women.

To our knowledge, only a limited number of observational studies have investigated the association between adherence to plant-based diets during pregnancy and risk of GDM. In their case-control study, Behzad et al. found that being in the third tertile of PDI score was associated with a 53% lower risk of GDM in Iranian pregnant women; however, there was no association between hPDI, uPDI, and GDM risk [25]. Another prospective cohort study among 2099 Chinese women suggested that greater adherence to a plant-based diet during the second trimester of pregnancy, as assessed by the overall pant-based diet index, was associated with a 57% lower GDM risk [22]. A meta-analysis of 14 epidemiologic studies also indicated that adherence to vegetarian diets may be associated with a 27% lower risk of type 2 diabetes [31]. Similarly, in a meta-analysis of nine prospective cohort studies, Qian et al. indicated that higher adherence to plant-based dietary patterns was associated with a 23% lower risk of developing type 2 diabetes compared to poorer adherence [32]. Likewise a systematic review found that a vegan diet was associated with lower prevalence or incidence of type 2 diabetes [33].

The term "plant-based" diet represents a wide definition [34] as it could either partially include a limited amount of foods derived from animals, such as the Mediterranean diet, or contain only plant-based foods like fruits, vegetables, and legumes, as seen in vegetarian and vegan diets [35]. Existing evidence suggests that greater adherence to the Mediterranean diet, characterized by high intake of vegetables, fruits, grains, fish, and legumes and low intake of red meat, poultry, and dairy products, is associated with a lower risk of GDM in a low-risk population [36–38]. Moreover, a high intake of dietary fiber during pregnancy seems to be particularly beneficial in preventing GDM [18, 39].

In spite of the 2020–2025 Dietary Guidelines for Americans recommendations a healthy plant-based diet is safe and effective for all stages of the life cycle [40]. Studies suggest that vegetarian diets may pose significant nutritional challenges, especially during pregnancy [41]. It is proposed that adherence to these diets may increase the risk of nutritional deficiencies, including inadequate supplies of vitamin B12 and vitamin D, iron, calcium, zinc, iodine, proteins, and essential fatty acids [42]. Therefore, pregnant women need to be fully aware of the quality of their diet to obtain all necessary nutrients. Since the association between adhering to plant-based diets and other pregnancy outcomes, such as birth weight, was not evaluated during our study, the potential health benefits of plant-based diets during pregnancy need further investigation.

There is a lack of information on the hormonal interactions that occur during the first and second trimesters of pregnancy and the molecular changes that are associated with insulin resistance in the third trimester of pregnancy [43–45]. In an intervention study, Bligh et al. indicated that plant-rich meals significantly enhanced the serum levels of glucagon-like peptide-1, a hormone that increases the secretion of insulin [46]. A plant-based diet is characterized by high intakes of dietary fibers, antioxidants, and micronutrients. Evidence from experimental studies has shown that viscous dietary fibers aid postprandial glucose metabolism immediately by slowing gastric emptying rates [47]. Likewise, the products derived from dietary fibers by microbiota (e.g., short chain fatty acids) are known to reduce liver glucose output, improve fat homeostasis, and affect gut microbiota [48, 49]. Antioxidant compounds, including polyphenols, naringenin,

Table 2 Dietary intakes of the study participants across tertiles of plant-based diet score

Variable	PDI				hPDI				uPDI			
	T1 (*n* = 220)	T2 (*n* = 204)	T3 (*n* = 210)	P-value	T1 (*n* = 213)	T2 (*n* = 215)	T3 (*n* = 206)	P-value	T1 (*n* = 206)	T2 (*n* = 230)	T3 (*n* = 198)	P-value
Energy (kcal/d)	1488.2 ± 512.4	1737.2 ± 508.2	2096.4 ± 693.3	< 0.001	1944.2 ± 620.2	1751.2 ± 573.4	1608.8 ± 649.8	< 0.001	2064.3 ± 708.2	1737.9 ± 486.7	1500.5 ± 556.2	< 0.001
Nutrients												
Carbohydrate (g/d)	190.7 ± 69.6	228.9 ± 65.3	282.3 ± 92.7	< 0.001	250.9 ± 77.4	227.2 ± 76.3	221.5 ± 99.1	0.001	271.2 ± 102.4	231.3 ± 68.3	196.2 ± 65.4	< 0.001
Total fat (g/d)	49.5 ± 20.8	52.8 ± 19.4	63 ± 26.2	< 0.001	61.7 ± 22.8	54.2 ± 20.7	48.9 ± 23.8	< 0.001	66.8 ± 23.5	54.9 ± 20.7	42.8 ± 18.3	< 0.001
Total protein (g/d)	60.0 ± 20.9	65.5 ± 18.2	77.0 ± 23.1	< 0.001	73.2 ± 20.7	67.4 ± 20.7	61.4 ± 23.1	< 0.001	77.6 ± 24.1	66.4 ± 18.9	57.9 ± 18.4	< 0.001
Saturated fat (g/d)	18.0 ± 5.7	19.0 ± 5.6	21.4 ± 7.2	< 0.001	21.5 ± 6.2	19.6 ± 5.8	17.2 ± 6.4	< 0.001	22.2 ± 6.5	19.4 ± 5.9	16.6 ± 5.4	< 0.001
PUFA (g/d)	17.6 ± 7.8	20.1 ± 6.4	24.5 ± 8.2	< 0.001	21.9 ± 7.8	20.7 ± 8.1	19.4 ± 8.1	0.007	23.0 ± 8.9	20.1 ± 7.4	18.9 ± 7.2	< 0.001
MUFA (g/d)	14.0 ± 4.5	15.6 ± 4.2	17.9 ± 5.8	< 0.001	17.2 ± 4.9	16.0 ± 5.0	14.2 ± 5.1	< 0.001	18.6 ± 5.5	15.7 ± 4.2	13.1 ± 4.2	< 0.001
Cholesterol (mg/d)	191.6 ± 131.8	187.5 ± 98.8	180.4 ± 118.5	0.60	228.6 ± 134.4	180.2 ± 90.0	149.8 ± 110.6	< 0.001	259.7 ± 139.2	178.5 ± 90.0	119.8 ± 67.9	< 0.001
Dietary fiber (g/d)	11.9 ± 5.4	15.0 ± 5.3	18.6 ± 6.6	< 0.001	15.1 ± 5.9	14.8 ± 6.4	15.5 ± 6.8	0.58	18.8 ± 7.0	14.9 ± 5.0	11.6 ± 4.9	< 0.001
Vitamin C (mg/d)	191.2 ± 108.3	251.7 ± 121.5	326.8 ± 218.9	< 0.001	247.3 ± 125.2	243.2 ± 126	277.0 ± 228.5	0.07	322.1 ± 228.4	252.0 ± 112.1	190.5 ± 106.6	< 0.001
Fruits (g/d)	289.6 ± 213.7	381.5 ± 227.2	471.7 ± 251.3	< 0.001	367.1 ± 226.2	363.7 ± 249.8	408.9 ± 249.7	0.10	514.4 ± 270.0	376.9 ± 205.1	242.2 ± 162.2	< 0.001
Vegetables (g/d)	205.3 ± 114.0	254.8 ± 111.1	316.9 ± 136.0	< 0.001	244.0 ± 113.8	257.8 ± 125.8	273.3 ± 145.5	0.06	313.7 ± 129.3	257.3 ± 101.2	201.6 ± 133.7	< 0.001
Nuts (g/d)	6.4 ± 7.3	9.9 ± 7.8	13.1 ± 11.2	< 0.001	9.2 ± 9.2	10.3 ± 10.3	9.8 ± 8.4	0.44	13.2 ± 10.8	10.2 ± 8.3	5.7 ± 7.1	< 0.001
Legumes (g/d)	6.5 ± 6	8.0 ± 4.9	9.2 ± 5.0	< 0.001	7.4 ± 3.8	8.1 ± 6.1	8.2 ± 6.0	0.27	10.0 ± 6.6	7.7 ± 4.5	5.8 ± 3.9	< 0.001
Grains (g/d)	156.9 ± 64.6	173.4 ± 58.1	203.5 ± 74.6	< 0.001	202.7 ± 75.2	172.9 ± 58.8	156.6 ± 63.7	< 0.001	181.6 ± 79.2	177.6 ± 61.9	173.5 ± 64.9	0.50
Tea (g/d)	14.6 ± 39.1	21.2 ± 42.4	25.6 ± 50.1	0.03	15.9 ± 32.1	17.0 ± 34.7	28.4 ± 60.1	0.006	20.7 ± 39.5	18.7 ± 33.0	21.9 ± 58.1	0.75
Potatoes (g/d)	62.5 ± 32.8	68.8 ± 28.3	82.0 ± 37.2	< 0.001	80.6 ± 33.5	72.5 ± 36.6	59.5 ± 27.7	< 0.001	66.8 ± 32.3	69.2 ± 32.1	77.5 ± 36.7	0.004
Sweets (g/d)	179.6 ± 139.8	244.6 ± 163.7	312.8 ± 187.4	< 0.001	288.9 ± 179.7	241.6 ± 177.5	202.1 ± 149.5	< 0.001	282.7 ± 196.0	241.8 ± 149.3	208.4 ± 165.8	< 0.001
Sugar sweetened beverages (g/d)	38.2 ± 84.2	68.2 ± 108.1	100.9 ± 109.0	< 0.001	90.6 ± 108.4	69.3 ± 117.5	45.2 ± 75.4	< 0.001	62.5 ± 103.4	71.3 ± 97.1	71.9 ± 111.8	0.59
Animal fat (g/d)	0.7 ± 1.4	1.0 ± 2.1	1.0 ± 2.3	0.19	1.3 ± 2.1	0.9 ± 2.2	0.4 ± 1.2	< 0.001	1.6 ± 2.9	0.7 ± 1.3	0.4 ± 0.9	< 0.001
Dairy (g/d)	336.5 ± 206.5	341.9 ± 216.0	390.8 ± 300.3	0.04	405.3 ± 28	364.4 ± 221.6	296.9 ± 217.1	< 0.001	451.8 ± 237.7	368.6 ± 265.1	242.3 ± 172.8	< 0.001
Egg (g/d)	23.9 ± 27.1	23.2 ± 19.2	20.4 ± 19.7	0.23	29.3 ± 28.4	21.0 ± 17.6	17.1 ± 17.6	< 0.001	33.9 ± 28.2	20.7 ± 18.0	12.8 ± 13.2	< 0.001
Red and processed meat (g/d)	23.5 ± 14.0	24.6 ± 15.4	24.1 ± 19.0	0.76	30.3 ± 15.8	23.6 ± 13.7	17.9 ± 16.7	< 0.001	31.1 ± 17.5	24.0 ± 15.3	16.7 ± 12.2	< 0.001
Fish and sea food (g/d)	1.8 ± 2.3	1.8 ± 2.4	1.3 ± 2.1	0.03	2.4 ± 2.4	1.7 ± 2.5	0.7 ± 1.4	< 0.001	2.5 ± 2.6	1.6 ± 2.4	0.7 ± 1.1	< 0.001

Abbreviations: PDI, overall plant-based diet index; hPDI, healthful plant-based diet index; uPDI, unhealthful plant-based diet index; CVD, cardiovascular diseases; PUFA, polyunsaturated fatty acid; MUFA, monounsaturated fatty acid

Table 3 Hazard ratio and 95% confidence intervals of GDM risk across tertiles of plant-based diet scores

Tertiles	T1	T2	T3
PDI score	52–79	80–106	107–134
Participants	221	204	210
Person-week	7919	7610	7652
Cases	36	19	24
HR and 95%CI			
Crude	1	0.55 (0.31, 0.96)	0.69 (0.41, 1.15)
P-value	-	0.03	0.16
Multivariate adjusted[1]	1	0.56 (0.32, 1.00)	**0.55 (0.30, 0.98)**
P-value	-	0.05	0.04
hPDI score	62–85	86–108	109–132
Participants	214	215	206
Person-week	7619	7923	7639
Cases	34	28	17
HR and 95%CI			
Crude	1	0.78 (0.47, 1.29)	**0.49 (0.27, 0.88)**
P-value	-	0.35	0.01
Multivariate adjusted[1]	1	0.74 (0.44, 1.23)	**0.43 (0.24, 0.78)**
P-value	-	0.25	< 0.001
uPDI score	58–82	83–107	108–132
Participants	207	230	198
Person-week	7348	8516	7317
Cases	35	24	20
HR and 95%CI			
Crude	1	**0.58 (0.35, 0.99)**	**0.57 (0.32, 0.98)**
P-value	-	0.04	0.04
Multivariate adjusted[1]	1	0.72 (0.42, 1.25)	0.72 (0.40, 1.30)
P-value	-	0.25	0.27

[1] adjusted for age, educational levels, physical activity, history of cardiovascular disease, prepregnancy hypertension, hypothyroidism and hyperthyroidism, prepregnancy body mass index, gestational weight gain, dietary energy intake and father income

Abbreviations: GDM, gestational diabetes mellitus; PDI, overall plant-based diet index; hPDI, healthful plant-based diet index; uPDI, unhealthful plant-based diet index; T, tertile

and vitamin C, can also improve insulin sensitivity, inflammation, and oxidative stress associated with GDM [50, 51]. Simultaneously, a plant-based diet has less saturated fat and animal protein, which may adversely affect insulin sensitivity [52, 53]. All of these possible biological mechanisms help explain why adherence to a plant-based diet could be linked to a lower risk of GDM.

The study has the advantage of being able to adjust for a wide range of covariates in the analyses. This is the first prospective birth cohort study to investigate the relationship between PDI, hPDI, and uPDI and the risk of developing GDM in the Middle East area. We also gathered a substantial amount of information using a standard protocol and valid and reliable tools that decreased information bias related to food intakes, demographic characteristics, and lifestyle-related behaviors. In addition, we used several valid and reliable questionnaires that were developed for use in the present birth cohort study [26]. Several limitations also need to be acknowledged when interpreting our findings. First, misclassification of dietary intakes could be caused by the use of FFQ to assess dietary intake. Second, even though we included multiple potential covariates, it's important to keep in mind the possibility of residual confounding. Third, due to a small number of participants, we need more large-scale cohort studies to confirm the findings. Fourth, we evaluated the dietary intake during the first trimester, and the association between adherence to plant-based diets during the second and third trimesters and GDM should be investigated in future research. Since pregnancy is a dynamic physiological state, dietary patterns could largely change across the trimesters in terms of food types and quantities. Often, nutrition counseling also plays a role in changing dietary habits. Therefore, it is critical to consider the temporal shift in dietary intakes in future research.

Conclusions

In conclusion, the results of this prospective birth cohort study suggest that greater adherence to the PDI and hPDI is associated with a reduced risk of GDM. No association was found between uPDI and GDM risk. Our findings suggest that adopting a plant-based diet during early pregnancy may be protective against GDM among the Iranian population. To confirm our findings regarding the association of plant-based diet patterns with GDM, further large-scale cohort studies are needed, considering the potential changes across trimesters in terms of food types and quantities, as well as other pregnancy outcomes such as birth weight.

List of abbreviations

BMI	Body mass index
CI	Confidence interval
CVD	Cardiovascular disease
FFQ	Food frequency questionnaire
GDM	Gestational diabetes mellitus
HR	Hazard ratio
hPDI	healthy plant-based dietary index
IPAQ	International physical activity questionnaire
MET	Metabolic Equivalents
PDI	Plant-based dietary index
uPDI	unhealthy plant-based dietary index

Acknowledgements
Not applicable.

Author contributions
AJ, SS-B, and MMK conceived and designed the study; EB, SP, AJ, and AE contributed to the data gathering; EB and SP analyzed the data; EB, SP, AJ, and AE wrote the first draft of the manuscript; SS-B and MMK critically revised the manuscript. All authors have read and approved the final manuscript. SS-B had primary responsibility for final content.

Funding
This study was supported by Semnan University of Medical Sciences (Grant number: A-10-371-7).

Data availability
The datasets used and/or analyzed during the current study will be available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the ethics committee of Semnan University of Medical Sciences. Written informed consent was obtained from all subjects/patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 31 March 2024 / Accepted: 11 October 2024
Published online: 18 October 2024

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