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Association between plant-based diets and depressive symptoms among Chinese middle-aged and older adults

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This study aimed to evaluate associations between plant-based diets and the prevalence of depressive symptoms (DepS) among Chinese middle-aged and older adults. This study included 3153 participants aged 45 and older. Dietary intake was collected using a food frequency questionnaire, and DepS was evaluated using the 9-item Patient Health Questionnaire. Foods were classified into 17 groups and three plant-based diet indices were created, including the overall plant-based diet index (PDI), healthful plant-based diet index (hPDI), and unhealthful plant-based diet index (uPDI). Compared to the lowest quartile, participants in the highest quartile of hPDI had lower odds of DepS (OR = 0.60; 95% CI: 0.40, 0.89). Conversely, the highest quartile of the uPDI was associated with higher odds of DepS (OR = 1.81; 95% CI: 1.16, 2.82). These findings supported that the quality of plant-based diets matters for mental health.

Depressive symptoms (DepS) are one of the most universal mental disorders[1], that frequently show up in a combination of mental and physical symptoms, accompanied by psychomotor and cognitive disorders[2]. Middle-aged and older populations are a high prevalence of DepS, and the detection rate among Chinese adults aged 45 and above was as high as 32.7% in 2018[3]. Previous studies showed that DepS have been associated with an increased risk of dementia[4], acute myocardial infarction[5], and suicide[6]. With the challenge of population aging and the substantial public health problem of DepS, it is imperative to find potentially modifiable risk factors to protect against the onset of DepS.

Sociodemographic characteristics, unhealthy habits, and poor health status are typically described as risk factors for DepS[7]. In the field of nutritional psychiatry, it's recognized that diet patterns may play a critical role in DepS. For instance, the Mediterranean dietary pattern[8] was positively associated with decreased risks of DepS, whereas the animal food pattern[9] and pro-inflammatory diet[10] were shown an inverse association. Plant-based diets (plant-based dietary patterns), which emphasize a higher intake of plant-source foods and a lower intake of animal-source foods[11], have been associated with decreased risks of hypertension[12], type 2 diabetes[13], and mortality[14]. Raising questions about whether these numerous potential benefits to human health extend to DepS.

Earlier research on vegetarian diets has not distinguished between healthier (high-quality) and unhealthier (low-quality) plant foods. However, mounting evidence shows that not all plant-source foods have health benefits[15], and the quality of plant-based diets has received considerable attention in recent years. For healthful plant-based diets, which contain more high-quality healthy plant foods (e.g., whole grains, fresh fruits, fresh vegetables, nuts, legumes, and tea) and less low-quality unhealthy plant foods (e.g., fruit juices, refined grains, sugar-sweetened beverages, sweets and desserts, and salt-preserved vegetable) and animal foods. While unhealthful plant-based diets indicate higher consumption of unhealthy plant foods and animal foods under the background of overall plant-based diets[11].

Up to now, many studies on the associations between various dietary patterns and mental health, but only three studies have explored the relationship between plant-based diets and DepS[16–18]. However, previous

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studies' results have been an inconsistent, and rare concern for general middle-aged and older adults, and no prior research on plant-based diets and DepS has been conducted in China. China was originally an East Asian country with predominantly grains and vegetables, but with rapid transition in dietary structure in the past decades, including an increased intake of animal products and more processed food[19]. Thus, we aimed to examine the associations between plant-based diets (reflected by the plant-based diet indices) and DepS risks among Chinese middle-aged and older adults, to discover potentially achievable dietary recommendations that may benefit mental health across minor changes in dietary nutrition consumption.

Results

The baseline characteristics of participants across quartiles of PDI are presented in Table 1. A total of 3153 participants were included in the current study, and the mean age was 62 (SD, 6.4) years, 6.76% of whom were reported with DepS. Participants with higher scores of PDI were more likely to have higher total energy intake (Table 1).

We initially examined the association between three plant-based diet indices and the risk of DepS, and the results are shown in Table 2. In the multivariable-adjusted model, a strong negative association was observed between higher hPDI scores and DepS. Compared with Q1, participants in Q4 of the hPDI scores had lower odds of DepS (OR = 0.60; 95% CI: 0.40, 0.89; $P_{trend} < 0.01$). In contrast, participants in the highest quartile of uPDI were associated with higher odds of DepS (OR = 1.81; 95% CI: 1.16, 2.82; $P_{trend} < 0.01$), compared with the lowest quartile (Table 2). Each 10-unit increment in uPDI was associated with a 51% (OR = 1.51; 95% CI: 1.20, 1.91) increased odds of DepS, whereas a per 10-unit increment of hPDI was associated with a 35% (OR = 0.65; 95% CI: 0.50, 0.85) decreased odds of DepS.

When the outcome variable was included as a continuous variable in the multivariable-adjusted model, a significant association of hPDI and uPDI with DepS was observed. There was an inverse association between hPDI scores and PHQ-9 scores, with a per 10-unit increment of hPDI scores associated with 28% lower odds of DepS (β = -0.28, 95% CI: −0.42, −0.15; $P < .001$), whereas uPDI scores were positively associated with a higher odds of DepS (β = 0.36, 95% CI: 0.25, 0.48; $P < .001$) (Table 3).

The RCS regression model was used to examine the non-linear relationships between PDIs and the risk of DepS. No significant non-linear relationship was observed between PDI and DepS odds. We found that higher hPDI scores were associated with monotonically decreasing DepS odds, while higher uPDI scores were related to monotonically increasing DepS odds. ($P_{nonlinear}$ for PDI = 0.363; $P_{nonlinear}$ for hPDI = 0.461; $P_{nonlinear}$ for uPDI = 0.102) (Fig. 1).

The relationship between individual food groups and DepS are reported in the Supplementary Material (Supplementary Table 2). For individual plant-based foods items, fresh fruits ($OR_{≥ 1\ time/\ d\ versus\ ≤1\ time/\ d}$ = 0.60; 95% CI: 0.42, 0.85) and tea ($OR_{≥1\ time/\ week\ versus\ never}$ = 0.42; 95% CI: 0.21, 0.84) were the dominant factors contributing to the positive association between PDI and hPDI. On the contrary, higher intake of refined grains ($OR_{≥ 1\ time/\ d\ versus\ ≤1\ time/\ d}$ = 3.30; 95% CI: 1.03, 10.55), sugar-sweetened beverages ($OR_{every\ day\ versus\ never}$ = 10.79; 95% CI: 3.43, 33.97), sweets and desserts ($OR_{every\ day\ versus\ never}$ = 1.52; 95% CI: 1.01, 2.28), salt-preserved vegetables ($OR_{≥1\ time/\ m\ versus\ never}$ = 1.71; 95% CI: 1.14, 2.57), and eggs ($OR_{≥ 1\ time/\ d\ versus\ ≤1\ time/d}$ = 1.36; 95% CI: 1.01, 1.82) contributed to the association between uPDI with higher odds of DepS. Interestingly, we also observed that daily intake of milk or dairy products was associated with lower odds of DepS ($OR_{every\ day\ versus\ never}$ = 0.63; 95% CI: 0.42, 0.95).

Discussion

In this cross-sectional study among Chinese middle-older aged adults, we found that adherence to healthy plant-based diets was associated with lower odds of DepS. In contrast, unhealthy plant-based diets were markedly associated with higher odds of DepS. These associations were independent of socioeconomic factors, lifestyles, and major chronic diseases.

A dietary pattern based on a high amount of plant foods (Planetary Health Diet, Mediterranean Diet, Vegetarian Diet) is not the same as plant-based diets. The key difference between plant-based diets and other dietary patterns is the unique three plant-based dietary indices. To date, only three studies have examined the relationship between plant-based diets and depression, two studies were conducted on adults (not over 55 years old) and the other was studied in a diabetic population. In a cross-sectional study of 435 women aged 20–50 years old, a plant-based diet, particularly healthful-rich plant foods, was associated with a decreased risk of depression compared with an unhealthy plant diet[16]. Mousavi et al. have reported that there was a reverse association between adherence to an overall plant-based diet, and a healthy plant-based diet and depression, but no significant

Table 1 | Baseline characteristics of the study participants across quartiles of PDI (*N* = 3153)

Characteristics	Quartiles of PDI				*P* value
	Q1 (*n* = 818)	Q2 (*n* = 685)	Q3 (*n* = 918)	Q4 (*n* = 732)	
Female, *n* (%)	694 (84.8)	603 (88.0)	792 (86.3)	645 (88.1)	0.178
Age, mean (SD), year	62.2 (6.2)	62.2 (6.5)	62.3 (6.4)	62.8 (6.4)	0.250
Education, high school and above, *n* (%)	411 (50.2)	341 (49.8)	492 (53.6)	399 (54.5)	0.497
Household income ≥40,000 CNY/year, *n* (%)	258 (31.5)	215 (31.4)	335 (36.5)	249 (34.0)	0.143
Married, *n* (%)	709 (86.7)	597 (87.2)	809 (88.1)	624 (85.3)	0.386
Active physical activity, *n* (%)	589 (72.0)	482 (70.4)	674 (73.4)	527 (72.0)	0.610
Current smoker, *n* (%)	68 (8.3)	42 (6.1)	66 (7.2)	46 (6.3)	0.313
Current alcohol drinker, *n* (%)	126 (15.4)	120 (17.5)	155 (16.9)	123 (16.8)	0.721
Energy intake, mean (SD), kcal/d	1995.2 (635.1)	2094.6 (638.9)	2131.9 (638.0)	2266.5 (623.4)	<0.001
BMI, mean (SD), kg/m^2	24.2 (2.9)	24.3 (3.0)	24.3 (3.2)	24.6 (3.0)	0.072
PHQ-9 score, mean (SD)	1.12 (2.13)	1.12 (1.92)	1.10 (1.85)	1.07 (2.12)	0.941
Diabetes, *n* (%)	90 (11.0)	75 (11.0)	93 (10.1)	54 (7.4)	0.065
CVD, *n* (%)	33 (4.0)	24 (3.5)	39 (4.3)	35 (4.8)	0.682
Hypertension, *n* (%)	430 (52.6)	323 (47.2)	456 (50.0)	379 (51.8)	0.160

Values are mean (SD) for continuous variables and percentage for categorical variables. Calculated by the Chi-square test and one-way ANOVA for qualitative and quantitative variables, respectively.
PDI overall plant-based diet index, *Q* quartiles, *SD* standard deviation, *BMI* body mass index, *PHQ-9* 9-item patient health questionnaire, *CVD* cardiovascular disease.

Table 2 | Logistic regression analyses of the association between quartiles of PDIs and DepS

	Q1	Q2	Q3	Q4	Per 10-unit increment	*P* trend
PDI						
Model 1	1 (reference)	1.09 (0.74, 1.62)	0.99 (0.68, 1.44)	0.92 (0.62, 1.38)	0.98 (0.74, 1.30)	0.619
Model 2	1 (reference)	1.11 (0.75, 1.65)	1.04 (0.71, 1.52)	0.97 (0.64, 1.46)	1.02 (0.77, 1.35)	0.838
Model 3	1 (reference)	1.11 (0.75, 1.66)	1.03 (0.71, 1.51)	0.97 (0.64, 1.47)	1.01 (0.76, 1.35)	0.823
hPDI						
Model 1	1 (reference)	0.84 (0.57, 1.24)	**0.68 (0.47, 0.97)**	**0.61 (0.41, 0.92)**	**0.66 (0.51, 0.87)**	0.009
Model 2	1 (reference)	0.85 (0.57, 1.25)	**0.68 (0.47, 0.98)**	**0.61 (0.41, 0.91)**	**0.66 (0.51, 0.87)**	0.008
Model 3	1 (reference)	0.86 (0.58, 1.26)	**0.66 (0.46, 0.96)**	**0.60 (0.40, 0.89)**	**0.65 (0.50, 0.85)**	0.006
uPDI						
Model 1	1 (reference)	**1.69 (1.10, 2.60)**	**1.87 (1.23, 2.85)**	**2.04 (1.34, 3.11)**	**1.59 (1.29, 1.97)**	<0.001
Model 2	1 (reference)	**1.63 (1.05, 2.51)**	**1.76 (1.15, 2.70)**	**1.83 (1.18, 2.84)**	**1.52 (1.21, 1.92)**	0.009
Model 3	1 (reference)	**1.62 (1.05, 2.51)**	**1.79 (1.17, 2.76)**	**1.81 (1.16, 2.82)**	**1.51 (1.20, 1.91)**	0.009

Model 1: adjusted for sex and age. Model 2: additionally adjusted for education level, household income, marital status, physical activity, smoking status, alcohol consumption, and total energy intake. Model 3: further adjusted for BMI, diabetes, CVD, and hypertension in addition to adjusted variables model 2.
PDIs plant-based diet indices, *PDI* overall plant-based diet index, *hPDI* healthful plant-based diet index, *uPDI* unhealthful plant-based diet index, *Q* quartiles, DepS depressive symptoms.
Bold values are statistically significant at $P < 0.05$.

Table 3 | Association between PDIs (per 10-unit increment) with DepS using linear regression

	PDI		hPDI		uPDI	
	β (95% CI)	*P* value	β (95% CI)	*P* value	β (95% CI)	*P* value
Model 1	−0.04 (−0.18, 0.10)	0.614	−0.28 (−0.41, −0.14)	<0.001	0.39 (0.29, 0.50)	<0.001
Model 2	−0.01 (−0.15, 0.13)	0.903	−0.28 (−0.41, −0.14)	<0.001	0.37 (0.25, 0.48)	<0.001
Model 3	−0.01 (−0.15, 0.13)	0.848	−0.28 (−0.42, −0.15)	<0.001	0.36 (0.25, 0.48)	<0.001

Model 1: adjusted for sex and age. Model 2: additionally adjusted for education level, household income, marital status, physical activity, smoking status, alcohol consumption, and total energy intake. Model 3: further adjusted for BMI, diabetes, CVD, and hypertension in addition to adjusted variables model 2. *P* values below 0.001 are presented as <0.001.
PDI overall plant-based diet index, *hPDI* healthful plant-based diet index, *uPDI* unhealthful plant-based diet index, *DepS* depressive symptoms.

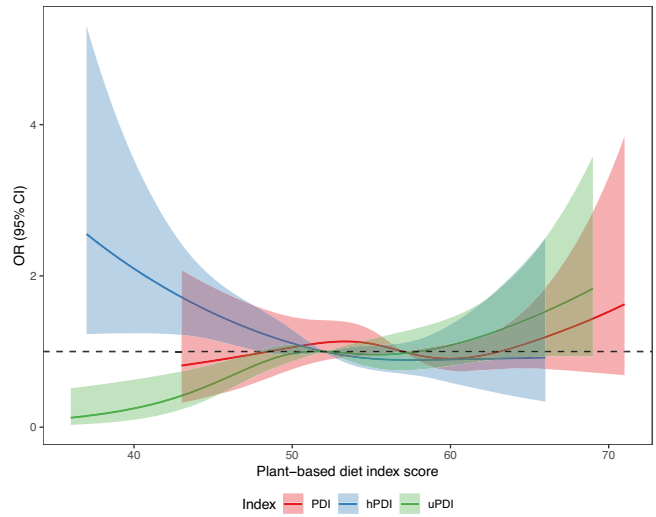

Fig. 1 | Association between PDIs and DepS using a restricted cubic splines regression model. PDIs plant-based diet indices, PDI overall plant-based diet index, hPDI healthful plant-based diet index, uPDI unhealthful plant-based diet index, DepS depressive symptoms. The RCS curves incorporating all confounders, sex, age, education level, household income, marital status, physical activity, smoking status, alcohol consumption, total energy intake, BMI, diabetes, CVD, and hypertension.

association was found between an unhealthy plant-based diet and depression[17]. Among 230 women with diabetes, an unhealthy plant diet had a greater risk of depression, while a healthy plant-based diet was associated with a lower risk of depression[18]. Our research showed that a healthy plant-based diet was significantly associated with lower odds of DepS, and an unhealthy plant-based diet was related to increased odds of DepS among Chinese middle-aged and older adults.

Several potential mechanisms may explain the observed association. First, plant foods are rich in antioxidants (e.g., vitamins and carotenoid compounds) and have potential protective effects against DepS by reducing the level of oxidative stress[20,21]. Second, vegetables and fruits are rich in folate, which is deficient and may lead to reduced availability of *S*-adenosylmethionine and increased homocysteine concentrations, which are important in the pathophysiology of depression[22]. Third, healthy plant-based diets such as yellow vegetables, green leafy vegetables, whole grains, coffee, and tea, rich in anti-inflammatory compounds (e.g., vitamins, fiber, flavonoids, and carotenoids)[23] were shown to influence the concentration of monoamines, which play a key role in regulating emotions[24]. On the contrary, unhealthy plant-based and animal-based foods containing sugar-sweetened beverages, refined grains, red or processed meat, and organ meats are pro-inflammatory foods[25]. Furthermore, healthy plant-based foods, including whole grains, vegetables, fruits, nuts, coffee, tea, and legumes, are rich in naturally occurring plant compounds polyphenols (e.g., soy isoflavones, tea, and cocoa flavanols, curcumin and coffee hydroxycinnamic acid, walnut flavanols, and citrus flavanones) that benefit mental health by upregulating the body's natural defense systems and stabilizing free radicals, decreasing oxidative damage, as well as producing neuroprotective properties by regulating specific cellular signaling pathways[26–28].

DepS are suffered by more than 300 million people worldwide[29]. In China, late-life DepS is also a serious public concern[30]. At the same time, China's food consumption patterns have changed considerably in the past decades, with growth in the consumption of processed foods and animal foods[19]. To the best of our knowledge, this study was the first to show the association between three types of plant-based diets and DepS in Chinese

middle-aged and older adults. The findings may contribute to the literature in that previous studies have focused on Iranian populations, while we were concerned with Chinese with unique dietary habits. For the food components, considering the greater consumption of preserved vegetables in China, we have creatively included salt-preserved vegetables in the category of unhealthy plant foods. Instead of consuming a single nutrient or food, individuals commonly consume several combinations of nutrients and foods daily, and our plant-based dietary model considers the cumulative and synergic effects of the overall diet. We also classified plant-based foods as healthy and unhealthy to better evaluate the potential association between the quality of plant-based diets and DepS. In addition, a series of covariate variables were taken into account in the adjustment model, including sociodemographic, lifestyle, and multimorbidity factors. Several limitations to the current study should be acknowledged. First, this study is a cross-sectional design and provides a hint for the benefits of healthy plant-based diets on DepS, but causality cannot be established. Notably, longitudinal evidence in this regard is needed. Second, the assessment measures used for outcomes only assess DepS and are not representative of a clinical diagnosis of depression. However, the PHQ-9 is the most widely used scale to assess nine DepS in the global background[31]. Furthermore, although numerous covariates were considered, we cannot rule out the residual confounder because of the observational study's nature.

Adherence to a healthy plant-based diet is associated with lower DepS odds, whilst an unhealthy plant-based diet is associated with higher DepS odds. Our findings suggested that a plant-based diet rich in healthier plant food may benefit DepS. More studies with high-quality and prospective designs are needed to corroborate our findings.

Materials and methods

Study design and population

The Lifestyle and Healthy Aging of Chinese Square Dancer Study (Healthy Dance Study) are designed to monitor the dietary nutrition and physical-psychological health of the Chinese population aged 45 and older. The inclusion criteria of the Healthy Dance Study were applied as follows: (i) age ≥45 years; (ii) regular participation in square dance currently, with frequency at least once a week; (iii) permanent resident population in the survey area (living in the area for more than 6 months before the survey); (iv) no participation in any clinical trial or other intervention programs in the past 3 months or the future. Participants who were diagnosed with deafness, dumb, or serious mental illness and were unable to complete the survey under the assistance of research staff were excluded. The present study was conducted from August 2020 to December 2021 in seven counties in China, including Beijing, Shanghai, Wuhan, Yichang, Xiangyang, Xiamen, and Chengdu. Each participant was given a face-to-face questionnaire by the trained researcher in a private, quiet room. All procedures adhered to the principles outlined in the Declaration of Helsinki. The study was approved by the Ethics Committee of Wuhan University (ethics number: WHU-LFMD-IRB2023046), and Wuhan University of Science and Technology (ethics number: 201925). All participants submitted an informed consent form.

Participants with missing baseline dietary information ($n = 4$) or who without complete the 9-item Patient Health Questionnaire (PHQ-9) ($n = 16$), or who had extreme energy consumption (<600 or >3500 kcal/d for women, <800 or >4200 kcal/d for men, $n = 428$) were excluded, and finally included 3153 individuals.

Assessment of depressive symptoms

DepS were evaluated by the most widely used (in the global context)[31] PHQ-9 depression scale of validated PRIME-MD diagnostic instrument, which has shown both sensitivity and specificity of 88% for depression[32]. The PHQ-9 evaluates each of the 9 DSM-IV criteria on a scale of 0 (not at all) to 3 (nearly every day) and finally adds them up to give a total score ranging from 0 to 27. The higher PHQ-9 score indicates greater symptoms of depression, with five categories none (0–4), mild (5–9), moderate (10–14), moderately severe (15–19), and severe depression (20–27)[32].

Plant-based diet indices

Dietary intake was assessed using a semi-quantitative food frequency questionnaire (SFFQ)[33]. Participants were asked how often they consumed an average of 64 food items in the past year, with eight response categories including "rarely or never", "1 time/month", "2–3 times/month", "1–2 times/week", "3–4 times/week", "5–6 times/week", "1 time/day", "2 times/day", and "≥3 times/day".

We classified all foods mentioned in SFFQ into 17 food groups[34,35], and three categories of food groups, including healthy plant foods (i.e., whole grains, fruits, vegetables, nuts, legumes, vegetable oil, tea), unhealthy plant foods (i.e., fruit juices, refined grains, sugar-sweetened beverage, sweets and desserts, and salt-preserved vegetable), and animal foods (i.e., animal fat, milk or dairy products, eggs, fish or seafood, and meat).

Binary scoring of the three food groups of vegetable oils, refined grains, and animal fats, with positive ("no" 1 point, "yes" 5 points) or negative ("no" 5 points, "yes" 1 point). The other fifteen food groups were ranked into quintiles and given either a positive or negative score. Positive scores were given as 5 points to participants in the highest quintile and 1 point to those in the lowest quintile; reverse scores were given as 1 point to participants in the highest quintile and 5 points to those in the lowest quintile.

Three plant-based diet indices (PDIs) were subsequently generated, the overall plant-based diet index (PDI), which emphasizes the consumption of more plant-based foods; the healthful plant-based diet index (hPDI), which is full of healthy plant-based foods; and conversely, the unhealthful plant-based diet index (uPDI), which is enriched with unhealthy plant foods[36]. In brief, all animal food groups were assigned a negative score. The overall PDI scored positively in all plant foods (healthy and less healthy). The hPDI scored positively in only healthy plant foods and negatively in less healthy plant foods. In contrast, the uPDI scored positively in less healthy plant foods and negatively in healthy plant foods. Minimum 1 point, maximum 5 points, and 17 food groups total theoretical score range 17–85. The higher the PDIs score of a participant, the greater his adherence to the various versions of plant-based diets. The components and score of plant-based diet indices are reported in the Supplementary Material (Supplementary Table 1).

Potential covariates

We collected demographic information, including age (years), sex (men/women), education (primary/secondary/university), household income (<20,000/ 20,000–39,999/≥40,000 CNY/year), marital status (married/single, divorced, or widowed), alcohol drinking (current/ past or never), smoking status (current/ past or never), CVD (presence/absence), diabetes (presence/absence), hypertension (presence/ absence) through self-report on the structured questionnaires. Body mass index (BMI, in kg/m^2) was assessed by dividing the weight in kilograms by the square of the height in meters and was included in the analysis as a continuous variable.

Total energy intake (kcal/d) was measured using the SFFQ and calculated according to the Chinese Food Composition Table (6th edition). Physical activity was calculated from the Physical Activity Scale for the Elderly (PASE)[37]. We divided all participants into two categories according to the World Health Organization's recommendations for adult physical activity[25]: participants who met the guideline were considered physically active, and those who did not meet the guideline defined as physically inactive.

Statistical methods

All data were analyzed using R software version 4.1.3 and SAS software version 9.4, and a two-sided $P < 0.05$ was considered statistically significant.

We compared the characteristics of the study population at baseline by quartiles of the PDI. Continuous variables were analyzed by analysis of variance (ANOVA), presented as means and standard deviations (SD), and categorical variables were expressed as numbers and percentages by the Chi-square test. Logistic regression analysis was conducted to determine the

association between three versions of plant-based diets and DepS, and odds ratios (ORs) and 95% confidence intervals (CIs) were estimated. *P* trend was tested using the median values of the quartiles for each PDIs. Linear regression analysis was used to explore the associations between PDIs (per 10-score increment) and PHQ-9. We successively adjusted for covariates regarding sociodemographic, lifestyle, and multimorbidity factors. Model 1 was adjusted for age and sex. Model 2 was further adjusted for education level, household income, marital status, physical activity, smoking status, alcohol drinking, and total energy intake. Model 3 was additionally adjusted for BMI and chronic diseases (CVD, diabetes, and hypertension). Restricted cubic splines (RCS) with four knots were used to examine the shape of the non-linear relationships. We further explored the associations of individual food groups in the plant-based diets with DepS by conducting logistic regression analyses for each of the individual food groups.

Data availability

The datasets used to support the findings of this study are available from the corresponding author upon reasonable request.

Code availability

The code generated during the current study are available from the corresponding author on reasonable request.

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Author contributions
S.R.: study conception and design; S.C., L.Z., and L.X.: data collection and data management; L.Z. and L.X.: data curation; S.C., S.T., C.H., and L.T.: data analysis of all sub-studies; J.Z., L.C., and W.Z.: data visualization; S.T., C.L., and S.C.: first manuscript draft; S.W. and Y.C.: revisions. All authors contributed to and accepted the final manuscript.

Competing interests
The authors declare no competing interests.

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