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Association between unhealthy plant-based diets and the metabolic syndrome in adult men and women: a population-based study in South Korea

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Abstract
No studies have investigated the associations between established plant-based diet indices and the metabolic syndrome (MetS). We evaluated the associations between an overall plant-based diet index (PDI), healthy PDI (hPDI), unhealthy PDI (uPDI) and the MetS in a nationally representative sample using data from 14 450 Korean adults (≥19 years) in the Korea National Health and Nutrition Examination Survey 2012–2016. Dietary intakes were assessed by a semi-quantitative FFQ. In the PDI, all plant foods received positive scores. In the hPDI, only healthy plant foods received positive scores. In the uPDI, only unhealthy plant foods received positive scores. All indices reverse scored animal food intake. Multivariable logistic regression models were used to examine the associations between three PDI and the MetS by sex, adjusting for potential risk factors. A total of 23·3 % of Korean adults had the MetS. In the overall study population, individuals in the highest quintile of uPDI had greater odds (OR 1·54, 95 % CI 1·28, 1·86, $P_{trend} < 0·001$) of the MetS than those in the lowest quintile. Higher uPDI score was associated with higher odds of hypertriacylglycerolaemia in men and abdominal obesity, high fasting glucose and hypertriacylglycerolaemia in women. No significant associations were observed between PDI, hPDI and the MetS. Greater adherence to unhealthy plant-based diets was associated with greater odds of the MetS and its components suggesting the importance of the quality of plant-based diet in South Korean adults. Sex differences may be considered when recommending plant-based diets for the prevention and management of metabolic diseases.

Key words: Plant-based diets: Metabolic syndrome: Korean population: Plant food quality: Sex differences

The metabolic syndrome (MetS), a cluster of conditions that includes several metabolic abnormalities (central obesity, elevated blood glucose, low levels of HDL-cholesterol, hypertriacylglycerolaemia and elevated blood pressure), is a strong predictor of type 2 diabetes, CVD and its mortality[1]. Globally, the prevalence of the MetS has been estimated to be as high as 39 %[2]. In the Asian-Pacific region, the prevalence ranges from 11 to 49 %[3].

Epidemiological studies have investigated the effect of plant food intake on the MetS, but findings have been inconsistent. Some studies reported a positive association between a plant-rich diet and the MetS or metabolic profiles (e.g. higher BMI and higher levels of TAG)[4–6], but others showed no association[7,8] or inverse association[9–11]. However, an important limitation in these previous studies is that they examined only the frequency of animal food intake (meat, fish, poultry and dairy products) without consideration of plant food consumption and did not assess the quality of plant foods (healthy and less healthy plant foods) which can influence metabolic risk factors[12–15].

Plant-based diet indices provide more comprehensive assessment of the diet in that it accounts for both plant foods and animal foods and distinguish the quality of plant foods. Recent studies using plant-based diet indices reported that plant-based diets may play an important role in chronic disease risk. Greater adherence to healthful plant-based diets, diets higher in nutrient-dense plant foods (i.e. fruits, vegetables, whole grains, nuts and legumes) and lower in refined carbohydrates, sugars and animal products were inversely associated with weight gain, hypertension, type 2 diabetes and CVD[16–19]. In contrast, unhealthful plant-based diets, diets higher in refined carbohydrates, sugars and lower in healthy plant foods and animal products, were associated with a higher risk of these cardiometabolic outcomes[16–20]. However, to our best of knowledge, no study has

Abbreviations: hPDI, healthy plant-based diet index; KNHANES, Korea National Health and Nutrition Examination Survey; MetS, metabolic syndrome; PDI, plant-based diet index; uPDI, unhealthy plant-based diet index.

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investigated whether plant-based diets or healthfulness of plant foods in the framework of an overall plant-based diet is associated with the MetS, a more proximal risk factor to these chronic conditions.

Furthermore, evidence on plant-based diets in Asian populations has been lacking although Asian population may have different dietary patterns, genetic and metabolic responses from Western populations[21–23]. In many Asian populations, particularly Koreans, a traditional diet is mainly composed of various plant foods with vegetables and rice[24]. Thus, more comprehensive examinations of plant-based diets are needed to understand if plant-based diets are related to the MetS in Asian populations who habitually consume relatively high amount of plant foods, and if the healthfulness or quality of plant foods is associated with the MetS. Also, sex-specific analysis may provide new insights on the diet–disease associations, but only a few studies have reported sex-specific results. Prior studies suggested that there may be sex difference on the association between dietary factors and chronic diseases[25,26].

In this context, we evaluated the associations between three different types of plant-based diets (overall plant-based diets, healthy plant-based diets and unhealthy plant-based diets) and odds of the MetS in a nationally representative sample of South Korean adults with high prevalence of the MetS[3].

Methods

Study population

This study was based on the fifth (2012), sixth (2013–2015) and seventh cycles (2016) of the Korea National Health and Nutrition Examination Survey (KNHANES). The KNHANES, conducted by the Korea Centers for Disease Control and Prevention, is an annual cross-sectional survey which assesses diet and health of the Korean population[27–29]. The KNHANES produces nationally representative estimates using a clustered, multistage and stratified sampling design. All participants provided written informed consent. The research was conducted according to the Declaration of Helsinki, and the protocol for KNHANES was approved by the Institutional Review Board of Korea Centers for Disease Control and Prevention.

Among 30 709 individuals ≥19 years (6293 in 2012, 6113 in 2013, 5976 in 2014, 5945 in 2015 and 6382 in 2016), we excluded the following individuals: 7755 with missing values on FFQ; 105 participants had extraordinary energy intake (<2092 or >20 920 kJ/d); 482 participants with CVD or stroke or cancer; 570 with missing values on MetS components and 7347 participants with missing information on covariates. A total of 14 450 Korean adults (5585 men and 8865 women) were included in this analysis.

Plant-based diet scores

Trained dietitians administered a validated 109-item semi-quantitative FFQ to assess participants' usual dietary intakes over the previous year[30]. Participants were asked to report the frequency with which they consumed a food item of a standard portion size. A standard portion size was defined as the average amount of a food item consumed per occasion in the Korean population. We added the amount and unit of a standard portion size (ml, g or number of items) for all food items to online Supplementary Table S1. Visual aids (two-dimensional bowls and plates, measuring cups and tablespoons) were used to illustrate portion size.

With the use of the approaches outlined in previous studies, we calculated scores for the overall plant-based diet index (PDI), healthy PDI (hPDI) and unhealthy PDI (uPDI)[16,17]. Briefly, each food item was categorised into eighteen food groups, and food groups were classified as healthful plant foods (i.e. whole grains, fruits, vegetables, nuts, legumes, tea and coffee), unhealthful plant foods (i.e. fruit juices, refined grains, potatoes, sweetened beverages, sweets and desserts and salty foods) and animal products (i.e. animal fat, dairy products, egg, fish or seafood, meat and miscellaneous animal foods) (online Supplementary Table S1). Food groups were considered healthful or unhealthful based on the reported associations in prior studies[16,17]. Sugar and cream that may be added to tea and coffee were asked separately in the questionnaire, allowing us to classify these beverages as healthy plant foods, sugar as an unhealthy plant food and cream as an animal food (animal fat). We considered salty foods (i.e. kimchi and other pickled vegetables) as unhealthful plant foods due to high Na content and prior associations with hypertension in the Korean population[31]. Although French fries are not how potatoes are mainly consumed in this population, we still classified potatoes as unhealthy plant foods because they are often stir fried with soya sauce, salt and oil and steamed potatoes are frequently consumed with salt. We grouped 109 food items into eighteen food groups as closely as possible to the previous studies of plant-based diet indices[16,19,20]. Foods that were unique to our sample were categorised by considering common food categorisation used in the Korean nutrient database[32]. To classify food items in the fruits and vegetables category, we used grouping set forth by the KNHANES[28]. We did not include vegetable oil as a food group, which was included in the original plant-based diet indices because the FFQ used in KNHANES did not assess consumption of oil.

After grouping food items to the appropriate food groups, we calculated energy-adjusted consumption of each of the eighteen food groups and divided their consumption into quintiles[33]. In all plant-based diet indices, animal foods were reverse scored. For the PDI, all plant food groups (regardless of healthfulness) were positively scored. For instance, participants in the highest quintile of vegetable consumption received a score of 5, whereas those in the lowest quintile received a score of 1. Conversely, participants in the highest quintile of meat consumption received a score of 1, whereas those in the lowest quintile received a score of five (reverse scored). For the hPDI, only the healthful plant foods received positive scores, whereas unhealthy plant foods received reverse scores. For the uPDI, only unhealthy plant foods received positive scores, and healthy plant received reverse scores. The theoretical range of PDI, hPDI and uPDI was 18–90. Nutrient intakes, including total energy intake, were calculated from the FFQ by multiplying amount of consumption of each food item by the nutrient content of each food item.

Measurement of metabolic risk factors

Trained researchers measured waist circumference, height, weight and blood pressure during a health examination. Waist circumference was measured to the nearest 0·1 cm at the narrowest point between the lowest rib and the uppermost lateral border of the right iliac crest. Blood samples were collected after an overnight fast, and all biochemical analyses were conducted within 2 h of blood sampling. Fasting plasma glucose, TAG and HDL-cholesterol were measured enzymatically using a Hitachi automatic analyser 7600 (Hitachi) in a central, certified laboratory. Blood pressure was measured with a Baumanometer mercury sphygmomanometer (W.A. Baum) after participants had rested for 5 min in a seated position. Systolic and diastolic blood pressures were measured at phase I and phase V Korotkoff sounds, respectively. Three readings of systolic blood pressure and diastolic blood pressure were recorded, and the average of the last two readings was used for data analysis. BMI was calculated as weight (kg) divided by height squared (m^2).

Definition of the metabolic syndrome

The MetS was defined as having ≥3 of any of the following[1]: (1) abdominal obesity (waist circumference >90 cm for men or >80 cm for women); (2) hyperglycaemia (fasting plasma glucose ≥ 100 mg/dl (5·55 mmol/l) or current use of insulin or oral hypoglycaemia medication or a physician's diagnosis); (3) hypertriacylglycerolaemia ≥150 mg/dl (1·70 mmol/l); (4) low HDL-cholesterol < 40 mg/dl (1·04 mmol/l) in men or <50 mg/dl (1·30 mmol/l) in women and (5) elevated blood pressure (systolic blood pressure/diastolic blood pressure ≥ 130/85 mmHg, or the use of antihypertensive medication).

Covariates

Participants completed a self-administered questionnaire that asked about socio-demographic characteristics (age, sex, education and income) and health behaviours (smoking status, alcohol consumption and physical activity). Answers on this questionnaire were verified in an in-person interview. We categorised education into three groups: ≤6 years (elementary school-level), 7–12 years (middle or high school level) and >12 years (college level). Income was categorised into three groups: low (first quartile), medium (second and third quartiles) and high (fourth quartile). Smoking status was categorised as never smokers, former smokers or current smokers. Alcohol intake was classified as never drinkers for past year, moderate drinkers (<2 times/week) and heavy drinkers (≥2 times/week). Participants were considered to be physically active if they reported walking for ≥30 min for ≥5 d per week or doing strength training for more than three times per week.

Statistical analysis

All data were analysed using SAS version 9.4 (SAS Institute), taking into account the number of sample units to produce nationally representative estimates. *P* values < 0·05 were considered as statistically significant. We examined socio-demographic characteristics, health behaviours and nutrient intakes (macronutrients as a percentage of total energy and micronutrients as per 1000 kcal) using percentages for categorical variables and means for continuous variables, stratified by sex. We tested for differences across quintiles of plant-based diet scores using linear regression models (PROC SURVEYREG procedure in SAS) for continuous variables or χ^2 tests for categorical variables.

To evaluate the associations between three plant-based diet scores and the MetS, we used multivariable logistic regression models to calculate the OR and 95 % CI. Model 1 adjusted for age and sex. Model 2 adjusted for age, sex, education, income, smoking status, alcohol intake, physical activity, BMI and total energy intake. We adjusted for BMI as a covariate because the MetS is a cluster of metabolic abnormalities which BMI may or may not have an impact. Given that BMI and central obesity may be highly co-linear, we did not adjust for BMI when abdominal obesity was the outcome. Then, as an exploratory analysis, we examined if there is effect measure modification by sex using cross-product terms between quintiles of plant-based diet scores and sex. We presented results for the overall study population and sex-specific estimates. Given the strong associations observed between uPDI and the MetS, we then assessed the associations between uPDI and components of the MetS (abdominal obesity, hyperglycaemia, hypertriacylglycerolaemia, low HDL-cholesterol and elevated blood pressure).

As a *post hoc* analysis, we further explored the influence of age by examining the potential non-linear associations between age and plant-based diet indices by adjusting for the quadratic version of age in addition to age as a continuous variable and tested for effect measure modification by age. We did not find significant interaction by age ($P_{interaction} > 0·5$).

Results

Characteristics of Korean adults

PDI ranged from 29 to 77 for men and 31–72 for women; hPDI ranged from 33 to 82 for men and 30–82 for women; uPDI ranged from 31 to 77 for men and 30–77 for women. However, the median scores were slightly higher for women in the highest quintiles of hPDI (median 67) and uPDI (median 63) than men in the highest quintiles of hPDI (median: 65) and uPDI (median: 62) when we examined these scores qualitatively. Korean men and women in the highest quintiles of PDI and hPDI were more likely to be older and to be never drinkers compared with those in the lowest quintiles (Table 1). In addition, they were more likely to have higher fasting plasma glucose. When we examined nutritional characteristics of the diets, those in the highest quintiles of PDI and hPDI consumed lower total energy; total fat, total protein and saturated fat as a percentage of energy, but higher carbohydrates as a percentage of energy, K, vitamin A and vitamin C (online Supplementary Table S2).

Those in the highest quintiles of uPDI were younger, more likely to have lower levels of education, more likely to have a low income, more likely to be current smokers and less likely to be physically active (Table 1). Those in the highest quintiles of uPDI consumed higher total energy, lower total protein and total fat as a percentage of energy, K, Ca, vitamin A and vitamin C (online Supplementary Table S2).

Table 1. Characteristics of South Korean adults according to quintiles of plant-based diet index (PDI), healthy plant-based diet index (hPDI) and unhealthy plant-based diet index (uPDI) scores in the Korea National Health and Nutrition Examination Survey 2012–2016*†
(Mean values and standard deviations; numbers and percentages)

	Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*
Overall PDI											
Men (*n* 5585) (*n*)	1194		977		1080		1289		1045		
Median	45		49		52		55		60		
Range	29–47		48–50		51–53		54–57		58–77		
Age (years)	34·9	0·4	37·6	0·4	40·8	0·4	43·0	0·4	45·8	0·4	<0·001
Education level											
≤6 years											<0·001
n	55		44		74		112		120		
%	3·5		2·5		5·2		6·7		8·4		
7–12 years											
n	650		476		476		582		447		
%	56·9		50·6		45·6		45·1		44·8		
>12 years											
n	489		457		530		595		476		
%	39·6		46·8		49·2		48·1		46·9		
Income level											
Low											
n	313		218		243		273		236		0·07
%	27·5		23·6		24·0		21·7		23·8		
Medium											
n	609		491		541		657		543		
%	50·2		48·5		49·5		51·7		51·8		
High											
n	272		268		296		359		266		
%	22·3		27·9		26·6		26·6		24·4		
Smoking status											
Never											
n	316		243		254		317		234		<0·001
%	28·0		27·7		25·1		27·3		23·0		
Former											
n	303		313		381		484		444		
%	23·8		28·8		33·0		33·8		40·4		
Current											
n	575		421		445		488		367		
%	48·2		43·5		41·9		38·9		36·6		
Alcohol intake											
Never											
n	84		87		113		173		215		<0·0001
%	6·7		8·4		9·5		13·1		19·3		
<2 times/week											
n	572		515		582		688		547		
%	51·1		55·2		56·9		55·0		54·0		
≥ 2 times/week											
n	538		375		385		428		283		
%	42·2		36·4		33·6		31·9		26·7		
Physical activity											
n	273		247		270		325		270		0·89
%	24·5		26·4		25·0		26·1		25·7		
BMI (kg/m^2)	24·4	0·1	24·5	0·1	24·6	0·1	24·4	0·1	24·5	0·1	0·64
WC (cm)	84·4	0·3	84·7	0·4	85·0	0·3	84·7	0·3	85·0	0·3	0·62
FPG (mg/dl)‡	97·0	0·6	98·1	0·8	98·8	0·7	99·6	0·6	100·3	0·8	0·004
TAG (mg/dl)‡	173·3	5·5	154·3	4·1	155·7	3·9	162·9	4·5	165·1	5·1	0·03
HDL-cholesterol (mg/dl)‡	48·7	0·4	48·8	0·4	47·3	0·4	47·5	0·3	46·2	0·4	<0·0001
SBP (mmHg)	117·3	0·4	118·2	0·4	118·5	0·5	118·5	0·4	118·1	0·5	0·23
DBP (mmHg)	78·4	0·3	78·8	0·3	79·1	0·4	79·0	0·3	79·0	0·4	0·58
Women (*n* 8865) (*n*)	1569		2014		1798		1599		1885		
Median	44		49		52		55		59		
Range	31–46		47–50		51–53		54–56		57–72		
Age (years)	35·1	0·3	39·1	0·3	41·4	0·4	44·0	0·4	47·3	0·3	<0·0001
Education level											
≤6 years											
n	76		164		211		230		364		<0·001
%	3·5		6·9		9·1		11·7		16·6		

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Table 1. (*Continued*)

	Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*
7–12 years											
n	719		929		893		790		978		
%	48·7		47·3		51·2		51·3		52·7		
>12 years											
n	774		921		694		579		543		
%	47·8		45·8		39·7		37·0		30·7		
Income level											
Low											
n	377		488		404		364		448		0·61
%	25·7		24·4		23·6		23·1		24·4		
Medium											
n	780		1024		948		797		958		
%	49·9		51·6		51·7		49·7		50·3		
High											
n	412		502		446		438		479		
%	24·4		24·0		24·7		27·2		25·3		
Smoking status											
Never											
n	1307		1752		1614		1471		1745		<0·001
%	80·9		85·1		88·5		91·1		92·1		
Former											
n	143		134		86		60		65		
%	10·1		7·1		5·3		3·9		3·7		
Current											
n	119		128		98		68		75		
%	8·9		7·8		6·2		5·0		4·2		
Alcohol intake											
Never											
n	318		504		528		487		686		<0·001
%	18·5		22·4		27·2		28·5		33·8		
<2 times/week											
n	978		1246		1089		983		1055		
%	64·2		63·8		64·5		62·8		57·9		
≥2 times/week											
n	273		264		181		129		144		
%	17·3		13·8		10·3		8·7		8·3		
Physical activity											
n	328		393		361		336		408		0·33
%	22·2		20·7		19·8		22·4		22·6		
BMI (kg/m²)	22·6	0·1	22·7	0·1	23·1	0·1	23·1	0·1	23·5	0·1	<0·001
WC (cm)	75·8	0·3	76·1	0·3	77·0	0·3	77·2	0·3	77·9	0·3	<0·001
FPG (mg/dl)‡	92·2	0·4	93·1	0·4	95·9	0·7	95·5	0·7	97·2	0·6	<0·001
TAG (mg/dl)‡	96·2	2·1	103·4	2·0	107·3	2·3	111·4	2·3	117·2	2·0	<0·001
HDL-cholesterol (mg/dl)‡	57·5	0·4	55·8	0·3	55·1	0·4	55·3	0·4	53·4	0·3	<0·001
SBP (mmHg)	107·9	0·4	109·6	0·4	111·3	0·4	112·9	0·5	114·9	0·5	<0·001
DBP (mmHg)	71·4	0·3	72·2	0·3	72·8	0·3	73·7	0·3	74·6	0·3	<0·001
hPDI											
Men (*n* 5585) (*n*)	1102		1028		1042		1255		1158		
Median	46		51		54		59		65		
Range	33–48		49–52		53–56		57–61		62–82		
Age (years)	33·2	0·3	36·5	0·4	39·0	0·4	44·9	0·4	49·1	0·4	<0·0001
Education level											
≤6 years											
n	29		39		61		120		156		<0·0001
%	2·1		3·0		3·8		7·6		10·5		
7–12 years											
n	545		494		484		582		528		
%	52·7		50·5		48·2		45·7		46·7		
>12 years											
n	528		495		497		553		474		
%	45·3		46·5		48·0		46·7		42·8		
Income level											
Low											
n	264		238		247		294		240		0·02
%	26·2		23·9		24·8		24·1		21·2		
Medium											
n	602		520		505		620		584		
%	52·5		50·7		47·5		50·4		50·1		

Table 1. (*Continued*)

	Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*
High											
n	236		260		290		341		334		
%	21·3		25·4		27·7		25·5		28·7		
Smoking status											
Never											
n	315		267		243		276		263		<0·001
%	30·8		28·6		24·5		22·7		24·6		
Former											
n	252		273		337		487		576		
%	22·4		25·6		29·2		37·0		46·3		
Current											
n	535		488		462		492		319		
%	46·8		45·8		46·3		40·3		29·1		
Alcohol intake											
Never											
n	106		97		118		167		184		<0·001
%	8·8		8·5		11·0		12·6		15·1		
<2 times/week											
n	686		579		533		577		529		
%	63·7		58·2		53·0		47·6		47·0		
≥2 times/week											
n	310		352		391		511		445		
%	27·5		33·3		36·0		39·8		37·9		
Physical activity											
n	264		243		245		316		317		0·40
%	24·5		24·5		25·1		25·7		28·3		
BMI (kg/m²)	24·1	0·1	24·3	0·1	24·6	0·1	24·7	0·1	24·6	0·1	0·002
WC (cm)	83·7	0·3	83·9	0·3	84·7	0·3	85·7	0·3	86·0	0·3	<0·001
FPG (mg/dl)‡	94·8	0·5	96·0	0·7	98·3	0·8	100·8	0·7	104·6	0·8	<0·001
TAG (mg/dl)‡	153·3	4·3	153·1	4·7	172·8	5·3	167·1	4·4	169·2	4·4	0·005
HDL-cholesterol (mg/dl)‡	47·4	0·4	48·9	0·4	47·6	0·4	47·8	0·4	47·0	0·4	0·002
SBP (mmHg)	115·9	0·4	116·9	0·4	117·5	0·4	119·9	0·5	120·7	0·5	<0·001
DBP (mmHg)	77·5	0·3	77·9	0·4	79·1	0·3	79·9	0·3	80·0	0·4	<0·001
Women (*n* 8865) (*n*)	1913		1872		1678		1742		1660		
Median	46		52		56		61		67		
Range	30–49		50–54		55–58		59–63		64–82		
Age (years)	33·5	0·3	37·7	0·3	42·1	0·3	46·5	0·3	50·7	0·3	<0·001
Education level											
≤6 years											
n	63		118		177		321		366		<0·001
%	2·8		5·1		9·0		15·3		19·2		
7–12 years											
n	909		876		803		839		882		
%	49·8		49·0		48·7		49·5		54·4		
>12 years											
n	941		878		698		582		412		
%	47·4		45·9		42·3		35·2		26·4		
Income level											
Low											
n	490		435		385		410		361		0·003
%	27·5		24·3		23·2		23·4		21·4		
Medium											
n	981		981		848		860		837		
%	50·4		51·5		50·8		50·1		50·7		
High											
n	442		456		445		472		462		
%	22·1		24·2		26·0		26·5		27·9		
Smoking status											
Never											
n	1610		1613		1509		1611		1546		<0·001
%	82·6		84·4		88·4		91·4		93·2		
Former											
n	145		139		84		57		57		
%	7·8		8·1		5·5		4·0		4·0		
Current											
n	158		120		85		74		74		
%	9·6		7·5		6·1		4·6		2·8		

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Table 1. (*Continued*)

	Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*
Alcohol intake											
Never											
n	372		429		464		573		685		<0·001
%	18·2		21·4		25·5		30·5		39·1		
<2 times/week											
n	1281		1212		1025		980		853		
%	68·1		65·7		63·3		57·9		52·6		
≥2 times/week											
n	260		231		189		189		122		
%	13·7		12·9		11·2		11·6		8·3		
Physical activity											
n	370		368		354		360		374		0·11
%	19·7		20·7		23·2		21·5		23·3		
BMI (kg/m²)	22·5	0·1	22·8	0·1	23·0	0·1	23·4	0·1	23·6	0·1	<0·001
WC (cm)	75·5	0·3	76·0	0·3	76·8	0·3	78·0	0·3	78·5	0·3	<0·001
FPG (mg/dl)‡	92·7	0·5	93·3	0·5	94·5	0·5	95·5	0·5	99·0	0·7	<0·001
TAG (mg/dl)‡	97·0	1·8	100·2	1·9	106·7	2·3	114·3	2·3	122·9	2·6	<0·001
HDL-cholesterol (mg/dl)‡	56·4	0·3	56·2	0·3	55·7	0·4	54·4	0·3	53·7	0·4	<0·001
SBP (mmHg)	107·7	0·3	109·0	0·3	111·2	0·4	113·8	0·4	116·6	0·5	<0·001
DBP (mmHg)	71·2	0·2	72·1	0·2	73·0	0·3	74·3	0·3	75·0	0·3	<0·001
uPDI											
Men (*n* 5585) (*n*)	1032		1116		1255		1109		1073		
Median	45		50		54		57		62		
Range	31–47		48–51		52–55		56–59		60–77		
Age (years)	44·4	0·4	42·3	0·4	39·9	0·4	38·1	0·4	37·0	0·4	<0·001
Education level											
≤6 years											
n	57		74		89		72		113		<0·0001
%	3·8		4·9		4·9		4·6		7·4		
7–12 years											
n	433		501		588		542		569		
%	43·2		45·8		47·2		50·2		56·9		
>12 years											
n	542		541		578		495		391		
%	53·0		49·3		47·9		45·2		35·7		
Income level											
Low											
n	193		223		268		267		332		<0·0001
%	19·6		21·2		22·3		31·4		31·4		
Medium											
n	463		571		683		588		536		
%	45·1		50·6		53·7		48·7		48·7		
High											
n	376		322		304		254		205		
%	35·3		28·2		24·0		19·9		19·9		
Smoking status											
Never											
n	239		271		313		254		287		<0·001
%	25·3		25·8		26·7		24·5		29·4		
Former											
n	428		448		425		336		288		
%	38·7		37·5		31·1		27·2		24·9		
Current											
n	365		397		517		519		498		
%	36·0		36·7		42·2		48·3		45·7		
Alcohol intake											
Never											
n	131		160		141		115		125		0·13
%	12·1		13·0		10·5		9·0		11·0		
<2 times/week											
n	563		561		662		586		532		
%	55·8		52·5		55·6		55·7		52·1		
≥2 times/week											
n	338		395		452		408		416		
%	32·1		34·5		33·9		34·3		36·9		
Physical activity											
n	296		289		315		271		214		0·004
%	29·1		26·5		26·5		24·9		21·3		

Table 1. (*Continued*)

	Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*
BMI (kg/m²)	24·7	0·1	24·9	0·1	24·4	0·1	24·2	0·1	24·1	0·1	<0·001
WC (cm)	85·6	0·3	85·8	0·3	84·3	0·3	84·2	0·3	84·2	0·3	<0·001
FPG (mg/dl)‡	101·0	0·7	99·7	0·7	98·6	0·6	97·6	0·7	97·0	0·7	0·001
TAG (mg/dl)‡	158·0	4·0	161·7	4·9	163·5	4·7	161·2	4·7	167·9	5·0	0·66
HDL-cholesterol (mg/dl)‡	47·1	0·3	46·9	0·3	48·2	0·4	48·7	0·4	47·7	0·4	0·001
SBP (mmHg)	118·7	0·5	118·1	0·5	118·5	0·4	118·0	0·5	117·2	0·4	0·13
DBP (mmHg)	79·5	0·4	79·5	0·3	78·9	0·3	78·5	0·4	78·0	0·4	0·01
Women (*n* 8865) (*n*)	1815		1829		1918		1661		1642		
Median	45		50		53		57		63		
Range	30–47		48–51		52–55		56–59		60–77		
Age (years)	46·2	0·3	44·3	0·3	41·7	0·3	38·8	0·4	35·4	0·4	<0·001
Education level											
≤6 years											
n	151		202		241		220		231		0·01
%	7·6		9·0		9·1		10·3		10·7		
7–12 years											
n	893		897		924		767		828		
%	48·6		50·8		49·8		48·7		52·5		
>12 years											
n	771		730		753		674		583		
%	48·8		40·2		41·1		41·0		36·8		
Income level											
Low											
n	299		376		432		443		531		<0·001
%	17·1		21·1		22·5		27·6		32·8		
Medium											
n	911		911		977		849		859		
%	50·1		49·5		51·3		50·7		51·7		
High											
n	605		542		509		369		252		
%	32·8		29·4		26·2		21·7		15·5		
Smoking status											
Never											
n	1663		1654		1723		1439		1410		<0·001
%	91·0		88·8		88·6		84·6		83·9		
Former											
n	89		93		95		113		98		
%	5·4		5·8		5·5		7·4		6·6		
Current											
n	63		82		100		109		134		
%	3·6		5·4		5·9		8·0		9·5		
Alcohol intake											
Never											
n	575		529		561		450		408		<0·001
%	29·2		26·8		26·5		25·1		21·9		
<2 times/week											
n	1078		1107		1149		992		1025		
%	61·8		61·7		62·5		61·0		64·4		
≥2 times/week											
n	162		193		208		219		209		
%	9·0		11·5		11·0		13·9		13·7		
Physical activity											
n	432		381		397		323		293		0·003
%	24·5		21·7		22·6		20·3		18·5		
BMI (kg/m²)	23·1	0·1	23·2	0·1	23·0	0·1	22·9	0·1	22·8	0·1	0·15
WC (cm)	76·9	0·3	77·0	0·3	76·8	0·3	76·7	0·3	76·4	0·4	0·65
FPG (mg/dl)‡	95·4	0·6	95·0	0·5	94·6	0·5	94·5	0·7	94·0	0·6	0·46
TAG (mg/dl)‡	105·3	2·3	108·7	2·2	107·9	2·0	105·9	2·1	106·1	2·2	0·76
HDL-cholesterol (mg/dl)‡	55·9	0·4	55·6	0·3	55·3	0·3	54·9	0·3	55·5	0·4	0·20
SBP (mmHg)	112·3	0·4	112·1	0·4	111·4	0·4	110·3	0·4	109·9	0·4	<0·001
DBP (mmHg)	73·6	0·3	73·4	0·3	73·1	0·3	72·3	0·3	72·2	0·3	0·0002

WC, waist circumference; FPG, fasting plasma glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure.
* We report means and standard deviations for continuous variables and frequencies and column percentages for categorical variables.
† *P* indicates statistical differences across quintiles of plant-based diet scores.
‡ To convert FPG in mg/dl to mmol/l, multiply by 0·0555. To convert TAG in mg/dl to mmol/l, multiply by 0·0113. To convert cholesterol in mg/dl to mmol/l, multiply by 0·0259.

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Association between plant-based diet indices and the metabolic syndrome and its components

In this sample, 23·3 % of the overall population had the MetS (27·2 % (*n* 1520) of men and 20·9 % of women (*n* 1851)). In the overall study population, those in the highest quintile of uPDI had 51 % higher odds of the MetS after adjusting for age and sex (Table 2). The association between uPDI and the MetS remained statistically significant when we further adjusted for sociodemographic characteristics, health behaviours and BMI. Those in the highest quintile of uPDI had 54 % higher odds (OR 1·54, 95 % CI 1·28, 1·86, $P_{trend} < 0·001$) of having the MetS than those in the lowest quintile. There was a stronger association between uPDI and the MetS in women (OR 1·62, 95 % CI 1·26, 2·09, $P_{trend} = 0·01$) than in men (OR 1·35, 95 % CI 1·03, 1·76, $P_{trend} = 0·02$) ($P_{for\ interaction} = 0·20$). For the association between plant-based diet indices and overall MetS, age was a strong confounder. There were substantial differences in the magnitude of the association when age was adjusted *v.* not adjusted. Associations between plant-based diet indices and the MetS did not change when we additionally adjusted for the quadratic version of age ($PDI_{quintile\ 5\ v.\ quintile\ 1}$:0·94, 95 % CI 0·78, 1·13); ($hPDI_{quintile\ 5\ v.\ quintile\ 1}$:1·19, 95 % CI 0·98, 1·46); ($uPDI_{quintile\ 5\ v.\ quintile\ 1}$:1·54, 95 % CI 1·28, 1·86).

We did not find a significant association between PDI, hPDI and the MetS. There was a significant interaction by sex for the association between PDI and the MetS ($P_{interaction} < 0·0001$), but none of the quintile results was significant for men or women.

In the overall study population that adjusted for sociodemographic factors, health behaviours and BMI (except for abdominal obesity), those in the highest quintile of uPDI had 19–42 % higher odds of abdominal obesity (OR 1·42, 95 % CI, 1·06, 1·42, $P_{trend} = 0·02$), high fasting glucose (OR 1·20, 95 % CI, 1·02, 1·41, $P_{trend} = 0·1$), hypertriacylglycerolaemia (OR 1·42, 95 % CI, 1·21, 1·67, P_{trend} <0·0001) and low HDL-cholesterol (OR 1·19, 95 % CI, 1·03, 1·38, $P_{trend} = 0·052$), respectively (Table 3). Women in the highest quintile of uPDI had 27–48 % higher odds of abdominal obesity (OR 1·48, 95 % CI, 1·22, 1·78, P_{trend} = 0·001), high fasting glucose (OR 1·27, 95 % CI, 1·02, 1·58, P_{trend} = 0·051) and hypertriacylglycerolaemia (OR 1·41, 95 % CI, 1·13, 1·76, $P_{trend} = 0·03$), respectively. Men in the highest quintile of uPDI had 42 % higher odds of hypertriacylglycerolaemia (95 % CI, 1·14, 1·77, P_{trend} = 0·002), respectively.

Discussion

This study found that greater adherence to uPDI (diets higher in refined grains, sweetened foods and sugars, salty foods and low in healthy plant foods and animal products) was associated with 54 % higher odds of the MetS in general Korean population. Higher uPDI was associated with higher odds of hypertriacylglycerolaemia in men, whereas higher uPDI was associated with higher odds of three components of the MetS (abdominal obesity, high fasting glucose and hypertriacylglycerolaemia) in women. The associations were independent of sociodemographic characteristics, health behaviours and BMI. These findings highlight that the quality of plant-based diet should be considered for the prevention of the MetS in a population who followed high plant-based diet and sex difference may exist on the association between plant-based diet and metabolic disease risk.

To the best of our knowledge, this is the first study to report associations between plant-based diets and the MetS. Our findings on uPDI and the MetS are broadly consistent with studies conducted in Western populations reporting adverse health outcomes of unhealthy plant-based diets. In US nurses and health care professionals, an increase in uPDI was associated with a greater weight gain over 4-year periods[18]. In the same cohorts, an increase in uPDI was associated with a higher risk of incident type 2 diabetes[16]. In a general population of middle-aged adults in the USA, greater adherence to uPDI was associated with an elevated risk of incident hypertension[19]. However, a study of Spanish university students found that unhealthful PDI was not associated with incident overweight/obesity[34].

There are several mechanisms through which unhealthy plant-based diets may be associated with the MetS. The food composition of an unhealthy plant-based diet would have higher intakes of unfavourable nutrients and food components and lower intakes of micronutrients and antioxidants, which could adversely affect the MetS and its components. High intake of added sugar from unhealthful plant foods could affect glycaemic control, lipid metabolism and weight gain[35]. High glycaemic index and load might also contribute to glucose metabolism and lipid profiles and thus may elevate the odds of the MetS. Reduced dietary fibre could affect glucose control, insulin sensitivity and increase inflammation[36]. Previous studies have shown that those in the highest quintile of uPDI had lower fibre and higher added sugar intake than those in the lowest quintile[17,19]. Cross-sectional studies have shown that higher intakes of K, Ca, vitamin A or vitamin C were associated with lower prevalence of the MetS[37–40]. These micronutrients and antioxidants have beneficial effects on glucose metabolism through reduced oxidative stress and improved endothelial function[41]. In the present study, those in the highest quintile of unhealthful plant-based diets had higher total energy intake but lower intake of K, Ca, vitamins A and C than those in the lowest quintile.

We did not find an association between healthy plant-based diets and the MetS in contrast to studies which found that healthy plant-based diets were inversely associated with weight gain, incident obesity, hypertension and type 2 diabetes[16–19,34]. This may be due to differences in dietary patterns in Asian populations and Western populations (e.g. higher consumption of plant foods and lower consumption of animal foods, particularly red and processed meats in Asian populations than Western populations)[21,42]. The traditional Korean diet is already high in plant foods, and vegetables are often incorporated into all meals as side dishes[43]. Thus, differences in dietary intakes captured by the healthy PDI may be less pronounced than in Western population, which may have limited the ability to detect an inverse association between hPDI and the MetS. Further, it is possible that the consumption of higher amounts of healthy plant foods in a population who already adapted to healthy plant-based diets may not have a significant change in metabolic responses.

The positive associations between unhealthy plant-based diets and the components of the MetS such as abdominal obesity,

Table 2. Metabolic syndrome according to quintiles (Q) of plant-based diet scores among South Korean adults*
(Odds ratios and 95 % confidence intervals; numbers)

	Overall plant-based diet index					Healthy plant-based diet index					Unhealthy plant-based diet index				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
Overall study population															
n	3155	2573	2963	2575	3184	2730	3032	2760	2935	2993	2977	2823	3128	2675	2847
n of cases	572	533	533	667	883	456	549	653	789	942	659	649	768	620	675
Model 1															
OR	1 (Reference)	0·90	0·94	0·93	0·92	1 (Reference)	0·95	1·05	1·03	1·05	1 (Reference)	1·22	1·43	1·38	1·51
95 % CI		0·77, 1·05	0·82, 1·09	0·80, 1·08	0·80, 1·07		0·81, 1·12	0·89, 1·23	0·87, 1·21	0·89, 1·25		1·05, 1·41	1·24, 1·66	1·18, 1·63	1·29, 1·78
P_{trend}	0·74					0·75					<0·0001				
Model 2															
OR	1 (Reference)	0·97	0·93	1·00	0·96	1 (Reference)	0·92	1·02	1·06	1·16	1 (Reference)	1·19	1·38	1·34	1·54
95 % CI		0·80, 1·16	0·77, 1·11	0·84, 1·20	0·80, 1·15		0·76, 1·12	0·84, 1·24	0·88, 1·28	0·95, 1·41		1·00, 1·41	1·16, 1·64	1·11, 1·61	1·28, 1·86
P_{trend}	0·89					0·20					<0·0001				
Men															
n	1194	977	1080	1289	1045	1102	1028	1042	1255	1158	1032	1116	1255	1109	1073
n of cases	317	242	293	367	301	230	210	267	393	420	304	318	353	265	280
Model 1															
OR	1 (Reference)	0·81	0·81	0·77	0·74	1·00	0·90	1·06	1·17	1·22	1·00	1·08	1·20	0·98	1·15
95 % CI		0·66, 1·00	0·66, 0·99	0·62, 0·95	0·59, 0·93		0·72, 1·14	0·85, 1·31	0·92, 1·48	0·96, 1·56		0·87, 1·34	0·96, 1·49	0·78, 1·23	0·93, 1·43
P_{trend}	0·047					0·11					0·26				
Model 2															
OR	1 (Reference)	0·79	0·79	0·80	0·78	1·00	0·83	0·92	1·01	1·18	1·00	0·99	1·33	1·05	1·35
95 % CI		0·62, 1·01	0·62, 1·02	0·62, 1·03	0·60, 1·02		0·63, 1·10	0·71, 1·18	0·76, 1·35	0·89, 1·57		0·78, 1·25	1·05, 1·69	0·80, 1·36	1·03, 1·76
P_{trend}	0·27					0·10					0·02				
$P_{for\ interaction}$	<0·001					0·08					0·20				
Women															
n	1569	2014	1798	1599	1885	1913	1872	1678	1742	1660	1815	1829	1918	1661	1642
n of cases	185	363	399	394	510	247	293	342	455	514	378	377	410	336	350
Model 1															
OR	1 (Reference)	1·18	1·28	1·27	1·20	1·00	0·89	0·87	0·90	0·92	1·00	1·25	1·35	1·50	2·10
95 % CI		0·93, 1·49	1·00, 1·63	0·99, 1·63	0·95, 1·51		0·71, 1·11	0·70, 1·09	0·72, 1·12	0·74, 1·15		1·02, 1·54	1·11, 1·64	1·22, 1·85	1·69, 2·63
P_{trend}	0·31					0·80					<0·001				
Model 2															
OR	1 (Reference)	1·28	1·29	1·40	1·21	1·00	0·92	0·97	1·00	1·09	1·00	1·19	1·20	1·21	1·62
95 % CI		0·97, 1·70	0·97, 1·72	1·04, 1·87	0·91, 1·61		0·71, 1·19	0·75, 1·27	0·77, 1·30	0·83, 1·43		0·95, 1·49	0·96, 1·50	0·96, 1·54	1·26, 2·09
P_{trend}	0·25					0·76					0·01				

* Model 1 was adjusted for age and sex. Model 2 was additionally adjusted for BMI, physical activity, smoking status, education level, income level, alcohol intake and total energy intake.

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Table 3. Metabolic syndrome components according to quintiles of unhealthy plant-based diet index (uPDI) scores among South Korean adults*
(Odds ratios and 95 % confidence intervals; numbers)

uPDI	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	P_{trend}
Overall study population						
Abdominal obesity						
n	2977	2823	3128	2675	2847	
n of cases	1000	934	1038	858	870	
OR	1 (Reference)	1·14	1·19	1·24	1·23	0·02
95 % CI		1·00, 1·29	1·04, 1·36	1·09, 1·42	1·06, 1·42	
High fasting glucose						
n	2977	2823	3128	2675	2847	
n of cases	782	780	853	731	741	
OR	1 (Reference)	1·15	1·17	1·22	1·20	0·1
95 % CI		0·99, 1·33	1·01, 1·36	1·05, 1·42	1·02, 1·41	
Hypertriacylglycerolaemia						
n	2977	2823	3128	2675	2847	
n of cases	647	699	847	805	909	
OR	1 (Reference)	1·08	1·18	1·32	1·42	<0·001
95 % CI		0·92, 1·26	1·01, 1·38	1·13, 1·54	1·21, 1·67	
Low HDL-cholesterol						
n	2977	2823	3128	2675	2847	
n of cases	1033	923	1050	827	839	
OR	1 (Reference)	1·05	1·19	1·16	1·19	0·052
95 % CI		0·92, 1·20	1·05, 1·37	1·01, 1·34	1·03, 1·38	
Elevated blood pressure						
n	2977	2823	3128	2675	2847	
n of cases	837	814	940	765	799	
OR	1 (Reference)	1·05	1·09	1·15	1·08	0·58
95 % CI		0·90, 1·23	0·93, 1·27	0·97, 1·35	0·92, 1·28	
Men						
Abdominal obesity						
n	1032	1116	1255	1109	1073	
n of cases	284	332	354	291	275	
OR	1 (Reference)	1·25	1·06	1·02	1·07	0·23
95 % CI		1·01, 1·54	0·85, 1·31	0·82, 1·28	0·86, 1·34	
High fasting glucose						
n	1032	1116	1255	1109	1073	
n of cases	434	419	423	346	342	
OR	1 (Reference)	0·87	0·96 0·77,	0·94	0·96	0·78
95 % CI		0·70, 1·08	1·19	0·76, 1·18	0·77, 1·20	
Hypertriacylglycerolaemia						
n	1032	1116	1255	1109	1073	
n of cases	400	430	500	449	457	
OR	1 (Reference)	0·94	1·15	1·13	1·42	0·002
95 % CI		0·76, 1·17	0·94, 1·41	0·92, 1·39	1·14, 1·77	
Low HDL-cholesterol						
n	1032	1116	1255	1109	1073	
n of cases	263	282	314	238	245	
OR	1 (Reference)	0·99	1·05	0·92	1·07	0·78
95 % CI		0·79, 1·25	0·84, 1·32	0·72, 1·18	0·83, 1·38	
Elevated blood pressure						
n	1032	1116	1255	1109	1073	
n of cases	439	455	465	416	363	
OR	1 (Reference)	1·03	1·05	1·22	0·98	0·30
95 % CI		0·82, 1·28	0·85, 1·29	0·97, 1·52	0·77, 1·24	
Women						
Abdominal obesity						
n	1815	1829	1918	1661	1642	
n of cases	625	648	701	596	592	
OR	1 (Reference)	1·11	1·19	1·34	1·48	0·001
95 % CI		0·93, 1·32	1·00, 1·42	1·11, 1·62	1·22, 1·78	
High fasting glucose						
n	1815	1829	1918	1661	1642	
n of cases	411	413	418	364	317	
OR	1 (Reference)	1·14	1·14	1·34	1·27	0·051
95 % CI		0·93, 1·40	0·94, 1·39	1·10, 1·64	1·02, 1·58	
Hypertriacylglycerolaemia						
n	1815	1829	1918	1661	1642	
n of cases	329	322	391	306	323	
OR	1 (Reference)	1·07 0·87,	1·23 1·01,	1·20 1·97,	1·41 1·13,	0·03
95 % CI		1·32	1·50	1·48	1·76	

Table 3. (*Continued*)

uPDI	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	P_{trend}
Low HDL-cholesterol						
n	1815	1829	1918	1661	1642	
n of cases	680	632	741	658	619	
OR	1 (Reference)	0·92	1·12	1·24	1·18	0·003
95 % CI		0·79, 1·07	0·95, 1·32	1·06, 1·45	1·00, 1·41	
Elevated blood pressure						
n	1815	1829	1918	1661	1642	
n of cases	444	449	460	345	319	
OR	1 (Reference)	1·18	1·15	1·12	1·23	0·35
95 % CI		0·98, 1·41	0·94, 1·41	0·91, 1·38	0·97, 1·54	

* Model was adjusted for age, sex, BMI (except for abdominal obesity), physical activity, smoking status, education level, income level, alcohol intake and total energy intake.

high fasting glucose and hypertriacylglycerolaemia were observed only in women. The median score of uPDI was slightly higher in women than in men in the highest quintiles of uPDI, which suggests that women may have consumed more unhealthy plant foods such as refined grains (e.g. white rice or noodles) than men. A prior study conducted in the Korean population found that the association between refined grain consumption and incident MetS was stronger in women than in men, and in some cases, elevated risk of chronic conditions were observed only in women[44,45]. Refined grains such as noodles are usually consumed with more unhealthy plant foods (salty plant foods such as kimchi or pickled radish, or white rice), which may explain the observed stronger associations between uPDI and several components of the MetS in women in our study[45]. Furthermore, in the setting of Asian populations, diet quality may have a stronger influence on metabolic risk factors among women compared with men. Previous studies have shown sex differences on the relationship between specific food or diet and metabolic risk factors such as lipid profiles, blood pressure or mortality[25,46–48]. Various factors could have affected sex difference, such as difference in biological factors (e.g. sex hormones), lifestyle factors including dietary habits or disease management[25].

Our results build upon studies of plant-based diets by assessing diets more comprehensively, that is, participants were ranked by frequency of consumption of all plant foods, healthy plant foods, unhealthy plant foods, and animal foods. In addition, this study had a large sample size, and adjusted for potential confounders rigorously. We also used data from a nationally representative sample which maximised generalisability of our findings.

However, several limitations should be taken into account in interpretation of our results. First, we were not able to establish temporality of exposure and outcome because the associations were examined in a cross-sectional design. The possibility of reverse causation cannot be overlooked because individuals with the MetS or any risk component of the MetS may have been advised by health care providers to consume healthy plant foods. Prospective studies on plant-based diets and the MetS are needed to confirm the associations observed in our study. Second, self-reported dietary intakes are subject to measurement error. However, the FFQ was validated, and the questionnaire showed reasonable reproducibility and validity[30]. Third, given that we used ranking-based scoring system, we were not able to determine the absolute level of plant food intake. Lastly, despite careful and rigorous adjustment of confounders, we cannot rule out the possibility of residual confounding.

In conclusion, greater adherence to unhealthy plant-based diets was associated with higher odds of the MetS and individual components (abdominal obesity, high fasting glucose, hypertriacylglycerolaemia, and low HDL-cholesterol) suggesting that it is important to consider the quality of plant foods consumed in general population following plant-based diet for the improvement of health outcomes. Stronger associations observed for women suggest that sex difference may be considered when recommending plant-based diets for prevention and management of metabolic diseases. Further research confirming our findings in prospective cohort studies is warranted among various population with different dietary backgrounds.

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Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114520002895

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