

Original research



Association between Food Inflammation Scores of Individuals and Hyperlipidemia in U.S. Adults: A Cross-Sectional Study from NHANES 2009–2018

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ABSTRACT

Background: Dietary inflammation has been associated with dyslipidemia, but the relationship between the newer Food Inflammation Scores of Individuals (FISI) and hyperlipidemia has not been well characterized. **Methods:** We analyzed 11 805 adults aged 20 years or older from five NHANES cycles (2009–2018). FISI34, FISI26-USDA, FISI26-CHINA, and a Dietary Inflammatory Index calculated without alcohol (DII) were derived from 24-h dietary recall data. Associations with hyperlipidemia were examined using survey-weighted logistic regression. Restricted cubic spline models, sex-stratified analyses, and prespecified subgroup analyses were performed. **Results:** In the fully adjusted model, higher FISI26-USDA and FISI26-CHINA scores were associated with greater odds of hyperlipidemia (OR 1.08, 95% CI 1.01–1.14, $P=0.016$; and OR 1.10, 95% CI 1.02–1.18, $P=0.015$, respectively). Compared with Q1, Q4 ORs were 1.35 (95% CI 1.11–1.64; $P=0.003$) for FISI26-USDA and 1.26 (95% CI 1.03–1.54; $P=0.024$) for FISI26-CHINA. FISI34 was not consistently associated with hyperlipidemia (continuous $P=0.210$; P for trend $=0.075$). The continuous DII association was weaker ($P=0.072$), although Q3 and the trend test remained significant. Restricted cubic splines supported approximately linear associations for FISI26-USDA, FISI26-CHINA, and DII (P for nonlinearity >0.05), whereas no overall association was detected for FISI34. In sex-stratified analyses, the FISI26 associations were more consistent among women. No significant interaction was observed across the FISI26-USDA subgroup analyses (all P for interaction >0.05). **Conclusions:** FISI26-USDA and FISI26-CHINA were positively associated with hyperlipidemia in U.S. adults, whereas FISI34 showed no consistent association and the DII association was less robust after multivariable adjustment. These findings support further prospective evaluation of FISI26-based measures in cardiometabolic research.

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1. Introduction

Hyperlipidemia is a common metabolic abnormality characterized by unfavorable circulating lipid concentrations and is closely linked to atherosclerotic cardiovascular disease and other cardiometabolic conditions [1][2]. With changes in global dietary habits, its prevalence has been rising year on year, and it has become a risk factor that seriously affects public health. Long-term lipid metabolism disorders significantly increase the risk of developing various chronic diseases, such as cardiovascular disease, diabetes, and non-alcoholic fatty liver disease [3][4].

Diet is central to lipid homeostasis, but its effects are not limited to nutrient quantity. Dietary patterns can also alter chronic low-grade inflammation, which in turn interacts with insulin signaling, hepatic lipid handling, oxidative stress, and lipoprotein metabolism [5]–[10]. This makes the inflammatory potential of the diet a plausible marker of metabolic health. The Dietary Inflammatory Index (DII) was developed to summarize the inflammatory potential of dietary intake on the basis of published evidence relating dietary components to inflammatory biomarkers [8]. It has been validated against circulating C-reactive protein [7] and has subsequently been applied in a wide range of epidemiologic settings. NHANES studies have examined the DII in relation to dyslipidemia, hyperlipidemia, and cardiometabolic outcomes [11]–[14]. Specifically, positive associations of

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higher DII scores with hyperlipidemia or dyslipidemia have been reported in NHANES analyses [11][12]. However, the DII uses a population-based scoring framework and does not directly incorporate whether an individual's intake meets nutrient reference values.

The Food Inflammation Index (FII) and the derived Food Inflammation Scores of Individuals (FISI) were introduced to provide a food- and person-level assessment that combines inflammatory tendency with actual intake and nutrient reference values [5][6].

Three FISI implementations were evaluated. FISI34 includes 34 dietary components and is calculated using U.S. Department of Agriculture (USDA) nutrient composition data together with U.S. nutrient reference values. FISI26-USDA uses a reduced 26-component framework with the same U.S.-based data and reference system, whereas FISI26-CHINA applies the 26-component framework using Chinese food composition data and Chinese nutrient reference values [5][6][15]. Thus, FISI34 and FISI26-USDA differ primarily in the number of included components, while FISI26-USDA and FISI26-CHINA differ mainly in the underlying food composition and reference-intake systems. These measures may provide complementary information to the DII, yet their associations with hyperlipidemia have not been established. We therefore examined the associations of FISI34, FISI26-USDA, FISI26-CHINA, and DII with hyperlipidemia among U.S. adults using NHANES 2009–2018 data. We further evaluated exposure-response patterns, descriptive sex-stratified associations, and consistency across prespecified subgroups.

2. Methods

2.1. Study design and participants

This cross-sectional study used publicly available data from five consecutive cycles of the National Health and Nutrition Examination Survey (NHANES), 2009–2010 through 2017–2018. NHANES uses a complex, multistage probability sampling design to obtain a representative sample of the U.S. civilian noninstitutionalized population [16]. The present report was prepared in accordance with the STROBE recommendations for observational studies [17]. NHANES protocols were approved by the National Center for Health Statistics Ethics Review Board, and written informed consent was obtained from participants.

A total of 49,693 participants were available across the five cycles. We excluded participants younger than 20 years ($n=20,858$), pregnant participants ($n=315$), participants with HIV infection ($n=91$), those receiving dialysis ($n=104$), and individuals weighing more than 136 kg or taller than 196 cm ($n=639$). Additional exclusions were made for missing hyperlipidemia status ($n=1,127$), missing or nonpositive dietary sampling weights ($n=2,247$), missing FISI34 ($n=1,802$), missing DII without alcohol ($n=2,697$), and missing variables required for the planned primary or sensitivity analyses ($n=7,760$). No additional participants were lost because of missing FISI26-USDA or FISI26-CHINA after the FISI34 restriction. Finally, 248 observations flagged as extreme FISI values by the prespecified Z-score-based data-cleaning rule were excluded. The final analytic sample comprised 11,805 adults (Figure 1).

2.2. Definition of hyperlipidemia

Hyperlipidemia was defined using the National Cholesterol Education Program framework adopted in prior NHANES research [2][12]. Participants were classified as having hyperlipidemia if any of the following criteria were met: triglycerides ≥ 150 mg/dL, total cholesterol ≥ 200 mg/dL,

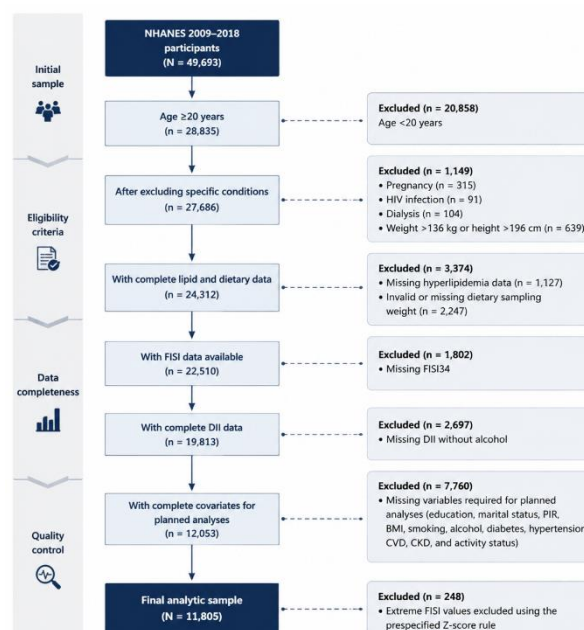


Figure 1. Flowchart of participant selection.

low-density lipoprotein cholesterol ≥ 130 mg/dL, high-density lipoprotein cholesterol ≤ 50 mg/dL in women or ≤ 40 mg/dL in men, or reported use of lipid-lowering medication.

2.3. Dietary assessment and dietary inflammatory scores

Dietary intake was assessed using NHANES 24-h dietary recall interviews. When two complete recall days were available, the mean intake across the two days was used. When the second recall was unavailable, the first-day record was used. This approach followed the FISI application used in prior NHANES work [6].

FISI was calculated by combining the inflammatory tendency score of each dietary component with the participant's intake and the corresponding nutrient reference value: $FISI = \sum (TIS_i \times Intake_i / NRV_i)$, where TIS_i is the inflammatory tendency score of component i , $Intake_i$ is the participant's daily intake, and NRV_i is the reference intake [5][6]. FISI34 used 34 dietary components with USDA nutrient composition data and U.S. nutrient reference values. FISI26-USDA used a 26-component framework with the same U.S.-based data and reference system, whereas FISI26-CHINA used the corresponding 26-component framework with Chinese food composition data and Chinese nutrient reference values [5][6][15]. Higher FISI values indicate a diet with greater inflammatory potential.

DII was calculated according to the literature-derived approach of Shivappa et al. [8]. The alcohol component was excluded from the DII used in this analysis, and alcohol consumption was modeled separately as a covariate. Higher DII values indicate a more pro-inflammatory diet.

2.4. Covariates

Covariates were selected a priori from previous NHANES studies of dietary inflammation and hyperlipidemia [11][12]. The primary adjustment set included age, sex, race/ethnicity, family poverty-to-income ratio (PIR), education level, body mass index (BMI), marital status, smoking status, alcohol consumption, diabetes, hypertension, cardiovascular disease

(CVD), and chronic kidney disease (CKD). Race/ethnicity was categorized as Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, or other race. Education was represented in five NHANES categories in the primary models. Marital status was classified as married/living with a partner or widowed/divorced/separated/never married. Smoking was categorized as never, former, or current smoking, and alcohol intake as lifetime abstinence, former drinking, current moderate drinking, or current heavy drinking. PIR, age, and BMI were entered as continuous variables in the primary regression models.

CVD included self-reported heart failure, coronary heart disease, angina, myocardial infarction, or stroke. Diabetes, hypertension, and CKD were derived from NHANES interview, examination, medication, and laboratory data using established NHANES definitions consistent with prior work [12][16]. Physical activity was retained in the analytic dataset for descriptive and propensity-score balance analyses but was not included in the prespecified primary regression adjustment set or in the subgroup analysis.

2.5. Statistical analysis

All analyses incorporated the NHANES complex survey design. A 10-year dietary weight was constructed from the 2-year day-1 dietary weight (WTDRD1) by multiplying the cycle-specific weight by 2/10 for each of the five survey cycles. Survey strata (SDMVSTRA) and primary sampling units (SDMVPSU) were retained, and variance estimates were obtained by Taylor linearization [16].

Continuous variables are presented as survey-weighted means with standard deviations, and categorical variables as unweighted counts with survey-weighted percentages. Baseline differences by hyperlipidemia status were assessed with design-based tests appropriate to variable type. Survey-weighted logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for hyperlipidemia. Each dietary score was analyzed both continuously and in quartiles, with the lowest quartile as the reference group. Trend tests were performed across quartiles.

Three models were fitted. Model 1: unadjusted. Model 2: adjusted for age, sex, and race/ethnicity. Model 3: additionally adjusted for family PIR, education level, BMI, marital status, smoking status, alcohol consumption, diabetes, hypertension, CVD, and CKD. In sex-stratified analyses, sex was omitted from the adjustment set. Restricted cubic spline models based on Model 3 were used to assess dose-response shape, with P values reported for the overall and nonlinear components.

FISI26-USDA was selected as the primary score for detailed subgroup analyses because it was constructed using U.S. food composition data and

U.S. nutrient reference values. Subgroups were defined by age (≤ 48 vs >48 years), race/ethnicity, education ($<$ high school, high school, $>$ high school), PIR (≤ 1.3 , >1.3 – 3.5 , >3.5), BMI (<25 , 25 – <30 , ≥ 30 kg/m²), smoking status, alcohol consumption, hypertension, diabetes, CVD, and CKD. Within each subgroup, the stratifying variable was removed from the adjustment set. Interaction terms between continuous FISI26-USDA and each subgroup variable were tested. All tests were two-sided, and $P < 0.05$ was considered statistically significant. Analyses were performed in R (version 4.5.1).

2.6. Propensity-score matching sensitivity analysis

As a sensitivity analysis, propensity-score matching (PSM) was used to improve comparability between participants with and without hyperlipidemia. The propensity score for hyperlipidemia status was estimated with an unweighted logistic model. One-to-one nearest-neighbor matching was performed with replacement, using an ATT estimand and a caliper of 0.2 [18]. Matching variables included age, sex, race/ethnicity, education, marital status, PIR, BMI, smoking, alcohol consumption, physical activity, hypertension, diabetes, CVD, and CKD. Survey weights were then used for post-matching balance assessment. Covariate balance was evaluated using absolute standardized mean differences (SMDs), with values below 0.10 considered the preferred target [19].

3. Results

3.1. Participant characteristics

The final sample included 11 805 participants, of whom 3 555 were classified as non-hyperlipidemic and 8 250 as hyperlipidemic (Table 1). The survey-weighted mean age was 47.5 years. Compared with participants without hyperlipidemia, those with hyperlipidemia were older (51.0 vs 39.5 years) and had a higher mean BMI (29.5 vs 26.6 kg/m²). Diabetes, hypertension, CVD, and CKD were also more common in the hyperlipidemia group (all $P < 0.001$). Mean FISI26-USDA and FISI26-CHINA values were modestly higher (less negative) among participants with hyperlipidemia ($P = 0.003$ and $P = 0.001$, respectively). DII was also higher in the hyperlipidemia group ($P = 0.027$). By contrast, FISI34 did not differ significantly between groups ($P = 0.068$).

Table 1 Baseline characteristics of the study population according to hyperlipidemia status

Characteristic	Overall (N=11 805)	Non-hyperlipidemia (N=3 555)	Hyperlipidemia (N=8 250)	P value
Age (Years), Mean (SD)	47.5 (16.7)	39.5 (15.2)	51 (16.1)	<0.001
Gender, n (%)				0.360
male	5751 (48%)	1762 (49%)	3989 (47.6%)	
female	6054 (52%)	1793 (51%)	4261 (52.4%)	
Race/Ethnicity, n (%)				<0.001

Mexican American	1588 (7.8%)	432 (7.9%)	1156 (7.8%)	
Other Hispanic	1118 (5.2%)	303 (5.5%)	815 (5%)	
Non-Hispanic White	5185 (69.3%)	1412 (65.2%)	3773 (71.2%)	
Non-Hispanic Black	2351 (9.7%)	887 (12.7%)	1464 (8.3%)	
Other Race	1563 (8%)	521 (8.7%)	1042 (7.7%)	
Education Level, n (%)				<0.001
<9th grade	759 (3%)	164 (2.6%)	595 (3.2%)	
9–11th grade	1284 (7.9%)	353 (7%)	931 (8.3%)	
High school graduate/GED	2568 (21.3%)	707 (18.9%)	1861 (22.3%)	
Some college or AA degree	3785 (32.7%)	1169 (32.8%)	2616 (32.7%)	
College graduate or above	3409 (35.1%)	1162 (38.7%)	2247 (33.5%)	
Marital Status, n (%)				<0.001
Married/Living with partner	7182 (64.1%)	1959 (57.7%)	5223 (67%)	
Widowed/Divorced/Separated/Never married	4623 (35.9%)	1596 (42.3%)	3027 (33%)	
Family PIR, Mean (SD)	3.1 (1.6)	3 (1.7)	3.2 (1.6)	<0.001
Body Mass Index, Mean (SD)	28.6 (6.1)	26.6 (5.9)	29.5 (5.9)	<0.001
Smoking Group, n (%)				<0.001
Never smoker	6913 (59.3%)	2270 (63.5%)	4643 (57.4%)	
Former smoker	2864 (25%)	681 (21.5%)	2183 (26.6%)	
Current smoker	2028 (15.7%)	604 (15%)	1424 (16%)	
Alcohol Group, n (%)				<0.001
Lifetime abstainers	1452 (9.8%)	430 (10.1%)	1022 (9.6%)	
Former drinkers	2673 (18.5%)	628 (14%)	2045 (20.5%)	
Current moderate drinkers	3917 (36.7%)	1170 (34.6%)	2747 (37.6%)	
Current heavy drinkers	3763 (35.1%)	1327 (41.3%)	2436 (32.3%)	
Physical Activity Status, n (%)				<0.001
Inactive	2193 (16.9%)	517 (13.2%)	1676 (18.6%)	
Active	9612 (83.1%)	3038 (86.8%)	6574 (81.4%)	

Diabetes, n (%)				<0.001
No	9871 (87.6%)	3289 (95%)	6582 (84.3%)	
Yes	1934 (12.4%)	266 (5%)	1668 (15.7%)	
Hypertension, n (%)				<0.001
No	7160 (65.3%)	2698 (80.3%)	4462 (58.7%)	
Yes	4645 (34.7%)	857 (19.7%)	3788 (41.3%)	
Cardiovascular Disease, n (%)				<0.001
No	10779 (92.8%)	3449 (97.9%)	7330 (90.6%)	
Yes	1026 (7.2%)	106 (2.1%)	920 (9.4%)	
Chronic Kidney Disease, n (%)				<0.001
No	10061 (87.5%)	3226 (92%)	6835 (85.5%)	
Yes	1744 (12.5%)	329 (8%)	1415 (14.5%)	
Food Inflammation Score Index (34-item), Mean (SD)	−6.3 (2.7)	−6.2 (2.7)	−6.4 (2.7)	0.068
Food Inflammation Score Index (26-item, USDA), Mean (SD)	−3.2 (1.3)	−3.2 (1.3)	−3.1 (1.2)	0.003
Food Inflammation Score Index (26-item, China), Mean (SD)	−2.6 (1.1)	−2.7 (1.1)	−2.6 (1.1)	0.001
Dietary Inflammatory Index (Without Alcohol), Mean (SD)	0.7 (1.7)	0.6 (1.7)	0.7 (1.7)	0.027

Values are unweighted counts with survey-weighted percentages for categorical variables and survey-weighted mean (SD) for continuous variables. PIR, poverty-to-income ratio; BMI, body mass index; CVD, cardiovascular disease; CKD, chronic kidney disease. Physical activity is shown descriptively but was not included in the prespecified primary regression adjustment set.

3.2. Associations of dietary inflammatory scores with hyperlipidemia

The main regression results are shown in Table 2. In Model 3, both FISI26 measures remained positively associated with hyperlipidemia when modeled continuously. The OR was 1.08 (95% CI 1.01–1.14; $P=0.016$) per one-unit increase in FISI26-USDA and 1.10 (95% CI 1.02–1.18; $P=0.015$) per one-unit increase in FISI26-CHINA. Compared with Q1, the Model 3 ORs for Q4 were 1.35 (95% CI 1.11–1.64; $P=0.003$) for FISI26-USDA and 1.26 (95% CI 1.03–1.54; $P=0.024$) for FISI26-CHINA. The corresponding trend tests were significant (P for trend = 0.001 and 0.011). FISI34 showed

a different pattern. The continuous association was not significant in Model 3 (OR 1.02, 95% CI 0.99–1.05; $P=0.210$), and the Q4 estimate was also nonsignificant (OR 1.14, 95% CI 0.94–1.39; $P=0.184$); the trend test did not reach statistical significance ($P=0.075$). For DII without alcohol, the continuous Model 3 estimate was 1.04 (95% CI 1.00–1.09; $P=0.072$). Q3 was associated with higher odds of hyperlipidemia (OR 1.26, 95% CI 1.03–1.53; $P=0.023$), whereas Q4 was not statistically significant ($P=0.076$); the overall quartile trend remained significant (P for trend = 0.032).

Table 2 Survey-weighted logistic regression associations of dietary inflammatory scores with hyperlipidemia

Exposure	Category	Model 1		Model 2		Model 3	
		OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value
FISI34	Continuous	0.98 (0.95–1.00)	0.073	1.03 (1.00–1.05)	0.054	1.02 (0.99–1.05)	0.210
	Q1	Reference		Reference		Reference	

	Q2	0.93 (0.80–1.08)	0.344	1.01 (0.86–1.17)	0.933	1.03 (0.87–1.21)	0.739
	Q3	1.02 (0.86–1.22)	0.787	1.23 (1.03–1.46)	0.024	1.23 (1.02–1.48)	0.028
	Q4	0.86 (0.72–1.04)	0.117	1.23 (1.02–1.48)	0.031	1.14 (0.94–1.39)	0.184
	<i>P</i> for trend		0.255		0.008		0.075
FISI26-USDA	Continuous	1.08 (1.03–1.13)	0.003	1.13 (1.07–1.20)	<0.001	1.08 (1.01–1.14)	0.016
	Q1	Reference		Reference		Reference	
	Q2	1.19 (0.97–1.47)	0.099	1.19 (0.95–1.48)	0.120	1.15 (0.93–1.42)	0.206
	Q3	1.32 (1.11–1.57)	0.002	1.45 (1.20–1.76)	<0.001	1.30 (1.07–1.59)	0.009
	Q4	1.37 (1.15–1.63)	<0.001	1.58 (1.30–1.91)	<0.001	1.35 (1.11–1.64)	0.003
	<i>P</i> for trend		<0.001		<0.001		0.001
FISI26-CHINA	Continuous	1.10 (1.04–1.17)	0.002	1.17 (1.09–1.25)	<0.001	1.10 (1.02–1.18)	0.015
	Q1	Reference		Reference		Reference	
	Q2	1.10 (0.91–1.34)	0.316	1.13 (0.92–1.38)	0.254	1.09 (0.89–1.33)	0.408
	Q3	1.30 (1.09–1.56)	0.004	1.43 (1.17–1.75)	<0.001	1.26 (1.03–1.53)	0.023
	Q4	1.25 (1.06–1.48)	0.010	1.49 (1.23–1.81)	<0.001	1.26 (1.03–1.54)	0.024
	<i>P</i> for trend		0.004		<0.001		0.011
DII without alcohol	Continuous	1.04 (1.00–1.09)	0.029	1.10 (1.05–1.15)	<0.001	1.04 (1.00–1.09)	0.072
	Q1	Reference		Reference		Reference	
	Q2	1.08 (0.89–1.32)	0.433	1.19 (0.97–1.45)	0.099	1.10 (0.89–1.35)	0.380
	Q3	1.25 (1.06–1.49)	0.010	1.47 (1.20–1.79)	<0.001	1.26 (1.03–1.53)	0.023
	Q4	1.19 (0.98–1.44)	0.075	1.49 (1.22–1.82)	<0.001	1.21 (0.98–1.50)	0.076
	<i>P</i> for trend		0.026		<0.001		0.032

Model 1: unadjusted. Model 2: adjusted for age, sex, and race/ethnicity. Model 3: additionally adjusted for family PIR, education level, BMI, marital status, smoking status, alcohol consumption, diabetes, hypertension, CVD, and CKD. Q1 is the reference quartile. DII was calculated without alcohol.

3.3. Sex-stratified analyses

Sex-stratified results are presented in Table 3. Associations of the FISI26 scores were more consistent among women. For FISI26-USDA, women in Q2, Q3, and Q4 had higher odds of hyperlipidemia than women in Q1 after full adjustment, with an OR of 1.51 (95% CI 1.14–2.00; $P=0.004$) for Q4 and a significant trend across quartiles (P for trend = 0.006). FISI26-CHINA showed a similar pattern in women, with ORs of 1.37 (95% CI 1.04–1.81; $P=0.026$) for Q3 and 1.35 (95% CI 1.02–1.78; $P=0.035$) for Q4 (P for trend = 0.020).

Among men, individual FISI26 quartile estimates were generally weaker. For FISI26-USDA, Q3 and Q4 were borderline in Model 3 ($P=0.055$ and $P=0.063$), although the quartile trend was significant ($P=0.016$). The FISI26-CHINA trend in men was not significant ($P=0.061$). DII showed a modest trend among women ($P=0.045$) but not men ($P=0.181$). FISI34 did not show a consistent graded association in either sex. Because a formal sex-by-score interaction test was not part of this analysis, these sex-specific differences should be interpreted descriptively.

Table 3 Sex-stratified survey-weighted logistic regression associations between dietary inflammatory score quartiles and hyperlipidemia

Exposure	Category	Model 1		Model 2		Model 3	
		OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Female							
FISI34	Q1	Reference		Reference		Reference	
	Q2	0.89 (0.69–1.14)	0.341	0.94 (0.74–1.21)	0.632	0.91 (0.71–1.18)	0.481
	Q3	1.06 (0.81–1.39)	0.677	1.31 (0.99–1.75)	0.060	1.26 (0.95–1.67)	0.103
	Q4	0.87 (0.68–1.11)	0.255	1.23 (0.95–1.60)	0.121	1.08 (0.82–1.41)	0.572
	P for trend		0.473		0.020		0.198
FISI26-USDA	Q1	Reference		Reference		Reference	
	Q2	1.47 (1.12–1.94)	0.006	1.50 (1.12–2.00)	0.006	1.37 (1.03–1.81)	0.032
	Q3	1.52 (1.19–1.94)	0.001	1.70 (1.29–2.25)	<0.001	1.46 (1.09–1.95)	0.011
	Q4	1.66 (1.30–2.13)	<0.001	1.96 (1.50–2.57)	<0.001	1.51 (1.14–2.00)	0.004
	P for trend		<0.001		<0.001		0.006
FISI26-CHINA	Q1	Reference		Reference		Reference	
	Q2	1.17 (0.91–1.51)	0.222	1.22 (0.92–1.62)	0.163	1.15 (0.86–1.53)	0.331
	Q3	1.48 (1.15–1.89)	0.002	1.66 (1.25–2.20)	<0.001	1.37 (1.04–1.81)	0.026
	Q4	1.44 (1.14–1.83)	0.003	1.76 (1.36–2.29)	<0.001	1.35 (1.02–1.78)	0.035
	P for trend		0.002		<0.001		0.020
DII without alcohol	Q1	Reference		Reference		Reference	
	Q2	1.16 (0.89–1.52)	0.265	1.29 (0.98–1.70)	0.066	1.17 (0.89–1.54)	0.247
	Q3	1.34 (1.03–1.73)	0.029	1.57 (1.20–2.07)	0.002	1.28 (0.98–1.68)	0.069
	Q4	1.40 (1.07–1.82)	0.015	1.78 (1.36–2.35)	<0.001	1.34 (1.00–1.79)	0.050
	P for trend		0.012		<0.001		0.045
FISI34	Q1	Reference		Reference		Reference	

	Q2	0.96 (0.77–1.18)	0.670	1.07 (0.86–1.33)	0.537	1.12 (0.89–1.41)	0.338
	Q3	0.95 (0.75–1.22)	0.703	1.14 (0.89–1.45)	0.300	1.17 (0.89–1.52)	0.257
	Q4	0.82 (0.63–1.06)	0.125	1.23 (0.96–1.59)	0.104	1.23 (0.94–1.61)	0.136
	P for trend		0.183		0.092		0.123
FISI26-USDA	Q1	Reference		Reference		Reference	
	Q2	1.03 (0.77–1.37)	0.838	1.02 (0.76–1.38)	0.869	1.03 (0.77–1.38)	0.836
	Q3	1.23 (0.98–1.55)	0.069	1.34 (1.07–1.69)	0.012	1.25 (1.00–1.58)	0.055
	Q4	1.15 (0.89–1.49)	0.272	1.33 (1.02–1.73)	0.036	1.29 (0.99–1.69)	0.063
	P for trend		0.099		0.005		0.016
FISI26-CHINA	Q1	Reference		Reference		Reference	
	Q2	1.08 (0.82–1.42)	0.602	1.09 (0.82–1.45)	0.553	1.07 (0.81–1.42)	0.626
	Q3	1.18 (0.93–1.49)	0.170	1.28 (1.01–1.63)	0.040	1.19 (0.93–1.52)	0.156
	Q4	1.07 (0.85–1.37)	0.551	1.28 (0.99–1.66)	0.056	1.23 (0.95–1.59)	0.116
	P for trend		0.327		0.018		0.061
DII without alcohol	Q1	Reference		Reference		Reference	
	Q2	1.03 (0.80–1.33)	0.838	1.11 (0.86–1.44)	0.416	1.05 (0.81–1.36)	0.719
	Q3	1.20 (0.97–1.49)	0.092	1.41 (1.12–1.78)	0.004	1.27 (1.00–1.61)	0.053
	Q4	0.96 (0.75–1.23)	0.727	1.20 (0.92–1.57)	0.178	1.09 (0.83–1.44)	0.526
	P for trend		0.745		0.031		0.181

Sex-stratified models omit sex from the adjustment set. Model 2 adjusts for age and race/ethnicity. Model 3 additionally adjusts for family PIR, education level, BMI, marital status, smoking status, alcohol consumption, diabetes, hypertension, CVD, and CKD. Q1 is the reference quartile. FISI, Food Inflammation Scores of Individuals; USDA, U.S. Department of Agriculture; DII, Dietary Inflammatory Index; PIR, poverty-to-income ratio; BMI, body mass index; CVD, cardiovascular disease; CKD, chronic kidney disease.

3.4. Restricted cubic spline analysis

Restricted cubic spline analyses are shown in Figure 2. FISI26-USDA, FISI26-CHINA, and DII were associated with hyperlipidemia overall (P for overall = 0.003, 0.005, and 0.008, respectively). Evidence for nonlinearity was not observed for any of these scores (P for nonlinearity = 0.382, 0.416, and 0.880, respectively), supporting an approximately linear dose-response pattern over the observed range. FISI34 showed neither a significant overall association (P = 0.479) nor evidence of nonlinearity (P = 0.430).

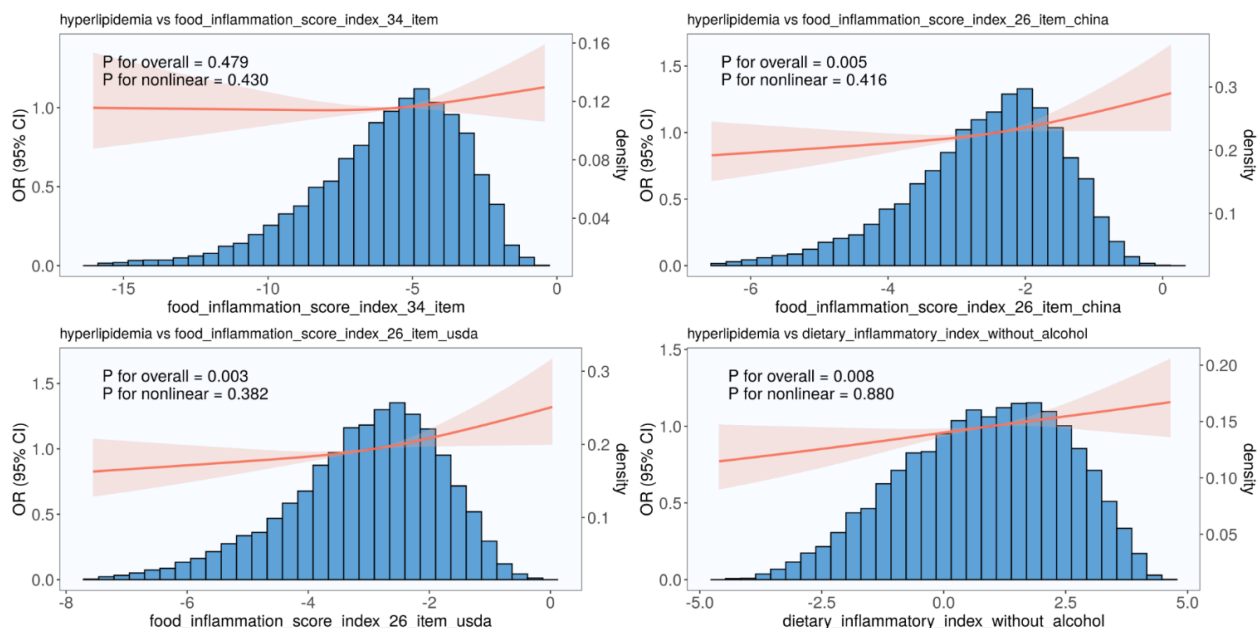


Figure 2. Restricted cubic spline associations of dietary inflammatory scores with hyperlipidemia. Panels show FISI34 (upper left), FISI26-CHINA (upper right), FISI26-USDA (lower left), and DII without alcohol (lower right). Curves are based on the fully adjusted model; shaded bands represent 95% CIs, and histograms show the exposure distributions. P values for overall association and nonlinearity are displayed in each panel. FISI, Food Inflammation Scores of Individuals; USDA, U.S. Department of Agriculture; DII, Dietary Inflammatory Index; CI, confidence interval.

3.5. Subgroup analyses

The association between continuous FISI26-USDA and hyperlipidemia was examined across prespecified demographic, socioeconomic, lifestyle, and clinical strata (Figure 3). Several subgroup-specific estimates were statistically significant, including participants older than 48 years (OR 1.11, 95% CI 1.02–1.22), other Hispanic participants (OR 1.24, 95% CI 1.05–1.46), those with PIR >1.3–3.5 (OR 1.15, 95% CI 1.06–1.26), former smokers (OR 1.15, 95% CI 1.02–1.29), and current moderate drinkers (OR 1.13, 95% CI 1.03–1.24). Positive associations were also observed among participants without diabetes, CVD, or CKD.

None of the interaction tests were statistically significant. P values for interaction ranged from 0.130 for PIR to 0.796 for BMI, indicating no clear evidence that the FISI26-USDA association differed across the examined subgroups. Accordingly, differences in significance between individual strata were treated as descriptive rather than evidence of effect modification.

3.6. Propensity-score matching sensitivity analysis

PSM substantially reduced baseline imbalance between the hyperlipidemia and non-hyperlipidemia groups. The weighted absolute SMD for the propensity score decreased from 0.9110 to 0.0445. Age decreased from 0.7154 to 0.0625, BMI from 0.4835 to 0.0807, hypertension from 0.4383 to 0.0178, and diabetes from 0.2933 to 0.0467. After matching, all measured covariates had weighted $|SMD| < 0.10$ except CVD, which showed mild residual imbalance ($|SMD| = 0.1085$). Detailed balance diagnostics are provided in Supplementary Table S1.

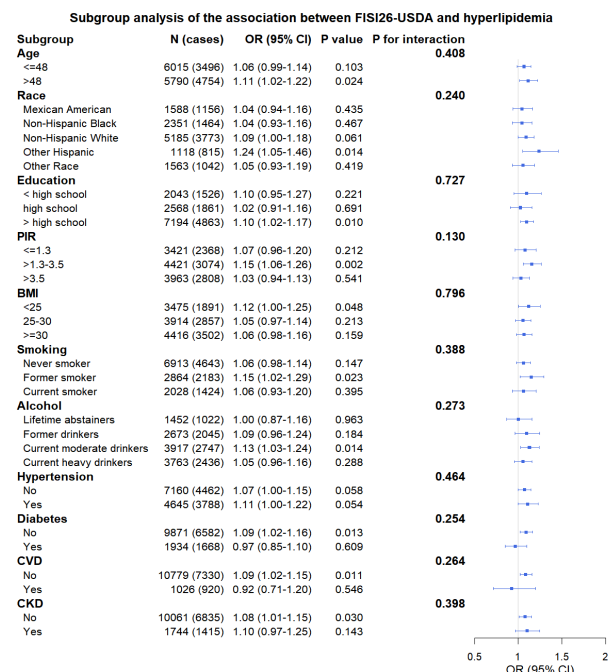


Figure 3. Subgroup analysis of the association between continuous FISI26-USDA and hyperlipidemia. Models were adjusted for the Model 3 covariates except the variable used for stratification. ORs are shown per one-unit increase in FISI26-USDA. P for interaction evaluates heterogeneity across levels of each subgroup. FISI, Food Inflammation Scores of Individuals; USDA, U.S. Department of Agriculture; OR, odds ratio; PIR, poverty-to-income ratio; BMI, body mass index; CVD, cardiovascular disease; CKD, chronic kidney disease.

4. Discussion

In this nationally representative cross-sectional analysis, the two 26-component FISI measures were the most consistent dietary inflammation scores in relation to hyperlipidemia. Both FISI26-USDA and FISI26-CHINA remained associated with higher odds of hyperlipidemia after adjustment for demographic, socioeconomic, lifestyle, and clinical factors, and both showed graded quartile associations. FISI34 did not show a consistent association, while the DII association was weaker after full adjustment. The spline analyses further suggested that the FISI26 associations were approximately linear over the observed ranges. Detailed subgroup analyses of FISI26-USDA did not identify statistically significant effect modification.

The DII findings are broadly compatible with earlier NHANES studies linking a more pro-inflammatory diet with hyperlipidemia or dyslipidemia [11][12]. Han et al. reported an independent association between DII and hyperlipidemia in NHANES 2005–2018 [12], and a more recent NHANES analysis also found higher dyslipidemia odds at higher DII levels [11]. The continuous DII estimate in our fully adjusted model was weaker than those reports, although the quartile trend remained significant. Several differences may contribute, including the study period, sample restrictions, covariate specification, and the use of a DII calculated without the alcohol component in the present analysis. The latter choice avoids embedding alcohol within both the exposure score and a separately adjusted alcohol variable, but it also changes the scale relative to studies using a conventional DII.

The contrast between FISI26 and FISI34 is noteworthy. FISI was developed to integrate inflammatory tendency scores with individual intake and nutrient reference values [5]. The 26-component variants were designed around a set of core components that could be implemented across both USDA and Chinese food composition systems, whereas FISI34 retains a broader nutrient set [5][6]. In this analysis, the broader score did not translate into a stronger association with hyperlipidemia. One possibility is that the additional components improve general dietary characterization but add variability that is less directly related to the lipid phenotype. Conversely, the 26-component scores may place relatively greater weight on nutrients that track the dietary patterns most relevant to lipid metabolism in this population. These interpretations remain hypotheses; the current data do not establish that one score is intrinsically superior.

The RCS results support a largely linear relationship for both FISI26 measures and DII, with no statistical evidence of nonlinearity. This differs from some previous DII work that identified threshold-like patterns [12]. Differences in score construction, especially exclusion of alcohol from DII, as well as differences in sample composition and covariate adjustment, may account for the discrepant shapes. The absence of significant subgroup interactions is equally important. Although several strata showed statistically significant within-group estimates, interaction testing did not support meaningful heterogeneity. Thus, the most defensible interpretation is that the FISI26-USDA association was broadly similar across the examined subgroups.

The sex-stratified analyses descriptively showed a more regular positive gradient among women, particularly for FISI26-USDA. This pattern is exploratory. Statistical significance in one sex and nonsignificance in the other does not demonstrate a true sex difference or effect modification, and no formal sex-by-score interaction test was performed. Although biological differences in lipid metabolism, adipose tissue distribution, hormonal signaling, and dietary behavior could contribute to heterogeneity, such explanations remain speculative and require direct testing in future studies.

Several biological pathways could link a pro-inflammatory diet with dyslipidemia. Diet-related activation of innate inflammatory pathways can increase pro-inflammatory cytokine signaling and oxidative stress, which may impair insulin action and alter hepatic lipid synthesis and lipoprotein turnover [9][10]. Inflammation and lipid metabolism also reinforce one another: lipid excess can promote inflammatory signaling, while inflammatory mediators can modify lipid handling and vascular function. A dietary score that captures both inflammatory tendency and the adequacy of relevant nutrient intake may therefore reflect multiple metabolic processes that converge on dyslipidemia.

This study has several strengths. It used five NHANES cycles, incorporated the complex survey design, compared three FISI implementations with DII, and examined both exposure-response shape and subgroup consistency. The analysis also retained the null and weaker findings for FISI34 and DII rather than restricting interpretation to statistically significant results. PSM markedly improved measured covariate balance, although mild residual imbalance in CVD remained.

The limitations are also important. First, the cross-sectional design prevents temporal or causal inference; individuals aware of abnormal lipid levels may have changed their diets, creating the possibility of reverse causation. Second, dietary scores were based on one or two 24-h recalls and are therefore vulnerable to day-to-day variation and recall error. Third, the complete-case approach led to substantial exclusions and may have introduced selection bias. Fourth, residual and unmeasured confounding cannot be excluded, even after multivariable adjustment or matching. Fifth, FISI is a relatively new metric, and clinically meaningful cut points have not yet been established. Finally, the PSM diagnostics showed a small residual imbalance in CVD, and matching cannot compensate for unmeasured differences between groups.

5. Conclusions

Among U.S. adults in NHANES 2009–2018, higher FISI26-USDA and FISI26-CHINA scores were associated with higher odds of hyperlipidemia after multivariable adjustment. The associations were approximately linear and were broadly consistent across prespecified FISI26-USDA subgroups. FISI34 was not consistently associated with hyperlipidemia, and the DII relationship was less robust after full adjustment. Prospective studies are needed to determine whether FISI26-based measures can improve dietary risk assessment or guide prevention strategies for dyslipidemia.

CRedit authorship contribution statement

Tao Wang: Writing – review & editing, Writing – original draft, Visualization, Methodology. **Taoqin Peng:** Writing – review & editing, Software, Methodology. **Yufan Xu:** Writing – review & editing, Visualization. **Chenggui Chang:** Writing – review & editing. **Hongliu Peng:** Writing – review & editing. **Xikui Lu:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

The free versions of Grammarly were used for spell-checking and grammar corrections. After using these tools, the author(s) reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Declaration of competing interests

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval and consent to participate

NHANES protocols were approved by the National Center for Health Statistics Ethics Review Board, and all participants provided informed consent. This secondary analysis used de-identified, publicly available data and did not involve new participant contact.

Data availability

NHANES data are publicly available from the U.S. Centers for Disease Control and Prevention National Center for Health Statistics website.

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