Original Article

Interactions of genetic and macronutrient intake with abdominal obesity among middle-aged vegetarians in Malaysia

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Background and Objectives: Evidence for gene-diet interactions is lacking among individuals with specific dietary practices including vegetarians. This study aimed to determine the interactions of rs174547 in the fatty acid desaturase 1 (*FADS1*) gene with macronutrient such as carbohydrate (particularly fibre), protein and fat intakes on abdominal obesity among middle-aged Malaysian vegetarians of Chinese and Indian ethnicity. **Methods and Study Design:** The present cross-sectional study was conducted among 163 vegetarians in Kuala Lumpur and Selangor, Malaysia. Dietary intakes of vegetarians were assessed by using a food frequency questionnaire. Waist circumference of vegetarians was measured by using a Lufkin tape W606PM. Genotypes of the rs174547 of vegetarians were determined by using Agena® MassARRAY. A multiple logistic regression model was used to determine the interactions of the rs174547 with macronutrient on abdominal obesity. **Results:** About 1 in 2 vegetarians (51.5%) had abdominal obesity. Individuals with CT and TT genotype at T3 intake of carbohydrates, protein, fat and fibre as well as individuals with TT genotype at T2 intake of carbohydrates and protein had higher odds of abdominal obesity ($p_{interation}$ <0.05). The gene-diet interaction remained significant for fibre intake (OR: 4.71, 95% CI: 1.25-17.74, $p_{interaction}$=0.022) among vegetarians with TT genotype at T2 intake of fibre after adjusting for age and sex and considering the effects of ethnicity and food groups. **Conclusions:** The rs174547 significantly interacted with fibre intake on abdominal obesity. A specific dietary fibre recommendation based on genetics is needed among Chinese and Indian middle-aged vegetarians.

Key Words: gene, macronutrient, vegetarian, middle-aged, abdominal obesity

INTRODUCTION

Global obesity is worsening over the past years and it is one of the most important global health issues. It is defined as excessive fat accumulation in the human body.[1] More than 650 million adults were diagnosed with obesity in 2016, which nearly triple the number in 1975.[2] While obesity is known to cause exacerbate impacts on human health such as cardiovascular disease (CVD) and type 2 diabetes (T2DM),[1] some obese individuals may have a lower risk of CVD and T2DM, whereas a subgroup of obese individuals with normal body mass index (BMI) was metabolically unhealthy.[1] The heterogeneous observations may be explained by the distribution of body fat, especially fat accumulation around the stomach and abdomen. Abdominal obesity is characterized by the ac-

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cumulation of subcutaneous and visceral fat that causes an increment in waist circumference.[1] BMI and waist circumference are two general ways of measuring obesity, with BMI represents general obesity, whereas waist circumference is used to measure abdominal obesity. Notably, the trends of the increases in abdominal obesity were faster than increases in general obesity.[3] Most importantly, abdominal obesity has been documented to be associated with mortality regardless BMI of an individual.[4] Monitoring of BMI alone may lead to an underestimation of the adverse health consequences as compared to the abdominal obesity.

Abdominal obesity is a multifactorial health outcome. A non-modifiable risk factor such as ageing is a natural process that is associated with the increase in abdominal white adipose tissue and fat deposition in skeletal muscle.[5] In Malaysia, the national surveillance revealed a higher prevalence of abdominal obesity among middle-aged adults aged 55 to 59 years (68.2%) as compared to middle-aged adults aged 40 to 44 years (57.6%).[6] On the other hand, diet is a modifiable risk factor for the prevention of abdominal obesity. For example, epidemiological studies have consistently found that vegetarian diets accentuate the risk of abdominal obesity in the United States and Malaysia.[7,8] Considering energy balance is the core concept of maintaining healthy body weight, the beneficial effects of a vegetarian diet on abdominal obesity may be due to the lower total energy intake among vegetarians.[7,9]

Notwithstanding the beneficial effects of vegetarian diet, abdominal obesity is common among vegetarians in Malaysia, whereby about two-fifths of vegetarians (43.6%) suffer from abdominal obesity.[10] The occurrence of abdominal obesity among vegetarians highlights the lack of effective interventions for the prevention and management of abdominal obesity among vegetarian population. The conventional "one size fits all" strategy focused on diet alone may not be effective to reduce abdominal fat due to individual differences among vegetarians, signalling the need to explore other strategies including the impacts of gene-diet interaction which was mediated through eating behaviours that cause weight gain.[11] Numerous studies found that variations in genes involved in macronutrient metabolism were strongly associated with abdominal obesity and obesity indices.[12,13] For instance, polymorphisms in the fatty acid desaturase 1 (*FADS1*) gene such as rs174547 may interact with nutrients on obesity-related traits.[14] Dietary intervention studies also found that genetic predisposition can modify the effects of low-calorie and low-fat diets on obesity parameters.[15,16] Whilst the impact of a gene-diet interaction on abdominal obesity is mediated through eating behaviours,[11] the interactions of rs174547 *FADS1* gene polymorphism with macronutrient such as carbohydrate (particularly fibre), protein and fat intake have not yet been discovered among middle-aged vegetarians. Although food intake characterized by food groups is closely associated with abdominal obesity in a meta-analysis and systematic review,[17] the effects of food groups on abdominal obesity have not been studied together with gene-diet interactions. Indeed, the potential roles of genetics and their interactions with diet as well as the effects of ethnicity and various food groups should be taken into consideration when designing a diet for a specific population. Combinatorial analysis of food groups with gene-diet interactions may provide new insights into personalized nutrition, as it provides individuals with more specific details and information to improve their own daily dietary intake, rather than relying solely on macronutrient intake. Thus, the present study aimed to gain insight into interactions of the rs174547 *FADS1* gene with macronutrient among middle-aged vegetarians in Malaysia after considering the potential influences of ethnicity and various food groups. The present study hypothesized that the food groups may influence the interaction of the rs174547 *FADS1* gene with dietary macronutrient on abdominal obesity among Chinese and Indian middle-aged vegetarians in Malaysia.

METHODS

Study design and respondents

Ethics approval of the present cross-sectional study was obtained from the research ethics committee from Universiti Putra Malaysia (JKEUPM-2021-291). The present study was a part of the undergoing main study focusing on the role of precision nutrition among adults with different dietary practices in Kuala Lumpur (the capital of Malaysia) and Selangor (the state in Malaysia with the highest population density). Vegetarianism is commonly practised among Buddhist (Chinese) and Hindus (Indian) followers in Malaysia as depicted in previous studies.[7,18] Therefore, recruitment was carried out among Chinese vegetarians and Indian vegetarians from the nine randomly selected community centres in Kuala Lumpur and Selangor. Signed informed consent of vegetarians was obtained before participation in the present study. A research leaflet containing the study information was distributed by the person in charge of the community centres before the data collection. Vegetarians with the following characteristics such as practising vegetarianism for less than 2 years, having a history of chronic medical conditions, and currently using medication to control their metabolic profile were excluded from the study. Middle-aged vegetarians between the ages of 40 and 60 from the main study dataset were screened and included in this study before the statistical analyses.

Socio-demographic background

Details of socio-demographic characteristics such as age, sex, ethnicity, education background, total income and marital status were collected through a self-administered questionnaire.

Dietary assessment

The dietary intake of vegetarians was assessed by using the Food Frequency Questionnaire (FFQ) by trained researchers.[19] A food album and a set of household measurements were used during the dietary assessment to increase data accuracy. Nutritionist Pro Software Version 4.0.0 (First Data Bank, Axxya Systems, San Bruno, CA) was used to generate the total energy intake (kcal) and total intake of macronutrient. The total intake of macronutrient was expressed in grams per day (g/day) and divided into three tertiles (T1: low, T2: medium, T3: high). Based on the Recommended Nutrient Intakes (RNIs) for Malaysians, the recommended total daily energy intake derived from carbohydrates, protein and fat were 50.0%-65.0%, 10.0%-20.0% and 25.0%-30.0%, respectively.[20] Dietary nutrient adequacy of carbohydrates, protein and fat was compared with the RNIs for Malaysians.[20] In terms of food groups, food items in FFQ were classified into 16 food groups together with the following food examples, namely whole grains (brown rice, wholemeal bread and oatmeal); refined cereals and grains (white rice, noodles and white bread); legumes and its products (green bean, split pea and chickpea); nuts and seeds (groundnut, cashew nut, mustard seed and sunflower seed); vegetables (green and dark leafy vegetables, ladyfinger, cruciferous and eggplant); fruits (papaya, mango, watermelon and guava); sugars and syrups (sugar, sweet and honey); Western fast foods (pizza, mashed potato, fries and burger); preserved and pickled products (salted egg and pickles); textured vegetable protein products (TVP) (mock meats), beverages (chocolate drink, carbonated drink, tea and coffee); condiments (thick soy sauce, light soy sauce and ketchup); eggs (chicken egg, duck egg and quail egg); milk and milk products (fresh milk, commercial milk and evaporated milk); oils and fats (margarine, olive oil and safflower oil) and confectionaries and snack (local desserts, cake, ice cream and snack). The classification of food groups was based on the FFQ used in the Malaysian Adult Nutrition Survey as well as previous nutrition studies and food characteristics in Malaysia.[19,21,22] In order to determine the food sources of dietary fibre, the contribution of food groups to dietary fibre intake was expressed in percentage (%) after dividing the total fibre of the food groups by the sum of the total dietary fibre for each respondent.

Anthropometric measurements

The body weight and height of vegetarians were measured by a trained researcher using calibrated instruments. Body weight was recorded to the nearest 0.1 kg using a TANITA digital scale (TANITA Corporation, USA). Height was recorded to the nearest 0.1 cm using a SECA213 portable rangefinder (SECA, Hamburg, Germany). Lufkin tape W606PM (Lufkin, USA) was used to measure the waist circumference of vegetarians and recorded in centimeters (cm) to the nearest 0.1 cm. Vegetarians were asked to stand barefoot and waist circumference measurement was taken between the mid-point of the lower costal border and the iliac crest. Vegetarians were defined as having abdominal obesity if waist circumference was ≥90.0 cm for males and ≥80.0 cm for females according to Asian cut-offs.[23] All anthropometric measurements were performed according to the standard protocol of the International Society for the Advancement of Kinanthropometry.[24]

SNP selection, DNA extraction and genotyping

The selected polymorphism of the present study was rs174547 of the *FADS1* gene due to its associations with obesity-related traits.[14,25] A total of 300 µL fasting venous blood specimen was used to extract genomic DNA using a DNA extraction kit (QIAamp DNA Blood Mini Kit, Qiagen, Germany). The quantity and quality of the extracted DNA were determined using a spectrophotometer (Nanodrop, USA) and gel electrophoresis on 0.8% agarose gel, respectively. Polymerase chain reaction (PCR) amplification was carried out to genotype the C/T polymorphisms of the rs174547 *FADS1* gene with the following primers: (i) forward primer: ACGTTGGATGGG-GACTTTTTGTTTTTGCTG, (ii) reverse primer: AC-GTTGGATGACAGTCACTCAGAAGACTGG, and (ii) unextended primer (UEP): CTGTTTTCACCTACGCA. PCR reaction was performed using a Peltier Thermal Cycler, DNA Engine Tetrad (BioRad, USA). Genotyping process was performed using the Agena® MassARRAY platform.

Statistical analyses

Data were analysed using IBM SPSS Statistics (Version 24) (SPSS Inc., Chicago, IL, USA). Continuous variables were checked for normality and presented as mean ± standard deviation (SD) for normally distributed data and median (interquartile range, IQR) for non-normally distributed data. Categorical variables were presented as frequency and percentage (n, %). Independent-sample t-test was used to determine the differences for normally distributed continuous variables. On the other hand, Mann–Whitney U test was used to determine the differences for non-normally distributed continuous variables. Pearson chi-square analysis was used to determine the associations of macronutrient and genotypes of the rs174547 *FADS1* gene with abdominal obesity. Simple logistic regression was applied to determine each interaction of the rs174547 *FADS1* gene with macronutrient on abdominal obesity under the genetic additive model. A multiple logistic regression model was used to investigate interactions of the rs174547 *FADS1* gene with all macronutrient together and further adjusting for potential confounders such as sex and age after considering the effects of ethnicity and various food groups under the genetic additive model. The statistical significance level for the Independent-sample t-test, Pearson chi-square analysis and Mann–Whitney U test was set at $p<0.05$. In addition, the statistical significance level for interaction between the rs174547 *FADS1* gene with macronutrient after considering the effects of ethnicity and food groups on abdominal obesity was set at $p_{interation} <0.05$.

RESULTS

General characteristics and prevalence of abdominal obesity

The general characteristics of vegetarians are displayed in Table 1. A total of 163 vegetarians (male: 30.7%; female: 69.3%), with an average age of 50±5 years from Selangor and Kuala Lumpur participated in the present study. The average number years for practicing vegetarianism was 14±10 years, whereby Indian vegetarians had a longer duration of practicing vegetarianism than Chinese vegetarians ($p<0.001$). More than half (57.1%) of vegetarians had achieved secondary education level and were married (66.3%). When the vegetarians were stratified by ethnicity, Chinese vegetarians had a higher total household income than Indian vegetarians ($p=0.008$). The genotype distribution CC, CT, and TT for the rs174547 *FADS1* gene were 29.4%, 35.6% and 35.0%, respectively. Furthermore, most Indian vegetarians had the TT genotype (75.0%) compared to Chinese vegetarians who were predominant with the CC genotype (50.5%) ($p<0.001$). In terms of abdominal obesity, about 1 in 2 vegetarians (51.5%) had abdominal obesity, with Indian vegetarians

Table 1. Characteristics and prevalence of abdominal obesity by ethnicity

Variable	Mean±SD or n (%)			*p* value
	Total (N=163)	Chinese (n=95)	Indian (n=68)	
Sex				0.005*
Male	50 (30.7)	21 (22.1)	29 (42.6)	
Female	113 (69.3)	74 (77.9)	39 (57.4)	
Age	50 ± 5	49 ± 5	50 ± 6	0.238
Education				0.176
Primary level or lower	25 (15.3)	16 (16.8)	9 (13.2)	
Secondary level	93 (57.1)	58 (61.1)	35 (51.5)	
Tertiary level	45 (27.6)	21 (22.1)	24 (35.3)	
Marital status				0.142
Single	31 (19.0)	21 (22.1)	10 (14.7)	
Married	108 (66.3)	64 (67.4)	44 (64.7)	
Divorced/Widowed	24 (14.7)	10 (10.5)	14 (20.6)	
Widowed				
Household income				0.008*
<RM 2300	44 (27.0)	17 (17.9)	27 (39.7)	
RM 2300–5599	64 (39.3)	42 (44.2)	22 (32.4)	
≤RM 5600	55 (33.7)	36 (37.9)	19 (27.9)	
Total years of practicing vegetarianism	14.0±10.2	9.9±7.9	19.7±10.5	<0.001*
Genotype of rs174547				<0.001*
CC	48 (29.4)	48 (50.5)	0 (0.0)	
CT	58 (35.6)	41 (43.2)	17 (25.0)	
TT	57 (35.0)	6 (6.3)	51 (75.0)	
Abdominal obesity				<0.001
Yes	84 (51.5)	34 (35.8)	50 (73.5)	
No	79 (48.5)	50 (64.2)	18 (26.5)	

*p<0.05 tested by Independent-sample t-test and Pearson chi-square.

(73.5%) had a higher prevalence of abdominal obesity than Chinese vegetarians (35.8%) (p<0.001).

The differences in dietary intake of vegetarians by ethnicity are depicted in Table 2. Overall, more than half of vegetarians had exceeded the recommendation for carbohydrates (58.9%). Whilst more than half of the vegetarians (57.7%) of vegetarians met the protein requirement, only 15.3% of the vegetarians achieved the requirement for fat intake. The present study found that there were differences in energy intake (Chinese: 2532±1292 kcal/day; Indians: 3597±1686 kcal/day, p<0.001), carbohydrate (Chinese: 452±240 g/day; Indians: 581±315 g/day, p=0.004), protein (Chinese: 69.2±33.9 g/day; Indians: 94.2±67.5 g/day, p=0.006) and fat (Chinese: 60.5±59.5 g/day; Indians: 113±62.4 g/day, p<0.001) between Chinese and Indian vegetarians. Type of fat consumed such as saturated fat (Chinese: 23.4±21.6 g/day; Indians: 58.8±42.8 g/day, p<0.001), monounsaturated fat (Chinese: 16.5±14.9 g/day; Indians: 23.4±16.6 g/day, p=0.024) was also different between Chinese vegetarians and Indian vegetarians. In terms of food groups, Chinese vegetarians had higher median intake of whole grains, TVP products (mock meats), eggs, beverages and condiments than Indian vegetarians (p<0.05). On the other hand, Indian vegetarians had a higher mean intake of refined cereals and median intake of confectionaries and snacks, nuts and seeds, milk and milk products and oil and fats than Chinese vegetarians (p<0.05).

Table 3 shows the associations of dietary intake and genotypes with abdominal obesity among vegetarians by ethnicity in the present study. Overall, the average energy intake was 2977±1556 kcal/day. A higher energy intake was observed among vegetarians with abdominal obesity (3369±1662 kcal/day) than vegetarians without abdominal obesity (2560±1321 kcal/day) (p<0.05). The average intakes of carbohydrates, protein, fat and fibre were 506±280 g/day, 79.6±52.0 g/day, 82.2±67.4 g/day and 56.3±38.6 respectively. Besides, vegetarians with abdominal obesity had a higher intake of carbohydrates (552±298 g/day) and fat (102±77.9 g/day) than vegetarians without abdominal obesity (carbohydrates: 457±253 g/day; fat: 61.0±45.5) (p<0.05). Pearson chi-square analyses also found that vegetarians with T3 intake of fat had a higher prevalence of abdominal obesity (71.9%) than vegetarians at T1 (31.4%) and T2 (49.1%) intake of fat (p<0.05). Despite this, the stratification analysis based on ethnicity found that there were no differences in total energy, carbohydrate and protein intake between vegetarians with abdominal obesity and vegetarians without abdominal obesity in both Chinese vegetarians and Indian vegetarians. Of these macronutrients, fat intake was higher among Indian vegetarians with abdominal obesity than Indian vegetarians without abdominal obesity (p=0.027), but not Chinese vegetarians. In terms of food groups, the overall analysis observed that whole grains, refined cereals, eggs, milk and milk products, oils and fats were higher among vegetarians with abdominal obesity than vegetarians without abdominal obesity. However, only refined cereals were associated with abdominal obesity among Chinese vegetarians (p=0.003), but not Indian vegetarians when vegetarians were stratified based on ethnicity.

Simple logistic regression that illustrates the effects of ethnicity and food groups as well as the interaction between the rs174547 *FADS1* gene and each macronutrient such as carbohydrate (particularly fibre), protein and fat on abdominal obesity under a genetic additive model is depicted in Table 4. Our study found that Indian vegetarians (OR: 4.98, 95% CI: 2.52-9.87,

Table 2. Dietary intake of vegetarians by ethnicity (n=163)

Variable	Total (N=163)	Chinese (n=95)	Indian (n=68)	*p* value
Energy intake, kcal/day †	2977±1556	2532±1292	3597±1686	<0.001*
Carbohydrate, g/day †	506±280	452±240	581±315	0.004*
% of energy from carbohydrate‡				0.001*
<50%	12 (7.4)	3 (3.2)	9 (13.3)	
50.0% - 65.0%	55 (33.7)	25 (26.3)	30 (44.1)	
>65.0%	96 (58.9)	67 (70.5)	29 (42.6)	
Protein, g/day †	79.6±52.0	69.2±33.9	94.2±67.5	0.006*
% of energy from protein‡				0.008*
<10.0%	69 (42.3)	32 (33.7)	37 (54.4)	
10.0% - 20.0%	94 (57.7)	63 (66.3)	31 (45.6)	
Fat, g/day †	82.2±67.4	60.5±59.5	112±62.4	<0.001*
% of energy from fat‡				<0.001*
<25.0%	90 (55.2)	65 (68.4)	25 (36.8)	
25.0% - 30.0%	25 (15.3)	16 (16.8)	9 (13.2)	
>30.0%	48 (29.5)	14 (14.8)	34 (50.0)	
Saturated fat, g/day†	38.2±28.0	23.4±21.6	58.8±42.8	<0.001*
Monounsaturated fat, g/day†	19.4±17.5	16.5±14.9	23.4±16.6	0.024*
Polyunsaturated fat, g/day †	13.9±11.9	12.6±10.3	16.0±13.6	0.066*
Dietary fibre, g/day †	56.3±38.6	53.1±41.1	61.0±34.3	0.205
Whole grains, g/day c	126 (170)	184 (170)	57 (175)	<0.001*
Refined cereals, g/day†	444±356	392±332	518±377	0.026*
Confectionaries and snacks, g/day §	31.9 (53.8)	25.2 (48.0)	40.0 (85.4)	0.020*
Western foods, g/day §	2.67 (11.2)	2.20 (9.70)	3.86 (16.6)	0.460
Vegetables, g/day†	570±504	570±625	570±518	0.996
Fruits, g/day §	460 (1079)	404 (869)	535 (1126)	0.081
Legumes, g/day§	136 (205)	155 (204)	116 (207)	0.539
Nuts and seeds, g/day §	7.11 (21.4)	5.85 (20.3)	9.25 (27.3)	0.013*
Sugars and syrups, g/day §	9.03 (18.6)	8.44 (14.8)	10.0 (26.9)	0.087
Preserved foods and pickles, g/day §	0.00 (1.85)	0.00 (2.64)	0.00 (0.00)	<0.001*
TVP products (mock meats), g/day §	1.87 (11.4)	3.09 (13.0)	0.00 (6.61)	0.020
Eggs, g/day §	0.00 (30.9)	23.1 (46.3)	0.00 (0.00)	<0.001*
Milk and milk products, g/day§	32.8 (223)	8.33 (32.1)	223 (324)	<0.001*
Beverages, g/day §	213 (366)	261 (383)	200 (353)	0.301
Oils and fats, g/day c	2.59 (9.77)	1.29 (5.33)	6.77 (14.8)	0.001*
Condiments, g/day c	4.25 (9.38)	6.14 (9.11)	1.73 (6.91)	<0.001*

% of energy from carbohydrates, protein and fat were classified based on the recommended RNIs for Malaysians.[20]
†Variables are presented as mean±SD and tested by Independent-sample t-test.
‡Variables are presented as n (%) and tested by Chi-square analysis.
§Variables are presented as median (IQR) and tested by Mann–Whitney U test.
*p<0.05.

p<0.001) were at greater risk of abdominal obesity than Chinese vegetarians. In terms of food groups, vegetarians at highest intake of refined cereals (OR: 5.40, CI%: 2.37-12.31, p<0.001), milk and milk products (OR: 4.36, CI%: 1.94-9.79, p<0.001) and eggs (OR: 3.29, 95% CI: 1.73-6.26, p<0.001) had higher odds of developing abdominal obesity than their counterparts (p<0.05). In addition, vegetarians at T2 intake of beverages had a higher odd of abdominal obesity (OR: 2.28, 95% CI: 1.06-4.93, p=0.036) than vegetarians at T1 intake of beverages. In contrast, vegetarians at T2 and T3 intake of whole grains (OR: 0.34, 95% CI: 0.15-0.74, p=0.007; OR: 0.31, 95% CI: 0.14-0.69, p=0.004) had lower odds of developing abdominal obesity than vegetarians at T1 intake of whole grains. For gene-diet interaction, in comparison with individuals with CC genotype at T1 intake of carbohydrates, individuals with TT genotype at T2 and T3 as well as CT genotype at T3 intake of carbohydrates had higher odds of abdominal obesity respectively (OR: 5.81, 95% CI: 1.95-17.31, $p_{interation}$=0.002; OR: 3.24, 95% CI: 1.31-8.91, $p_{interation}$=0.012; OR: 3.13, 95% CI: 1.05-9.31, $p_{interation}$=0.040) under a genetic additive model. For interaction between *FADS* gene and protein, individuals with TT genotype at T2 and T3 as well as CT genotype at T3 intake of protein had higher odds of abdominal obesity (OR: 3.83, 95% CI: 1.08-13.50, $p_{interation}$=0.037; OR: 4.89, 95% CI: 1.94-12.29, $p_{interation}$=0.001; OR: 3.40, 95% CI: 1.06-10.89, $p_{interation}$=0.039) than those with CC genotype at T1 intake of protein under a genetic additive model. For fat, individuals with CT genotype and TT genotype at T3 intake of fat had higher odds of abdominal obesity (OR: 6.93, 95% CI: 1.78-26.96, p=0.005; OR: 7.56, 95% CI: 2.92-19.55, $p_{interation}$<0.001) than individuals with CC genotype at T1 intake of fat under a genetic additive model. For interaction between *FADS1* gene and fibre, individuals with CT genotype and TT genotype at T3 intake of fibre had higher odds of abdominal obesity (OR: 8.39, 95% CI: 2.25-31.30, p=0.002; OR: 2.59, 95% CI: 1.08-6.25, $p_{interation}$=0.034). In the multiple logistic regression, (Table 4), the gene-diet interaction remained significant for fibre intake (OR: 4.71, 95% CI: 1.25-17.74, $p_{interation}$=0.022) among vegetarians with TT genotype at T2 intake of fibre after adjusting for potential confounders and considering the effects of ethnicity and various food groups under a genetic additive model. Apart from gene-fibre interaction, the present study found

Table 3. Associations of energy intake, macronutrient intakes, fibre, food groups and genotypes of rs174547 *FADS1* gene with abdominal obesity by ethnicity

Variable	Total (n=163)			Chinese vegetarians (n=95)			Indian vegetarians (n=68)		
	Abdominal obesity (n=84)	Non-abdominal obesity (n=79)	*p* value	Abdominal obesity (n=34)	Non-abdominal obesity (n=61)	*p* value	Abdominal obesity (n=50)	Non-abdominal obesity (n=18)	*p* value
Energy intake, kcal/day	3369±1662	2560±1321	0.001*	2781±1319	2394±1266	0.163	3768±1762	3123±1385	0.165
Carbohydrate, g/day	552±298	456±252	0.028*	490±231	431±244	0.254	595±331	542±270	0.542
Tertile 1	22 (41.5)	31 (58.5)	0.154	13 (33.3)	26 (66.7)	0.347	9 (64.3)	5 (35.7)	0.648
Tertile 2	29 (52.7)	26 (47.3)		8 (28.6)	20 (71.4)		21 (77.8)	6 (22.2)	
Tertile 3	33 (60.0)	22 (40.0)		13 (46.4)	15 (53.6)		20 (74.1)	7 (25.9)	
Protein, g/day	86.9±62.1	71.9±37.3	0.067	67.5±24.3	70.2±38.4	0.711	100±75.5	77.9±33.8	0.237
Tertile 1	22 (43.1)	29 (56.9)	0.059	14 (37.8)	23 (62.2)	0.773	8 (57.1)	6 (42.9)	0.296
Tertile 2	26 (46.4)	30 (53.6)		12 (31.6)	26 (68.4)		14 (77.8)	4 (22.2)	
Tertile 3	36 (64.3)	20 (35.7)		8 (40.0)	12 (60.0)		28 (77.8)	8 (22.2)	
Fat, g/day	102±77.9	61.0±45.5	<0.001*	72.2±57.0	53.9±42.8	0.175	122±64.3	84.9±47.8	0.027*
Tertile 1	16 (31.4)	35 (68.6)	<0.001*	10 (23.3)	33 (76.7)	0.057	6 (75.0)	2 (25.0)	0.027*
Tertile 2	27 (49.1)	28 (50.9)		18 (48.6)	19 (51.4)		9 (50.0)	9 (50.0)	
Tertile 3	41 (71.9)	16 (28.1)		6 (40.0)	9 (60.0)		35 (83.3)	7 (16.7)	
Dietary fiber, g/day	64.0±54.9	55.5±40.2	0.261	54.6±43.7	52.3±39.9	0.795	70.4±61.0	66.2±40.0	0.785
Tertile 1	22 (40.7)	32 (59.3)	0.135	14 (34.1)	27 (65.9)	0.708	8 (61.5)	5 (38.5)	0.086
Tertile 2	32 (59.3)	22 (40.7)		9 (32.1)	19 (67.9)		23 (88.5)	3 (11.5)	
Tertile 3	30 (54.5)	25 (45.5)		11 (42.3)	15 (57.7)		19 (65.5)	10 (34.5)	
Whole grains			0.005*			0.418			0.560
Tertile 1	37 (69.8)	16 (30.2)		8 (50.0)	8 (50.0)		29 (78.4)	8 (21.6)	
Tertile 2	24 (43.6)	31 (56.4)		13 (34.2)	25 (65.8)		11 (64.7)	6 (35.3)	
Tertile 3	23 (41.8)	32 (58.2)		13 (31.7)	28 (68.3)		10 (71.4)	4 (28.6)	
Refined cereals			<0.001*			0.003*			0.242
Tertile 1	19 (35.2)	35 (64.8)		11 (26.8)	30 (73.2)		8 (61.5)	5 (38.5)	
Tertile 2	24 (44.4)	30 (55.6)		7 (24.1)	22 (75.9)		17 (68.0)	8 (32.0)	
Tertile 3	41 (74.5)	14 (25.5)		16 (64.0)	9 (36.0)		25 (83.3)	5 (16.7)	
Confectionaries and snacks			0.160			0.196			0.987
Tertile 1	26 (48.1)	28 (51.9)		14 (36.8)	24 (63.2)		12 (75.0)	4 (25.0)	
Tertile 2	24 (44.4)	30 (55.6)		8 (25.0)	24 (75.0)		16 (72.7)	6 (27.3)	
Tertile 3	34 (61.8)	21 (38.2)		12 (48.0)	13 (52.0)		22 (73.3)	8 (26.7)	
Western foods			0.142			0.531			0.123
Low	35 (45.5)	42 (54.5)		15 (32.6)	31 (67.4)		20 (64.5)	11 (35.5)	
High	49 (57.0)	37 (43.0)		19 (38.8)	30 (61.2)		30 (81.1)	7 (18.9)	
Beverages			0.107			0.095			0.307
Tertile 1	22 (41.5)	31 (58.5)		7 (24.1)	22 (75.9)		15 (62.5)	9 (37.5)	
Tertile 2	34 (61.8)	21 (38.2)		16 (50.0)	16 (50.0)		18 (78.3)	5 (21.7)	
Tertile 3	28 (50.9)	27 (49.1)		11 (32.4)	23 (67.6)		17 (81.0)	4 (19.0)	

*$p<0.05$ tested by Independent-sample t-test and Pearson chi-square.

Table 3. Associations of energy intake, macronutrient intakes, fibre, food groups and genotypes of rs174547 *FADS1* gene with abdominal obesity by ethnicity (cont.)

Variable	Total (n=163)			Chinese vegetarians (n=95)			Indian vegetarians (n=68)		
	Abdominal obesity (n=84)	Non-abdominal obesity (n=79)	*p* value	Abdominal obesity (n=34)	Non-abdominal obesity (n=61)	*p* value	Abdominal obesity (n=50)	Non-abdominal obesity (n=18)	*p* value
Oils and fats			0.018*			0.166			0.437
Tertile 1	26 (48.1)	28 (51.9)		18 (40.9)	26 (59.1)		8 (80.0)	2 (20.0)	
Tertile 2	21 (39.6)	32 (60.4)		7 (22.6)	24 (77.4)		14 (63.6)	8 (36.4)	
Tertile 3	37 (66.1)	19 (33.9)		9 (45.0)	11 (55.0)		28 (77.8)	8 (22.2)	
Condiments			0.184			0.246			0.133
Tertile 1	32 (60.4)	21 (39.6)		11 (47.8)	12 (52.2)		21 (70.0)	9 (30.0)	
Tertile 2	23 (42.6)	31 (57.4)		8 (25.8)	23 (74.2)		15 (65.2)	8 (34.8)	
Tertile 3	29 (51.8)	27 (48.2)		15 (36.6)	26 (63.4)		14 (93.3)	1 (6.7)	
rs174547						0.717			0.751
CC	16 (33.3)	32 (66.7)	0.001*	16 (33.3)	32 (66.7)		-	-	
CT	28 (48.3)	30 (51.7)		15 (36.6)	26 (63.4)		13 (76.5)	4 (23.5)	
TT	40 (70.2)	17 (29.8)		3 (50.0)	3 (50.0)		37 (72.5)	14 (27.5)	

*$p<0.05$ tested by Independent-sample t-test and Pearson chi-square.

Table 4. Simultaneous effects of ethnicity, food groups and interactions of rs174547 *FADS1* gene with macronutrient and fibre intakes on abdominal obesity using backward method of logistic regression

Variable, classification and genotype	Crude OR (95% CI)	*p* value	Adjusted OR (95% CI)	*p* value
Intercept			0.06 (0.16) [a]	
Ethnicity				
Chinese	Reference	-	-	-
Indian	4.98 (2.52–9.87)	<0.001**	5.18 (1.86–14.43)	0.002**
Food group				
Whole grains, g/day				
Tertile 1	Reference			
Tertile 2	0.34 (0.15–0.74)	0.007**		
Tertile 3	0.31 (0.14–0.69)	0.004**		
Refined cereals, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.47 (0.68–3.20)	0.327	1.24 (0.50–3.05)	0.644
Tertile 3	5.40 (2.37–12.31)	<0.001**	5.32 (2.09–13.52)	<0.001**
Confectionaries and snacks, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	0.86 (0.40–1.84)	0.700		
Tertile 3	1.74 (0.81–3.74)	0.153		
Western foods, g/day				
Low	Reference	-	-	-
High	1.59 (0.86–2.95)	0.143		
Vegetables, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.16 (0.55–2.47)	0.700		
Tertile 3	1.04 (0.49–2.19)	0.924		
Fruits, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.69 (0.79 0 3.62)	0.179		
Tertile 3	1.12 (0.53–2.37)	0.770		
Legumes, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.08 (0.51–2.29)	0.847		
Tertile 3	0.89 (0.42–1.89)	0.773		
Nuts and seeds, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.34 (0.63–2.86)	0.444		
Tertile 3	1.25 (0.59–2.66)	0.564		
Sugars and syrups, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.12 (0.53–2.39)	0.767		
Tertile 3	1.87 (0.87–4.00)	0.108		
Preserved foods and pickles, g/day				
Low	Reference	-	-	-
High	0.69 (0.36–1.33)	0.268		
TVP products (mock meats), g/day				
Low	Reference	-	-	-
High	1.23 (0.66–2.29)	0.516		
Eggs, g/day				
Low	Reference	-	-	-
High	3.29 (1.73–6.26)	<0.001*		
Milk and milk products, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	1.60 (0.74–3.47)	0.230		
Tertile 3	4.36 (1.94–9.79)	<0.001*		
Beverages, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	2.28 (1.06–4.93)	0.036*		
Tertile 3	1.46 (0.68–3.13)	0.328		
Oils and fats, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	0.71 (0.33–1.52)	0.375		
Tertile 3	2.09 (0.97–4.52)	0.059		

All variables with $p<0.05$ in the binary univariate logistic regression (Model 1) proceeded with multiple logistic regression (Model 2). Multiple logistic regression was adjusted for age and sex using backward method under genetic additive model. [a] Intercept: Coefficient (Standard Error), Nagelkerke R2=0.328, Cox & Snell R Square=0.246, Omnibus tests ($p<0.001$), Hosmer & Lemeshow test ($p=0.886$), classification percentage: 73.0%. * $p_{interation}<0.05$. ** $p<0.05$.

Table 4. Simultaneous effects of ethnicity, food groups and interactions of rs174547 *FADS1* gene with macronutrient and fibre intakes on abdominal obesity using backward method of logistic regression

Variable, classification and genotype	Crude OR (95% CI)	*p* value	Adjusted OR (95% CI)	*p* value
Condiments, g/day				
Tertile 1	Reference	-	-	-
Tertile 2	0.49 (0.23–1.05)	0.067		
Tertile 3	0.71 (0.33–1.51)	0.367		
Gene – macronutrient interaction				
Carbohydrate, g/day				
Tertile 1				
CC	Reference	-	-	-
CT	2.20 (0.74-6.49)	0.154		
Tertile 2				
TT	5.81 (1.95-17.31)	0.002*		
Tertile 3				
CT	3.13 (1.05-9.31)	0.040*		
TT	3.24 (1.31-8.91)	0.012*		
Protein, g/day				
Tertile 1				
CC	Reference	-	-	-
Tertile 2				
CT	1.86 (0.73-4.72)	0.195		
TT	3.83 (1.08-13.50)	0.037*		
Tertile 3				
CT	3.40 (1.06-10.89)	0.039*		
TT	4.89 (1.94-12.29)	0.001*		
Fat, g/day				
Tertile 1				
CC	Reference	-	-	-
Tertile 2				
CT	2.07 (0.78-5.51)	0.142		
TT	1.65 (0.54-5.05)	0.378		
Tertile 3				
CT	6.93 (1.78-26.96)	0.005*		
TT	7.56 (2.92-19.55)	<0.001*		
Dietary fibre, g/day				
Tertile 1				
CC	Reference	-	-	-
Tertile 2				
CT	2.52 (0.93–6.83)	0.070	1.71 (0.53–5.56)	0.373
TT	3.02 (0.93–9.83)	0.066	4.71 (1.25–17.74)	0.022*
Tertile 3				
CT	8.39 (2.25–31.3)	0.002*	2.43 (0.49–11.82)	0.272
TT	2.59 (1.08–6.25)	0.034*	0.63 (0.18–2.17)	0.466

All variables with $p<0.05$ in the binary univariate logistic regression (Model 1) proceeded with multiple logistic regression (Model 2). Multiple logistic regression was adjusted for age and sex using backward method under genetic additive model. a Intercept: Coefficient (Standard Error), Nagelkerke R^2=0.328, Cox & Snell R Square=0.246, Omnibus tests ($p<0.001$), Hosmer & Lemeshow test (p=0.886), classification percentage: 73.0%.
* $p_{interation}<0.05$. ** $p<0.05$.

that being Indian (OR: 5.18, 95% CI: 1.86-14.43) and vegetarians at T3 intake of refined cereals (OR:5.32, 95% CI: 2.09-13.52) remained as significant factors in the final model of multiple logistic regression. The further analysis of the contribution to fibre intake by various food groups shows that fruits, vegetables, refined cereals, whole grains and legumes were the top five food groups that contributed to fibre intake among Chinese vegetarians, whereas fruits, vegetables, legumes, refined cereals and whole grains were the first five major sources of fibre for Indian vegetarians (Figure 1a and 1b). Furthermore, Chinese vegetarians had higher dietary fibre that was contributed by whole grains, TVP products (mock meat) and condiments than Indian vegetarians ($p<0.05$).

DISCUSSION

To the best of our knowledge, the current study is the first study to determine the interactions of the rs174547 *FADS1* gene with macronutrient such as carbohydrate (particularly fibre), protein and fat intake with abdominal obesity after considering the effects of ethnicity and various food groups among middle-aged vegetarians. In bivariate analysis, we observed that vegetarians with a higher intake of carbohydrates, fat, refined cereals, eggs, milk and milk products, oil and fats were at greater risk of abdominal obesity. However, further analysis based on ethnicity found that refined cereals were associated with abdominal obesity in Chinese vegetarians but not Indian vegetarians. These results implicate the importance to consider ethnic differences when examining associations of various factors on abdominal obesity, particularly

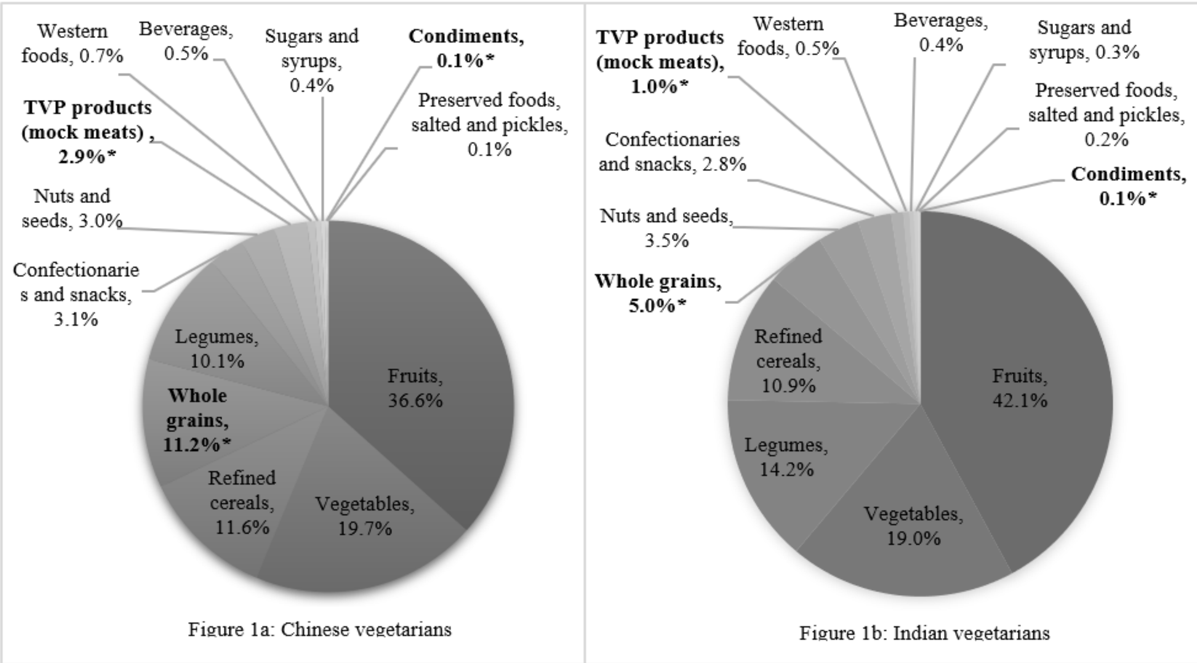

Figure 1. Comparison of contribution to dietary fibre intake (%) by food groups between (a) Chinese vegetarians and (b) Indian vegetarians. The top three food groups that contributed to dietary fibre intake were fruits, vegetables and refined cereals among Chinese vegetarians and fruits, vegetables and legumes among Indian vegetarians. Chinese vegetarians had significantly higher dietary fibre that contributed by whole grains, TVP products (mock meat) and condiments than Indian vegetarians. Other food groups including eggs, milk and milk products as well as oils and fats are not shown in the pie charts as the percentage is less than 0.1% $^{*}p<0.05$ tested by Independent-sample t-test.

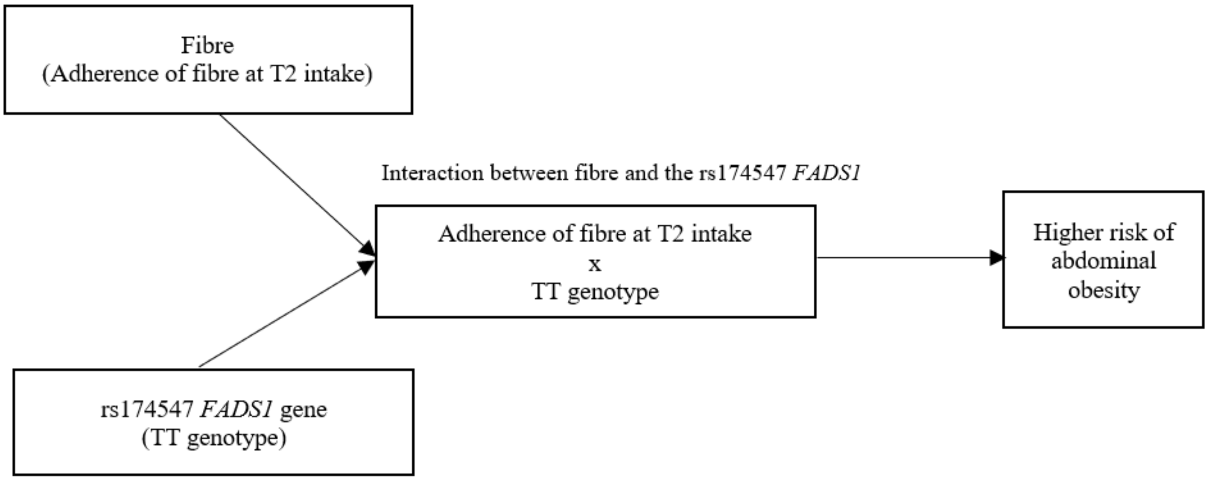

Figure 2. A conceptual diagram to display an interaction of the rs174547 *FADS1* gene with fibre intake on abdominal obesity. Multiple logistic regression found the gene-diet interaction remained significant for fibre intake among vegetarians with TT genotype at T2 intake of fibre after considering effects of ethnicity and food groups as well as adjusting for age and sex under the genetic additive model.

among Malaysian population with multiracial backgrounds. Meanwhile, the gene-diet interaction analysis found that vegetarians with TT genotype from the T2 intake of fibre were more susceptible to abdominal obesity as compared to their counterparts after considering the effects of ethnicity and food groups.

In the present study, more than half of vegetarians had abdominal obesity, which is lower than the general population in Malaysia aged between 40–44 years (57.6%) and 55–59 years (68.2%)[6] but higher than the vegetarians with the mean age of 47±13 (43.6%) in Malaysia.[10] A plausible reason to explain the high prevalence of abdominal obesity in middle age may be due to decline of testosterone in men and estrogen in women. Testosterone levels of males achieve their peak level during the puberty stage and begin to decline by 1.0% annually between ages 20 to 30 before the attainment of lowest levels after age 70.[26] Notably, declines in testosterone increase the levels of steroid hormone binding globulin that prevent adipocyte fat metabolism. As a result, the fat mass is redistributed and predominantly accumulates in the abdomen in males.[26] On the other hand, the increased risk of abdominal obesity among middle-aged female vegetarians could be possibly due to the changes in estrogen during the menopause stage. Adipose tissue is a primary site for estrogen production and metabolism. It is primarily located in the subcutaneous and gluteofemoral regions before the menopause stage. However, it starts to shift to the visceral adipose tissue compartment during the menopause stage and causes abdominal obesity.[26] The further analysis of abdominal obesity by ethnicity depicted that Indian vegetarians were more susceptible to abdominal obesity than Chinese vegetarians. The differential risk of abdominal obesity between Chinese vegetarians and Indian vegetarians may be due to the variations in genetics profile and personal behaviour .[27,28]

To date, genome-wide association studies have consistently shown that polymorphisms of the *FADS1* gene were associated with obesity and obesity-related traits such as blood lipids.[14,25] In our study, we observed that individuals with TT genotype of the rs174547 *FADS1* gene were associated with a greater risk of abdominal obesity, which in congruent with a previous study that found vegetarians with the TT genotype of the rs174547 *FADS1* gene had greater odds of metabolic syndrome.[29] However, the association between the rs174547 *FADS1* gene and abdominal obesity disappear when we analyse our data based on ethnicity, which may be possibly due to the distribution of genotypes of the rs174547 *FADS1* gene by ethnicity. We found that Indian vegetarians were the main carriers of the TT genotype, followed by CT genotypes but none of the Indian vegetarians had the CC genotype. On the other hand, Chinese vegetarians had an even distribution of CC and CT genotypes but small numbers of TT genotypes. We hypothesized the absence of CC genotype among Indian vegetarians as well as small numbers of Chinese vegetarians with TT genotype may mask the association between the rs174547 *FADS1* gene and abdominal obesity in our study.

It is speculated that the increasing trend of abdominal obesity is probably due to the overconsumption of energy-dense food.[26] Likewise, the present study observed an imbalance in macronutrient energy distribution among middle-aged vegetarians. Overall, we found that more than half of vegetarians (58.9%) exceeded the recommended percentage of energy intake derived from carbohydrates and only 15.3% of vegetarians met the recommended intake of fat, which may explain the high prevalence of abdominal obesity among middle-aged vegetarians. These results are similar to a previous study conducted in Sri Lanka that observed carbohydrates comprised 70.0% of total energy intake as compared to 19.0% of fat in the daily diet.[30] Indeed, the present study found that there were differences in carbohydrates and fat intake between vegetarians with abdominal obesity and vegetarians without abdominal obesity. These findings are consistent with previous studies conducted among the general population.[30,31] For instance, a positive association was observed between a high carbohydrate diet and abdominal obesity, whereby individuals with higher carbohydrate intakes were associated with a larger waist circumference.[30] The exact mechanism is unclear but the type of carbohydrate may underpin the explanation. Carbohydrates derived from refined grains and potatoes were positively associated with abdominal obesity, whereas carbohydrates derived from fruit and vegetable were protective against abdominal obesity,[31] making it essential for the selection of proper sources of carbohydrates for optimal health. On the other hand, literature has demonstrated that low-fat diet exerted similar protective effects as low carbohydrate diet and the Mediterranean diet in reducing hepatic fat content and abdominal obesity.[32,33] However, a low carbohydrate-high fat diet experienced a greater loss in abdominal obesity than a low-fat diet alone among middle-aged adults as compared to a low-fat diet.[34] In addition, studies showed that dietary fat explained at least 2.0% of adiposity and 0.4-2.5% increment in dietary fat energy increasing the total fat mass by 10.0kg.[35,36]

The higher amount of carbohydrates observed in the present study may be possibly attributed to the higher frequency of rice, noodle, and bread consumption among Malaysian vegetarians. For example, the previous vegetarian study in Malaysia reported that rice, porridge, bread and noodle were the top four items consumed by vegetarians.[37] Nonetheless, the effects of macronutrient intake on obesity are controversial. While some studies showed higher fat lower carbohydrate intake is beneficial for obesity management,[38,39] inconsistencies exist in other.[40] Further research is needed to evaluate how subdivisions of energy, fat, carbohydrate and protein intakes can be manipulated in optimising obesity management. In our study, we considered the potential impact of ethnic differences on macronutrient (carbohydrate, protein, fat and fibre), types of fat, and various food groups intake and their possible influence on abdominal obesity. Differences in macronutrient intake by ethnicity are recognized globally and in Malaysia.[41] We observed that Indian vegetarians had higher intakes of carbohydrate, protein, fat, saturated fat and monounsaturated fat than did Chinese vegetarians. Likewise, dietary intakes for West (Peninsular) Malaysia and East (Sabah and Sarawak) indicate that protein and fat are different between the three main ethnicities of Malay, Chinese and Indian.[42] Although no published data reported the type of fat consumed between Chinese vegetarians and Indian vegetarians, the high amount of total fat intake, saturated fat and monounsaturated fat consumed among Indian vegetarians than Chinese vegetarians in the present study may be due to the cooking method and common use of ghee in Indians cooking. In terms of cooking method, a local study found that a large proportion of Chinese preferred boiled and soup vegetables than Indians,[43] which may be one of the possible reasons to explain the different types of fat consumed in our study. In terms of ghee, ghee is a type of clarified butter, which is usually high in saturated fat (45.0-65.0%) and monosaturated fat (32.0%) that is produced from milk or butter from animals.[44] The usage of ghee in Indians cooking may contribute to higher levels of saturated fat and monounsaturated fat in Indian vegetarians than in Chinese vegetarians in the present study. Besides, Indians consumed more foods high in energy density than Chinese such as *nasi briyani, thosai, vadai* and *prata*, which are usually high in oils and fats.[45] To date, a previous study investigated the fatty acids intake of different ethnicities in Malaysia, and they found that Malays had a higher intake of saturated fat than Chinese and Indians school children.[46] However, to the best of knowledge, research on fatty acid intake by ethnicity among vegetarians is lacking in Malaysia. A recent published study has developed a FFQ for multi-ethnic population to determine the type of fatty acid intakes among Malaysian adults and they found that the developed a FFQ showed moderate correlations with the blood fatty acid composition, which is suggested to be used as a future questionnaire tool to assess population fatty acid intake.[47] Considering the impact of types of fat consumption on human health, local researchers may use the FFQ developed by Yeok and colleagues[47] to determine the fatty acid intake across Chinese vegetarians and Indian vegetarians for better health management. In terms of fibre intake, we did not find any difference between Chinese vegetarians and Indian vegetarians, which contradicts a previous study conducted among the general population in Malaysia.[48] This may be explained by the no difference in the top three food groups that contributed to total fibre in both Chinese vegetarians and Indian vegetarians in our study. With regards to food groups, Indian vegetarians had a higher intake of refined cereals, confectionaries and snacks, oil and fats than Chinese vegetarians, which may be possibly due to the frequent visit of Indians to the Malaysian Mamak food stalls that stay operate after midnight.[49]

To the best of our knowledge, the present study is the first study to report the interaction effects of the rs174547 *FADS1* gene with macronutrient such as carbohydrate (particularly fibre), protein and fat intake after considering the potential influences of ethnicity and various food groups on abdominal obesity. Despite a lack of published data to elucidate the interaction between the rs174547 *FADS1* gene and macronutrient on abdominal obesity, the association between the rs174547 *FADS1* gene and abdominal obesity may be modulated by the blood lipid levels, consumption of dietary fat and long-chain polyunsaturated fatty acids.[25] For example, a high-fat diet was associated with lower levels of HDL-c and triglyceride.[50] A systematic review and meta-analysis found that a long-term low-fat diet contributed to the reduction in total cholesterol, LDL-c, triglycerides and increased levels of HDL-c among overweight and obese respondents.[51] In addition, a previous study showed that the C-allele of the rs174547 FADS1 gene was reported with a lower LDL-c level in a population-based prospective cohort study in Sweden.[52] Further, the C-allele of the rs174547 *FADS1* gene interacted with the lowest tertile of long-chain n-3 polyunsaturated fatty acids that reported a lower risk of high LDL-c.52 These previous findings suggest that different levels of fat and long-chain polyunsaturated fatty acids, as well as blood lipids, modulate the associations between the rs174547 *FADS1* gene and abdominal obesity. In our study, the rs174547 *FADS1* gene interacted with fibre intake on abdominal obesity. Individuals with TT genotype of the rs174547 *FADS1* gene from the T2 intake of fibre had greater odds of abdominal obesity than their counterparts. Although there was no observed interaction between the TT genotype and T3 intake of fibre on abdominal obesity, we noticed the odds ratio of abdominal obesity was greatly reduced among individuals with TT genotype and at T3 intake of fibre than individuals with TT genotype of the rs174547 *FADS1* gene from the T2 intake of fibre. These findings suggest that the association of fibre intake with abdominal obesity is dependent on the rs174547 *FADS1* gene and the amount of fibre consumed. We do not know the exact mechanism, but it is possible that proper meal planning of nutrient intake is deemed important in the prevention of abdominal obesity. For instance, the amount of fibre intake needs to be carefully planned as excessive intake of fibre may contribute to certain side effects such as bloating and stomach cramping, whereas deficient intake of fibre may lead to constipation.[53] Furthermore, fruits, vegetables, refined cereals, whole grains and legumes were the top main fibre sources for vegetarians. Of these food groups, refined cereal was identified as a contributor to abdominal obesity in the final model of the gene-diet interaction in our study. On top of the total dietary fibre and genetics profile, the present study suggests that vegetarians should plan wisely about the type of fibre sources at the same time. Considering this is the first study to elucidate the interactions of the rs174547 *FADS1* gene and macronutrient such as carbohydrate (particularly fibre), protein and fat on abdominal obesity, the underlying mechanisms deserve further investigation.

The present study has several notable strengths. To the best of our knowledge, the present study is the first gene-diet interaction study to elucidate how the rs174547 *FADS1* gene interacts with macronutrient such as carbohydrate (particularly fibre), protein and fat intake on abdominal obesity after considering the potential influences of ethnicity and various food groups among Chinese and Indian middle-aged vegetarians. We hypothesized that these findings are useful for future researchers to design personalized nutrition advice for middle-aged vegetarians for the prevention of abdominal obesity. Besides, the associations of ethnicity, macronutrient intake, food groups, and genotype of the rs174547 *FADS1* gene have been determined. Future studies can design an appropriate intervention study based on studied factors associated with abdominal obesity among middle-aged vegetarians. Nonetheless, several limitations need to be highlighted in the present study. Firstly, the present study was unable to determine the causality of macronutrient and the rs174547 *FADS1* gene with abdominal obesity due to the current cross-sectional study design. Future researchers can reaffirm the associations of the studied factors and gene-diet interaction using prospective studies. Secondly, the dietary interview using FFQ may be subjected to recall bias. However, the dietary assessment was conducted by trained researchers and multiple standardised local household tools were used to increase the accuracy during the dietary assessment. The present study only focused on the rs174547 *FADS1* gene and the interaction effects of other potential variants of the *FADS1* gene with macronutrient intakes remain obscure. Nevertheless, the rs174547 *FADS1* gene could be a good candidate polymorphism to capture the interaction between genetic variants of the *FADS1* gene and macronutrient intake on abdominal obesity due to the associations of the rs174547 *FADS1* gene with obesity-related traits. Considering the sample sizes by ethnicity are less than the recommended number (n=100) for multiple logistic regression analysis,[54] our study did not separate vegetarians into Chinese vegetarians and Indian vegetarians when determining the interactions of macronutrient intake with the rs174547 *FADS1* gene on abdominal obesity. Future research may increase the sample size and duplicate the present research by stratifying vegetarians into different ethnicities. Nevertheless, the present study is considered the first study to investigate the potential role of ethnicity on the interactions of macronutrient intake with the rs174547 *FADS1* gene on abdominal obesity in the multiple logistic regression, which can be served as a reference for future researchers.

Conclusion

The present study found that middle-aged vegetarians with high dietary carbohydrate, fat, refined cereals, eggs, milk and milk products, oils and fats intake as well as the

TT genotype of the rs174547 *FADS1* gene had a higher risk of abdominal obesity before stratification of vegetarians based on ethnicity. There were interactions of the rs174547 *FADS1* gene with fibre intake on abdominal obesity after considering the potential influences of ethnicity and various food groups among middle-aged vegetarians. Personalized nutrition focusing on the dietary fibre, genetics profile and ethnicity may serve to tackle abdominal obesity among middle-aged Malaysian vegetarians as compared to conventional dietary advice. For instance, healthcare professionals could emphasize careful planning of fibre intake to reduce the risk of abdominal obesity among Malaysian middle-aged vegetarians with different ethnicities and genetic profile.

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AUTHOR DISCLOSURE
The authors declare this work has no conflict of interest.

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