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The dietary phytochemical index and its relation to polycystic ovary syndrome: a case–control study

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Abstract

Background Polycystic ovary syndrome (PCOS), a hormonal disorder affecting women of reproductive age, can be significantly impacted by diet. This study explores the relationship between a diet rich in phytochemicals, measured by the Dietary Phytochemical Index (DPI), and PCOS, along with associated health markers.

Methods A case–control study design was implemented with 480 individuals diagnosed with PCOS based on the Rotterdam criteria, paired with 480 controls matched in terms of age and BMI. The evaluation encompassed dietary intake, anthropometric measurements, and hormonal/metabolic markers. Additionally, the DPI score was determined based on the consumption of phytochemical-rich foods. The study also examined PCOS-related complications like acne and irregular menstrual cycles, as well as mental health using the Beck Depression Inventory (BDI-II) scores.

Results Women with PCOS had significantly lower DPI scores (32.42 vs 43.87, $p < 0.001$) compared to the control group, indicating a less phytochemical-rich diet. The DPI scores coincided with higher levels of hormones typically associated with PCOS, including Luteinizing Hormone (LH), Dehydroepiandrosterone Sulfate (DHEA-S), and testosterone. Additionally, these scores were associated with markers of metabolic dysfunction such as C-reactive Protein (CRP), Fasting Blood Sugar (FBS), and Homeostatic Model Assessment for Insulin Resistance (HOMA-IR), while positively correlating with Sex Hormone-Binding Globulin (SHBG) (all $p < 0.050$).). Higher DPI scores were associated with a significantly reduced risk of PCOS (OR: 0.13, 95% CI: 0.08, 0.23, P for trend: 0.001) and its complications, including acne and irregular menstrual cycles. Interestingly, a positive association emerged, suggesting better mental health (lower BDI-II scores) with higher DPI scores.

Conclusions In conclusion, this study indicates that lower DPI scores are associated with a higher incidence and severity of PCOS, suggesting that a phytochemical-rich diet could potentially benefit the management of PCOS by enhancing hormonal profiles, metabolic health, and mental well-being in women.

Keywords Polycystic ovary syndrome (PCOS), Dietary Phytochemical Index (DPI), Diet, Hormones, Metabolism, Mental health

Introduction

Polycystic Ovary Syndrome (PCOS), a multifaceted health issue impacting women in their reproductive phase, is marked by irregular hormone levels, impaired ovary functioning, and disruptions in metabolic processes [1]. Complementary to conventional treatments, dietary interventions have emerged as a vital approach

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in managing PCOS [2, 3]. The role of diet in regulating chronic inflammation is crucial, as it may contribute to the development of insulin resistance and hyperandrogenism, which are key aspects of PCOS [4]. Furthermore, untreated PCOS is linked to various complications, such as menstrual disorders, type 2 diabetes, mental health issues like depression, and metabolic syndrome [5].

Numerous studies have emphasized the potential of healthy dietary patterns, rich in antioxidants and anti-inflammatory properties, in helping to modulate PCOS symptoms [6, 7]. Research has shown that adhering to beneficial dietary indices, such as the Healthy Eating Index [8], the Dietary Diversity Score (DDS) [9], and the Dietary Inflammatory Index (DII) [7], can significantly reduce the likelihood of developing PCOS and its associated components, including inflammation, insulin resistance, and hyperandrogenism. Although the ideal diet for managing PCOS is not yet fully understood, and its overall impact on PCOS risk remains relatively unknown, research suggests that certain dietary patterns may help alleviate symptoms and improve health outcomes for individuals with this condition [10]. Considering this, phytochemical-rich diets, which focus on plant-based compounds, have the potential to target the inflammatory processes underlying PCOS development, thereby improving insulin resistance and hyperandrogenism [11].

Phytochemical-rich foods, including fruits, vegetables, and whole grains, are known for their contributions to weight management, better glycemic control, and reduced complications [12, 13]. Phytochemicals, a diverse group of plant compounds, have been demonstrated to regulate carbohydrate and lipid metabolism while exhibiting anti-inflammatory and antioxidant properties [14]. To assess the impact of diets rich in these phytochemical-abundant foods and to better comprehend how phytochemical mixtures in human diets influence health outcomes, researchers developed the "Dietary Phytochemical Index" (DPI) [15]. This index serves as an approximation of the overall phytochemical content in one's diet and has been tested in various clinical settings to lower inflammation and blood glucose levels [13, 16, 17]. However, despite the growing interest in the potential benefits of phytochemicals for PCOS management, there is a significant knowledge gap regarding the specific association between the dietary phytochemical index and PCOS. Most previous research has primarily focused on individual phytochemicals or specific food groups, limiting our understanding of the broader impact of PDI on PCOS outcomes.

To improve the understanding of how dietary phytochemicals, influence the development of PCOS, we conducted a comparative case-study. Our primary goal was to explore the potential connection between DPI scores and PCOS, including related symptoms and outcomes. To the best of our knowledge, no prior research has examined the association between DPI and PCOS risk. Consequently, to shed light on this unexplored yet crucial topic, we assessed DPI in relation to metabolic risk factors, inflammation, PCOS occurrence, and severity using a case–control study design. We hypothesized that higher DPI scores may contribute to better symptom management and more favorable PCOS results.

Materials and methods

Study design

This BMI and age-matched case–control study aimed to investigate the levels of PDI in women with and without PCOS. Participants provided written consent and received detailed explanations about the study objectives and methods. General characteristics were assessed using reliable questionnaires, face-to-face interviews, and specific measurements. The study was carried out in accordance to the Declaration of Helsinki and was received approval from The Second People's Hospital of Liaocheng (Approval Number: 2023-LCR-031). The study adhered to all relevant protocols and standards. Participants provided written consent for their participation. Informed consent was obtained from all participants.

Sample size

The sample size was calculated based on the prevalence of PCOS as the dependent variable [18], using the formula $N=[(Z1-\alpha/2)2 \quad P(1-P)]/\mathrm{d}2$. With $P=0.29$, $\mathrm{d}=4.03$, and $\alpha=0.05$, a sample size of 450 subjects was determined. To account for a 10% probability of sample loss, a total of 490 newly diagnosed subjects with PCOS and 490 controls were enrolled.

Participants

The study population consisted of women diagnosed with PCOS who were consecutively recruited from the Department of Gynaecology at the Second People's Hospital of Liaocheng, China, between May 2020 and October 2022. Only new cases between the ages of 19 and 48 years were included to minimize the possibility of significant dietary changes during the diagnosis period. Some cases were also selected from multiple clinics to enhance the generalizability of the results. The diagnosis of PCOS was made by expert gynecologists based on the Standard Rotterdam Criteria, which require the presence of two of the following criteria: clinical or biochemical hyperandrogenism, menstrual irregularities, and ovaries with multiple cysts. Only individuals who were newly diagnosed with PCOS by the gynecologists were included as new cases. Participants with a history of certain diseases and conditions, such as congenital adrenal hyperplasia, hyperprolactinemia, androgen-secreting tumor, thyroid dysfunction, hyperprolactinemia, Cushing's syndrome, eating disorders, gonadotropin regression, premature ovarian failure and congenital adrenal hyperplasia, as well as those using specific medications or following special diets, were excluded. Women who consumed more than 4200 kcal or less than 800 kcal, as well as those who reported consuming fewer than 35 food items on the FFQ, were not included in the research. The two groups (PCOS and controls) were matched for BMI and age via a frequency matching manner. The control group was chosen from the same facility. Women with a modified Ferriman-Gallwey (mF-G) score below 8 and regular menstrual cycles were deemed suitable for inclusion in the control group. A total of 480 individuals in the control group and 480 eligible PCOS cases were interviewed regarding their dietary habits and provided biological samples, achieving a participation rate of 96%.

Dietary intake assessment

A semi-quantitative FFQ, validated in the Chinese population, was utilized to assess the participants' typical dietary intake over the previous year [19]. An expert dietitian conducted in-person interviews with the participants to complete the questionnaires. The frequency and portion sizes of each food and beverage item were documented and converted into daily intake and gram measurements using common household units. The recorded daily food intake in grams was then inputted into Nutritionist IV software for the computation of total energy and nutrient intake. The Dietary Phytochemical Index (DPI) was calculated using McCarty's formula [15], which considers the percentage of calorie intake derived from phytochemical-rich foods. The DPI includes a variety of phytochemical-rich foods such as fruits, whole grains, seeds, vegetables, nuts, legumes, soy products, and olive oil. Potatoes were excluded due to their low phytochemical content and their typical consumption as a source of starch.

Physical activity assessment

The International Physical Activity Questionnaire (IPAQ) was employed to evaluate the participants' level of physical activity. They indicated the frequency and duration physical activities undertaken in the previous 7 days. The level of physical activity was quantified in metabolic equivalent hours per day (METs/h/day).

Anthropometric measurements

Standardized protocols were used to measure anthropometric indices. Weight was measured with a Seca digital scale accurate to 0.1 kg, with participants lightly dressed and shoeless. Height was measured with a tape measure while standing, shoulders relaxed, and without shoes. Waist circumference (WC) was measured with a non-elastic tape at the midpoint between the lower rib margin and the top of the iliac crest. Body Mass Index (BMI) was calculated as weight divided by height squared.

Biochemical parameters

During an overnight fast of 10–12 h within the follicular phase (days 3 to 5), blood samples were collected for glucose level assessment using the glucose oxidase method. Subsequently, total cholesterol (TC), high-density lipoprotein (HDL), and triglyceride (TG) levels were measured employing commercial diagnostic tools. The LDL was considered via Friedewald's formula. To evaluate endocrine function, tests were conducted on serum follicle-stimulating hormone (FSH), luteinizing hormone (LH) [20], dehydroepiandrosterone sulfate (DHEA-S), prolactin, sex hormone-binding globulin (SHBG), and testosterone. The assays used were enzyme-linked immunosorbent assay (ELISA) for serum prolactin, FSH, and LH (Beijing Gersion Bio-Technology Co. Ltd., Beijing, China). Chemiluminescence immunoassay (Roche, Germany) was employed for measuring DHEA-S and SHBG. C-reactive protein (CRP) was assessed using an ELISA kit from Shanghai, China. Serum Insulin was evaluated through Chemiluminescence immunoassay by Roche Diagnostic (Basel, CH). Insulin resistance was evaluated using the Homeostatic Model Assessment 2 for insulin resistance (HOMA2-IR), which was computed using a HOMA2 calculator (http://www.dtu.ox.ac.uk/homacalculator) based on fasting insulin and glucose levels.

Mental health assessments

The Mental Health Questionnaire includes assessments for eating disorders and depression. To evaluate food cravings, the Food Craving Questionnaire-Trait (FCQ-T) is employed [21], which consists of 39 items scored on a 6-point scale from "never" to "always." This helps in understanding the intensity of food cravings.

To gauge the depression symptoms, the Beck Depression Inventory-II (BDI-II) is utilized. This test comprises 21 items, and it is well-thought-out "normal" when scores range from 1–10. A higher total score in the BDI-II indicates more severe depressive symptoms [22].

Assessment of other variables

The study measured participants' SES via factors like education, employment, family size, car ownership, housing, and travel experience through a self-reported questionnaire, then grouped them into 3 SES categories. Hirsutism scores were calculated using the modified Ferriman–Gallwey score, which ranges from 1 to 36. Scores equal to or greater than 6 indicate significant hirsutism [23].

Statistical analysis

The research utilized Stata version 14.0 for Windows (Stata Corp, College Station, Texas, USA) to conduct statistical analyses. Normal distribution of continuous variables was assessed using the Shapiro–Wilk test. Records with missing data were excluded due to the small percentage of missing information, which was less than 1% and considered to be randomly missing. Mean values (standard deviation) for quantitative variables were presented using the t-test method, while qualitative variables were expressed as percentages using the chi-square method for comparisons between two groups. Participants were divided into DPI tertiles, and their characteristics were compared across these groups. ANOVA or Kruskal–Wallis tests were employed for between-group analyses of continuous variables, while chi-square tests were used for categorical variables. Multivariable models were utilized to calculate odds ratios (OR) and 95% confidence intervals in both crude and adjusted models. Logistic regression was applied in various models to explore the association between DPI and PCOS, with the first tertile of DPI serving as the reference point in all analyses. The trend of ORs across increasing DPI Tertiles was assessed by treating the tertile categories as an ordinal variable in the analyses. Statistical significance was determined using a two-sided test with a significance level set at $p < 0.05$. We employed a multivariate analysis to disentangle the effects of various dietary components, thereby isolating the specific impact of DPI score on PCOS symptoms. This approach enabled us to conclude that the observed associations are primarily driven by phytochemical intake. Additionally, we compared the effects of vegetarian and non-vegetarian diets on clinical and hormonal parameters in women with PCOS. Specifically, we categorized women as non-vegetarian if they consumed meat, chicken, fish, or eggs at least 5 days a week for the past year, and as vegetarian if they strictly adhered to a plant-based diet.

Results

Analysis was performed on 480 PCOS cases and 480 controls (96% participation rate). Twenty contributors were excluded due to insufficient data, such as dietary intake or biochemical variables.

The demographic characteristics and relevant parameters of the case and control groups are presented in Table 1. The mean for BMI and age were 28.71 kg/m^2 and 32.05 years in cases, and 28.58 kg/m^2 and 32.64 years in controls, indicating a BMI- and age-matched study design. As a result of this matching, there were

Table 1 Demographic characteristics and biochemical parameters in case and control groups

Variable	*Case (n = 480)*	*Control (n = 480)*	*P*
DPI (mean)	32.42 ± 10.40	43.87 ± 13.4	< 0.001
Age (years)	32.05 ± 6.9	32.64 ± 10.12	0.593
Age at menarche (years)	13.02 ± 3.45	13.32 ± 5.06	0.296
Weight [22]	74.84 ± 9.63	74.68 ± 9.63	0.834
BMI (kg $^{m-2}$)	28.71 ± 3.35	28.58 ± 3.3.32	0.544
Waist circumference (cm)	91.7 ± 9.6	89.05 ± 9.52	0.811
Physical activity (MET/day)	58.16 ± 6.1	58.43 ± 6.2	0.545
Marital status			0.885
Married, *n* (%)	335 (51.1)	333 (49.9)	
Single, *n* (%)	141 (29.6)	143 (30)	
Others, *n* (%)	4 (1.0)	4 (1.0)	
Familial history of PCOS, *n* (%)	99 (21)	73 (15.2)	0.028
Irregular menstrual cycle, *n* (%)	346 (72.1)	0 (0)	< 0.001
Acne, *n* (%)	256 (82.1)	56 (17.9)	< 0.001
Education, *n* (%)			0.339
Less than high school	220 (45.8)	242 (50.4)	
High school diploma	140 (29.2)	126 (26.3)	
Bachelor's or higher	120 (25.0)	112 (23.3)	
Socioeconomic status (SES), *n* (%)			0.247
low	174 (36.3)	199 (41.5)	
middle	118 (51.5)	111 (48.5)	
high	188 (39.2)	170 (35.4)	
Endocrine hormones			
Testosterone (ng/dl)	60.02 ± 4.8	42.32 ± 9.42.6	< 0.001
FSH (IU/l)	13.52 ± 3.82	9.55 ± 2.6	< 0.001
LH (IU/l)	19.99 ± 8.6	8.85 ± 4.6	< 0.001
LH/FSH ratio	1.48 ± 0.36	0.93 ± 0.19	< 0.001
Prolactin (pmol/ L)	378.9 ± 37.08	380.03 ± 37.15	0.656
DHEA-S (μg/dl)	279.8 ± 120.9	124.12 ± 6.41	< 0.001
SHBG (nmol/l)	29.22 ± 10.40	40.69 ± 13.46	< 0.001
Metabolic risk factors			
CRP (ng/ ml)	1.9 ± 0.8	1.05 ± 0.38	< 0.001
HOMA-IR (mmol/l)	3.76 ± 0.71	2.41 ± 0.33	< 0.001
FBS (mg/ dl)	94.1 ± 17.8	90.8 ± 12.58	0.001
TG (mg/ dl)	155.75 ± 32.14	144.15 ± 34.4	< 0.001
LDL (mg/ dl)	149.88 ± 28.9	131.1 ± 29.7	< 0.001
TC (mg/ dl)	168.9 ± 24.9	153.04 ± 42.84	< 0.001
HDL (mg/ dl)	39.48 ± 5.64	39.41 ± 7.33	0.873
DBP (mmHg)	77.02 ± 8.1	76.53 ± 10.1	0.407
SBP (mmHg)	124.16 ± 13.8	122.54 ± 16.43	0.099
Mental Health			
FCQ-T	22.06 ± 7.1	34.04 ± 7.7	< 0.001
BDI-II	14.60 ± 1.18	8.53 ± 3.8	< 0.001
Hirsutism score	12.35 ± 1.25	5.53 ± 3.9	< 0.001
Dietary intake			
Total energy (kcal/day)	2224.2 ± 302.14	2188.7 ± 305.31	0.070

Table 1 (continued)

Variable	*Case (n = 480)*	*Control (n = 480)*	*P*
Carbohydrate (gr/day)	300.2 ± 62.8	291.84 ± 65.15	0.043
Protein (gr/day)	80.1 ± 16.9	80.43 ± 16.8	0.759
Fat (gr/day)	78.10 ± 16.1	77.7 ± 16.08	0.722
Fiber (gr/day)	20.38 ± 6.87	24.93 ± 4.8	< 0.001

Data are expressed as mean ± SD, or proportion *n* (%)

Abbreviations: *DPI* dietary phytochemical index, *BMI* body mass index, *TG* triglyceride, *FBS* fasting blood sugar, *LDL-C* low-density lipoprotein cholesterol, *HDL-C* high-density lipoprotein cholesterol, *Total-C* total cholesterol, *WC* Waist circumference, *HOMA2-IR* Homeostatic Model Assessment Insulin Resistance, *DHEA-S* Dehydroepiandrosterone androstenedione, *SHBG* Sex Hormone Binding Globulin, *FCQ-T* Food Craving Questionnaire-Trait, *BDI-II* Beck Depression Inventory-II

P-value less than 0.05 was considered significant

P-value based on Independent samples and chi-square test

no significant differences observed in weight and WC between women with PCOS and healthy individuals ($P > 0.05$). The case group exhibited lower DPI values compared to the control group (32.42 vs 43.87, $p = < 0.001$). Concerning demographic characteristics, the cases exhibited higher levels of CRP, FBS, HOMA-IR, TC, TG, LDL, and a greater percentage of individuals with a familial history of PCOS compared to the controls (all $P < 0{\cdot}05$). The levels of DBP, SBP, and HDL were slightly elevated in the cases compared to the controls, but this difference did not reach statistical significance. No significant differences were found between the case and control groups regarding age at menarche, marital status, SES, education level, and physical activity (all $P > 0{\cdot}05$). The mental health including FCQ-T and BDI-II scores of the subject with PCOS were significantly higher compared those of the control group ($p = < 0.001$).

In terms of PCOS-related endocrine hormone parameters, the cases had significantly higher levels of LH, LH/FSH ratio, Prolactin, DHEA-S, and total testosterone, while showing lower levels of SHBG (all $P < 0{\cdot}001$). According to the provided data, the case group had significantly higher rates of Acne (82% vs. 17%, $p = < 0.001$) and hirsutism score (12.35 vs 5.53, $p = < 0.001$) compared to the controls. The prevalence of PCOS symptoms among the case group, including menstrual disorders, was 72%, with acne reported in 82% of the cases (Table 1).

When DPI scores were categorized into tertiles, cumulative trends across the tertiles of DPI were observed for metabolic variables and endocrine hormones in women with PCOS (case) and the control group. (Table 2). Statistically significant trends were particularly evident in the case group. Women with PCOS in the highest tertiles had lower LH, LH/FSH ratio, DHEA-S, and total testosterone levels, while also exhibiting lower levels of SHBG compared to those in the lowest tertiles. Patients in the highest tertiles of DPI, indicating a higher adherence to a healthier diet, showed significantly lower levels of Testosterone (DPI $T_{3 \text{ vs } T1}$: 52.08 vs. 67.77, $p = 0.001$), LH (DPI $_{T\,3 \text{ vs } T1}$: 17.5 vs. 21.77, $p < 0.001$), DHEA-S (DPI $_{T\,3 \text{ vs } T1}$: 245.08 vs. 304.09, $p < 0.001$), and higher levels of SHBG (DPI $_{T\,3 \text{ vs } T1}$: 39.1 vs. 20.99, $p = 0.001$). Regarding metabolic variables outcomes, patients in the highest tertiles of DPI had lower levels of CRP (1.22 vs 2.45), FBS (88.5 vs 99.5), TC (168 vs 174), HOMA-IR (3.54 vs 3.98), DBP (76 vs 78), and SBP (120 vs 129) compared to those in the lowest tertiles (all $P < 0{\cdot}05$). However, there were no significant differences observed across tertiles of DPI for Prolactin, TG, LDL, and HDL. No significant associations were found for other biomarkers. In summary, individuals in the highest tertiles of DPI, indicating a healthier diet, were associated with lower disturbances in metabolic and endocrine hormones parameter.

Table 3 display comparative analysis of clinical and hormonal parameters in women with PCOS and control women, classified by dietary habits. In women with PCOS ($n = 480$), the vegetarian group had a higher DPI score (42.29 ± 6.1) than the non-vegetarian group (29.0 ± 6.1) with $p < 0.001$, and in the control group ($n = 480$), the vegetarian group also scored higher (51.65 ± 5.1 vs. 33.33 ± 5.1), resulting in an overall significant difference ($p < 0.001$) in dietary patterns' effects on DPI scores. The analysis of clinical and hormonal parameters in women with PCOS indicates that vegetarian women generally have lower Testosterone levels and better hormonal profiles compared to non-vegetarian women, with significant differences in FSH, LH, and DHEA-S levels. FSH levels are markedly higher in non-vegetarian PCOS women (15.10 ± 2.97 IU/l) compared to vegetarians (8.93 ± 1.05 IU/l), $p < 0.001$. LH levels follow a similar trend, being elevated in non-vegetarians (20.85 ± 7.6 IU/l) versus vegetarians (17.50 ± 1.74 IU/l), $p < 0.001$. However, the LH/FSH ratio remains consistent across both groups (1.9 ± 0.33 for vegetarians vs. 1.83 ± 0.22 for non-vegetarians, $p = 0.156$). Specifically, non-vegetarians showed higher FSH and LH levels, a greater LH/FSH ratio, and elevated CRP levels, suggesting increased metabolic disturbances. Additionally, non-vegetarian women had higher total cholesterol and hirsutism scores, while vegetarian women exhibited higher SHBG levels. These findings highlight the potential benefits of vegetarian diets in managing PCOS symptoms and improving metabolic health.

Table 4 displays the specific PCOS complications in women with PCOS and the control group, categorized by the tertiles of the DPI score. PCOS subjects in the highest tertiles of DPI diet score exhibited lower FCQ-T (DPI $_{T3 \text{ vs } T1}$: 25.14 vs. 33.47, $p < 0.001$) and hirsutism score (DPI $_{T3 \text{ vs } T1}$: 7.93 vs. 15.99, $p < 0.001$) compared to those in the lowest tertile. Furthermore, individuals in

Table 2 Associations of DPI across Tertiles with metabolic variables and Endocrine hormones in women with PCOS and control group

	Cases (*n* = 480)			***P* value**	**Control (*n* = 480)**			***P* value**
	DPI Tertiles				**DPI Tertiles**			
Variables	**T1**	**T2**	**T3**		**T1**	**T2**	**T3**	
Testosterone (ng/dl)	69.77 ± 7.4	52.94 ± 5.29	52.8 ± 5.4	0.001	44.11 ± 6.26	45.28 ± 5.16	40.36 ± 11.1	**< 0.001**
FSH (IU/l)	15.25 ± 5.4	14.9 ± 1.39	8.93 ± 5.3	< 0.001	12.91 ± 4.54	13.81 ± 1.36	6.58 ± 1.08	< 0.001
LH (IU/l)	21.77 ± 6.9	19.61 ± 1.36	17.5 ± 7.4	< 0.001	11.69 ± 3.4	12.79 ± 2.68	6.14 ± 6.96	0.327
LH/FSH ratio	1.42 ± 0.2	1.31 ± 0.21	1.95 ± 0.35	0.156	0.9 ± 0.2	0.92 ± 0.21	0.93 ± 0.35	0.156
Prolactin (pmol/ L)	378.5 ± 35.5	379.69 ± 37.9	378.82 ± 38.7	0.955	373.5 ± 38.4	378.5 ± 37.1	382.1 ± 36.9	0.286
DHEA-S (μg/dl)	304.9 ± 13.9	274.63 ± 19.05	245.08 ± 15.38	0.001	163.78 ± 48.1	179.08 ± 37.6	86.41 ± 8.6	0.330
SHBG (nmol/l)	20.99 ± 7.9	32.20 ± 1.36	39.1 ± 9.8	0.001	23.74 ± 6.1	32.2 ± 1.1	48.47 ± 12.37	**< 0.001**
CRP (ng/ ml)	2.45 (1.1, 3.2)	1.69 (1.01, 2.2)	1.22 (0.8, 2.2)	< 0.001	1.01 ± 0.4	1.05 ± 0.4	1.06 ± 0.37	0.776
HOMA-IR (mmol/l)	3.98 ± 0.86	3.64 ± 0.5	3.54 ± 0.53	0.001	2.49 ± 0.31	2.41 ± 0.35	2.41 ± 0.32	0.233
FBS (mg/ dl)	99.66 ± 12.5	91.23 ± 12.6	88.5 ± 13.37	< 0.001	93.68 ± 11.79	90.52 ± 13.49	90.4 ± 12.17	0.232
TG (mg/ dl)	156.44 ± 32.5	153.38 ± 31.1	157.56 ± 32.73	0.517	143.4 ± 42.9	147.92 ± 46.3	142.18 ± 45.6	0.452
LDL (mg/ dl)	147.4 ± 29.45	150.85 ± 27.4	152.76 ± 29.5	0.236	126.56 ± 30.4	131.09 ± 30.4	132.01 ± 29.2	0.492
TC (mg/ dl)	168.68 ± 24.32	165.16 ± 24.5	174.7 ± 24.6	0.012	145.38 ± 41.9	153.22 ± 41.66	154.32 ± 43.6	0.398
HDL (mg/ dl)	39.72 ± 6.1	38.6 ± 4.3	40.1 ± 6.1	0.057	39.54 ± 7.5	39.5 ± 7.1	39.59 ± 7.4	0.764
DBP (mmHg)	78.19 ± 9.1	75.6 ± 7.3	76.87 ± 6.86	0.011	78.99 ± 13.4	77.27 ± 9.7	75.68 ± 9.6	0.057
SBP (mmHg)	129.19 ± 15.1	120.17 ± 10.9	120.8 ± 12.15	0.001	130.14 ± 21.6	122.95 ± 14.64	120.95 ± 15.9	**0.001**

Abbreviations: *DPI* dietary phytochemical index, *BMI* body mass index, *TG* triglyceride, *FBS* fasting blood sugar, *LDL-C* low-density lipoprotein cholesterol, *HDL-C* high-density lipoprotein cholesterol, *Total-C* total cholesterol, *WC* Waist circumference, *HOMA2-IR* Homeostatic Model Assessment Insulin Resistance, *DHEA-S* Dehydroepiandrosterone androstenedione, *SHBG* Sex Hormone Binding Globulin

The DPI measurements for each tertiles are as follows: 28.97 ± 1.53 in tertiles 1, 38.56 ± 3.01 in tertiles 2, and 51.43 ± 3.99 in tertiles 3

P-value less than 0.05 was considered significant

P-values were calculated using the one-way ANOVA

the highest tertile of DPI were more likely to have lower BDI-II scores (DPI $_{\text{T3 vs T1}}$: 12.67 vs. 14.90, $p = 0.234$) compared to those in the lowest tertile, although this difference did not reach statistical significance, it holds clinical importance.

In Table 5, illustrations of OR and 95% confidence intervals are presented for the association between DPI scores and PCOS, as well as related complications. The final analysis model, after multivariate adjustment, revealed that individuals in the highest tertile of DPI score had a significantly reduced odds ratio for PCOS (OR: 0.13, 95% CI: 0.08–0.23). This means that compared to those in the lowest tertile of DPI, those in the highest tertile had 87% lower odds of having PCOS. This significant association remained after controlling for marital status, BMI, age, physical activity, socioeconomic status, energy intake, carbohydrate, and fiber intakes. A linear decrease was observed among the dietary DPI tertiles for the odds ratio of PCOS (P trend = 0.045). Similar findings were detected for PCOS-related complications, such as Acne (DII $_{\text{T3 vs DII T1}}$: OR = 0.12; 95%CI 0.08, 0.18, p trend = 0.023) and Irregular menstrual cycle (DII $_{\text{T3 vs DII}}$ T1: OR = 0.17; 95%CI 0.12, 0.25, p trend = 0.02).

Discussion

To the best of our knowledge, this study is the first to investigate the link between the DPI and PCOS, along with its associated complications. The findings indicated that individuals adhering to a healthier diet, reflected in higher DPI scores, had lower odds of having PCOS. Specifically, those in the highest DPI tertile had an 87% reduced likelihood of PCOS and fewer related complications. Additionally, our study reveals significant connections between DPI scores and various metabolic, endocrine, and clinical factors in women with PCOS, exploring the potential role of dietary phytochemicals in the syndrome's etiology. We observed that women with PCOS have significantly lower DPI scores, which are associated with elevated hormone levels related to PCOS and markers of metabolic dysfunction. Higher DPI scores are linked to a reduced risk of PCOS-related complications, such as acne and irregular menstrual cycles, and better mental health, as shown by lower BDI-II scores. Our findings also highlight the potential advantages of a vegetarian diet in alleviating PCOS symptoms and enhancing metabolic health. Specifically, vegetarians exhibited lower levels of FSH and LH, a reduced LH/FSH ratio, and decreased CRP levels, indicating

Table 3 Comparative Analysis of Clinical and Hormonal Parameters in Women with PCOS and Control Women, Classified by Dietary Habit: Vegetarian vs. Non-Vegetarian

	Cases ($n = 480$)			Control ($n = 480$)			
Variables	**Vegetarian group**	**Non-vegetarian group**	***P* value [a]**	**Non-vegetarian group**	**Vegetarian group**	***P* value [b]**	***P* value**
DPI score	42.29 ± 6.1	29.0 ± 6.1	< 0.001	33.33 ± 5.1	51.65 ± 5.1	**< 0.001**	< 0.001
Testosterone (ng/dl)	52.53 ± 5.1	62.0 ± 5.46	0.054	45.0 ± 5.46	41.36 ± 11.1	**< 0.001**	< 0.001
FSH (IU/l)	8.93 ± 1.05	15.10 ± 2.97	< 0.001	13.59 ± 2.55	6.59 ± 1.78	< 0.001	**< 0.001**
LH (IU/l)	17.50 ± 1.74	20.85 ± 7.6	**< 0.001**	12.52 ± 2.9	6.15 ± 1.26	0.136	0.002
LH/FSH ratio	1.9 ± 0.33	1.83 ± 0.22	0.156	0.9 ± 0.22	0.94 ± 0.33	0.156	**< 0.001**
Prolactin (pmol/ L)	378.8 ± 38.7	379.3 ± 36.5	0.960	377.3 ± 37.34	382.1 ± 36.9	0.175	0.283
DHEA-S (µg/dl)	245.8 ± 1.50	291.8 ± 10.1	**< 0.001**	175.33 ± 40.1	88.4 ± 8.06	0.138	**< 0.001**
SHBG (nmol/l)	39.9 ± 9.88	25.82 ± 8.1	**< 0.001**	30.12 ± 5.1	49.48 ± 12.36	**< 0.001**	**0.002**
CRP (ng/ ml)	1.22 ± 0.37	2.12 ± 1.32	**< 0.001**	1.04 ± 0.39	1.06 ± 0.36	0.630	**< 0.001**
HOMA-IR (mmol/l)	3.54 ± 0.53	3.84 ± 0.74	**< 0.001**	2.43 ± 0.35	2.41 ± 0.32	0.463	**< 0.001**
FBS (mg/ dl)	88.5 ± 13.38	96.2 ± 18.7	**< 0.001**	91.3 ± 13.79	90.44 ± 12.17	0.468	**< 0.001**
TG (mg/ dl)	157.18 ± 32.7	155.12 ± 31.4	0.467	146.8 ± 45.4	142.18 ± 45.66	0.269	0.051
LDL (mg/ dl)	148.88 ± 28.63	152.76 ± 29.5	0.201	129.9 ± 30.45	132.02 ± 29.21	0.461	0.072
TC (mg/ dl)	167.1 ± 24.4	174.4 ± 25.6	0.008	151.29 ± 41.7	153.64 ± 43.6	0.445	0.671
HDL (mg/ dl)	40.1 ± 6.01	39.24 ± 5.5	0.122	39.17 ± 7.2	39.6 ± 7.41	0.540	0.231
FCQ-T	31.7 ± 22.34	34.83 ± 2.36	0.209	21.8 ± 8.06	22.2 ± 7.57	0.630	**< 0.001**
BDI-II	12.33 ± 1.33	14.49 ± 1.46	0.129	8.43 ± 4.03	8.60 ± 3.78	0.633	**< 0.001**
Hirsutism score	7.93 ± 8.93	13.87 ± 1.07	**< 0.001**	5.43 ± 0.6	5.6 ± 2.7	**0.633**	**< 0.001**

Values are presented as mean ± standard deviation. *Abbreviations*: see Table 2

[a] $p < 0.05$ vegetarian PCOS vs. non-vegetarian PCOS

[b] healthy vegetarian women vs. healthy non-vegetarian

$p < 0.05$ PCOS vs. healthy women

Table 4 Associations of DPI across Tertiles with Specific PCOS Complications in Women with PCOS and control group

	Cases ($n = 480$)			***P* value**	Control ($n = 480$)			***P* value**
	DPI Tertiles				**DPI Tertiles**			
Variables	**T1**	**T2**	**T3**		**T1**	**T2**	**T3**	
FCQ-T	33.47 ± 2.3	27.46 ± 2.2	25.14 ± 2.7	< 0.001	21.36 ± 8.13	22.02 ± 8.06	22.2 ± 7.57	0.776
BDI-II	14.99 ± 1.7	13.92 ± 1.1	12.67 ± 1.36	0.234	8.18 ± 4.06	8.51 ± 4.03	8.6 ± 3.78	0.776
Hirsutism score	15.99 ± 1.12	11.08 ± 1.96	7.93 ± 1.02	< 0.001	5.18 ± 2.06	5.51 ± 2.03	5.6 ± 1.78	0.777
Irregular menstrual cycle, *n* (%)								
No	49 (10)	121 (25)	277 (57)	0.001	All subject have regular menstrual cycle			-
Yes	1 (2)	30 (21.5)	3 (6)					
Acne, *n* (%)								
No	31 (6.5)	134 (28)	260 (54)	0.001	76 (15.8)	64 (13.3)	84 (17.5)	0.001
Yes	19 (4)	20 (4.5)	17 (3.5)		127 (26.5)	90 (18.8)	39 (8.1)	

Abbreviations: *DPI* dietary phytochemical, *FCQ-T* Food Craving Questionnaire-Trait, *BDI-II* Beck Depression Inventory-II

The DPI measurements for each tertiles are as follows: 28.97 ± 1.53 in tertiles 1, 38.56 ± 3.01 in tertiles 2, and 51.43 ± 3.99 in tertiles 3

P-value less than 0.05 was considered significant

P-values were calculated using the one-way ANOVA test for comparisons of continuous variables AND Fisher's exact test p-values for comparisons of categorical variables

fewer metabolic disturbances, lower total cholesterol, and reduced hirsutism scores. However, when comparing vegetarian scores with DPI scores, patients with the highest DPI scores demonstrated significantly improved endocrine profiles compared to those with the lowest scores. This underscores the notion that the quality

Table 5 Association between DPI score and PCOS and some complication

Variable	OR (95% CI)			
	Crud Model	**Model 1[a]**	**Model 2[a]**	$P_{\text{for trend}}$*
PCOS				
DPI tertiles				**0.001**
Tertile 1	Ref	Ref	Ref	
Tertile 2	**0.24 (0.16 to 0.36)**	**0.19 (0.11 to 0.31)**	**0.13 (0.07 to 0.23)**	
Tertile 3	**0.10 (0.07 to 0.15)**	**0.16 (0.10 to 0.25)**	**0.13 (0.08 to 0.23)**	
Acne				
DPI tertiles				**0.001**
Tertile 1	Ref	Ref	Ref	
Tertile 2	**0.47 (0.28 to 0.57)**	**0.41 (0.29 to 0.57)**	**0.43 (0.30 to 0.61)**	
Tertile 3	**0.11 (0.08 to 0.17)**	**0.12 (0.08 to 0.17)**	**0.12 (0.08 to 0.18)**	
Irregular menstrual cycle				
DPI tertiles				**0.002**
Tertile 1	Ref	Ref	Ref	
Tertile 2	**0.51 (0.36 to 0.72)**	**0.52 (0.37 to 0.73)**	**0.54 (0.38 to 0.77)**	
Tertile 3	**0.16 (0.11 to 0.23)**	**0.16 (0.10 to 0.25)**	**0.17 (0.12 to 0.25)**	

Model 1[a]-Adjusted for marital status, BMI, age, and physical activity

Model 2[a]-Adjusted for marital status, BMI, age, and physical activity, socioeconomic status, energy intake, carbohydrate and fiber intakes

* *P* for trend based on logistic regression

of one's diet—rather than simply categorizing it as vegetarian or non-vegetarian—is crucial for effective PCOS management. It emphasizes the need to prioritize overall dietary quality in addressing PCOS, rather than focusing exclusively on dietary labels.

PCOS is a complex endocrine disorder characterized by hormonal imbalances, insulin resistance, and reproductive abnormalities [1]. The role of diet in the development and management of PCOS has gained significant attention in recent years [2]. Consistent with previous research [18, 24], our study demonstrated that individuals with PCOS had altered levels of metabolic and endocrine markers compared to healthy controls. Specifically, women with PCOS exhibited higher levels of LH, LH/FSH ratio, Prolactin, DHEA-S, and total testosterone, along with lower levels of SHBG. These hormonal imbalances are characteristic features of PCOS and are known to contribute to the clinical manifestations of the syndrome, such as hirsutism and acne [25]. Our results also indicated that individuals with PCOS had lower DPI values, reflecting poorer adherence to a diet rich in phytochemicals compared to healthy controls. Notably, higher DPI scores were associated with improved metabolic and endocrine profiles in women with PCOS, including lower levels of testosterone, LH, DHEA-S, and higher levels of SHBG. These findings suggest that a diet rich in phytochemicals may have a beneficial impact on hormonal regulation and metabolic function in individuals with PCOS. Moreover, phytochemicals may modulate sex hormone metabolism and signaling pathways, thereby helping to regulate hormonal imbalances in PCOS [26]. For example, some phytochemicals have been found to inhibit aromatase activity, leading to a decrease in estrogen levels [26]. Additionally, they may influence the production and metabolism of androgens, such as testosterone, by interacting with enzymes involved in androgen synthesis and metabolism [14, 27].

The observed trends across DPI tertiles further support the notion that dietary phytochemical intake plays a role in modulating the pathophysiology of PCOS. Women in the highest tertiles of DPI demonstrated better metabolic and endocrine profiles, as evidenced by lower levels of inflammatory markers (CRP), glucose dysregulation (FBS, HOMA-IR), and blood pressure (DBP, SBP). Moreover, the study found no difference in the average carbohydrate intake between women with PCOS and those without. Conversely, the results suggested that this may be attributed to phytochemical properties. These results highlight the potential therapeutic implications of dietary interventions in managing PCOS-related metabolic disturbances. Numerous studies have highlighted the inverse relationship between dietary phytochemical intake, particularly from vegetables and fruits, and cardiometabolic risk factors, insulin resistance, and dyslipidemia [14, 16, 17]. This study contributes to this body of evidence by focusing on women with PCOS. Mechanistically, phytochemicals present in plant-based foods have been shown to exert anti-inflammatory, antioxidant, and hormone-regulating effects [11, 13, 16, 26], which may contribute to the observed associations between DPI scores and PCOS parameters. Previous studies have suggested that phytochemicals such as flavonoids, polyphenols, and carotenoids can modulate insulin sensitivity, reduce oxidative stress, and regulate hormonal balance, all of which are relevant in the context of PCOS pathogenesis [28].

The rising occurrence of mental health problems among women with PCOS, as demonstrated by elevated BDI-II scores, underscores the importance of addressing psychological welfare in the holistic management of the condition [22]. Psychosocial factors such as stress, anxiety, and depression can significantly impact the well-being and treatment results for individuals with PCOS. Therefore, a comprehensive approach that combines mental health assistance with medical treatments is crucial for thorough care. Furthermore, the increased presence of acne and hirsutism in women with PCOS aligns with the typical indications of hyperandrogenism, a key feature of the syndrome. These skin-related symptoms can have significant psychosocial implications and may lead to decreased self-confidence and quality of life among affected individuals [29]. In this research, individuals in the highest DPI tertile were more likely to exhibit lower BDI-II scores compared to those in the lowest tertile. While this difference did not reach statistical significance, it holds clinical importance. Additionally, PCOS individuals in the top DPI diet score tertiles showed lower hirsutism scores than those in the lowest tertile, demonstrating another advantageous aspect of a diet rich in phytochemicals. Some authors also propose that women with PCOS may struggle with controlling their dietary intake and appetite [21], as indicated in our study by high PCQ-T scores compared to controls, which could lead to increased caloric intake and metabolic abnormalities. Individuals in the highest DPI tertiles were linked to lower PCQ-T scores, further highlighting the positive impact of phytochemical properties. The increased prevalence of mental health issues in women with PCOS may stem from hormonal imbalances, psychosocial stressors, and the influence of visible symptoms like acne and hirsutism on self-esteem. The study results suggest a potential association between dietary patterns (represented by DPI scores) and mental health outcomes, possibly through neuroprotective effects, inflammation modulation, and gut microbiota composition [16, 30]. Incorporating mental health support, nutritional guidance, and stress management into the comprehensive care of individuals with PCOS can address these multifaceted factors and enhance overall well-being and quality of life.

The findings of this study revealed that individuals with higher adherence to a healthier diet, as indicated by higher DPI scores, had a reduced risk of PCOS and fewer PCOS-related complications. These results are in line with previous research, which has consistently suggested that dietary factors play a critical role in the pathogenesis and management of PCOS [2, 13, 16]. The findings of this study are consistent with previous research that has suggested a potential role of diet in the development and management of PCOS. Several studies have reported associations between specific dietary patterns and the risk of PCOS. For example, a high intake of refined carbohydrates and sugars has been linked to an increased risk of PCOS [31], while a diet rich in fruits, vegetables, whole grains, and lean proteins has been associated with a lower risk [32]. These findings highlight the importance of considering overall dietary quality rather than focusing on individual nutrients or food groups alone. The observed association between higher DPI scores and a reduced risk of PCOS may be attributed to the beneficial effects of phytochemicals found in plant-based foods. Phytochemicals are bioactive compounds that are abundant in fruits, vegetables, whole grains, legumes, and herbs. They possess [7, 11, 13, 16] various properties, including antioxidant, anti-inflammatory, and hormone-regulating effects, which may contribute to the prevention and management of PCOS [13, 14, 16]. Phytochemicals have been shown to modulate insulin sensitivity, reduce oxidative stress, regulate hormonal balance, and improve lipid profiles, all of which are relevant factors in PCOS pathophysiology. The mechanism underlying the protective effects of phytochemicals against PCOS is likely multifactorial. Phytochemicals such as flavonoids, lignans, and polyphenols have been shown to enhance insulin sensitivity by promoting glucose uptake, improving pancreatic beta-cell function, and reducing insulin resistance [33]. These compounds may also exert anti-inflammatory effects by inhibiting pro-inflammatory pathways and reducing the production of inflammatory cytokines [20]. In addition, phytochemicals may influence sex hormone metabolism and signaling pathways, thereby helping to regulate hormonal imbalances commonly observed in PCOS [14, 27].

While our research primarily focused on the differences in the DPI scores, we also compared vegetarian and non-vegetarian diets, further supporting the idea that dietary quality is essential for managing PCOS. This study emphasizes the necessity for dietary modifications as part of comprehensive care for this condition. It highlights the significant influence of dietary habits on hormonal profiles in women with PCOS, showing that vegetarian women tend to have lower levels of testosterone, FSH, and LH than non-vegetarians. These findings suggest that plant-based diets may help reduce hyperandrogenism and enhance insulin sensitivity, potentially alleviating symptoms of PCOS [34]. The lower hormone levels in vegetarians indicate a more balanced hormonal profile, which could improve ovarian function and fertility. In contrast, non-vegetarian women exhibited higher levels of inflammatory markers and cholesterol, contributing to metabolic disturbances. Previous studies support these findings, indicating that vegetarian diets can enhance menstrual regularity and lower androgen levels [35]. Notably, the DPI scores seems to have a greater impact on hormonal and metabolic health in women with PCOS than the vegetarian index alone. Patients with the highest scores on the DPI scores demonstrated significantly better endocrine profiles compared to those with the lowest scores, reinforcing the notion that the quality of the diet—beyond just its vegetarian or non-vegetarian classification—is crucial for managing PCOS.

It is worth noting that while the present study found a significant association between higher DPI scores and a reduced risk of PCOS, causality cannot be established due to the cross-sectional nature of the study design. Longitudinal studies and randomized controlled trials are needed to further investigate the effects of dietary patterns and phytochemical intake on the development and progression of PCOS.

A key strength of this study was its substantial sample size and high participation rate, with controls devoid of major PCOS risk factors. Furthermore, the utilization of a FFQ alongside a comprehensive evaluation with adjustments for potential confounders was another advantage. The study also encompassed a range of PCOS-related complications. Despite the strengths of this study, including a large sample size and rigorous data collection, there are several limitations that should be acknowledged. First, the study relied on self-reported dietary intake, which is subject to recall bias and may not accurately reflect actual dietary habits. Additionally, the study population consisted of Chinese women, which limits the generalizability of the findings to other populations. Furthermore, as with any observational study, there may be residual confounding factors that were not accounted for in the analysis.

In conclusion, the findings of this case–control study suggest that a higher adherence to a diet rich in phytochemicals, as indicated by higher DPI scores, is associated with a reduced risk of PCOS and improved metabolic and hormonal profiles in women with PCOS. These findings support the growing body of evidence highlighting the importance of dietary factors in the prevention and management of PCOS. Further research is warranted to elucidate the underlying mechanisms and to determine the optimal dietary recommendations for PCOS prevention and treatment.

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Patient consent for publication
Not applicable.

Authors' contributions
Yasong Chi: Conceptualization, Methodology, Software. Ruiqin Yue: Data curation, Writing- Original draft preparation. Yanru Lv: Investigation and Supervision. Wei Liao: Software, Validation. Yasong Chi, Ruiqin Yue, Yanru Lv, Haiyan Li, Wei Liao.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The research received approval from The Second People's Hospital of Liaocheng (Approval Number: 2023-LCR-031). The study adhered to all relevant protocols and standards. Participants provided written consent for their participation.

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