Mal J Nutr 31(3): 337-349, 2025

A balanced diet improves body composition in women with high body fat, across both variants of the FTO rs9939609 polymorphism

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ABSTRACT

Background: The *FTO rs9939609* variant is linked to obesity risk. This study evaluated the effect of a 28-day balanced diet, based on the Indonesian dietary guidelines, on body composition in women with high body fat (>35%), stratified by *FTO rs9939609* genotype. **Methods:** In a randomised controlled trial, 38 women aged 18–25 years were assigned to four groups: DAC (Diet-AT/AA, *n*=12), DTH (Diet-TT, *n*=8), CAC (Control-AT/AA, *n*=10), and CTH (Control-TT, *n*=8). All participants received nutrition education. A general linear model (GLM), adjusted for age and physical activity, was used to assess gene-diet interactions. **Results:** DAC group showed significant reductions in body weight (-1.3±1.6 kg) and waist-hip ratio (-0.03±0.05; $p<0.05$). DTH group had significant decreases in body weight (-1.7±1.8 kg), body mass index (BMI) (-0.7±0.8 kg/m²), and visceral fat (-0.6±0.7; $p<0.05$). GLM analysis showed that diet significantly affected body weight (β:-1.67; $p=0.005$), BMI (β:-0.40; $p=0.030$), and visceral fat (β:-0.46; $p=0.043$). However, genotype had no significant effect and no gene-diet interaction was observed. **Conclusion:** A balanced diet effectively improved body composition of young women with high body fat, regardless of *FTO rs9939609* genotype. These results suggested that dietary interventions may outweigh genetic predisposition in influencing obesity-related outcomes. Further research with larger samples and longer follow-up is recommended.

Keywords: balanced diet, body composition, *FTO rs9939609*, obese women

INTRODUCTION

Indonesia's nutritional guidelines have shifted from "Four Healthy Five Perfect" to the more comprehensive "Balanced Nutrition Guidelines" (*Pedoman Gizi Seimbang*). These emphasise dietary variety, hygiene, physical activity, and weight control. For practical purposes, Regulation No. 41/2014 introduced tools like "My Meal Dish" (*Isi Piringku*) and the "Balanced Nutrition Pyramid" (*Tumpeng Gizi Seimbang*), offering clear guidance on portion sizes for carbohydrates, proteins, vegetables and fruits, along with hydration and exercise. The guidelines address both undernutrition and overnutrition to improve public health (Inamah *et al.*, 2024; Indonesian Ministry of Health, 2014).

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doi: https://doi.org/10.31246/mjn-2025-0018

A balanced diet with the right mix of macronutrients, micronutrients, and bioactive compounds supports overall health. Diets like the Mediterranean or traditional Asian patterns help protect against metabolic syndrome and other health issues by promoting optimal energy and mitochondrial function. Nutritious, tasty, affordable, and easily accessible food is important (García-García *et al.*, 2020). Recent studies highlighted that traditional Indonesian foods may support weight management due to their lower energy density compared to modern foods. However, portion control remains important, as total energy per portion is similar. A diverse intake of these foods can help meet nutritional needs while managing calories (Mirnawati *et al.*, 2023).

Genetic factors, alongside dietary habits, play a crucial role in obesity development. One of the most extensively researched genetic variants associated with obesity is the *FTO rs9939609* polymorphism (Madrigal-Juarez *et al.*, 2023). This polymorphism includes TT, TA, and AA genotypes, with allele A (TA and AA) considered a "risk allele", while TT represents the "non-risk allele" or wild genotype (Pratamawati *et al.*, 2024). Evidence indicates that individuals with the A risk allele of the *FTO rs9939609* gene tend to have significantly greater body weight (BW), body mass index (BMI), waist circumference (WC), hip circumference (HC), and waist-to-hip ratio (WHR) compared to those with the TT wild type (Nindrea & Thongwichian, 2024; Pratamawati *et al.*, 2024). A meta-analysis further demonstrated that carriers of the A allele in the *FTO rs9939609* polymorphism exhibit increased body fat (Gholamalizadeh *et al.*, 2022; Harris, 2023). Harris (2023) suggested that WHR may be a more reliable indicator of cardiovascular disease than BMI.

No studies have examined how the *FTO rs9939609* polymorphism interacts with a balanced diet, based on the Indonesian guidelines, to affect body composition in high-body fat women, especially among the Sundanese. This research investigated the impact of a balanced diet on body composition across *FTO rs9939609* genotypes in young women with high body fat.

METHODOLOGY

Study population

This study followed the CONSORT guidelines (Figure 1) and was conducted from November 2023 to January 2024 at the Nutrition and Nursing Laboratories, Faculty of Sports and Health Education, Indonesian Education University (UPI). Sample size was calculated for two independent groups, assuming a standard deviation (*SD*) of 7.71, a 1kg fat loss difference, 0.05 significance level, and 80% power. Ten subjects were required per group. However, due to recruitment limits, the control groups had only eight participants, potentially reducing the power to detect small effects (Sudigdo & Sofyan, 2014). The study recruited 39 obese women from a preliminary study in Bandung, West Java. Of these, 38 participants completed the intervention.

Inclusion criteria were Sundanese women aged 18–25 years with body fat >35% (Wong *et al.*, 2021), light to moderate physical activity or infrequent exercise, normal fasting blood glucose, and signed informed consent. Exclusion criteria included pregnancy, breastfeeding, chronic illness, regular use of antioxidants or phytopharmaceuticals, or participation in other studies. Participants were excluded if they withdrew, met exclusion criteria during the study, or failed to complete the required tests.

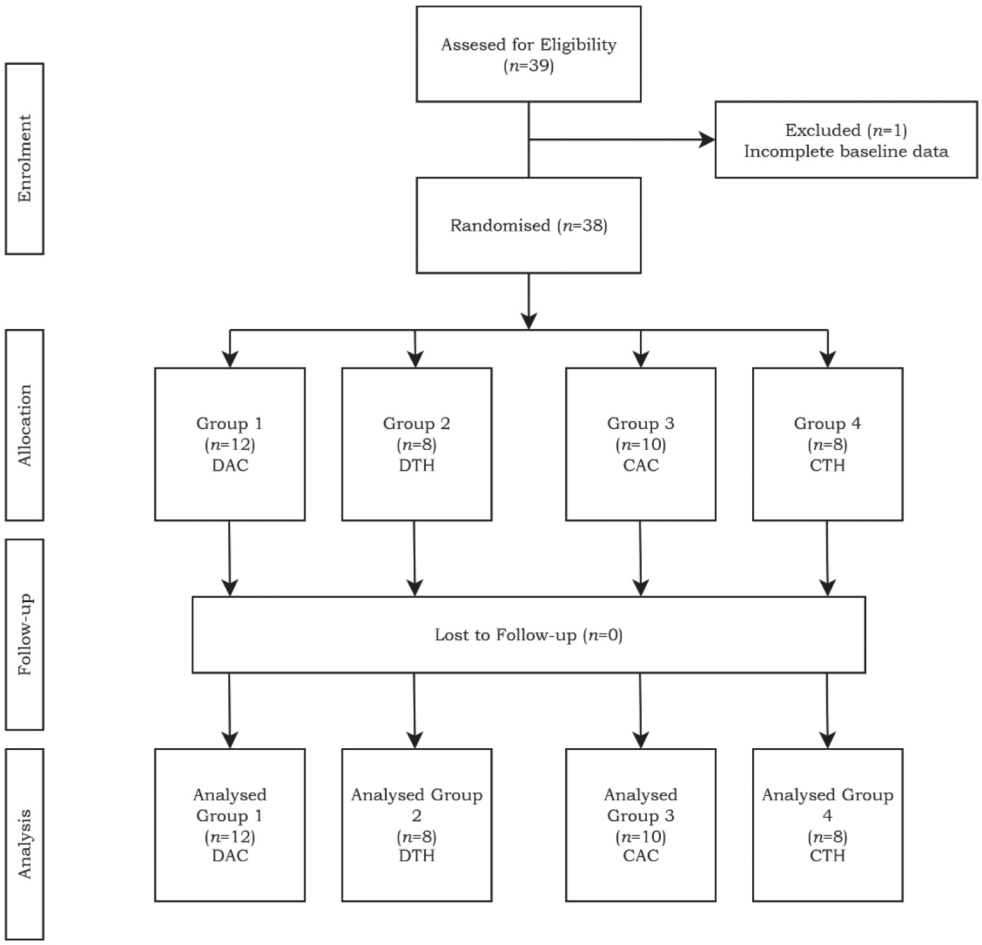

Figure 1. CONSORT diagram showing the flow of participants through each stage of a randomised controlled trial

Ethnicity was confirmed through the ethnic backgrounds of parents and grandparents.

This 28-day randomised controlled trial (RCT) used a parallel-group design. Participants were block-randomised by *FTO rs9939609* genotype (AA/TA or TT) into four groups: two intervention groups – DAC (Diet-AT/AA) and DTH (Diet-TT), and two control groups – CAC (Control-AT/AA) and CTH (Control-TT). All participants received nutrition education. The study was approved by the Research Ethics Committee, Faculty of Medicine, Padjadjaran University (No. 285/UN6.KEP/EC/2023).

Dietary intervention

During the 28-day intervention, participants received three daily meals, i.e., breakfast, lunch, and dinner, based on the Indonesian balanced nutrition guidelines. The diet provided 1100–1500 kcal/day with 45–55% carbohydrates, 15–20% protein, and 20–25% fat (Indonesian Ministry of Health, 2014). Meal portions were standardised, except for those with allergies or dietary restrictions. Caloric distribution ranged from 300–500 kcal for breakfast and 400–500 kcal each for lunch and dinner. Each meal included carbohydrates, animal and plant proteins, vegetables,

and fruits. Carbohydrates were mainly complex sources, while proteins focused on low-fat options, with half from plants. Fats prioritised monounsaturated and polyunsaturated types. Meal composition followed the "*Isi Piringku*» principle and daily portions adhered to the "*Tumpeng Gizi Seimbang*" guidelines (Indonesian Ministry of Health, 2014).

"*Isi Piringku*" is Indonesia's healthy eating guide, recommending a plate divided into 35% vegetables, 15% fruits, 35% staple foods (e.g., rice, noodles), and 15% protein (e.g., fish, eggs, tofu). The "*Tumpeng Gizi Seimbang*" pyramid visually represents balanced nutrition, with staple foods at the base, followed by fruits and vegetables, then proteins, and sugar, salt, and fat at the top to be limited. Control group participants received only nutrition education without a prescribed diet. Their energy needs were assessed based on resting energy expenditure (REE) and physical activity.

Compliance

Participants' compliance was monitored daily. They photographed each meal before and after eating and submitted the images via chat. Study staff reviewed these to estimate consumption based on leftovers. Participants also reported any food eaten outside the provided meals. Intervention group participants were only allowed study-provided food, except for fruits and vegetables. Eating other foods was deemed non-compliant. Those with compliance below 75% were excluded from the analysis.

Nutrition education

Nutrition education was delivered via Zoom before the intervention, using PowerPoint and videos. Topics included balanced diet guidelines, food safety, and healthy lifestyle habits like stress management and sleep.

Dietary assessment

At baseline, dietary intake was assessed using two 24-hour diet recalls – one weekday and one weekend day. During the intervention, control groups completed another 2x24-hour diet recall, while intake for diet groups was based on the provided meals. All data were analysed for calorie and nutrient contents using Nutrisurvey 2007, with references from the Indonesian Food Composition Table (Indonesian Ministry of Health, 2017).

Anthropometric and body composition assessments

After a 12-hour overnight fast, all participants underwent anthropometric and body composition evaluations. Assessments of BW, BMI, total body fat percentage (% BF), visceral fat (VF), subcutaneous fat (SF) and skeletal muscle (SM) in total, trunk, arms, and legs, respectively, were done using an OMRON Karada Body Composition Monitor (HBF-375, Kyoto, Japan). Height was measured with a SAGA stadiometer to the nearest 0.1 cm (SG AU AL 01, Bekasi, Indonesia). BMI was calculated using the formula: BMI = body weight/ height^2 (kg/m^2). WC and HC were measured using a Medline tape to the nearest 0.5cm (OneMed, Jakarta, Indonesia). WHR was calculated and assessed according to clinical risk thresholds, with a WHR greater than 0.85 indicating higher risk for women.

Deoxyribonucleic acid (DNA) isolation, polymerase chain reaction (PCR) analysis, and sequencing

Venous blood (±3 cc) was collected from each participant into an EDTA (ethylenediaminetetraacetic acid) tube. Genomic DNA was extracted from 200 µl of buffy coat using the Genomic DNA Mini Kit (Geneaid, Taiwan). The purity of extracted DNA was assessed with a Nanodrop ND 1000 Spectrophotometer

(Thermo Scientific, USA). DNA quality was confirmed via agarose gel electrophoresis. The *FTO rs9939609* genotype variant was determined using the SNP Genotyping Assay (IDT, Singapore) and analysed via One-Step Real-Time Polymerase Chain Reaction (RT-PCR) on a thermocycler (Applied Biosystems, Foster City, CA, USA). The RT-PCR thermal conditions were as follows: 1) Initial denaturation at 95°C for 10 minutes, 2) Denaturation for 40 cycles at 96°C for 15 seconds, and 3) Annealing/extension at 60°C for 1 minute. Genotyping results were analysed using the Allele Discrimination software, following the manufacturer's standard protocols (Applied Biosystems, Foster City, CA, USA). A 10% duplicate analysis was conducted for validation.

Data analysis

Data were statistically analysed with IBM SPSS Windows version 26.0 (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used to assess the normality of the data. Participants were divided into A allele carriers vs. T homozygote groups and balanced diet groups vs. control groups. The variance (analysis of variance, ANOVA) between groups at baseline and endline was analysed. Paired *t*-tests for calorie intake, macronutrients, BW, BMI, WC, HC, WHR, %BF, VF, SF (total, trunk, arms, legs), and SM (total, trunk, arms, legs) were calculated by subtracting the results of measurements or assessments after intervention with measurement or assessment results before intervention. The mean differences for the parameters mentioned above between A allele carriers and TT genotype, as well as the effects of gene, diet, and gene-diet interaction, were compared using a General Linear Model (GLM). Data are presented as mean±*SD*, with statistical significance determined at $p<0.05$.

RESULTS

Participants' baseline general characteristics and body composition

A total of 39 participants were recruited in November 2023, of which one participant dropped out before the intervention (did not complete baseline tests), leaving 38 who completed it. Table 1 shows the participants' general characteristics. Participants' baseline body composition did not differ significantly between groups (Table 2). The participants' mean±*SD* BW, BMI, HC, VF, %BF, and SF (total, trunk, arms, and legs) were highest in

Table 1. Participants' general characteristics

Variable	*n*	*%*	*Mean±SD*
Age (years)			
18-25	38	100.0	21.0±2.0
Latest education			
High school	30	78.9	-
College	8	21.1	
Occupation			
Student	18	73.7	-
Private employee	3	7.9	
Public employee	3	7.9	
Others	4	10.5	
FTO rs9939609 variant			
AA/TA	22	57.9	-
TT	16	42.1	

SD: Standard deviation

Table 2. Changes in body composition between groups after diet intervention based on *FTO rs9939609* gene variant

Variables		*DAC (n=12)*	*DTH (n=8)*	*CAC (n=10)*	*CTH (n=8)*	*p*-value†
Body weight (kg)	Before	84.2±14.4	87.5±8.2	82.4±12.2	83.5±12.5	0.847
	After	82.9±15.1	85.8±7.8	82.7±12.1	83.6±11.9	0.951
	Δ	-1.3±1.6	-1.7±1.8	0.3±1.2	0.1±1.6	0.017*
	p-value‡	0.013*	0.029*	0.530	0.819	
Body mass index (kg/m^2)	Before	33.6±5.8	35.9±3.8	34.5±3.2	33.6±4.3	0.676
	After	33.4±6.3	35.2±3.3	34.6±3.0	33.8±4.1	0.818
	Δ	-0.3±0.8	-0.7±0.8	0.10±0.6	0.2±0.8	0.071
	p-value‡	0.239	0.035*	0.474	0.401	
Waist circumference (cm)	Before	98.1±11.8	97.8±6.4	97.2±11.6	99.4±9.6	0.977
	After	94.5±12.3	96.3±3.5	97.0±6.6	98.4±9.7	0.809
	Δ	-3.6±5.7	-1.4±6.3	-0.2±8.6	1.0±6.9	0.676
	p-value‡	0.071	0.483	0.959	0.499	
Hip circumference (cm)	Before	116.6±11.2	120.0±8.6	115.1±8.9	116.8±8.0	0.747
	After	115.8±12.0	117.6±5.2	116.1±9.6	115.1±7.7	0.956
	Δ	-0.8±3.2	-2.4±5.8	1.01±4.8	-1.7±5.5	0.475
	p-value‡	0.350	0.352	0.475	0.917	
Waist-hip ratio	Before	0.84±0.05	0.82±0.03	0.84±0.07	0.85±0.04	0.633
	After	0.81±0.06	0.81±0.02	0.84±0.06	0.85±0.06	0.250
	Δ	-0.03±0.05	-0.01±0.04	-0.01±0.08	0.00±0.06	0.688
	p-value‡	0.049*	0.526	0.833	0.830	
Visceral fat	Before	13.7±6.5	18.9±7.8	15.0±4.0	14.1±5.6	0.275
	After	13.4±6.6	18.3±7.4	15.2±3.9	14.2±5.4	0.336
	Δ	-0.3±0.6	-0.6±0.7	0.2±0.6	0.1±0.8	0.076
	p-value‡	0.130	0.046*	0.392	0.671	
Total body fat (%)	Before	38.4±3.3	40.3±2.3	39.3±2.8	39.1±2.7	0.544
	After	38.5±3.4	40.6±2.6	39.6±2.7	38.7±4.0	0.526
	Δ	-0.1±0.6	0.2±0.9	0.4±0.7	-0.4±2.5	0.703
	p-value‡	0.593	0.508	0.142	0.697	
Resting metabolism (kcal)	Before	1597±190	1632±115	1564±170	1579±170	0.853
	After	1574±201	1603±105	1565±169	1579±160	0.969
	Δ	-22±20	-29±31	0±18	-0±25	0.020*
	p-value‡	0.003*	0.033*	0.974	0.978	
Total subcutaneous fat (%)	Before	36.7±3.9	38.9±2.5	38.1±2.9	37.6±3.2	0.500
	After	36.6±4.0	39.1±2.9	38.5±2.7	38.0±3.4	0.368
	Δ	-0.1±0.6	0.2±0.9	0.4±0.7	0.4±0.5	0.270
	p-value‡	0.569	0.488	0.081	0.067	
Subcutaneous trunk (%)	Before	32.9±4.9	35.3±3.0	33.9±3.4	33.5±3.7	0.609
	After	32.8±5.2	35.1±3.1	34.2±3.2	33.8±3.9	0.671
	Δ	-0.0±0.6	-0.2±0.6	0.3±0.5	0.3±0.6	0.240
	p-value‡	0.789	0.483	0.096	0.236	
Subcutaneous arms (%)	Before	50.6±5.8	54.8±3.4	54.0±4.2	53.0±2.8	0.182
	After	52.5±3.3	56.6±3.5	54.6±4.0	54.6±4.0	0.134
	Δ	2.0±6.0	2.1±4.0	0.6±1.4	1.6±1.4	0.885
	p-value‡	0.285	0.219	0.224	0.262	

Table 2. Changes in body composition between groups after diet intervention based on *FTO rs9939609* gene variant *(continued)*

Variables		*DAC (n=12)*	*DTH (n=8)*	*CAC (n=10)*	*CTH (n=8)*	*p*-value†
Subcutaneous legs (%)	Before	51.6±4.6	56.5±3.8	54.0±5.0	53.7±4.3	0.144
	After	51.6±4.3	57.0±4.5	54.7±4.7	54.2±4.8	0.094
	Δ	-0.0±1.0	0.5±2.2	0.8±1.5	0.5±1.2	0.691
	p-value‡	0.976	0.465	0.157	0.280	
Total skeletal muscle (%)	Before	23.0±1.4	21.9±1.2	22.4±1.4	22.5±0.9	0.220
	After	22.9±1.4	21.6±1.2	22.2±1.2	22.3±1.1	0.165
	Δ	-0.1±0.3	-0.3±0.7	-0.2±0.4	-0.2±0.4	0.895
	p-value‡	0.156	0.242	0.170	0.178	
Skeletal trunk (%)	Before	16.4±1.9	15.3±1.1	15.9±1.4	16.0±1.5	0.475
	After	16.4±2.0	15.3±1.2	15.7±1.4	15.9±1.6	0.472
	Δ	0.0±0.3	-0.0±0.3	-0.2±0.3	-0.1±0.3	0.503
	p-value‡	0.905	0.920	0.096	0.242	
Arms skeletal (%)	Before	19.0±4.5	16.9±2.5	18.6±3.4	18.5±3.6	0.655
	After	19.1±4.7	16.9±2.7	18.3±3.4	18.3±3.7	0.665
	Δ	0.1±0.6	0.0±0.7	-0.3±0.5	-0.2±0.5	0.319
	p-value‡	0.397	0.922	0.115	0.215	
Skeletal legs (%)	Before	34.2±14.4	36.1±1.3	36.6±1.4	36.4±0.7	0.209
	After	36.9±1.3	35.7±1.0	36.3±1.3	36.3±1.0	0.168
	Δ	-0.2±0.4	-0.4±1.0	-0.3±0.6	-0.1±0.6	0.947
	p-value‡	0.084	0.365	0.216	0.487	

All values are in mean±*SD*

†Analysis of variance (ANOVA) test between groups; ‡Paired sample *t*-test inter-participant before and after intervention period

*Significant at $p<0.05$; DAC (Diet-AT/AA); DTH (Diet-TT); CAC (Control-AT/AA); CTH (Control-TT)

the DTH group. The participants' mean WC and WHR were highest in the CTH group. The participants' mean skeletal muscle (total, trunk, arms, and legs) was higher in the DAC group.

Differences in body composition before and after intervention

Changes in body composition after diet administration based on the participant's *FTO rs9939609* gene variant are shown in Table 2. Results showed that the DAC group's BW, HC, and WHR significantly decreased before and after a balanced diet intervention for 28 days. BMI, WC, and VF of participants in the DAC group also decreased, but the changes were insignificant. Meanwhile, the DTH group showed that BW, BMI, and VF were significantly reduced before and after the balanced diet intervention for 28 days. WC, HC, and WHR in the DTH group also decreased, but they were insignificant. In contrast, CAC and CTH groups experienced neither significant increases nor decreases in all anthropometric and body composition indicators. The control groups experienced increased BW, BMI, VF, and SF (total, trunk, arms, and legs), although the increases were insignificant.

Changes in nutritional intake during intervention

ANOVA results (Table 3) showed no significant differences in energy, fat, protein, or carbohydrate intakes across groups before the intervention. During the intervention, however, significant differences in fat and carbohydrate

Table 3. Energy and nutrient intakes before and during the intervention period

Variables		*DAC (n=12)*	*DTH (n=8)*	*CAC (n=10)*	*CTH (n=8)*	*p*-value†
Energy (kcal)	Before	1518±569	1387±768	1423±344	1909±987	0.398
	During	1371±94	1367±56	1692±655	1549±607	0.830
	Δ	-146±571	-20±789	269±563	-359±613	0.207
	p-value‡	0.845	0.944	0.169	0.208	
Protein (g)	Before	48.7±21.2	65.7±94.7	41.5±19.4	61.4±45.8	0.531
	During	57.2±3.7	57.0±2.3	62.2±30.3	62.0±27.2	0.756
	Δ	8.5±21.8	-8.7±94.7	20.8±34.6	0.6±30.4	0.415
	p-value‡	0.016*	0.327	0.047*	0.674	
Fat (g)	Before	73.6±32.9	62.7±37.8	61.1±21.2	92.1±54.2	0.308
	During	33.5±2.8	32.9±2.2	78.7±35.8	66.6±30.7	0.001*
	Δ	-40.1±32.5	-29.8±36.6	17.6±40	-25.5±32.5	0.004*
	p-value‡	0.001*	0.042*	0.197	0.062	
Carbohydrate (g)	Before	171.6±77.4	143.7±65.5	178.8±54.0	210.3±98.6	0.373
	During	213.6±14.5	215.7±8.4	184.0±64.8	173.2±58.5	0.006*
	Δ	42.0±77.2	72.0±68.4	5.1±79.9	-37.1±79.4	0.037*
	p-value‡	0.119	0.021*	0.878	0.208	

All values are in mean±*SD*

†Analysis of variance (ANOVA) test between groups; ‡Paired sample *t*-test inter-participant before and during intervention period

*Significant at $p<0.05$; DAC (Diet-AT/AA); DTH (Diet-TT); CAC (Control-AT/AA); CTH (Control-TT)

intakes emerged. Participants in the balanced diet groups (Groups 1 and 2) consumed less fat and more carbohydrates than those in the control groups (Groups 3 and 4). Energy and protein intakes remained consistent across all groups. These findings indicated that the balanced diet groups adjusted their nutrient intakes in line with dietary guidelines, which were 15–20% protein, 20–25% fat, and 55–65% carbohydrates. In contrast, control groups diverged from these recommendations, with protein under 16%, fat over 35%, and carbohydrates below 55% of total energy.

Main effect analysis of gene, diet, and gene-diet interactions on body composition

This section compared the average differences of the parameters mentioned for allele A carriers and genotype TT to analyse diet, genes, and gene-diet interactions (Table 4). After the different test results were found to be significant on the parameters of BW, BMI, WHR, and VF, a GLM test was carried out to determine the influence of genes, diet, and gene-diet interactions. Before proceeding with the inter-participant effect test, the Levene's homogeneity test was carried out. Test results showed that all data had a homogeneous distribution. Table 4 shows that diet intervention factors significantly affected BW [*Adjusted* β *(SE)*=-1.67 (0.72); p=0.005; *CI* 95%: -3.13 to -0.21], BMI [*Adjusted* β *(SE)*=-0.40 (0.35); p=0.030; *CI* 95%: -1.12 to 0.31], and VF [*Adjusted* β *(SE)*=-0.46 (0.33); p=0.043; *CI* 95%: -1.13 to 0.21]. The results were adjusted for age and physical activity level. Meanwhile, gene factors did not have a significant

Table 4. Effects of *FTO rs9939609* polymorphism, balanced diet, and gene-diet interaction, unadjusted and adjusted for age and physical activity

Predictor	*Unadjusted β (SE)*	*95% CI*	*p-value*	*Adjusted β (SE)*	*95% CI*	*p-value*
Body weight (BW)						
Gene *FTO* factor	-0.11 (0.73)	-1.60 – 1.37	0.611	-0.26 (0.78)	-1.85 – 1.33	0.652
Diet factor	-1.57 (0.66)	-2.91 – -0.23	0.002*	-1.67 (0.72)	-3.13 – -0.21	0.005*
FTO × Diet Interaction	-0.30 (1.01)	-2.34 – 1.76	0.772	0.04 (1.15)	-2.31 – 2.39	0.971
Age	–		–	0.05 (0.14)	-0.24 – 0.34	0.727
Physical activity score	–		–	-0.87 (1.62)	-4.16 – 2.42	0.594
Body mass index (BMI)						
Gene *FTO* factor	-0.11 (0.36)	-0.62 – 0.84	0.518	0.06 (0.38)	-0.72 – 0.84	0.560
Diet factor	-0.38 (0.32)	-1.03 – -0.28	0.013*	-0.40 (0.35)	-1.12 – 0.31	0.030*
FTO × Diet interaction	-0.55 (0.50)	-1.56 – 0.46	0.276	-0.41 (0.57)	-1.57 – 0.74	0.471
Age	–		–	-0.29 (0.79)	-0.11 – 0.17	0.662
Physical activity score	–		–	0.03 (0.07)	-1.90 – 1.33	0.719
Waist-hip ratio (WHR)						
Gene *FTO* factor	0.01 (0.03)	-0.05 – 0.07	0.505	0.02 (0.03)	-0.04 – 0.08	0.527
Diet factor	-0.02 (0.02)	-0.07 – 0.03	0.357	-0.01 (0.03)	-0.06 – 0.04	0.410
FTO × Diet interaction	-0.01 (0.04)	-0.07 – 0.08	0.880	-0.02 (0.04)	-0.10 – 0.07	0.707
Age	–		–	0.00 (0.00)	-0.01 – 0.01	0.879
Physical activity score	–		–	0.08 (0.06)	-0.04 – 0.20	0.183
Visceral fat (VF)						
Gene *FTO* factor	-0.06 (0.34)	-0.74 – 0.63	0.433	0.10 (0.36)	-0.82 – 0.63	0.494
Diet factor	-0.49 (0.31)	-1.11 – 0.13	0.012*	-0.46 (0.33)	-1.13 – 0.21	0.043*
FTO × Diet interaction	-0.26 (0.47)	-1.21 – 0.69	0.580	-0.14 (0.53)	-1.21 – 0.44	0.799
Age	–		–	0.07 (0.06)	-0.06 – 0.20	0.275
Physical activity score	–		–	0.00 (0.74)	-1.50 – 1.50	1.000

β (coefficient beta): the effect of a predictor; *SE*: Standard error; 95% *CI*: Confidence Interval 95%; Adjusted β: test analysis was adjusted for age and physical activity
*Significant at $p<0.05$

impact on them. Moreover, diet and gene factors did not significantly affect WHR.

DISCUSSION

The AA genotype has been identified as the variant associated with a higher risk of obesity across diverse ethnic populations in Asia (Pratiwi *et al.*, 2025). However, a previous study stated that in the Indonesian population, the FTO *rs9939609* gene variant does not appear to be significantly associated with an elevated risk of obesity (Pratamawati *et al.*, 2024). A study on Korean women found that the A risk allele was linked to higher BW, BMI, and HC. Additionally, individuals carrying this allele had a 1.28 times greater risk of obesity compared to those with the TT genotype (Ponce-Gonzalez *et al.*, 2023). A study on premenopausal women found that the *rs9939609* polymorphism was associated with increased BW and fat mass, particularly in individuals with the AA genotype compared to those with the AT and TT genotypes (Ağagündüz & Gezmen-karadağ, 2019). This previous research suggests that the *rs9939609* variant is possibly involved in obesity development in women, more precisely, in already obese women.

The lack of significant baseline differences in body composition between groups supports the study's internal validity, ensuring that changes were due to the intervention, not pre-existing factors. The FTO rs9939609 variant has shown mixed results in diet-related studies. One study found that a 3-year Mediterranean diet reduced body fat but had no significant effects on weight, BMI or body circumference, with no notable difference in weight loss between A allele carriers and TT genotype participants (Di Renzo *et al.*, 2018).

It has also been reported that participants carrying the A allele exhibited the lowest BW increase during a three-year follow-up after a Mediterranean diet intervention concerning participants without the mutation (TT genotype) (Razquin *et al.*, 2010). According to a previous study, a three-month intervention with a partial meal replacement hypocaloric diet led to reductions in BW, fat mass, WC, and systolic blood pressure across all groups. Moreover, in the A allele group, low-density lipoprotein cholesterol, insulin and homeostatic model assessments for insulin resistance (HOMA-IR) improved (De Luis *et al.*, 2020).

This study showed that a 28-day balanced diet significantly reduced BW, BMI, WHR, and VF. In contrast, control groups showed non-significant increases in weight and fat measures, along with reduced skeletal muscle. The dietary groups also had improved nutrient intakes by lowering fat and increasing carbohydrate consumption in line with dietary guidelines (Wang *et al.*, 2023). These findings are consistent with previous research that suggests balanced diets, emphasising a higher proportion of carbohydrates and moderate protein intakes, can lead to favourable changes in body composition and metabolic health (Koemel *et al.*, 2025). Notably, the control groups did not adhere to these recommendations, exhibiting excessive fat intake and insufficient carbohydrate consumption, which may contribute to the continued risks associated with obesity and metabolic disorders (Kirkpatrick *et al.*, 2019).

A previous Indonesian study found that a 14-day balanced, low-calorie diet significantly improved body composition and reduced leptin levels in 39 obese women, leading to decreases in weight, BMI, fat mass, and other adiposity markers, while increasing fat-free mass percentage (Suyardi *et al.*, 2005). The novel dietary intervention programme called Optimized Nutri-Dense Meals, designed according to the Dietary Reference Intakes (DRIs) in Japan, showed reductions in VF (Shobako *et al.*, 2024). The present study is the first to explore the effects of a dietary intervention based on the Indonesian Balanced Nutrition Guidelines in relation to the *FTO rs9939609* polymorphism, offering a novel foundation for promoting balanced nutrition as a healthy lifestyle.

Based on the results, BW, BMI, and VF were strongly influenced by diet but not by *FTO* factors. Meanwhile, WHR was not influenced by these two factors (genes or diet), suggesting that other factors such as physical activity level, sleep duration, hormonal status, stress, and gut microbiota composition may contribute to the regulation of body fat distribution and adiposity (Maruszczak *et al.*, 2025). Changes in body composition were also not influenced by gene-diet interactions. Therefore, a balanced diet intervention affects body composition, confirming its ability to reduce BW, BMI, and VF.

Unlike previous studies showing *FTO*-related effects with Mediterranean diet therapy, this study found no significant influence of the *FTO* polymorphism. In this respect, the *FTO* did not impact the effect of nutritional intervention in the current study, which is also supported

by other studies using other kinds of diet intervention (Abbate *et al.*, 2020; Dorling *et al.*, 2021). Di Renzo *et al.* (2018) demonstrated that the reduction in % gynoid fat was strongly linked to the Mediterranean diet, highlighting the dominant role of dietary intervention in improving body composition. Although the *FTO rs9939609* variant did not significantly affect outcomes in this short-term study, further research is needed before dismissing its role in broader dietary interventions. Adjusted analyses highlighted that physical activity can moderate the impact of *FTO* polymorphisms, particularly *rs9939609*, on body fat. While A allele carriers are more prone to higher body fat and BMI, regular physical activity can reduce this genetic risk, emphasising the importance of lifestyle in shaping genetic outcomes (King *et al.*, 2024).

Obesity is a multifactorial condition influenced by a complex interplay of genetic, environmental, behavioural, and metabolic factors (Lin & Li, 2021; Pineda *et al.*, 2024). However, variables like physical activity, sleep, gut microbiota, and psychological stress also contribute to obesity risk and treatment response; future research should adopt a more integrative approach to better understand individual variability in dietary intervention outcomes (Sochacka *et al.*, 2024). The lack of significant gene-diet interaction in this study does not rule out the role of the *FTO rs9939609* variant in obesity. It suggests that other factors like intervention duration, ethnic-specific genetics, diet differences, and lifestyle elements such as activity, gut health, sleep, stress, and hormones may influence outcomes.

Previous research suggests that lifestyle factors like exercise and specific dietary fats can offset *FTO*-related obesity risk, potentially masking genotype effects in this study. The short duration and small sample size may have limited the ability to detect significant differences. Despite this, the balanced diet intervention improved body composition regardless of *FTO rs9939609* genotype. Future research should include longer interventions and broader biological assessments to better understand gene-diet interactions. Overall, balanced diet had a greater impact than the *FTO* variant, showing effectiveness across both gene variants studied.

CONCLUSION

This study demonstrated that a 28-day balanced diet significantly improved body composition, including reductions in BW, BMI, VF, and WHR in the intervention groups. Although the balanced diet intervention significantly improved body composition across all *FTO rs9939609* genotypes, the role of this SNP in influencing dietary outcomes cannot be entirely ruled out. The absence of significant gene-diet interactions in this study may be attributed to unmeasured confounding factors, such as sleep, stress, gut microbiota, and hormonal regulation, as well as the short intervention duration. Therefore, future research with longer follow-up periods and more comprehensive variable control is recommended.

Acknowledgement

The authors express their gratitude to Vetty Nur Aeni and the student team for their data collection collaboration. The authors also appreciate all the respondents who participated in this research.

Authors' contributions

Novitasari P, conceptualisation, methodology, software, formal analysis, data curation, writing – original draft, visualisation, and project administration; Rimbawan R, conceptualisation, methodology, validation, investigation, supervision, and writing – review & editing; Hardinsyah H, conceptualisation, methodology,

validation, investigation, supervision, and writing – review & editing; Riyadi H, conceptualisation, methodology, validation, investigation, supervision, and writing – review & editing.

Conflict of interest

All authors declare that there are no conflicts of interest.

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