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Dietary patterns derived from reduced rank regression and their associations with metabolic syndrome in middle-aged and older adults: A cross-sectional study in Selangor, Malaysia

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ABSTRACT

Metabolic syndrome (MetS) is a rising public health concern in Malaysia, with a 35.9% adult prevalence reported by the 2023 National Health and Morbidity Survey. This cross-sectional study, based on secondary data analysis, aimed to investigate the association between a dietary pattern (DP) derived using reduced rank regression (RRR) and MetS among Malaysian adults aged 45 years and older. A total of 230 participants (89 men, 141 women) were recruited via stratified random sampling from Puchong, Serdang, and Kajang. The ethnic composition of the sample was 59% Chinese, 22% Malay, and 19% Indian. Dietary data were collected using a validated food frequency questionnaire, and MetS was defined according to the Joint Interim Statement (JIS) criteria. Thirty-one percent of participants were identified as having MetS. RRR identified a DP characterised by high intakes of total fat, fibre, and percentage sugar but low in dietary energy density, explaining 58% of the variation in metabolic risk response variables. Multivariable regression models, adjusted for age, gender, ethnicity, and smoking status were used to examine associations between DP scores, MetS, and its individual components. Among women, each 1-SD increase in adherence to the identified DP was associated with higher body mass index (β = 0.061; 95% CI: 0.000–0.123), greater waist circumference (β = 0.049; 95% CI: 0.012–0.086), a three-fold increase in the odds of elevated fasting blood glucose (OR = 3.23; 95% CI: 1.07–9.79), and reduced odds of low HDL-C (OR = 0.27; 95% CI: 0.08–0.97). No significant associations were observed among men. The identified DP defined by high consumption of fat, fibre, and free sugars, coupled with low energy density, was paradoxically associated with both risk-enhancing and risk-reducing metabolic parameters. The pattern was positively associated with hyperglycaemia and central obesity, while demonstrating an inverse association with low HDL-C concentrations.

Keywords: *Metabolic syndrome; dietary patterns; reduced rank regression; middle-aged to older adults and Malaysia*

INTRODUCTION

Metabolic syndrome (MetS) comprises a cluster of metabolic abnormalities including central obesity, dyslipidaemia,

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hypertension and impaired glucose metabolism, collectively elevating the risk of cardiovascular disease and type 2 diabetes mellitus (Swarup et al., 2025). The likelihood of developing MetS increases with age, due to age-related changes in body composition, hormonal fluctuations and declining physical activity (Yustisia et al., 2025). Among modifiable risk factors, diet plays a critical role in influencing metabolic health.

Recent research has shifted from examining individual nutrients to investigating whole DPs, recognising that foods are consumed in combination rather than in isolation (Kelly et al., 2018). Unhealthy DPs, characterised by high intakes of processed foods, added sugars, and saturated fats alongside low intakes of fruits, whole grains, vegetables, and lean proteins, are directly associated with metabolic abnormalities (Suliga et al., 2022). Excessive calorie intake leads to weight gain and central obesity, a key component of MetS (Rakhra et al., 2020). Diets high in refined carbohydrates and added sugars provoke rapid increases in glucose and contribute to insulin resistance (Bhardwaj et al., 2016). Consumption of high-glycaemic-index foods and sugar-sweetened beverages (SSBs) has been linked to MetS by impairing glucose metabolism (Deshpande et al., 2017). Moreover, diets rich in cholesterol, saturated fats, and trans fats exacerbate dyslipidaemia by raising low-density lipoprotein cholesterol levels (LDL-C) (Ruuth et al., 2021), while sodium-rich diets increase BP and contribute to hypertension (Grillo et al., 2019). Conversely, adherence to healthy DPs, such as the Mediterranean diet or the Dietary Approaches to Stop Hypertension (DASH) eating plan, reduces MetS risk, improves lipid profiles, and supports moderate weight loss (Akhlaghi, 2020; Scaglione et al., 2025).

In Malaysia, a nation with a diverse food culture influenced by Malay, Chinese and Indian traditions, the dietary habits vary substantially across ethnic groups. While some traditional diets emphasise minimally processed foods, a shift towards Western-style DPs high in processed foods and sugary beverages raises concerns for long-term metabolic health (Goh et al., 2020). Previous studies investigating the association between DPs and MetS in Malaysian adults have predominantly employed principal component analysis (PCA) and factor analysis (FA) (Izzati & Shahar, 2018; Shyam et al., 2020). While useful for data reduction, these exploratory methods are solely driven by correlations among food groups and do not incorporate outcome-related information during pattern derivation. As a result, PCA and FA may fail to capture dietary exposures that are optimally predictive of cardiometabolic outcomes, a limitation that can be addressed by reduced rank regression (RRR).

In contrast, RRR is a statistical approach that identifies DPs aligned with hypothesised pathways linking diet to (Weikert & Schulze, 2016). Its focus on disease-related outcomes makes it well suited for studying the relationship between DPs and MetS in this study (Frankenfeld, 2021). RRR has been successfully applied in other populations to explore diet-MetS relationships (Coxall et al., 2024; Piernas et al., 2022; Shoja et al., 2023).

To our knowledge, no study has investigated the association between DPs derived using RRR and MetS among middle-aged to older Malaysians. To address this gap, this study employed RRR to identify a DP associated with MetS and its components in Malaysian adults aged 45 years and above. This study further demonstrates the value of outcome-driven approaches like RRR in diverse populations and clarifies the complex interactions between DPs and metabolic risk, contributing meaningful evidence to the literature and laying the foundation for future research on chronic disease prevalence in Malaysia.

METHODOLOGY

Study design and location

This cross-sectional study employed secondary data analysis using an ethically approved dataset that included sociodemographic, clinical, and lifestyle information from an ethnically diverse sample of Malaysian adults aged ≥45 years. Secondary data analysis was selected because the existing dataset was well-established, ethically approved, and contained detailed information on sociodemographic, clinical, and lifestyle factors that aligned closely with the objectives of the present study on MetS. Furthermore, the dataset comprised a diverse ethnic composition of middle-aged and older Malaysian adults, making it well-suited for the current research question. Three urban cities in Selangor, Malaysia namely Puchong, Serdang, and Kajang were included in this study. Data were collected between June 2016 and August 2018 as part of a larger study on osteopenia and osteoporosis prevalence in the urban adult population of Malaysia. The study methods were previously published (Yeap et al., 2020). All participants received detailed study information and provided written informed consent in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Universiti Putra Malaysia (FPSK (FR16) P002, dated May 9, 2016). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement guidelines (Von Elm et al., 2007).

Recruitment and eligibility criteria

Participants were recruited via stratified random sampling approach from the national voters' registry in Puchong, Serdang and Kajang (Yeap et al., 2020). Malaysian adults aged 45 to 90 years were invited to schedule health screening appointments at the Puchong Specialist Centre (PSC). Exclusion criteria included prior diagnoses or treatment for osteoporosis (including calcitriol or alfacalcidol), secondary causes of osteoporosis, renal impairment (eGFR < 60 mL/min/1.73 m2), metabolic bone disorders, malabsorption, thyroid disorders, immobility, use of medications affecting bone health (e.g., corticosteroids, phenytoin, methotrexate, cyclosporine, oral contraceptives), or recent computed tomography scans.

These criteria, including the exclusion of individuals with osteopenia and osteoporosis, were established based on the objectives of the original primary study, which focused on bone health outcomes. As this is a secondary analysis of that dataset, the same criteria were retained.

Data collection and measurements

Anthropometric and biochemical measurements

Height (cm), weight (kg), and body mass index (BMI, kg/m²) were assessed. Height was measured barefoot to the nearest 0.1 cm, and weight to one decimal place. BMI was calculated as weight divided by height squared (m²).

Seven millilitres of blood were collected using sodium fluoride tubes for FBG and plain tubes for fasting serum lipids (total cholesterol, TG, HDL-C, LDL). Samples were transported on ice to the Chemical Pathology Laboratory, FMHS, UPM, centrifuged, and analysed the same day on a Cobas c311 automated biochemistry analyser (Roche Diagnostics) using UV enzymatic reference with hexokinase and enzymatic colorimetric methods. Calibration and quality control were performed according to standard laboratory procedures.

Definition of metabolic syndrome

MetS was defined based on the Joint Interim Statement (JIS) criteria, requiring at least three of the following components: 1) central obesity (WC: males ≥90 cm and females ≥80 cm (Asian cut-off); 2) elevated TG >1.7 mmol/L; 3) low HDL-C: males <1.0 mmol/L and females <1.3 mmol/L; 4) elevated BP: SBP ≥130 or a DBP ≥85 mmHg; 5) disorders of glycaemia that include T2DM (FBG: ≥5.6 mmol/L) (Alberti et al., 2009).

Dietary assessment

Dietary data were collected using a validated semi-quantitative FFQ (Norimah Jr et al., 2008), comprising 126 food items to evaluate participants' typical dietary habits over the past years. Food items were collapsed into 13 food groups based on nutrient profiles or cooking methods (Supplementary Table 1). Participants reported consumption frequency (per day, week, month, year or never) and the number of servings per occasion. Standard serving sizes were assigned based on Album Saiz Sajian Makanan Malaysia 2002/2003 (Food Portion Sizes of Malaysian Foods Album, 2002/2003). Participants who failed to complete the FFQ were excluded via listwise deletion. Conversion of frequency to daily intake (grams or calories) was carried out using the formula:

Amount of food (g) per day = frequency X serving size X total servings X weight per serving (Norimah Jr et al., 2008).

Dietary pattern analysis

DPs were derived using the RRR model in Stata Statistical Software (StataCorp, 2019), which identifies a linear combinations of food groups that maximise variation in the response variables hypothesised to affect health (Hoffmann et al., 2004). Predictors included 13 food groups: cereals, fish and seafood, meat, eggs, legumes, milk products, vegetables, fruits, SSBs and drinks, alcohol, condiments, spreads, and sauces. Response variables were total energy density, total fibre energy, total fat energy, and free sugar percentage, which have been previously associated with MetS (Appannah et al., 2020; Lazarova & Jessri, 2022; Livingstone & McNaughton, 2017; Thom & Lean, 2017).

Four DPs were derived, which explained the cumulative variation: DP1 (58%), DP2 (24%), DP3 (12%), and DP4 (0.5%). DP1, which explained the greatest proportion of variance, was selected for subsequent analyses, based on the rationale that the primary pattern reflected the strongest diet-disease relationship (Appannah et al., 2014). While DP1 explained the largest proportion of dietary variance, selection was based primarily on its correlations with response variables, consistent with RRR methodology (see Table 1). DP1 was selected because it showed the strongest and most consistent associations with cardiometabolic risk factors (Coxall et al., 2024; Denova-Gutiérrez et al., 2010), indicating superior biological relevance compared to the remaining patterns.

The RRR model calculates DP z-scores for each respondent as a linear, weighted combination of all their standardised food group intakes, using weights that are unique to each DP. Higher intakes of foods with positive factor loadings increase the DP z-score, whereas higher intakes of foods with negative factor loadings decrease the DP z-score. The chosen DP1 z-scores were divided into tertiles, with each tertile representing a different level of adherence to the identified DP, from lowest to highest.

Statistical analysis

Data were analysed using IBM SPSS Statistics v27 (IBM Corp, 2020). Descriptive statistics were presented as mean ± SD for normally distributed variables, and median (IQR) for non-normally distributed variables.

Associations between MetS components and sociodemographic factors were assessed using t-test, Kruskal-Wallis, ANOVA, or Mann-Whitney tests. Binary logistic regression and linear regression models were used to determine independent predictors of MetS. Significance was set at $p < 0.05$ with a 95% CI.

Table 1

Correlations between response variables and DPs derived by RRR

Response variable	DP1	DP2	DP3	DP4
Total energy density	-0.15	0.85	0.47	0.16
Total fibre density	0.47	-0.26	0.37	0.75
Total fat energy	0.77	0.10	0.26	-0.57
Free sugar percentage	0.40	0.43	-0.75	0.27

Note: DP: Dietary Pattern; RRR: Reduced Rank Regression.

RESULTS

Study population characteristics

A total of 230 middle-age and older adults participated in this study, 89 males (39%) and 141 females (61%) as shown in Table 2. Forty-seven percent of the participants were under 60 years old and 53% were 60 years and above. The majority of the participants were Chinese (59%), followed by Malays (22%) and Indians (19%). Six percent of the study population reported smoking, while 17% consumed alcohol.

Table 2

Sociodemographic factors of the study population (n=230)

	(N)	(%)	Mean ± SD
Gender			
Male	89	38.7	
Female	141	61.3	
Age (years)			62.13 ±10.02
<60	107	46.5	
≥60	123	53.5	
Ethnicity			
Malay	50	21.7	
Chinese	135	58.7	
Indian	45	19.6	
Smoking			
No	217	94.4	
Yes	13	5.6	
Alcohol			
No	190	82.6	
Yes	40	17.4	

Dietary patterns

The first DP was carried forward in this study as it explained the largest proportion of variation in the response variables. DP 1 was negatively correlated with total energy density, (r = -0.15) and positively correlated with total fibre density (r = 0.47), total fat energy (r = 0.77), free sugar percentage (r = 0.40). Accordingly, DP 1 is referred to as the "high total fat, fibre, sugar and low in energy density" DP.

The factor loadings of each food group in the "high total fat, fibre, sugar and low in energy density" DP are presented in Table 3. Factor loadings represent correlations between the food groups and the DP score, indicating the contribution of each food group to the DP. Positive values indicate that the corresponding food groups are associated with the DP, while negative values indicate inverse association. In this DP, Legumes (r = 0.62) and condiments (r = 0.56) exhibit a strong positive correlation and were the main contributors. SSBs and drinks (r = 0.32), fruits (r = 0.29), milk products (r = 0.28), and meat (r = 0.20) demonstrated moderate positive correlations with the DP. Other food groups, including fish and seafood (r = 0.12), vegetables (r = 0.11), alcohol (r = 0.08), spreads (r = 0.05) showed minimal contribution to the DP. Cereals (r = -0.22) and sauces (r = -0.09) were negatively correlated with this DP.

Overall, this DP reflects higher consumption of legumes and condiments, along with moderate intake of SSBs, fruits and vegetables, and lower intake of cereals and sauces. This combination suggests a mixed DP that includes both traditional plant-based components and higher sugar components. The presence of fibre-rich food may have beneficial effects on lipid profiles, while the inclusion of SSBs may contribute to higher FBG levels. This may explain the complex associations observed between this DP and metabolic outcomes.

Table 3

Factor loadings of food groups for the "high total fat, fibre, sugar and low in energy density" DP

Food Groups	Factor Loadings
Legumes	0.62
Condiments	0.56
SSB and drinks	0.32
Fruits	0.29
Milk products	0.28
Meat	0.20
Fish and seafood	0.12
Vegetables	0.11
Alcohol	0.08
Spreads	0.05
Eggs	0.04
Sauces	-0.09
Cereals	-0.22

Note: DP: Dietary Pattern

Prevalence of metabolic syndrome and its components

Table 4 shows the prevalence of MetS and mean or median values of its individual components. Among the participants, 31% had MetS. A total of 24% of the study population exhibited abnormal FBG levels, with a median value of 5.0 mmol/L (IQR = 0.8). For SBP, 61% had abnormal values. The median SBP was 133 mmHg (IQR = 18). For DBP, 33% had abnormal values, with a mean of 80 ± 11 mmHg. Abnormal TG levels were observed in 23% of the participants. The TG level had a median of 1.3 mmol/L (IQR = 0.7). For HDL-C levels, 18% had abnormal values, with a median HDL-C level of 1.5 mmol/L (IQR = 0.6). Abnormal WC was observed in 64% of participants. The median WC was 86.5 cm (IQR = 14.0). Regarding BMI, 6.6% were underweight, 44.4% were overweight, and 49% were in the normal weight category. The overall median BMI was 24.5 kg/m^2 (IQR = 6.0).

Gender, age, and ethnic differences in MetS components

Significant differences in MetS components were observed by gender, age, and ethnicity (Table 5). Males had higher WC (median 91 cm, IQR 12.1 vs. 84 cm, IQR 15.7) and TG (1.4 mmol/L, IQR 0.8 vs. 1.2 mmol/L, IQR 0.7) but lower HDL-C (1.3 mmol/L, IQR 0.4 vs. 1.6 mmol/L, IQR 0.6) than females ($p < 0.01$). Participants under 60 years had higher DBP (81.9 ± 11.5 mmHg) compared to participants above 60 (77.8 ± 11.0 mmHg; $p = 0.006$), with no other age differences. Among ethnic groups, Indians showed the highest WC (92 cm, IQR 13.5) and FBG (5.2 mmol/L, IQR 1.6), while Chinese had higher HDL-C levels (1.6 mmol/L, IQR 0.6) compared to Malays and Indians (both 1.3 mmol/L, IQR 0.5; $p < 0.05$). No significant ethnic differences were found in TG or SBP.

Table 4

Prevalence of metabolic syndrome, its components, and other CVD risk factors in the study population (n=230)

	N (%)	Median (IQR)
Metabolic Syndrome status*		
Yes	71 (30.9)	
No	159 (69.1)	
FBG (mmol/l)		
< 5.6 mmol/L	174 (75.7)	5.0 (0.8)
≥ 5.6 mmol/L	56 (24.4)	
TG level (mmol/l)		
< 1.7 mmol/L	178 (77.4)	1.3 (0.7)
≥ 1.7 mmol/L	52 (22.6)	
HDL-C level (mmol/l)		
Men: ≥ 1 mmol/L Women: ≥ 1.3 mmol/L	189 (82.2)	1.5 (0.6)
Men: < 1 mmol/L Women: < 1.3 mmol/L	41 (17.8)	
WC (cm)		
Men: < 90 cm Women: < 80 cm	82 (35.6)	86.5 (14.0)
Men: ≥ 90 cm Women: ≥ 80 cm	148 (64.3)	
BMI (kg/m^2) **		
Underweight <18.5 kg/m2	15 (6.5)	24.5 (6.0)
Normal 18.5–24.9 kg/m2	113 (49.1)	
Overweight ≥25 kg/m2	102 (44.3)	
SBP (mm Hg)		
< 130 mm Hg	90 (39.1)	133 (18)
≥ 130 mm Hg	140 (60.9)	
		Mean ± SD
DBP (mm Hg)		
< 85 mm Hg	155 (67.4)	80 ± 11
≥ 85 mm Hg	75 (32.6)	

*Notes: CVD: Cardiovascular diseases. * JIS definition (Alberti et al., 2009). ** (World Health Organization, 2000).*

Table 5

Metabolic Syndrome Components by Gender, Age Group, and Ethnicity (n = 230)

MetS component	Male median (IQR)	Female median (IQR)	p-value[a] (Gender)	Age < 60 median (IQR)	Age ≥ 60 median (IQR)	p-value[c] (Age)	Malay median (IQR)	Chinese median (IQR)	Indian median (IQR)	p-value[e] (Ethnicity)
WC (cm)	91 (12.1)	84 (15.7)	<0.001	86.8 (14)	87 (14)	0.763	89.5 (14.1)	83.8 (15.8)	92 (13.5)	<0.001
FBG (mmol/L)	5.1 (1.2)	4.9 (0.7)	0.294	4.9 (0.7)	5.0 (1.0)	0.585	5.0 (0.9)	4.9 (0.6)	5.2 (1.6)	0.015
HDL-C (mmol/L)	1.3 (0.4)	1.6 (0.6)	<0.001	1.4 (0.5)	1.5 (0.5)	0.097	1.3 (0.4)	1.6 (0.6)	1.3 (0.5)	<0.001
TG (mmol/L)	1.4 (0.8)	1.2 (0.7)	0.004	1.3 (0.7)	1.2 (0.6)	0.480	1.2 (1.0)	1.2 (0.7)	1.4 (0.6)	0.320
SBP (mm Hg)	134 (15)	131 (20)	0.268	131 (18)	134 (18)	0.206	136.5 (17)	132 (18)	131 (19)	0.104
	Mean ± SD	**Mean ± SD**	**p-value[b]**	**Mean ± SD**	**Mean ± SD**	**p-value[d]**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**p-value[f]**
DBP (mm Hg)	82.2 ± 10.3	78.2 ± 11.8	0.010	81.9 ± 11.5	77.8 ± 11.0	0.006	79.8 ± 9.4	79.5 ± 12.2	80.4 ± 11.3	0.903

*Notes: a Mann-Whitney test was used to determine the significant difference between males and females. b.t-test was used to determine the significant difference between males and females. c Mann-Whitney test was used to determine the significant difference between participants aged <60 and participants aged ≥60. d t-test was used to determine the significant difference between participants aged <60 and participants aged ≥60. e Kruskal-Walli's test was used to determine the significant difference between MetS components and Ethnicity. f one way ANOVA test was used to determine the significant difference between MetS components and Ethnicity *p<0.05 is considered significant.*

Association between dietary pattern and MetS components

Table 6 shows the association between DP z-scores and MetS components assessed using linear regression analysis. An increase of 1 SD in DP z-score was associated with 0.061 (95% CI: 0.000-0.123) higher BMI in study females. Additionally, an increase of 1 SD in DP z-score was associated with a significantly higher WC among females, with an increase of 0.049 cm (95% CI: 0.012-0.086) in the unadjusted model, which remained significant after adjusting for age, ethnicity, gender, and smoking, with an increase of 0.055 cm (95% CI: 0.017-0.093). There were no other significant association were observed between DP z-score and other MetS components even after adjustment for covariates.

Table 6

Association between "high total fat, fibre, sugar and low in energy density" DP z score and metabolic syndrome components

MetS components	Male (n = 89)		Female (n = 141)		Total[a] (n = 230)	
	β	95% CI	β	95% CI	β	95% CI
BMI						
Unadjusted model	-0.026	-0.069, 0.017	0.061	0.000, 0.123*	0.013	-0.025, 0.051
Model 1	-0.029	-0.071, 0.012	0.057	-0.006, 0.120	0.009	-0.029, 0.047
Model 2	-0.029	-0.071, 0.012	0.057	-0.006, 0.120	0.009	-0.029, 0.047
WC						
Unadjusted model	-0.002	-0.032, 0.027	0.049	0.012, 0.086*	0.019	-0.005, 0.044
Model 1	-0.007	-0.035, 0.022	0.054	0.016, 0.092*	0.020	-0.004, 0.044
Model 2	-0.007	-0.035, 0.022	0.055	0.017, 0.093*	0.020	-0.004, 0.044
FBG						
Unadjusted model	0.008	-0.063, 0.079	0.023	-0.047, 0.094	0.014	-0.035, 0.063
Model 1	-0.002	-0.072, 0.069	0.026	-0.046, 0.098	0.011	-0.038, 0.060
Model 2	-0.002	-0.071, 0.067	0.026	-0.047, 0.098	0.012	-0.037, 0.061
HDL-C						
Unadjusted model	0.007	-0.061, 0.075	0.003	-0.068, 0.047	0.010	-0.043, 0.062
Model 1	0.010	-0.058, 0.079	0.009	-0.063, 0.082	0.010	-0.039, 0.058
Model 2	0.010	-0.058, 0.079	0.012	-0.060, 0.085	0.009	-0.039, 0.058
TG						
Unadjusted model	0.037	-0.081, 0.155	-0,058	-0.188, 0,072	-0.009	-0.097, 0.079
Model 1	0.037	-0.082, 0.157	-0.061	-0.194, 0.072	-0.007	-0.095, 0.080
Model 2	0.037	-0.082, 0.157	-0.064	-0.198, 0.069	-0.007	-0.094, 0.081
SBP						
Unadjusted model	0.017	-0.010, 0.045	-0.023	-0.062, 0.016	-0.001	-0.025, 0.023
Model 1	0.019	-0.009, 0.047	-0.019	-0.058, 0.021	0.002	-0.002, 0.026
Model 2	0.019	-0.009, 0.047	-0.018	-0.058, 0.021	0.002	-0.022, 0.026
DBP						
Unadjusted model	0.003	-0.034, 0.039	-0.013	-0.061, 0.036	-0.005	-0.036, 0.025
Model 1	0.002	-0.034, 0.038	-0.018	-0.067, 0.031	-0.007	-0.037, 0.023
Model 2	0.002	-0.034, 0.038	-0.016	-0.065, 0.033	-0.007	-0.038, 0.023

*Notes: Model 1: Adjusted for Age and Ethnicity. Model 2: Adjusted as in Model 1 plus Smoking. Models 1 and 2 were further adjusted for gender across the full total sample. *p-value <0.05.*

Table 7 shows association between tertiles of DP, MetS and its components assessed using logistic regression analysis. Females in the highest tertile of the “high total fat, fibre, percentage sugar and low in energy density” DP had odds of elevated FBG that were significantly three times higher (OR = 3.231; 95% CI: 1.067-9.791), compared to females in the lowest tertile of the DP after adjusting for age and ethnicity and smoking. Conversely, females with the higher adherence to the identified DP had significantly lower odds of having lower HDL-C level (OR = 0.270; 95% CI: 0.075-0.970) compared to females with lowest tertiles of the DP after adjusting for age, ethnicity, and smoking.

Table 7

Odds Ratios (95% CI) between the tertiles of ‘high total fat, fibre, percentage sugar and low in energy density’ DP and metabolic syndrome and its components

Metabolic Components[a]	Group	Unadjusted OR (95% CI) 2nd vs 1st	Unadjusted OR (95% CI) 3rd vs 1st	Adjusted OR (95% CI) 2nd vs 1st	Adjusted OR (95% CI) 3rd vs 1st
Metabolic Syndrome (MetS)	Males	0.894 (0.311, 2.565)	0.579 (0.200, 1.679)	0.894 (0.311, 2.565)	0.579 (0.200, 1.679)
	Females	0.622 (0.238, 1.628)	0.703 (0.273, 1.813)	0.622 (0.238, 1.628)	0.703 (0.273, 1.813)
	Total[b]	0.700 (0.355, 1.379)	0.668 (0.337, 1.325)	0.700 (0.346, 1.416)	0.664 (0.329, 1.340)
Overweight / Obese	Males	0.889 (0.306, 2.579)	0.436 (0.148, 1.279)	0.889 (0.306, 2.579)	0.436 (0.148, 1.279)
	Females	0.749 (0.314, 1.786)	1.263 (0.536, 2.977)	0.749 (0.314, 1.786)	1.263 (0.536, 2.977)
	Total[b]	0.810 (0.428, 1.531)	0.922 (0.488, 1.742)	0.735 (0.379, 1.427)	0.864 (0.450, 1.661)
Abdominal Obesity	Males	0.817 (0.272, 2.450)	0.609 (0.209, 1.777)	0.817 (0.272, 2.450)	0.609 (0.209, 1.777)
	Females	1.000 (0.240, 2.378)	1.682 (0.664, 4.262)	0.978 (0.401, 2.427)	1.640 (0.631, 4.264)
	Total[b]	0.979 (0.503, 1.904)	1.169 (0.596, 2.293)	0.847 (0.425, 1.687)	1.083 (0.544, 2.157)
Elevated SBP	Males	0.791 (0.263, 2.375)	1.524 (0.486, 4.781)	0.791 (0.263, 2.375)	1.524 (0.486, 4.781)
	Females	0.707 (0.310, 1.614)	0.952 (0.410, 2.210)	0.833 (0.351, 1.977)	1.087 (0.452, 2.616)
	Total[b]	0.686 (0.360, 1.308)	1.037 (0.536, 2.007)	0.825 (0.420, 1.619)	1.175 (0.593, 2.326)
Elevated DBP	Males	1.033 (0.348, 3.066)	1.525 (0.529, 4.392)	1.033 (0.348, 3.066)	1.525 (0.529, 4.392)
	Females	1.528 (0.590, 3.958)	1.667 (0.640, 4.340)	1.520 (0.558, 4.142)	1.871 (0.690, 5.077)
	Total[b]	1.202 (0.605, 2.389)	1.458 (0.739, 2.877)	1.247 (0.610, 2.546)	1.505 (0.748, 3.028)

*Notes: [a]Model adjusted for age, ethnicity and smoking. [b] Model adjusted for gender, age, ethnicity, and smoking. *p-value < 0.05.*

Table 7 (continued)

Odds Ratios (95% CI) between the tertiles of 'high total fat, fibre, percentage sugar and low in energy density' DP and metabolic syndrome and its components

Metabolic Components[a]	Group	Unadjusted OR (95% CI) 2nd vs 1st	Unadjusted OR (95% CI) 3rd vs 1st	Adjusted OR (95% CI) 2nd vs 1st	Adjusted OR (95% CI) 3rd vs 1st
Elevated FBG	Males	1.252 (0.389, 4.029)	0.679 (0.205, 2.249)	1.252 (0.389, 4.029)	0.679 (0.205, 2.249)
	Females	1.286 (0.417, 3.960)	2.272 (0.947, 7.857)	1.612 (0.501, 5.191)	3.231 (1.067, 9.791) *
	Total[b]	1.163 (0.543, 2.494)	1.553 (0.740, 3.258)	1.251 (0.564, 2.776)	1.699 (0.791, 3.647)
Lower HDL-C level	Males	2.126 (0.618, 7.314)	1.007 (0.269, 3.767)	2.126 (0.618. 7.314)	1.007 (0.269, 3.767)
	Females	0.595 (0.211, 1.678)	0.291 (0.084, 1.011)	0.532 (0.180, 1.572)	0.270 (0.075, 0.970) *
	Total[b]	1.000 (0.459, 2.178)	0.512 (0.211, 1.244)	0.98 (0.440, 2.220)	0.510 (0.207, 1.258)
Elevated TG	Males	2.476 (0.307, 3.020)	0.963 (0.307, 3.020)	2.503 (0.821, 7.627)	1.015 (0.315, 3.276)
	Females	0.786 (0.280, 2.202)	0.524 (0.169, 1.620)	0.841 (0.290, 2.438)	0.500 (0.158, 1.587)
	Total[b]	1.229 (0.594, 1.501)	0.676 (0.305, 1.501)	1.411 (0.654, 3.045)	0.718 (0.315, 1.638)

*Notes: [a]Model adjusted for age, ethnicity and smoking. [b] Model adjusted for gender, age, ethnicity, and smoking. *p-value < 0.05.*

DISCUSSION

This study found that the overall prevalence of MetS among middle-aged and older Malaysian adults was 31%. Among the components of MetS, elevated SBP (61%) and increased WC (64%) were the most prevalent cardiometabolic risk factors. Significant gender differences were observed, with males having higher WC and TG levels, but lower HDL-C levels compared to females. Ethnic differences were also notable with Indian participants having the highest FBG and WC, while Chinese participants had the highest HDL-C levels. The identified DP was characterized by foods high in percentage of energy from fat, fibre, and sugar, and low in dietary energy density. This DP was positively associated with higher WC among females, both before and after adjusting for age, ethnicity, and smoking. Moreover, higher adherence to this DP was linked to increased odds of elevated FBG and decreased odds of low HDL-C levels in females, after adjusting for age, ethnicity, and smoking. This DP contains a combination of both protective (legumes, fruits, vegetables) and harmful (SSBs) food components, suggesting a mixed dietary profile rather than purely adverse pattern.

Our finding of a 31% prevalence of MetS among middle-aged and older Malaysian adults is broadly consistent with earlier national studies. According to a nationwide community-based cross-sectional survey conducted in 2023, the overall prevalence of MetS among Malaysian adults aged 18 years and above was reported at 35.9%(Wan et al., 2025). Another cross-sectional study involving Malaysian adults aged 18 years and above, conducted in Johor, Malaysia, between 2016 and 2018, found that 32.2% of the respondents had MetS using the JIS definition (Iqbal et al., 2020). These figures indicate that MetS remains a common health concern in the Malaysian population.

This study also revealed significant gender and ethnic differences in MetS components among middle-aged and older Malaysian adults. Males demonstrated substantially higher waist circumference (WC) compared to females (91 cm vs. 84 cm, $p < 0.001$), aligning with findings from the Malaysian Community Salt Survey (Ambak et al., 2021) and supporting evidence that males generally exhibit greater abdominal obesity due to distinct body fat distribution patterns and lifestyle factors (Chan et al., 2017; Ye et al., 2023). Ethnic variations in WC were equally notable, with Indian participants showing the highest median values, followed by Malays and Chinese. This observation corresponds with national data indicating Malaysian Indians' elevated risk for central obesity (Mohamud et al., 2011), potentially attributable to DPs characterized by higher consumption of refined carbohydrates, fried foods, and sugar-sweetened beverages, coupled with lower physical activity levels (Cai et al., 2016; Chong et al., 2023).

The analysis of lipid profiles revealed marked gender disparities, with females exhibiting significantly higher HDL-C levels than males (1.6 mmol/L vs. 1.3 mmol/L, $p < 0.001$), consistent with established patterns of more favourable lipid profiles in premenopausal women (Holven & van Lennep, 2023; Hughes et al., 2021). Conversely, males showed elevated triglyceride levels ($p = 0.004$), reflecting their typically less advantageous cardiometabolic profile (Kolovou et al., 2009). The gender gap in triglycerides narrows with age, as postmenopausal women experience rising levels due to estrogen decline and associated metabolic changes (Bittner, 2008). Ethnic differences in HDL-C were particularly striking, with Chinese participants demonstrating superior levels compared to Malays and Indians. This pattern may reflect dietary practices resembling the "healthy" DP identified in regional studies, characterized by higher intake of whole grains, fruits, and vegetables, alongside lower consumption of processed foods (Whitton et al., 2018; Song et al., 2021).

Notable ethnic variations emerged in fasting blood glucose levels, with Indian participants displaying the highest median values. This finding correlates with DPs prevalent among Malaysian Indians that emphasize sugar-sweetened beverages and high-fat foods, known contributors to insulin resistance (Balasubramanian et al., 2020). Blood pressure (BP) analysis revealed age-related differences, with participants under 60 years exhibiting higher diastolic blood pressure (DBP) than their older counterparts ($p = 0.006$), consistent with physiological understanding of arterial stiffening processes (Laurent & Boutouyrie, 2020; Maksuti et al., 2016). Postmenopausal women in the study showed elevated DBP values compared to men, supporting existing literature on estrogen's protective cardiovascular effects and its decline's impact on vascular function (Lima et al., 2012). These comprehensive findings underscore the complex interplay of gender, ethnicity, and age in shaping metabolic risk profiles within Malaysia's diverse population.

The “high total fat, fibre, sugar, and low energy density” DP identified in this study is characterized by high intakes of legumes, condiments, SSBs, fruits, milk products, meat, seafood, vegetables, and alcohol, alongside a low intake of cereals. This pattern, which explained 58% of the variance in selected response variables (fat, fibre, sugar, and energy density), reflects both traditional and transitional dietary influences in Malaysia. This DP shares similarities with the “mixed” DP identified in the Malaysian Adult Nutrition Survey (MANS), which included high consumption of legumes, fruits, and vegetables (Shyam et al., 2020). However, a notable difference lies in cereal intake which was low in our study compared to MANS. This observation could be due to the age and predominant ethnicity in this study. For instance, since Chinese older population made up the largest ethnic group in this study, they may have preferred traditional carbohydrate sources and condiments over ready-to-eat cereals such as white rice and rice-based foods (nasi, laksa, bubur nasi), roti, roti canai, and tosai.

Two DPs identified in the “Mediators of Atherosclerosis in South Asians Living in America (MALSALA)” study shared similarities with our identified DP (Gadgil et al., 2015), the “fried snacks, sweets, and high-fat dairy” pattern and the “fruits, vegetables, nuts, and legumes” pattern. The presence of SSBs and high fat items in our DP aligns with the first MALSALA pattern, which was associated with insulin resistance and lower HDL-C levels. Conversely, the high intakes of legumes, vegetables, and fruits in our DP resemble the second MALSALA pattern, which showed protective association with insulin resistance and hypertension. The existence of both protective components and harmful components in this DP may explain the mixed metabolic association observed in our population. While sugar and fat components may contribute to insulin resistance and elevated FBG, the fibre-dense and nutritious foods may be associated with beneficial effects on lipid profile, particularly HDL-C.

The combination of SSBs, high-fat foods, and processed condiments in our DP makes its share some features with Westernised DPs, which are known to be linked to obesity and metabolic abnormalities (Chen et al., 2023). However, unlike the Westernised DPs, it also includes consumption of fibre-rich foods such as legumes and fruits, highlighting its mixed nature.

Our DP was significantly associated with elevated FBG and lower odds of reduced HDL-C, but only among females. This gender-specific association is similar to previous findings. For instance, a Brazilian study found that the Western DP was associated with increased abdominal fat only in females (Vilela et al., 2014). Similarly, a cohort study in China found that high adherence to a Westernised DP significantly increased obesity risk in females (Chen et al., 2023). Although our identified DP shares some components with these patterns, it also includes beneficial foods such as legumes, fruits and vegetables, reflecting a more mixed DP. These associations may be influenced by hormonal and behavioural differences. Postmenopausal females experience estrogen decline, leading to increased visceral adiposity and insulin resistance (Nouri-Keshtkar et al., 2023). This biological shift, combined with high sugar and fat intake, likely contributes to the elevated FBG observed in female participants. At the same time, the presence of fibre-rich and nutritious food in the DP may explain the beneficial association observed with HDL-C.

Furthermore, females adhering to our DP had lower odds of reduced HDL-C, possibly due to the inclusion of foods rich in fibre such as legumes and fruits, as well as fish, as they are high in unsaturated fats like omega-3 fatty acids, which have been shown to support HDL cholesterol synthesis and function. This combination of dietary components may work synergistically to improve lipid profiles, counteracting some of the negative metabolic effects associated with the DP high sugar component (Hernáez et al., 2019; Kenneth, 2024). A study from North China similarly reported that a balanced DP rich in fruit and aquatic products (fish, shrimp, and shellfish) increased HDL-C in elderly adults (Song et al., 2021). While no significant associations were observed in males, this may be attributed to sample size limitations or differing metabolic responses. The larger female sample in our study may have increased statistical power to detect these associations.

Diets high in added sugars particularly from SSBs and sweetened condiments and saturated fats can promote insulin resistance by causing spikes in blood glucose and overexposure to dietary lipids, eventually contributing to visceral fat accumulation and increased WC and BMI (Kazemi et al., 2020; Weickert & Pfeiffer, 2018). Additionally, post-menopausal estrogen decline further exacerbates insulin resistance and central adiposity in females, emphasising this relationship.

This study exhibits several notable strengths. First, it is the first study in Malaysia to examine associations between DPs and MetS, utilizing targeted response variables such as energy density, fibre, fat, and sugar to uncover diet-disease pathways relevant to our population. Second, our analysis was conducted in a real-world context, particularly among middle-aged and older adults in suburban areas in one most populous state in Malaysia namely Selangor. However, limitations must be acknowledged. Our predominantly Chinese sample does not reflect Malaysia's true ethnic composition, limiting generalizability of the results. The cross-sectional design also prevents us from inferring causality, and the use of a FFQ may have introduced potential recall bias and misclassification of dietary intake. Additionally, the small sample size could have reduced statistical power for the subgroup analyses. Furthermore, the participants were originally recruited for an osteoporosis study, the inclusion and exclusion criteria may have influenced the characteristics of the sample, which could limit the generalization of the results.

Future research should focus on longitudinal and intervention studies to assess whether modifying this RRR-derived DP can reduce MetS risk. Further investigation into gender-specific mechanisms, especially the postmenopausal metabolic shifts observed in females, would clarify biological pathways. The findings of this study carry several implications for clinical practice and public health nutrition. From an intervention perspective, strategies aimed at mitigating MetS risk should focus on decreasing consumption of SSBs and high-fat condiments, alongside increasing intake of fibre-rich and nutrient-dense foods. In clinical settings, routine assessment of DPs may facilitate the delivery of personalised dietary counselling, with particular attention to women, who appear to exhibit greater metabolic vulnerability to the identified pattern. Additionally, community-based nutrition programmes that promote healthful adaptations of traditional Malaysian dietary practices may be efficacious. Finally, these results provide empirical support for the future revision of dietary guidelines targeting middle-aged and older adults in Malaysia.

CONCLUSION

This study highlights a high prevalence of MetS among middle-aged and older Malaysian adults, with notable gender and ethnic disparities in cardiometabolic risk factors. A distinct DP characterised by high intakes of fat, fibre, and free sugars but low energy density was identified, demonstrating dual metabolic associations both adverse and potentially protective particularly among females. These findings suggest that DPs in this population reflect complex nutrient combinations rather than binary healthy or unhealthy classifications. Future longitudinal and intervention studies are required to confirm these associations and inform public health strategies aimed at reducing MetS risk in this population.

AUTHOR CONTRIBUTIONS

Mona Yehia Hobbi contributed to the investigation, formal analysis, writing – original draft, and writing – review and editing of the manuscript. Geeta Appannah contributed to the conceptualization, investigation, formal analysis, supervision, and writing – review and editing of the manuscript. Subashini Chellappah Thambiah contributed to the conceptualization, investigation, and writing – review and editing of the manuscript. Swan Sim Yeap contributed to the investigation, resources, data curation, and writing – review and editing of the manuscript. Intan Nureslyna Samsudin contributed to the conceptualization, investigation, and writing – review and editing of the manuscript. Salmiah Md-Said contributed to the investigation and writing – review and editing of the manuscript. Siti Yazmin Zahari-Sham contributed to the investigation and writing – review and editing of the manuscript. Fen Lee Hew contributed to the investigation and writing – review and editing of the manuscript. Subapriya Suppiah contributed to the investigation and writing – review and editing of the manuscript.

ETHICS APPROVAL

Ethical approval was granted by the Ethics Committee of Universiti Putra Malaysia (Approval reference: FPSK (FR16) P002, dated May 9, 2016).

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CONFLICT OF INTEREST

The authors declare no conflicts of interest in this work.

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SUPPLEMENTARY MATERIALS

Table 1: FFQ Food Items categorised into Food Groups.

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