A healthy plant–based diet is favorably associated with cardiometabolic risk factors among participants of South Asian ancestry

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ABSTRACT

Background: Plant-based diets are recommended for chronic disease prevention, yet there has been little focus on plant-based diet quality among participants of South Asian ancestry who consume a predominantly plant-based diet.

Objectives: We evaluated cross-sectional and prospective associations between plant-based diet quality and cardiometabolic risks among participants of South Asian ancestry who are living in the United States.

Methods: We included 891 participants of South Asian ancestry who completed the baseline visit in the Mediators of Atherosclerosis in South Asians Living in America (MASALA) study. The prospective analysis included 735 participants who completed exam 2 (∼5 years after baseline). The plant-based diet quality was assessed using 3 indices: an overall plant-based diet index (PDI) that summarizes the consumption of plant foods, a healthy PDI (hPDI) that measures consumption of healthy plant foods, and an unhealthy PDI (uPDI) that reflects consumption of less healthy plant foods.

Results: At baseline, the PDI score was inversely associated with fasting glucose. We observed inverse associations between PDI and hPDI scores and HOMA-IR, LDL cholesterol, weight, and BMI (all P values < 0.05). Higher scores on the hPDI, but not PDI, were associated with lower glycated hemoglobin, higher adiponectin, a smaller visceral fat area, and a smaller pericardial fat volume. Each 5-unit higher hPDI score was associated with lower likelihoods of fatty liver (OR: 0.76; 95% CI: 0.64, 0.90) and obesity (OR: 0.88; 95% CI: 0.80, 0.97). There were no associations between uPDI scores and cardiometabolic risks. Prospectively, after covariate adjustment for baseline values, each 5-unit higher hPDI score was associated with an 18% lower risk of incident type 2 diabetes (OR: 0.82; 95% CI: 0.67, 1.00).

Conclusions: A higher intake of healthful plant–based foods was associated with a favorable cardiometabolic risk profile. Dietary recommendations to lower chronic disease risks among participants of South Asian ancestry should focus on the quality of plant-based foods. *Am J Clin Nutr* 2022;116:1078–1090.

Keywords: plant-based diets, cardiovascular disease, diabetes, South Asians, Asian Indians, cardiometabolic, diet, epidemiology

Introduction

Poor diet is a major, preventable risk factor for chronic disease and is a leading risk factor for deaths globally (1). Plant-based diets have been widely proclaimed to lower chronic disease risks (2), although existing evidence has been somewhat mixed, with some studies reporting no association and others reporting

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Supplemental Figure 1 and Supplemental Tables 1–3 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn.

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Abbreviations used: CT, computed tomography; HbA1C, glycated hemoglobin; hDPI, healthy plant–based diet index; hsCRP, high-sensitivity C-reactive protein; MASALA, Mediators of Atherosclerosis in South Asians Living in America; MET, metabolic equivalents of task; PDI, plant-based diet index; Q, quintiles; T2D, type 2 diabetes; uPDI, unhealthy plant–based diet index.

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a lower risk of chronic disease (3). Previous studies have dichotomized plant-based diets as vegetarian or nonvegetarian based on the exclusion of some or all animal foods, and have not distinguished between the healthfulness of plant foods. From a public health standpoint, before promoting a vegetarian dietary pattern for chronic disease reduction, it is crucial to differentiate the quality of plant-based foods, as less healthy plant foods and healthy plant foods have opposing effects on cardiometabolic risks (4–7).

One of the fastest growing ethnic groups in the United States is people of South Asian ancestry, which includes people with ancestry from India, Pakistan, Bangladesh, Sri Lanka, Nepal, and Bhutan (8). A significant proportion (~40%) of these are vegetarian due to their cultural traditions and religious beliefs (9). Despite this, people from South Asian countries have disproportionately higher rates of cardiovascular disease and type 2 diabetes (T2D) (10–12) and, on average, develop these conditions 10 years earlier than other racial and ethnic groups (12, 13). This paradox may partly be due to the healthfulness of the plant-based foods consumed by participants from South Asia. However, there is limited evidence regarding the associations between healthful and unhealthful plant-based diets and cardiometabolic risks among participants from South Asian countries living in the United States.

Given these important gaps in the literature, the goal of the current study was to examine both cross-sectional and prospective associations between healthy and unhealthy plant–based dietary patterns and cardiometabolic risks among participants in the Mediators of Atherosclerosis in South Asians Living in America (MASALA) study. To capture the overall quality of a plant-based diet, we previously developed an overall plant-based diet index (PDI), a healthful PDI (hPDI), and an unhealthful PDI (uPDI). We adapted these indices to reflect foods consumed as part of the South Asian diet. We hypothesized that the hPDI scores but not uPDI scores would be favorably associated with cardiometabolic risks in a cohort of participants from South Asian countries living in the United States.

Methods

Study population

The MASALA study is a community-based, prospective, cohort study of South Asian men and women recruited from the San Francisco Bay area and the greater Chicago area. Detailed methods, study objectives, and a description of the MASALA cohort have been published previously (14). Briefly, to be eligible for the MASALA study, participants had to have South Asian ancestry (self-reported), have at least 3 grandparents who were born in the South Asian subcontinent, be aged 40–84 years, and have the ability to speak and/or read English, Hindi, or Urdu. The MASALA study excluded those with cardiovascular disease at baseline. The baseline clinical examination was conducted in 906 participants between October 2010 and March 2013. The second clinical examination was conducted between September 2015 and March 2018 ($n = 749$). As was done in prior studies (15), we excluded those with implausible energy intakes (<800 kcal/d or >4000 kcal/d for men; <500 kcal/d or >3500 kcal/d for women; $n = 13$) and those with missing data ($n = 2$). The current study includes 891 participants at baseline for the cross-sectional analysis and 735 participants at follow-up for the prospective analysis (**Supplemental Figure 1**). The MASALA study protocol was approved by the Institutional Review Boards of Northwestern University and the University of California, San Francisco. The current analysis protocol was approved by the Institutional Review Board of Brigham and Women's Hospital, Boston, MA. All participants provided written informed consent.

Dietary assessment and PDI scores

At baseline, we assessed dietary intakes over the past 12 months using a previously validated, ethnic-specific, semi-quantitative FFQ designed to assess dietary intakes of participants from South Asia (16). The FFQ consists of 163 items, with 61 items unique to the South Asian diet. For each food item, we computed the number of servings consumed per day from the frequency (day, week, month, year, never) and the serving size (average, small, large). For each item, the average serving size was provided. A small serving size was considered to be 0.5 of the average serving size, whereas a large serving size was 1.5 of the average. Foods were categorized into 19 predefined subgroups based on the similarity of their nutrient content, likeness, and their culinary use in the South Asian diet (**Supplemental Table 1**).

We previously developed 3 plant-based diet indices to reflect the quality of plant-based foods in a person's diet (17). In the current study, we adapted these indices to include foods consumed by participants from South Asia. Based on empirical evidence, the 20 food groups were categorized as healthy plant foods (whole grains, fruits, vegetables, herbs and spices, nuts, legumes, tea, and coffee), less healthy plant foods (refined grains, deep-fried snacks and pickles, potatoes, coconut, sugar-sweetened beverages, sweets, and desserts), and animal foods (animal fat, dairy, egg, fish or seafood, meat, miscellaneous animal foods, and milk-based desserts; Supplemental Table 1). Food groups (in servings/day) were ranked into quintiles (Q) and each quintile was assigned a score between 1 and 5. For the PDI, healthy and less healthy plant food groups were given positive scores (Q1 = 1, Q2 = 2, Q3 = 3, Q4 = 4, Q5 = 5), while animal food groups were given reverse scores (Q5 = 1, Q4 = 2, Q3 = 3, Q2 = 4, Q1 = 5). For the hPDI, we assigned positive scores to healthy plant food groups and reverse scores to less healthy plant food groups and animal food groups. For uPDI, we gave positive scores to less healthy plant food groups and reverse scores to healthy plant food groups and animal food groups. Because alcohol has different associations with various health outcomes, we did not include this as a food group, but adjusted for it in analyses. The 20 food group scores for an individual were summed to obtain the indices, with a theoretical range of 20–100, where higher scores indicate greater adherence to the diet index.

Ascertainment of cardiometabolic risk factors

Our primary outcome variables are cardiometabolic risk factors. After a 12-hour fast, participants visited the clinical field centers to obtain measures of cardiometabolic risk. At baseline, we obtained measures of subclinical atherosclerosis, measures of glycemia and dyslipidemia, anthropometry, blood pressure,

and computed tomography (CT) body composition measures. At follow-up (~5 years after baseline), we obtained measures of body weight, fasting glucose, glycated hemoglobin (HbA1c), and serum lipids.

Subclinical atherosclerosis

High-resolution B-mode ultrasonography (at University of California, San Francisco, the General Electric Vivid 7 ultrasound was used; at Northwestern, a Siemens Acuson Sequoia C256 was used) was conducted for measurements of right and left internal and common carotid artery intima media thicknesses using protocols described previously (18). Cardiac CT scans were performed using a cardiac-gated CT scanner (at the University of California, San Francisco, a Phillips 16D scanner or a Toshiba MSD Aquilion 64 was used; at Northwestern, a Siemens Sensation Cardiac 64 Scanner was used) using methods described previously (19). For each of the 4 major coronary arteries, Agatston scores were used to measure coronary artery calcium, and the sum of the unadjusted score was used (20).

Measures of glycemia and dyslipidemia

Fasting blood samples were obtained after a 12-hour fast. Participants who were not taking diabetes medications underwent a 75-g oral glucose tolerance test. At baseline and follow-up, fasting plasma glucose was measured using the hexokinase method (Ortho Clinical Diagnostics, Johnson & Johnson). Baseline fasting insulin was measured by sandwich immunoassay (Roche Elecsys 2010, Roche Diagnostics), and baseline insulin resistance was assessed by the HOMA-IR as fasting insulin (μIU/mL) × fasting glucose (mmol/L) ÷ 22.5 (21). The β-cell function (a surrogate measure of insulin sensitivity) was estimated at baseline using the oral disposition index, which was calculated as ($\Delta\text{insulin}_{0-30} \div \Delta\text{glucose}_{0-30}$) × (1 ÷ fasting insulin) (22). At baseline and follow-up, T2D was defined by the use of a glucose-lowering medication, fasting plasma glucose ≥7.0 mmol/L, and/or glucose ≥11.1 mmol/L at 2 hours after the challenge (23). We classified incident T2D as the presence of diabetes at follow-up in a participant who had no T2D at baseline.

At baseline, serum lipid values, including triglycerides and HDL cholesterol levels, were measured using enzymatic methods (Quest). LDL cholesterol was calculated using the Friedewald formula (24). Baseline high-sensitivity C-reactive protein (hsCRP) was measured using the BNII nephelometer (Siemens Healthcare Diagnostics). Serum total adiponectin was measured using Millipore Luminex adipokine panel A (EMD Millipore).

Body composition measures

Body weight, height, and waist circumference were measured using standardized methods (14). BMI was calculated as weight in kilograms divided by height in meters squared. Overweight was defined as a BMI ≥23.0 kg/m^2 and obesity was defined as a BMI ≥27.5 kg/m^2 (25). The abdominal visceral and subcutaneous fat areas were measured using CT scans of the abdomen using standardized protocols described previously (14). Noncontrast cardiac CT scans were used to quantify the pericardial fat volume and hepatic fat attenuation (14, 26). Fatty liver was defined as attenuation of <40 Hounsfield units (27).

Other cardiometabolic risk factors

Blood pressure was measured in a seated position using an automated blood pressure machine (V100 Vital Signs Monitor, GE Healthcare). The average of the last 2 readings was used to determine systolic and diastolic blood pressure. Hypertension was defined as the use of antihypertensive medication or blood pressure ≥140/90 mm Hg.

Assessment of covariates

At the baseline visit, all participants visited the clinical field center to provide informed consent and information on their personal history, demographics, socioeconomic status, medical history, family history, alcohol intake, and medication use. Intentional physical activity was assessed using the Typical Week's Physical Activity Questionnaire and quantified as total metabolic equivalent (MET) minutes per week (28). The sum of cultural traditional measures was assessed using a traditional cultural beliefs scale, consisting of 7 items, that was specifically developed for this cohort. The items were scored on a Likert scale, with lower scores representing stronger traditional South Asian beliefs (29). Total energy intake was assessed from the FFQ as kilocalories per day. All interviews were conducted by trained bilingual study staff in English, Hindu, or Urdu.

Statistical analysis

Baseline characteristics of study participants across quartiles of the 3 plant-based diet indices were compared using general linear regression adjusted for age, sex, and total energy for continuous variables and using the chi-square test for categorical variables. Tests for linear trend were conducted by assigning the median value to each quartile and treating this as a continuous variable in the regression model.

To quantify the associations between plant-based diet indices and cardiometabolic risk factors, we used multivariable general linear regression for continuous outcomes and logistic regression for categorical outcomes. For all linear models, we tested the assumptions of normality, linearity, and homogeneity by examining plots of residuals compared with predicted values and normal probability plots of residuals. Outliers were identified by a visual examination of the residual plots. When there was evidence of heteroscadasticity, we log-transformed the outcome variable and re-examined residual plots. In the first multivariable model, we adjusted for age, sex, study site, education, smoking status, alcohol, family history of diabetes, years lived in the United States, physical activity, diabetes medication use, cholesterol-lowering medication use, hypertension medication use, the sum of cultural traditional measures, and total energy. For all prospective analyses, we additionally adjusted for the baseline value of the cardiometabolic risk factor. Because BMI can be a potential mediator of the association between diet and the cardiometabolic risk, we adjusted for it separately in model 2. For all prospective associations, we adjusted for the baseline value

of the covariates and the baseline value of the corresponding outcome measure. For all glycemia measures as an outcome, to minimize confounding due to prevalent disease, we excluded participants with T2D. For all linear associations, results are presented as the unit change (or the percentage change for log-transformed variables) in the outcome per 5-unit higher PDI, hPDI, or uPDI score. We tested for potential effect modifications by age and sex by including a cross-product term between these variables and the diet indices. Because these associations were not a priori, we corrected for multiple testing by setting the threshold for statistical significance to $P_{\text{interaction}} < 0.001$ (0.05 ÷ [22 outcomes × 2 effect modifiers]). For all other statistical analyses, significance was set at a P value < 0.05. All statistical tests were 2-sided and performed using SAS, version 9.4 (SAS Institute).

Results

At baseline, compared with participants in quartile 1 of the PDI or hPDI scores, participants in quartile 4 had lived in the United States for fewer years, had stronger cultural tradition beliefs, were less likely to be current smokers and consume alcohol, and had lower BMIs and smaller waist circumferences. Participants with higher hPDI scores were likely to be older, female, and spend less time watching TV each week. Compared with participants with the lowest uPDI scores (quartile 1), participants with higher uPDI scores were likely to be younger, had lived in the United States for fewer years, had stronger cultural beliefs, and were less likely to consume alcohol (**Table 1**). Distributions of food groups (in servings/day) and baseline cardiometabolic risk factors by quartiles of the indices are shown in **Supplemental Tables 2** and **3**, respectively.

In fully adjusted models at baseline, each 5-unit higher PDI score was associated with a lower percentage difference in fasting glucose (−1.03 ± 0.35%; $P < 0.01$; **Table 2**). A 5-unit higher hPDI score, but not PDI score, was associated with a lower HbA1c (0.43% ± 0.14%; $P < 0.01$). Each 5-unit higher PDI or hPDI score was associated with a 3.46%–4.02% lower log-HOMA-IR value ($P < 0.05$). Although higher scores on the PDI and hPDI were associated with greater insulin sensitivity or β-cell function, these associations did not reach statistical significance. Higher scores on all 3 indices were associated with lower LDL cholesterol ($P < 0.05$). On one hand, each 5-unit higher hPDI score was associated with a 5.68% (2.25%) lower hsCRP concentration, but this association was attenuated and no longer significant after adjusting for BMI. On the other hand, hPDI scores were positively associated with adiponectin (2.32 ± 1.08 mg/dL; $P < 0.05$) even after BMI adjustment.

Higher scores on the PDI and hPDI were favorably associated with body composition and ectopic fat measures. For each 5-unit higher PDI or hPDI score, weight was lower by 0.72 kg (0.28 kg) and 0.75 kg (0.24 kg), respectively ($P < 0.05$). Each 5-unit higher PDI score was associated with a 0.22 kg/m^2 (0.10 kg/m^2) lower BMI, and each 5-unit higher hPDI score was associated with a 0.28 kg/m^2 (0.09 kg/m^2) lower BMI ($P < 0.05$). On one hand, when we examined the likelihoods of overweight (BMI ≥23 kg/m^2) and obesity (BMI ≥27.5 kg/m^2), each 5-unit higher PDI score was associated with a 14% lower likelihood (OR: 0.86; 95% CI: 0.77, 0.97) of obesity but was not associated with overweight (OR: 0.95; 95% CI: 0.84, 1.07). On the other hand, each 5-unit higher hPDI score was associated with a 13% lower likelihood (OR: 0.87; 95% CI: 0.79, 0.97) of overweight and a 12% lower likelihood (OR: 0.88; 95% CI: 0.80, 0.97) of obesity (**Figure 1**). After BMI adjustment, a higher hPDI score was associated with a smaller visceral fat area (−2.55 ± 0.92 cm^2; $P < 0.01$), a smaller pericardial fat volume (−1.31 ± 0.49 cm^3; $P < 0.01$), and higher hepatic fat attenuation (0.511 ± 0.194; $P < 0.01$), indicating less fat in the liver. For each 5-unit higher hPDI score, the likelihood of fatty liver was lower by 24% (OR: 0.76; 95% CI: 0.64, 0.90). We found no evidence for an association between any of the 3 plant-based diet scores and subclinical atherosclerosis, hypertension, or metabolic syndrome.

In prospective analyses, for each 5-unit higher hPDI score, the likelihood of incident T2D ($n = 45$ cases) was lower by 18% (OR: 0.82; 95% CI: 0.67, 1.00). Although nonsignificant, each 5-unit higher uPDI score was associated with an 18% likelihood of incident T2D (OR: 1.18; 95% CI: 0.9, 1.51). We found no evidence of an association between baseline diet scores and changes in measures of fasting glucose, HbA1c, triglycerides, HDL cholesterol, or LDL cholesterol. However, each 5-unit higher PDI score at baseline was associated with less weight gain (−0.21 ± 0.11 kg; $P = 0.05$) at follow-up (**Table 3**).

We found no evidence for an effect modification by age or sex on the association between plant-based diet indices and cardiometabolic risk markers ($P_{\text{interaction}} > 0.01$).

Discussion

In this analysis of plant-based diet quality and cardiometabolic risks among South Asian adults living in the United States, we found that a healthy plant–based diet was associated with favorable measures of glycemic control, insulin resistance, a lower body weight, a lower BMI, favorable measures of adipokines and ectopic fat measures, and a lower incidence of T2D. However, we found no evidence for an association between an unhealthy plant–based diet and cardiometabolic risks. Our findings fill the current knowledge gap regarding the quality of plant-based foods in cardiometabolic risk prevention in an ethnic group with a high proportion of vegetarians and high cardiometabolic risks.

Vegetarianism has often been promoted as a healthy eating pattern, but there has been little to no focus on the quality of plant-based foods. While an overall plant-based diet was associated with some favorable measures of cardiometabolic risk in our cohort, those with greater adherence to a healthy plant–based diet had a far more favorable cardiometabolic risk profile. Although our study found no evidence for a higher cardiometabolic risk among those with the highest uPDI scores, many of these associations, albeit nonsignificant, were in the direction of a higher risk, especially for measures of ectopic fat and incident T2D. Importantly, compared to those in the lowest quartile of uPDI scores, participants in the highest quartile consumed fewer servings of fruits, vegetables, and nuts and more servings of potatoes, refined grains, deep-fried snacks, sweets, and coconut. These food groups have all been previously associated with a higher cardiometabolic risk (6, 30).

The strong, inverse associations between higher hPDI scores, but not PDI or uPDI scores, and ectopic fat measures, including

TABLE 1 Baseline descriptive characteristics of MASALA participants by quartiles of plant-based diet indices[1]

Characteristic	Quartiles				*P*-trend
	1	2	3	4	
Overall plant-based diet index					
Participants, *n*	211	229	211	240	
Mean ± SEM	51.1 ± 0.25	58.6 ± 0.12	63.8 ± 0.10	71.1 ± 0.24	
Age, years	54.8 ± 0.68	55.5 ± 0.62	54.7 ± 0.64	55.9 ± 0.63	0.41
Sex, % female	47.4	42.4	52.6	46.3	0.66
Years lived in the US, years	29.1 ± 0.69	26.6 ± 0.62	26.2 ± 0.64	26.3 ± 0.63	0.004
Birth country	—	—	—	—	0.09
India	74.4	83.8	87.7	88.3	
Pakistan	9	5.24	0.95	2.5	
Bangladesh	1.42	0.87	0	0	
Nepal	0.47	0	0.47	0.83	
Sri Lanka	2.84	0.87	0.47	0	
Other	11.9	9.22	10.41	8.37	
Bachelor's degree or more, %	84.4	86.0	88.6	91.7	0.01
Questionnaire in Hindi or Urdu, %	4.27	5.24	4.74	3.33	0.56
Family income >$75,000, %	74.5	73.4	75.6	70.9	0.49
Sum of cultural traditions measures[2]	15.8 ± 0.45	14.1 ± 0.41	12.9 ± 0.43	13.3 ± 0.42	<0.0001
Smoking category, %					
Never	79.1	80.4	82.9	90.0	0.001
Former	16.1	15.7	15.6	7.5	
Current	4.7	3.9	1.4	2.5	
Tobacco pack-year consumption	2.53 ± 0.42	1.68 ± 0.38	1.48 ± 0.40	0.50 ± 0.39	0.001
Alcohol, % with 1+ drinks/week	43.1	38.0	26.1	25.0	<0.0001
Physical activity, MET-min/week	9970 ± 289	10113 ± 265	10343 ± 275	10159 ± 271	0.56
TV watching, min/week	565 ± 33	547 ± 30	536 ± 31	558 ± 31	0.85
BMI, kg/m2	26.7 ± 0.29	26.1 ± 0.27	25.9 ± 0.28	25.4 ± 0.28	0.002
Waist circumference, cm	93.9 ± 0.71	92.9 ± 0.65	92.4 ± 0.67	91.1 ± 0.66	0.006
Controlled hyperlipidemia, %	77.2	78.2	84.7	77.9	0.53
Hypertension, %	37.9	45.4	37.4	39.2	0.75
Diabetes categories, %	—	—	—	—	
Normal	60.0	58.8	62.7	64.6	0.34
Prediabetes	18.1	20.6	17.7	15.0	
Diabetes	21.9	20.6	19.6	20.4	
Family history of diabetes, %	61.6	52.1	52.7	55.0	0.23
Medication use, %					
Diabetes medication	17.5	15.7	14.7	16.3	0.68
Hypertension medication	31.3	33.6	26.5	29.6	0.38
Cholesterol-lowering medication	32.7	31.0	25.1	29.2	0.25
Cardiometabolic risk factors					
Triglycerides,[3] mmol/L	1.14 ± 1.01	1.12 ± 1.01	1.12 ± 1.01	1.15 ± 1.01	0.396
LDL-C, mmol/L	3.05 ± 0.059	2.95 ± 0.054	2.85 ± 0.056	2.74 ± 0.055	<0.0001
HDL-C, mmol/L	1.32 ± 0.023	1.32 ± 0.021	1.31 ± 0.021	1.27 ± 0.021	0.099
Fasting glucose,[3] mmol/L	2.12 ± 1.006	2.10 ± 1.006	2.10 ± 1.006	2.07 ± 1.006	0.02
HbA1c, %	6.16 ± 0.061	6.01 ± 0.056	6.08 ± 0.059	5.98 ± 0.057	0.08
β-cell function[3,4]	1.32 ± 1.03	1.37 ± 1.03	1.39 ± 1.032	1.46 ± 1.03	0.04
HOMA-IR[4]	1.58 ± 1.02	1.48 ± 1.02	1.47 ± 1.02	1.48 ± 1.02	0.06
Subcutaneous fat area, cm2	245 ± 6.89	232 ± 6.42	235 ± 6.69	242 ± 6.49	0.80
Visceral fat area, cm2	142 ± 3.79	133 ± 3.54	131 ± 3.60	130 ± 3.54	0.02
Pericardial fat volume, cm3	61.5 ± 1.98	59.1 ± 1.84	58.0 ± 1.89	54.3 ± 1.86	0.01
Hepatic fat attenuation, HU	53.4 ± 0.738	55.0 ± 0.69	56.4 ± 0.703	56.2 ± 0.69	0.005
C-reactive protein,[3] mg/L	1.18 ± 1.03	1.15 ± 1.03	1.13 ± 1.03	1.10 ± 1.03	0.13
Adiponectin, mg/dL	54.9 ± 1.02	53.9 ± 1.02	56.1 ± 1.02	54.8 ± 1.02	0.77
Coronary artery calcium score	2.24 ± 1.06	2.07 ± 1.06	2.26 ± 1.06	2.14 ± 1.06	0.80
Common carotid IMT, mm	0.937 ± 1.01	0.93 ± 1.006	0.937 ± 1.01	0.926 ± 1.01	0.32
Internal carotid IMT, mm3	1.06 ± 1.01	1.07 ± 1.01	1.06 ± 1.01	1.05 ± 1.01	0.26
Foods, servings/d					
Whole grains	1.72 ± 0.07	1.88 ± 0.065	2.15 ± 0.07	2.18 ± 0.07	<0.0001
Fruits	2.00 ± 0.10	2.40 ± 0.09	2.49 ± 0.09	2.48 ± 0.09	0.001
Vegetables	4.15 ± 0.14	4.50 ± 0.13	4.65 ± 0.14	4.79 ± 0.13	0.001
Herbs and spices	2.37 ± 0.10	2.89 ± 0.09	3.09 ± 0.09	3.39 ± 0.09	<0.0001
Tea and coffee	2.13 ± 0.10	2.12 ± 0.09	2.06 ± 0.09	2.13 ± 0.09	0.91

(*Continued*)

TABLE 1 (*Continued*)

Characteristic	Quartiles 1	2	3	4	*P*-trend
Nuts	0.647 ± 0.044	0.745 ± 0.04	0.773 ± 0.042	1.06 ± 0.041	<0.0001
Legumes	0.748 ± 0.049	1.05 ± 0.045	1.2 ± 0.046	1.64 ± 0.046	<0.0001
Vegetable oils	0.133 ± 0.015	0.127 ± 0.014	0.089 ± 0.015	0.124 ± 0.015	0.40
Sugar-sweetened beverages	0.294 ± 0.034	0.330 ± 0.031	0.375 ± 0.032	0.358 ± 0.032	0.13
Potatoes	0.324 ± 0.031	0.307 ± 0.028	0.427 ± 0.029	0.328 ± 0.029	0.43
Refined grains	0.838 ± 0.051	0.786 ± 0.047	0.847 ± 0.049	1.037 ± 0.048	0.005
Deep-fried snacks	0.433 ± 0.034	0.447 ± 0.032	0.594 ± 0.033	0.766 ± 0.032	<0.0001
Sweets	0.537 ± 0.042	0.574 ± 0.038	0.554 ± 0.04	0.648 ± 0.039	0.09
Coconut	0.051 ± 0.015	0.07 ± 0.013	0.084 ± 0.014	0.142 ± 0.014	<0.0001
Dairy	3.78 ± 0.13	3.62 ± 0.12	3.47 ± 0.12	3.25 ± 0.12	0.002
Animal fat	0.603 ± 0.045	0.457 ± 0.041	0.434 ± 0.042	0.263 ± 0.042	<0.0001
Meat	0.630 ± 0.029	0.396 ± 0.027	0.194 ± 0.028	0.001 ± 0.027	<0.0001
Egg	0.418 ± 0.025	0.307 ± 0.023	0.186 ± 0.024	0.078 ± 0.023	<0.0001
Fish and seafood	0.259 ± 0.015	0.16 ± 0.014	0.089 ± 0.015	0.019 ± 0.014	<0.0001
Miscellaneous animal foods	0.285 ± 0.016	0.225 ± 0.015	0.166 ± 0.015	0.108 ± 0.015	<0.0001
Milk desserts	0.193 ± 0.013	0.164 ± 0.012	0.158 ± 0.012	0.134 ± 0.012	0.001
Healthy plant–based diet index					
Participants, *n*	217	244	218	212	
Mean ± SEM	50.1 ± 0.29	59.2 ± 0.13	65.4 ± 0.11	73.2 ± 0.27	
Age, years	53.0 ± 0.64	54.2 ± 0.59	56.0 ± 0.62	58.0 ± 0.64	<0.0001
Sex % female	28.6	46.7	55.1	58.0	<0.0001
Years lived in the US, years	29.1 ± 0.67	26.7 ± 0.60	25.9 ± 0.63	26.4 ± 0.64	0.002
Birth country	—	—	—	—	0.0003
India	74.7	82.4	88.1	90.1	
Pakistan	7.83	5.74	2.29	1.42	
Bangladesh	0.46	0.82	0.92	0	
Nepal	0	0.82	0.46	0.47	
Sri Lanka	1.84	2.46	2.29	5.66	
Other	15.2	9.43	7.8	7.1	
Bachelor's degree or more, %	85.3	88.5	89.0	88.2	0.35
Questionnaire in Hindi or Urdu, %	3.69	6.56	4.59	2.36	0.33
Family income >$75,000, %	72.1	74.0	77.6	70.2	0.90
Sum of cultural traditions measures[2]	14.7 ± 0.44	14.1 ± 0.40	14.0 ± 0.42	13.2 ± 0.44	0.03
Smoking category, %					
Never	71.0	84.0	86.7	91.5	<0.0001
Former	21.2	15.2	11.5	6.1	
Current	7.8	0.8	1.8	2.4	
Tobacco pack-year consumption	3.210 ± 0.41	1.33 ± 0.37	1.04 ± 0.39	0.52 ± 0.40	<0.0001
Alcohol, % with 1+ drinks/week	45.6	35.7	29.4	20.3	<0.0001
Physical activity, MET-min/week	10102 ± 282	9934 ± 256	10013 ± 271	10570 ± 279	0.25
TV watching, min/week	640 ± 32	521 ± 29	517 ± 30	533 ± 31	0.02
BMI, kg/m2	26.5 ± 0.29	26.5 ± 0.26	25.6 ± 0.28	25.3 ± 0.28	0.002
Waist circumference, cm	93.4 ± 0.69	93.8 ± 0.63	91.6 ± 0.66	91.1 ± 0.68	0.004
Controlled hyperlipidemia, %	75.9	77.6	80.8	83.9	0.03
Hypertension, %	37.5	40.9	36.7	45.3	0.20
Diabetes categories, %					
Normal	55.6	62.6	66.5	61.4	0.38
Prediabetes	23.6	15.6	16.1	16.2	
Diabetes	20.8	21.8	17.4	22.4	
Family history of diabetes, %	58.4	53.6	54.8	54.5	0.51
Medication use, %					
Diabetes medication	13.8	17.2	14.7	18.4	0.33
Hypertension medication	27.2	30.7	28.9	34.4	0.16
Cholesterol-lowering medication	27.2	27.5	27.5	36.3	0.50
Cardiometabolic risk factors					
Triglycerides,[3] mmol/L	1.14 ± 1.01	1.12 ± 1.01	1.11 ± 1.01	1.16 ± 1.01	0.72
LDL-C, mmol/L	3.02 ± 0.058	2.90 ± 0.052	2.87 ± 0.055	2.78 ± 0.057	0.005
HDL-C, mmol/L	1.30 ± 0.022	1.30 ± 0.02	1.32 ± 0.021	1.30 ± 0.022	0.66
Fasting glucose,[3] mmol/L	2.11 ± 1.01	2.10 ± 1.006	2.08 ± 1.01	2.09 ± 1.01	0.28
HbA1c, %	6.12 ± 0.06	6.11 ± 0.054	6.00 ± 0.057	5.99 ± 0.059	0.09
β-cell function[3,4]	1.32 ± 1.03	1.41 ± 1.03	1.44 ± 1.03	1.39 ± 1.03	0.23
HOMA-IR[4]	1.57 ± 1.02	1.56 ± 1.02	1.43 ± 1.02	1.43 ± 1.02	<0.0001

(*Continued*)

TABLE 1 (*Continued*)

Characteristic	Quartiles 1	2	3	4	*P*-trend
Subcutaneous fat area, cm2	244 ± 6.71	247 ± 6.17	239 ± 6.58	224 ± 6.66	0.04
Visceral fat area, cm2	141 ± 3.67	141 ± 3.34	127 ± 3.56	125 ± 3.67	<0.0001
Pericardial fat volume, cm3	63.1 ± 1.94	59.4 ± 1.75	55.5 ± 1.86	54.2 ± 1.92	0.001
Hepatic fat attenuation, HU	53.4 ± 0.723	54.7 ± 0.652	56.1 ± 0.696	57.0 ± 0.712	<0.0001
C-reactive protein,[3] mg/L	1.21 ± 1.03	1.18 ± 1.03	1.08 ± 1.03	1.09 ± 1.03	0.006
Adiponectin, mg/dL	53.8 ± 1.02	53.4 ± 1.02	55.7 ± 1.02	56.9 ± 1.02	0.02
Coronary artery calcium score	2.21 ± 1.06	2.13 ± 1.06	2.27 ± 1.06	2.10 ± 1.06	0.71
Common carotid IMT, mm	0.939 ± 1.01	0.938 ± 1.01	0.93 ± 1.01	0.921 ± 1.01	0.03
Internal carotid IMT, mm3	1.08 ± 1.01	1.062 ± 1.01	1.058 ± 1.01	1.041 ± 1.01	0.006
Foods, servings/d					
Whole grains	1.50 ± 0.067	1.97 ± 0.06	2.10 ± 0.06	2.38 ± 0.07	<0.0001
Fruits	1.90 ± 0.094	2.17 ± 0.085	2.51 ± 0.09	2.84 ± 0.093	<0.0001
Vegetables	3.78 ± 0.136	4.44 ± 0.123	4.67 ± 0.131	5.25 ± 0.135	<0.0001
Herbs and spices	2.45 ± 0.093	3.01 ± 0.085	3.06 ± 0.090	3.26 ± 0.092	<0.0001
Tea and coffee	2.01 ± 0.094	2.183 ± 0.085	2.23 ± 0.090	2.00 ± 0.093	0.951
Nuts	0.539 ± 0.042	0.744 ± 0.038	0.886 ± 0.040	1.09 ± 0.041	<0.0001
Legumes	0.716 ± 0.047	1.122 ± 0.043	1.353 ± 0.046	1.581 ± 0.047	<0.0001
Sugar-sweetened beverages	0.11 ± 0.015	0.106 ± 0.014	0.129 ± 0.015	0.13 ± 0.015	0.25
Potatoes	0.503 ± 0.033	0.351 ± 0.03	0.272 ± 0.031	0.237 ± 0.032	<0.0001
Refined grains	0.385 ± 0.03	0.39 ± 0.027	0.312 ± 0.029	0.288 ± 0.03	0.008
Deep-fried snacks	1.236 ± 0.048	0.926 ± 0.043	0.803 ± 0.046	0.558 ± 0.047	<0.0001
Sweets	0.610 ± 0.034	0.630 ± 0.031	0.587 ± 0.033	0.427 ± 0.034	<0.0001
Coconut	0.849 ± 0.039	0.629 ± 0.035	0.504 ± 0.037	0.338 ± 0.038	<0.0001
Dairy	0.115 ± 0.014	0.079 ± 0.013	0.117 ± 0.014	0.044 ± 0.014	0.006
Animal fat	3.46 ± 0.122	3.42 ± 0.111	3.73 ± 0.118	3.49 ± 0.121	0.50
Meat	0.624 ± 0.043	0.494 ± 0.039	0.357 ± 0.042	0.254 ± 0.043	<0.0001
Egg	0.585 ± 0.03	0.313 ± 0.027	0.195 ± 0.029	0.093 ± 0.03	<0.0001
Fish and seafood	0.363 ± 0.025	0.256 ± 0.023	0.195 ± 0.024	0.154 ± 0.025	<0.0001
Miscellaneous animal foods	0.218 ± 0.016	0.14 ± 0.014	0.094 ± 0.015	0.061 ± 0.015	<0.0001
Milk desserts	0.283 ± 0.016	0.205 ± 0.014	0.166 ± 0.015	0.119 ± 0.016	<0.0001
Unhealthy plant–based diet index					
Participants, *n*	229	224	217	221	
Mean ± SEM	51.9 ± 0.24	59.2 ± 0.10	63.9 ± 0.09	70.4 ± 0.20	
Age, years	56.3 ± 0.64	55.6 ± 0.62	55.8 ± 0.64	53.4 ± 0.65	0.005
Sex, % female	53.2	45.1	43.3	46.2	0.12
Years lived in the US, years	28.1 ± 0.64	27.7 ± 0.63	27.0 ± 0.64	25.1 ± 0.65	0.002
Birth country	—	—	—	—	0.07
India	81.2	79.5	88.0	86.4	
Pakistan	5.68	6.7	3.23	1.81	
Bangladesh	0.44	0.89	0.46	0.45	
Nepal	0.87	0.45	0	0.45	
Sri Lanka	0.87	0.45	1.38	1.36	
Other	10.9	12.1	6.90	9.48	
Bachelor's degree or more, %	89.1	86.2	88.5	87.3	0.76
Questionnaire in Hindi or Urdu, %	1.31	5.36	6.45	4.52	0.08
Family income >$75,000, %	74.4	75.6	73.2	70.8	0.32
Sum of cultural traditions measures[2]	15.0 ± 0.43	14.2 ± 0.42	14.3 ± 0.42	12.4 ± 0.43	<0.0001
Smoking category, %					
Never	80.8	82.1	83.4	86.9	0.05
Former	14.9	14.7	12.9	11.8	
Current	4.4	3.13	3.69	1.36	
Tobacco pack-year consumption	1.56 ± 0.40	2.07 ± 0.39	1.15 ± 0.40	1.25 ± 0.41	0.35
Alcohol, % with 1+ drinks/week	39.3	35.7	31.8	24.4	0.0006
Physical activity, MET-min/week	10432 ± 273	10212 ± 267	10283 ± 273	9644 ± 278	0.07
TV watching, min/week	520 ± 31	574 ± 30	555 ± 31	559 ± 31	0.48
BMI, kg/m2	26.1 ± 0.28	26.3 ± 0.27	25.9 ± 0.28	25.8 ± 0.29	0.39
Waist circumference, cm	93.0 ± 0.67	92.7 ± 0.66	92.7 ± 0.67	91.7 ± 0.69	0.22
Controlled hyperlipidemia, %	75.3	79.7	76.7	86.2	0.02
Hypertension, %	43.7	39.7	36.9	39.8	0.32

(*Continued*)

TABLE 1 (*Continued*)

Characteristic	Quartiles 1	2	3	4	*P*-trend
Diabetes categories, %					
Normal	60.1	62.8	57.7	65.6	0.54
Prediabetes	18.4	17.5	20.9	14.5	
Diabetes	21.5	19.7	21.4	19.9	
Family history of diabetes, %	58.3	55.8	52.7	54.2	0.32
Medication use, %					
Diabetes medication	17.5	13.0	17.1	16.7	0.87
Hypertension medication	30.6	30.4	30.9	29.4	0.83
Cholesterol-lowering medication	29.7	31.3	28.6	28.5	0.65
Cardiometabolic risk factors					
Triglycerides,[3] mmol/L	1.12 ± 1.01	1.12 ± 1.01	1.14 ± 1.01	1.15 ± 1.01	0.14
LDL-C, mmol/L	2.98 ± 0.056	2.87 ± 0.055	2.90 ± 0.056	2.81 ± 0.057	0.06
HDL-C, mmol/L	1.34 ± 0.021	1.31 ± 0.021	1.28 ± 0.021	1.29 ± 0.022	0.06
Fasting glucose,[3] mmol/L	2.11 ± 1.01	2.09 ± 1.01	2.11 ± 1.01	2.07 ± 1.01	0.035
HbA1c, %	6.11 ± 0.06	6.01 ± 0.06	6.05 ± 0.06	6.04 ± 0.06	0.47
β-cell function[3,4]	1.34 ± 1.03	1.38 ± 1.03	1.42 ± 1.03	1.42 ± 1.03	0.18
HOMA-IR[4]	1.52 ± 1.02	1.50 ± 1.02	1.50 ± 1.02	1.47 ± 1.02	0.31
Subcutaneous fat area, cm2	236 ± 6.70	239 ± 6.34	241 ± 6.57	239 ± 6.71	0.78
Visceral fat area, cm2	130 ± 3.62	139 ± 3.52	132 ± 3.60	133 ± 3.67	0.74
Pericardial fat volume, cm3	57.2 ± 1.89	58.6 ± 1.84	57.2 ± 1.88	59.3 ± 1.93	0.57
Hepatic fat attenuation, HU	55.5 ± 0.706	55.3 ± 0.687	55.3 ± 0.703	55.1 ± 0.721	0.71
C-reactive protein,[3] mg/L	1.13 ± 1.03	1.16 ± 1.03	1.11 ± 1.03	1.15 ± 1.03	0.89
Adiponectin, mg/dL	56.2 ± 1.02	53.2 ± 1.02	55.2 ± 1.02	54.9 ± 1.02	0.58
Coronary artery calcium score	2.21 ± 1.06	2.28 ± 1.058	2.07 ± 1.06	2.13 ± 1.06	0.46
Common carotid IMT, mm	0.925 ± 1.01	0.937 ± 1.01	0.934 ± 1.01	0.932 ± 1.01	0.46
Internal carotid IMT, mm[3]	1.06 ± 1.01	1.05 ± 1.01	1.06 ± 1.01	1.07 ± 1.01	0.45
Foods, servings/d					
Whole grains	2.10 ± 0.068	2.02 ± 0.066	1.88 ± 0.067	1.94 ± 0.069	0.06
Fruits	2.71 ± 0.093	2.43 ± 0.09	2.27 ± 0.092	1.97 ± 0.094	<0.0001
Vegetables	5.32 ± 0.131	4.77 ± 0.128	4.24 ± 0.131	3.74 ± 0.133	<0.0001
Herbs/spices	3.22 ± 0.091	3.15 ± 0.089	2.90 ± 0.091	2.51 ± 0.093	<0.0001
Tea and coffee	2.57 ± 0.088	2.18 ± 0.086	2.12 ± 0.088	1.54 ± 0.09	<0.0001
Nuts	1.04 ± 0.041	0.882 ± 0.04	0.749 ± 0.041	0.572 ± 0.042	<0.0001
Legumes	1.15 ± 0.05	1.16 ± 0.049	1.17 ± 0.05	1.29 ± 0.051	0.09
Sugar-sweetened beverages	0.141 ± 0.015	0.143 ± 0.014	0.110 ± 0.015	0.078 ± 0.015	0.002
Potatoes	0.200 ± 0.032	0.312 ± 0.031	0.380 ± 0.032	0.479 ± 0.032	<0.0001
Refined grains	0.246 ± 0.029	0.346 ± 0.028	0.365 ± 0.029	0.43 ± 0.03	<0.0001
Deep-fried snacks	0.521 ± 0.046	0.812 ± 0.045	0.964 ± 0.046	1.25 ± 0.047	<0.0001
Sweets	0.325 ± 0.032	0.542 ± 0.031	0.646 ± 0.032	0.765 ± 0.033	<0.0001
Coconut	0.400 ± 0.039	0.629 ± 0.038	0.614 ± 0.039	0.69 ± 0.04	<0.0001
Dairy	0.028 ± 0.014	0.073 ± 0.013	0.137 ± 0.014	0.12 ± 0.014	<0.0001
Animal fat	4.05 ± 0.117	3.51 ± 0.114	3.38 ± 0.117	3.11 ± 0.119	<0.0001
Meat	0.48 ± 0.043	0.416 ± 0.042	0.449 ± 0.043	0.387 ± 0.044	0.203
Egg	0.407 ± 0.031	0.349 ± 0.03	0.272 ± 0.031	0.147 ± 0.031	<0.0001
Fish and seafood	0.380 ± 0.024	0.311 ± 0.023	0.173 ± 0.024	0.093 ± 0.024	<0.0001
Miscellaneous animal foods	0.227 ± 0.015	0.111 ± 0.015	0.115 ± 0.015	0.055 ± 0.015	<0.0001
Milk desserts	0.224 ± 0.016	0.214 ± 0.015	0.178 ± 0.016	0.155 ± 0.016	0.001

[1]Values are age, sex, and calorie-adjusted means (SEM) or percentages, calculated using linear regression for continuous variables and chi-square tests for categorical variables. Abbreviations: HbA1c, glycated hemoglobin; HU, Hounsfield units; IMT, intima media thickness; MASALA, Mediators of Atherosclerosis in South Asians Living in America; MET, metabolic equivalents of task.

[2]Higher scores indicate weaker traditional cultural beliefs.

[3]Values were log-transformed to obtain a normal distribution of the residuals and transformed back into geometric means.

[4]The β-cell function was measured using the oral disposition index.

the visceral fat area, hepatic fat attenuation, and the pericardial fat volume, are particularly striking. Ectopic fat accumulation in the abdomen, liver, and around the heart is a major risk factor for cardiometabolic diseases, independent of overall and central adiposity (31–34). Therefore, our finding of a strong, inverse association between a healthy plant–based diet and ectopic fat depots is significant for several reasons. First, compared to other ethnic groups, participants from South Asian countries have less favorable body composition profiles, including more visceral fat, more pericardial fat, and a higher prevalence of fatty liver (35),

TABLE 2 Cross-sectional associations between plant-based diet scores and measures of cardiometabolic risk among participants with South Asian ancestry, aged 40–84 years, in the MASALA study[1]

			PDI		hPDI		uPDI	
	n[2]	Model[3]	Score	P value	Score	P value	Score	P value
Subclinical measures of atherosclerosis								
Coronary artery calcium score[4]	884	1	−3.25 ± 4.93	0.50	−0.138 ± 4.19	0.97	0.447 ± 5.14	0.93
		2	−2.51 ± 4.93	0.60	1.10 ± 4.20	0.79	0.428 ± 5.12	0.93
Common carotid IMT, mm3	890	1	−0.002 ± 0.503	0.99	−0.115 ± 0.427	0.79	0.472 ± 0.522	0.37
		2	0.177 ± 0.499	0.72	0.104 ± 0.426	0.81	0.519 ± 0.517	0.32
Internal carotid IMT, mm3	889	1	−0.749 ± 0.667	0.26	−0.759 ± 0.568	0.18	0.210 ± 0.694	0.76
		2	−0.598 ± 0.564	0.36	−0.563 ± 0.564	0.32	0.229 ± 0.685	0.74
Glycemia measures among nondiabetics								
Fasting glucose,[4] mmol/L	664	1	−1.12 ± 0.347	0.001	−0.592 ± 0.299	0.05	−0.725 ± 0.354	0.04
		2	−1.03 ± 0.347	0.003	−0.521 ± 0.298	0.08	−0.668 ± 0.352	0.06
HbA1c, %	660	1	−0.284 ± 0.163	0.08	−0.476 ± 0.138	0.001	0.180 ± 0.165	0.28
		2	−0.224 ± 0.161	0.17	−0.428 ± 0.137	0.002	0.224 ± 0.163	0.17
β-cell function[4,5]	543	1	4.15 ± 2.42	0.09	2.44 ± 2.07	0.24	0.52 ± 2.52	0.83
		2	3.73 ± 2.42	0.13	2.11 ± 2.07	0.31	0.15 ± 2.51	0.95
HOMA-IR[4]	613	1	−4.97 ± 1.87	0.006	−5.24 ± 1.61	0.001	−3.13 ± 1.95	0.10
		2	−3.46 ± 1.65	0.03	−4.02 ± 1.42	0.004	−1.68 ± 1.72	0.32
Lipids								
Triglycerides,[4] mmol/L	888	1	0.465 ± 1.127	0.68	−0.116 ± 0.962	0.90	1.11 ± 1.17	0.34
		2	1.05 ± 1.11	0.35	0.557 ± 0.950	0.56	1.31 ± 1.15	0.25
HDL-C, mmol/L	888	1	−0.003 ± 0.008	0.67	0.009 ± 0.007	0.19	−0.003 ± 0.008	0.76
		2	−0.007 ± 0.008	0.34	0.004 ± 0.007	0.53	−0.004 ± 0.008	0.64
LDL-C, mmol/L	881	1	−0.088 ± 0.019	<0.0001	−0.045 ± 0.016	0.006	−0.046 ± 0.020	0.02
		2	−0.081 ± 0.019	<0.0001	−0.040 ± 0.016	0.02	−0.042 ± 0.020	0.04
Inflammation and adipokines								
C-reactive protein,[4] mg/L	878	1	−2.71 ± 2.64	0.29	−5.68 ± 2.25	0.009	−1.27 ± 2.74	0.64
		2	−0.67 ± 2.42	0.78	−2.95 ± 2.07	0.15	−0.84 ± 2.49	0.73
Adiponectin, mg/dL	869	1	1.00 ± 1.28	0.43	2.86 ± 1.09	0.009	0.09 ± 1.32	0.95
		2	0.57 ± 1.27	0.65	2.32 ± 1.08	0.03	−0.05 ± 1.31	0.97
Body composition measures								
Weight, kg	891	1	−0.720 ± 0.280	0.01	−0.750 ± 0.241	0.002	−0.428 ± 0.295	0.15
BMI, kg/m2	889	1	−0.222 ± 0.102	0.03	−0.279 ± 0.087	0.001	−0.051 ± 0.107	0.63
Waist circumference, cm	889	1	−0.514 ± 0.241	0.03	−0.620 ± 0.205	0.003	−0.264 ± 0.251	0.29
		2	−0.041 ± 0.142	0.77	−0.084 ± 0.121	0.49	−0.084 ± 0.147	0.57
Subcutaneous fat area, cm2	812	1	0.92 ± 2.33	0.69	−2.81 ± 1.97	0.16	2.04 ± 2.44	0.40
		2	3.31 ± 1.74	0.06	1.09 ± 1.48	0.46	1.94 ± 1.83	0.29
Visceral fat area, cm2	866	1	−3.04 ± 1.31	0.02	−4.55 ± 1.11	<0.0001	0.62 ± 1.37	0.65
		2	−1.51 ± 1.08	0.16	−2.55 ± 0.92	0.006	0.81 ± 1.12	0.47
Pericardial fat volume, cm3	878	1	−1.34 ± 0.658	0.04	−2.26 ± 0.559	<0.0001	0.636 ± 0.690	0.36
		2	−0.586 ± 0.570	0.30	−1.31 ± 0.487	0.007	0.852 ± 0.594	0.15
Hepatic fat attenuation, HU	875	1	0.377 ± 0.246	0.13	0.751 ± 0.207	0.0003	−0.095 ± 0.256	0.71
		2	0.201 ± 0.229	0.38	0.511 ± 0.194	0.009	−0.121 ± 0.238	0.61

[1]Values represent multivariable-adjusted changes in cardiometabolic risk markers (β ± SE or % increase ± SE for log-transformed variables) for each 5-unit increase in plant-based diet scores, calculated using multivariable linear regression. Abbreviations: HbA1C, glycated hemoglobin; hPDI, healthy plant–based diet index; HU, Hounsfield units; IMT, intima media thickness; MASALA, Mediators of Atherosclerosis in South Asians Living in America; PDI, plant-based diet index; uPDI, unhealthy plant–based diet index.

[2]Numbers of participants vary due to missing values for outcome variables or covariates or to outliers.

[3]Multivariable-adjusted model 1 was adjusted for age, sex, study site, education (Bachelor's degree or higher, yes compared with no), smoking status (never, former, current), alcohol (yes compared with no), family history of diabetes (any first-degree biological relatives), years lived in the United States, physical activity (MET-min/week), total energy, diabetes medication use, cholesterol-lowering medication use (yes compared with no), hypertension medication use (yes compared with no), and the sum of cultural traditional measures using multivariable linear regression. Multivariable model 2 was additionally adjusted for BMI (kg/m^2).

[4]Values were log-transformed to obtain a normal distribution of the residuals. For outcomes that were log-transformed, values represent percentage increases in outcome variable for every 5-unit increase in the diet index score.

[5]The β-cell function was measured using the oral disposition index.

which may partially explain the disparities in cardiovascular risks by ethnicity (35–38). Second, given that a substantial proportion of participants from South Asia are vegetarian, for effective health promotion it is crucial to advocate for the consumption of healthy plant–based diets rather than the simple exclusion of animal foods. Third, because there are limited therapeutic options for lowering ectopic fat, consumption of a healthy plant–based diet remains among the strongest, modifiable risk factors for

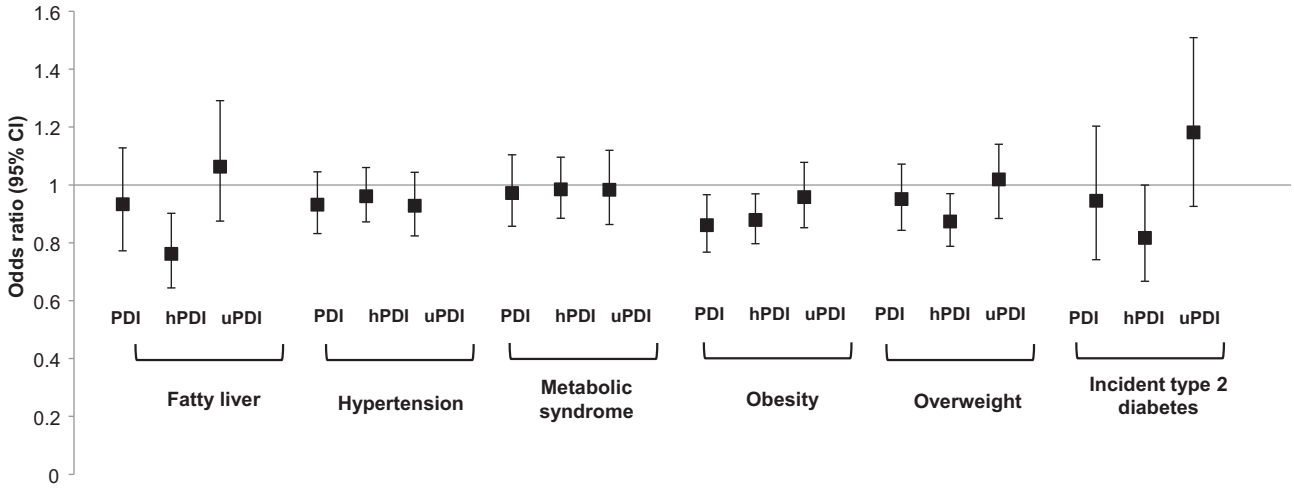

FIGURE 1 Likelihood (ORs and 95% CIs) of fatty liver ($n = 878$; cases = 80), hypertension ($n = 891$; cases = 357), metabolic syndrome ($n = 889$; cases = 306), obesity ($n = 891$; cases = 270), overweight ($n = 891$; cases = 677), and incident type 2 diabetes ($n = 45$) per 5-unit increase in the PDI, hPDI, or uPDI score. The multivariable model was adjusted for age, sex, study site, education (Bachelor's degree or higher, yes compared with no), smoking status (never, former, current), alcohol (yes compared with no), family history of diabetes (any first-degree biological relatives), years lived in the United States, exercise (MET-min/week), total energy, diabetes medication use, cholesterol-lowering medication use (yes compared with no), hypertension medication use (yes compared with no), sum of cultural traditional measures, and BMI (except for obesity and overweight) using logistic regression (PROC LOGISTIC, SAS Institute). Fatty liver is defined as liver-spleen attenuation <40 Hounsfield units. Hypertension is defined using the National Cholesterol Education Program criteria as having blood pressure ≥140/90 mmHg or being on medication. Obesity is defined as a BMI ≥27.5 kg/m^2. Overweight is defined as a BMI ≥23 kg/m^2. Abbreviations: hPDI, healthy plant–based diet index; MET, metabolic equivalents of task; PDI, plant-based diet index; uPDI, unhealthy plant–based diet index.

prevention of ectopic fat accumulation. Although our study is cross-sectional, our findings are similar to those in the Multi-Ethnic Study of Atherosclerosis cohort, where a higher dietary quality score based on the principles of a Mediterranean-type diet was associated with lower ectopic fat depots, including less visceral fat and less pericardial fat, and a lower prevalence hepatic steatosis, but not with subcutaneous fat measures (39). Future studies will need to confirm our findings with a prospective design.

TABLE 3 Prospective associations between plant-based diet indices and change in cardiometabolic risk markers among participants with South Asian ancestry, aged 40–84 years, in the MASALA study[1]

			PDI		hPDI		uPDI	
	n[2]	Model[3]	Score	P value	Score	P value	Score	P value
Glycemia measures among nondiabetics								
Fasting glucose,[4] mmol/L	556	1	−0.400 ± 0.321	0.21	−0.348 ± 0.271	0.20	0.003 ± 0.322	0.99
		2	−0.374 ± 0.320	0.24	−0.313 ± 0.270	0.25	0.015 ± 0.321	0.96
HbA1c, %	553	1	0.064 ± 0.170	0.71	0.034 ± 0.145	0.82	0.158 ± 0.170	0.36
		2	0.064 ± 0.171	0.71	0.033 ± 0.145	0.82	0.158 ± 0.171	0.36
Lipids								
Triglycerides,[4] mmol/L	733	1	−0.629 ± 0.964	0.51	−0.499 ± 0.821	0.54	0.598 ± 0.993	0.55
		2	−0.608 ± 0.966	0.53	−0.413 ± 0.825	0.61	0.546 ± 0.993	0.58
HDL-C, mmol/L	732	1	0.005 ± 0.006	0.36	0.003 ± 0.005	0.52	0.004 ± 0.006	0.51
		2	0.006 ± 0.006	0.31	0.004 ± 0.005	0.46	0.004 ± 0.006	0.46
LDL-C, mmol/L	728	1	−0.027 ± 0.021	0.19	−0.006 ± 0.017	0.74	0.005 ± 0.021	0.81
		2	−0.026 ± 0.021	0.20	−0.007 ± 0.017	0.70	0.007 ± 0.021	0.74
Body composition measures								
Weight, kg	730	1	−0.209 ± 0.106	0.05	0.004 ± 0.091	0.96	−0.072 ± 0.109	0.51

[1] Values represent multivariable-adjusted changes in cardiometabolic risk markers ($\beta \pm$ SE or % increase ± SE for log-transformed variables) for each 5-unit increase in plant-based diet scores, calculated using multivariable linear regression. Abbreviations: HbA1C, glycated hemoglobin; hPDI, healthy plant–based diet index; MASALA, Mediators of Atherosclerosis in South Asians Living in America; PDI, plant-based diet index; uPDI, unhealthy plant–based diet index.

[2] Numbers of participants vary due to missing values for outcome variables or to outliers.

[3] Multivariable-adjusted model 1 was adjusted for age, sex, study site, education (Bachelor's degree or higher, yes compared with no), smoking status (never, former, current), alcohol (yes compared with no), family history of diabetes (any first-degree biological relatives), years lived in the United States, physical activity (MET-min/week), total energy, diabetes medication use, cholesterol-lowering medication use (yes compared with no), hypertension medication use (yes compared with no), the sum of cultural traditional measures, and the baseline value of the corresponding cardiometabolic risk marker using multivariable linear regression. Multivariable model 2 was additionally adjusted for BMI (kg/m^2).

[4] Values were log-transformed to approximate a normal distribution of the residuals.

While MASALA only accrued 45 incident T2D cases over an average of 5 years of follow-up, we were still able to identify that for each 5-unit higher hPDI score, the risk of incident T2D was lower by 18%. Importantly, the uPDI was associated, although nonsignificantly, with an 18% higher risk of T2D. The symmetry of these associations also supports the need to focus on the quality of plant-based foods for chronic disease reduction. This is of particular importance in a South Asian population, where the prevalence of T2D is high (11) and individuals often develop the disease at a younger age and a lower BMI (13).

It is possible that the degree of processing may have affected the observed associations. For instance, foods in the uPDI are all highly processed, while certain foods in the hPDI are unprocessed. When we accounted for the degree of processing in the hPDI by creating 2 subindices, a processed hPDI and an unprocessed hPDI, the findings were not materially different between these 2 subindices and the overall hPDI (Supplemental Tables 2 and 3). This may be because the quality of plant-based diets could be a more important indicator than the degree of processing, although our study was not designed to examine this research question. Additionally, a modified hPDI that included fish, poultry, and yogurt was not associated with LDL cholesterol and adiponectin, which is not surprising given how animal foods are consumed as part of the diet. Among participants from South Asia, consumption of processed meats is not high and, when animal foods are typically consumed, they replace vegetables.

Our findings are consistent with previous studies that examined the associations between vegetarianism and cardiometabolic risks among those from South Asia. In a random sample of 1038 people of Asian Indian descent in the United States, vegetarianism—defined as a primarily lacto-vegetarian diet without consumption of eggs, meat, fish, or poultry—was associated with lower odds of prevalent T2D but not metabolic syndrome or obesity (40). Our study is the first to document an inverse association between healthy plant–based diets and incident T2D among participants from South Asia. In an earlier analysis of the MASALA study, Gadgil et al. (41) identified a dietary pattern with consumption of fruits, vegetables, nuts, and legumes that is like the hPDI, and found this pattern to be associated with lower HOMA-IR values. More recently, in the MASALA study, Jin et al. (42) found that a vegetarian diet—defined as a diet without consumption of meat, fish, or poultry—was associated with lower BMIs; lower measures of visceral fat, total and LDL cholesterol, and fasting glucose; insulin resistance; and lower odds of fatty liver and coronary artery calcium (only in men). However, this study did not differentiate between the quality of plant-based foods. For example, there were no differences between vegetarians and nonvegetarians in the consumption of low-quality plant foods, such as refined grains, snacks, sugar, candy, jams, sugar-sweetened beverages, and starchy vegetables, or in the consumption of high-quality plant foods, such as fruits, nuts, and vegetables. In another Asian population, higher uPDI scores, but not hPDI scores, were associated with a higher risk of incident metabolic syndrome (HR: 1.44; 95% CI: 1.26, 1.64) (43). Similar to our findings, when examining individual components, higher adherence to the uPDI was associated with 46% higher odds (95% CI: 25%, 71%) of abdominal obesity in this group. Although not among participants from South Asia, a comprehensive meta-analysis found an inverse association between an overall PDI score and T2D, with the hPDI score having stronger, inverse associations with T2D (44).

In addition to its health benefits, a healthy plant–based diet is also environmentally sustainable, as it is in line with the universal healthy reference diet recommended by the EAT-Lancet commission on healthy diets from sustainable food systems (45). Like the universal healthy reference diet or the planetary health diet, the hPDI is based on increasing consumption of healthy foods, such as vegetables, fruits, whole grains, legumes, and nuts, and decreasing consumption of unhealthy foods, such as red meat, sugar, and refined grains. Importantly, like the planetary health diet, a diet that scores high on the hPDI not only focuses on healthy plant–based foods but also allows for moderate consumption of some animal foods. This is particularly useful in a South Asian population, where dairy consumption is common even among those who do not consume meat and where more than a third of the population consumes eggs, fish, or meat on a weekly basis (46). For example, in our study, those in the highest quartile of the hPDI scores consumed, on average, 0.09 servings per day of meat, while those in the lowest quartile consumed, on average, 0.59 servings of meat per day. Although the US Dietary Guidelines for Americans consider sustainability to be beyond their scope, it is critical to incorporate environmental sustainability to provide Americans with a more holistic recommendation. In fact, a recent study by Blackstone and colleagues (47) noted that among the 3 different diets recommended by the 2015–2020 Dietary Guidelines, the healthy vegetarian diet produced a 42%–84% lower environmental burden than the other 2 diets.

The strengths of the current study include the availability of dietary data, collected with a previously validated, ethnic-specific FFQ that captured foods unique to the South Asian diet. The MASALA study is the only prospective cohort of participants from South Asia in the United States with detailed data on subclinical atherosclerosis, body composition, and fasting blood measures. In addition to traditional risk factors, we were able to account for confounding due to ethnic-specific measures, such as adherence to cultural traditions. Still, our findings need to be interpreted in the context of a few limitations. First, although we adjusted for a comprehensive list of confounders, residual confounding remains a possibility given the observational nature of the study. Second, we did not have data on all cardiometabolic risk factors at follow-up. Third, we were limited in our power for the prospective analyses, as we only had 45 incident T2D cases. However, continued follow-up of the MASALA cohort will determine whether the uPDI is associated with a higher risk of incident T2D. At the same time, we will also be able to examine associations between hPDI scores, uPDI scores, and incident cardiovascular outcomes. Fourth, measurement errors are inevitable in collecting FFQ data. However, these are likely nondifferential in nature and will, therefore, result in attenuated associations. Fifth, although we collected dietary data at follow-up, we did not include information on changes in diet between the 2 cycles, as this was outside the scope of the present study. Finally, this study was conducted among a cohort of participants with South Asian ancestry who had a high socioeconomic status. It is not clear whether these findings extend to participants living in South Asia and participants of South Asian ancestry with a lower socioeconomic background.

In conclusion, we found that while consuming an overall plant-based diet was associated with lower cardiometabolic risks, the risks were much lower for those consuming a healthy plant–based diet. Future intervention and policy efforts to lower cardiometabolic risks in this high-risk population should focus on promoting a healthy plant–based diet, since it is associated with better health outcomes and is also environmentally sustainable.

The authors' responsibilities were as follows—SNB, FBH, and AMK: designed the research; NRK and AMK: provided essential materials; SNB, CMS, and UPG: analyzed data and performed the statistical analysis; SNB: wrote paper; SNB and AMK: share responsibility for the final content; and all authors: edited the manuscript and read and approved the final manuscript.

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The authors report no potential conflicts of interest relevant to this manuscript.

Data Availability

Data described in the article, code book, and analytic code will not be made publicly available. Further information, including the procedures to obtain and access data from the MASALA (Mediators of Atherosclerosis in South Asians Living in America) study, is described at https://www.masalastudy.org/for-researchers.

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