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The Effect of Local Food-Based Dietary Recommendations and Physical Activity on Glycemic Control in Patients with Type 2 Diabetes Mellitus

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ABSTRACT

Background: Type 2 Diabetes Mellitus (T2DM) is a major global health issue that requires integrated management strategies. Indigenous dietary practices and physical activity may offer culturally relevant and sustainable interventions. This study aimed to assess the effect of local food-based dietary recommendations (FBR), alone and in combination with physical exercise (PE), on glycemic control in patients with T2DM.
Methods: In a quantitative study and employing a pre-post experimental design, 69 participants were enrolled and randomly assigned to three groups of FBR (n=24), FBR together with physical exercise (FBR+PE) (n=24) and standard care control (n=21). The intervention lasted 4 weeks and the pre- and post-intervention assessments were dietary adherence, physical activity compliance, and glycemic control parameters (fasting blood glucose, 2-h postprandial glucose, and glycated albumin).
Results: The FBR and FBR+PE groups showed an increase in dietary intake adherence to several nutrients. The FBR+PE group exhibited significant improvement in all glycemic control parameters after the intervention period. Notably, the combined intervention group exhibited a significantly greater reduction in glycated albumin level when compared to the control and FBR-only groups.
Conclusion: Integrating local FBR with physical activity could enhance glycemic control in T2DM and can be a promising strategy for management of culturally relevant diseases.

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Introduction

Type 2 diabetes mellitus (T2DM) has emerged as one of the most notable public health challenges of the 21st century, affecting approximately 589 million adults worldwide, with projections suggesting that this number would rise to 853 million by 2050. The global economic burden of diabetes has increased by 338% over the past 17 years and reached approximately USD 1 trillion by 2024. Indonesia ranks fifth in the world for the highest prevalence of diabetes, with 20.4 million cases, an increase from 10.6% in 2021 to 11.3% in 2024 (1). Lifestyle modification, particularly dietary recommendations, and physical exercise have been recognized as a diabetes management method for achieving optimal glycemic control, in addition to pharmacological interventions (2). A meta-analysis by Sagastume *et al.* showed that structured lifestyle interventions can reduce hemoglobin A1c (HbA1c) level by 0.15% [−0.25 to −0.05] when compared to the standard care (3).

It was shown that dietary adherence and structured physical activity can lead to notable improvements in fasting blood glucose, fasting plasma insulin, glycated hemoglobin, and nutritional status ($p<0.05$) (4-6). Patients who adhere to dietary recommendations are 3.56 times more likely to achieve good glycemic control (7). Additionally, a study by Zhao *et al.* showed that exercise could greatly reduce HbA1c and body mass index (BMI) among patients with T2DM and obesity (8). Several factors can affect patients' non-compliance with dietary recommendations, including food availability and dietary habits that are influenced by cultural factors. The use of local foods in the developing dietary recommendations may increase compliance by improving accessibility and acceptability (9).

Although many studies confirmed the effectiveness of diet and exercise for T2DM, few have investigated culturally tailored dietary interventions using local foods combined with structured physical activity. Moreover, there is limited evidence on the short-term impact of using glycated albumin (GA) as a marker. Therefore, this study used GA as the marker of glycemic control, which serves as an alternative short-term glycemic control marker to the commonly used HbA1c, offering superior sensitivity to plasma glucose fluctuations and remaining unaffected by hemoglobin metabolism or conditions that falsely alter HbA1c level. This study also addressed the lack of culturally tailored, local food-based interventions combining diet and physical activity for short-term glycemic control in Indonesia. This study aimed to investigate the combined impact of specific local food-based dietary recommendations (FBR) and structured physical exercise on glycemic control in patients with T2DM.

Materials and Methods

This quantitative study in 2025 employed a randomized controlled pre-post experimental study with a control group. Participants were randomly assigned to one of three groups using a computer-generated randomization method including FBR education only, FBR combined with physical exercise (PE) (FBR+PE) and the standard care (control). The study population included patients with T2DM aged 50-64 years in Malang City, Indonesia. Cluster random sampling was conducted across the selected primary healthcare centers from 16 community health centers. Simple randomization was performed using a random generator application so that each community health center had an equal chance of being assigned to the intervention and control groups. After selecting the three community health centers for the intervention and control groups, data collection of potential respondents was conducted, with the inclusion criteria as patients with T2DM aged 50-64 years, able to communicate verbally, and able to read and write and the exclusion criteria of suffering from complications requiring a special diet, such as heart disease, kidney failure, or stroke (based on a diagnosis determined by a doctor).

Regarding intervention protocol and FBR group, participants received education based on FBR developed using the WHO's Optifood software. FBR incorporated nutrient-dense local foods (e.g., corn rice, tempeh, mackerel, moringa leaves, and kepok bananas) and was optimized to meet ≥65% of the recommended nutrient intake for key nutrients (Table 1 and Table 2). The program used a Behavior Change Technique (BCT) framework, delivered weekly over 4 weeks (goal setting, problem-solving, demonstrations, and feedback), and supported by educational materials (booklet and video). Participants maintained a dietary log throughout the study period and were followed up via home visits or phone calls.

Regarding FBR+PE group, in addition to FBR education, participants engaged in structured, supervised physical exercise guided by nurse from a diabetic clinic (Pediscare), in the form of diabetic foot exercises. The participants also got recommendation about the combination of aerobic exercise and muscle strength training that could be done independently at home, such as walking regularly about 3-5 days a week for 30-45 minutes, with a total of 150 minutes per week according to the guidelines of the Indonesian Endocrinology Association (10). The BCT framework was similarly applied, integrating both dietary and exercise components weekly. Participants also completed dietary logs and were followed via home visits or phone calls. The control group received standard care from the healthcare center, which included general diabetes education and routine follow-ups, without specific recommendations on local food selection or physical exercise.

Table 1: Dietary recommendations for T2DM patients aged 50-64 years.

No	Recommendation	Serving Size*	
		Female (1700 Kcal)	Male (2200 Kcal)
1	3 meals/day	1 serving of white rice=120 g (2 scoops)	1 serving of white rice=160 g (3 scoops)
	Including 7 servings of corn rice per week or 1 serving of corn rice per day	1 serving of corn rice=80 g (5 tbsp)	1 serving of corn rice=120 g (2 scoops)
2	3x/day of animal protein (meat: beef/chicken/ fish, eggs) consumed at least three times:		
	a. Fish, at least tongkol of 2 Servings per week; mackerel 1 serving per week	1 serving of tongkol=30 g (slice)	1 serving of tongkol=60 g (1 small fish); mackerel fish=70 g (1 medium-sized)
	b. White meat such as chicken: 7 servings/ week	1 serving of chicken=45 g (1 piece of lower breast)	1 serving of chicken=50 g (1 slice of lower breast)
	c. Eggs (chicken eggs, quail eggs): 3 servings per week	1 serving of egg=1 egg	1 serving of egg=1 egg
3	Consuming soybeans and its by-products of at least 3 servings/ day, including:		
	a. Tempeh 2 servings/day	1 serving of tempeh=50 g (1 big chunk)	1 serving of tempeh=50 g (1 big slice)
4	Nuts, particularly Koro (Lima beans) of 1 serving/week)	1 serving=30 g	1 serving=30 g
5	Consuming 4 servings of vegetables per day as:		
	a. 2 servings/day of green leafy vegetables (king's salad, papaya leaf, cassava leaf, spinach, morning glory, etc.), including moringa leaves	1 serving of greenies=50 g (5 sdm) Moringa: 1 serving/week	1 serving of greenies=75 g (5 ladles/7.5 tbsp) 2 servings/week
	b. 2 servings/day of other vegetables (e.g., chayote, broccoli, long beans, eggplant, bamboo shoots, bean sprouts, etc.)		
6	Consuming 2 servings of fruit per day, which includes at least:		
	a. 3 servings of kepok bananas per week	1 serving of banana=135 g (1 piece)	3 (1 serving of kepok banana=160 g)
	b. Vitamin A-rich fruit (papaya)	4 servings, 1 serving of papaya=100 g (1 long slice)	4 serving (1 serving of papaya=165 g (1.5 fruit))
	c. Vitamin C-rich fruit (guava, crystal guava, orange)	5 servings/week, 1 serving of guava=120 g (1/2 medium-sized fruit)	3 servings (1 serving of guava=240 g (1 medium-sized guava))

*Serving sizes were based on the median portion intake. T2DM: Type 2 Diabetes Mellitus. (11)

The primary outcome measures were glycemic control parameters including fasting blood glucose (FBG), 2-hour postprandial glucose (2h PPG), and GA. Measurements were taken pre- and post-intervention. Dietary adherence was measured using 24-hour dietary recall, food records, and a semiquantitative food frequency questionnaire (SQ-FFQ) tailored to the FBR. Physical activity was assessed using the short international physical activity questionnaire (IPAQ-S) and the exercise log. Venous blood was collected by trained phlebotomists after an 8-10 hour fasting. FBG and 2h PPG were measured using the glucose oxidase–peroxidase method, while GA was assessed enzymatically.

All procedures involved human participants and were in accordance with the ethical standards of the institutional and national research committee (Ethical approval has been obtained from the Ethics Commission of the Faculty of Medicine, Public Health and Nursing, Gadjah Mada University with no. KE/FK/0674/EC/2021). After obtaining the data that met the criteria, random sampling was performed to determine the study subjects using a random generator application. A minimum of 20 participants per group was determined based on power calculations, with a 25% anticipated dropout rate. A total of 75 participants were recruited; while 69 completed the study (Control: n=21, FBR: n=24, FBR+PE: n=24). The sample size estimation was based on parameters of $Z\alpha=1.96$ for a two-tailed significance level ($\alpha=0.05$), $Z\beta=0.84$ corresponding to 80% power, standard deviation (σ)=0.7, and expected mean difference (δ)=0.67.

Table 2: Dietary recommendations for T2DM patients in different groups.

Recommended Foods	Median (min–max) (%)			*P* value
	Control group (n=21)	FBR group (n=24)	FBR+PE group (n=24)	
		FBR group (n=24)	FBR+PE group (n=24)	
Corn rice				
Pre-intervention	3.5 (0–200)	14.3 (0–100)	14.3 (0–100)	0.778
Post-intervention	14.3 (0–239.3)[a]	55.4 (7.1–150)[b]	75 (0–207.1)[b]	0.026*
P value	0.000	0.000	0.000	
Δpre-post	0 (−32.14–139.29)[a]	28.57 (−7.14–135.71)[b]	44.64 (0–207.14)[b]	0.001*
Tongkol				
Pre-intervention	50 (0–350)	50 (0–150)	100 (0–200)	0.527
Post-intervention	100 (0–187.5)	100 (12.5–225)	100 (0–375)	0.674
P value	0.000	0.001	0.126	
Δpre-post	25 (−225–162.5)	69.27±79.9	34.89±105.16	0.241
Mackerel				
Pre-intervention	0 (0–400)	0 (0–300)	0 (0–300)	0.371
Post-intervention	25 (0–250)[b]	87.5 (0–375)[b]	0 (0–425)[a]	0.008*
P value	0.003	0.005	0.248	
Δpre-post	25 (−350–250)[a.b]	71.87 (−150–375)[a]	0.0 (−275–425)[b]	0.045*
Tempeh				
Pre-intervention	50 (21.4–150)	32.1 (0–150)	100 (14.3–150)	0.012
Post-intervention	39.3 (3.6–139.3)[a]	47.3 (16.1–108.9)[a.b]	66.9 (21.43–105.4)[b]	0.003*
P value	0.020	0.511	0.049	
Δpre-post	−28.26±35.53[a]	5.58±49.67[b]	−18.38±42.58[a.b]	0.030*
Koro				
Pre-intervention	0 (0–300)	0 (0–400)	0 (0–300)	0.292
Post-intervention	25 (0–300)	112.5 (0–525)	87.5 (0–425)	0.062
P value	0.000	0.001	0.066	
Δpre-post	25 (-150–300)	75 (−300–425)	47.92±116.08	0.054
Green leaves vegetables				
Pre-intervention	21.4 (0–150)	28.5 (0–100)	42.8 (7.1–200)	0.007*
Post-intervention	41.1 (16.1–144.6)	39.3 (19.6–114.3)	47.3 (16.1–107.1)	0.326
P value	0.023	0.022	0.721	
Δpre-post	11.9±(−50–57.14)	17.85 (−66.07–78.57)	4.46 (−167.86–64.29)	0.392
Moringa leaves				
Pre-intervention	25 (0–300)	0 (0–300)	0 (0–300)	0.185
Post-intervention	0 (0–125)[a]	150 (0–450)[b]	100 (0–375)[b]	0.000*
P value	0.000	0.000	0.000	
Δpre-post	−25 (−175–100)[a]	112.5 (0–450)[b]	84.89 (−50–275)[b]	0.000*
Kepok Banana				
Pre-intervention	0 (0–233.3)	33.3 (0–233.3)	0 (0–66.7)	0.001*
Post-intervention	50 (0–216.6)[a]	95.8 (0–283.3)[b]	95.8 (16.7–266.7)[b]	0.001*
P value	0.000	0.005	0.000	
Δpre-post	8.33 (−100–75)[a]	65.27±102.7[b]	102.43±77.76[b]	0.001*
Fruits rich in vitamin A content				
Pre-intervention	25 (0–100)	37.5 (0–175)	75 (0–525)	0.001*
Post-intervention	25 (0–131.25)[a]	56.3 (0–137.5)[b]	50 (18.7–187.5)[b]	0.024*
P value	0.995	0.127	0.109	
Δpre-post	6.25±49.6	13.8±34.43	−15.6 (−506.25–62.5)	0.099
Vitamin C-rich fruit				
Pre-intervention	20 (0–80)	26.7 (0–100)	36.7 (0–280)	0.092
Post-intervention	25 (0–90)[a]	50 (10–150)[b]	47.5 (5–116.7)[b]	0.023*
P value	0.023	0.004	0.898	
Δpre-post	11.11±38.52	26.18±41.28	6.66 (−265–116.67)	0.214

[a,b] show a difference during the intervention. % corn rice control vs. FBR (0.021); control vs. FBR+PE (0.028); mackerel control vs. FBR+PE (0.03); FBR vs. FBR+PE (0.005); tempeh control vs. FBR+PE (0.001); moringa leaves control vs. FBR (0.000); control vs. FBR+PE (0.000); Kepok control vs. FBR (0.001); control vs. FBR+PE (0.002); Fruits vitamin A control vs. FBR (0.028); control vs. FBR+PE (0.011); Fruit vitamin C control vs. FBR (0.011); control vs. FBR+PE (0.029). FBR: Food-based dietary recommendations, PE: Physical exercise.

Statistical analysis was performed to compare numerical variables across multiple unpaired groups using one-way ANOVA for normally distributed data and the Kruskal-Wallis test for non-normally distributed data. Normality was assessed using the Shapiro-Wilk test for each group (Control, FBR, and FBR+PE). The data were presented as mean±SD or median (IQR), as appropriate. When ANOVA showed significant differences, Tukey's HSD post-hoc test was conducted; for Kruskal-Wallis, post-hoc pairwise comparisons were applied. Within group pre–post comparisons were analyzed using the paired t-test for normally distributed data and the Wilcoxon signed-rank test for non-normal data. All analyses were conducted using IBM SPSS Statistics (version 31, Chicago, IL, USA), with a significance level set at $p<0.05$.

Results

The characteristics of the respondents showed that most of them were pre-elderly (50-59 years old), while females were dominated across all groups (Table 3). No notable gap in educational background was found among the three groups. Although some respondents had received educational plan regarding T2DM and nutrition, the majority had never attended an educational class. Based on the results of SQ-FFQ processing, it was known that in the FBR and FBR+PE groups, there was a significant increase in compliance with recommendations on local food ingredients, including corn rice, moringa leaves, and kepok banana ($p<0.05$). In addition, the consumption of green vegetables, vitamin-rich fruits, and animal side dishes, especially tongkol (tuna) and mackerel, increased slightly among the three groups.

The compliance with recommendations for local food consumption also affected the intake of nutrients in patients with T2DM. As presented in

Table 3: Demographic characteristics and diseases of the respondents.

Variable	Control group (n=21)	FBR group (n=24)	FBR+PE group (n=24)	**P* value
Age (years)	58 (51–63)	59 (52–64)	58.5 (51–63)	0.482
Duration (years)	6 (0.83–11)	5 (0.5–22)	8 (0.8–20)	0.422
Gender				
Male	9 (42.9%)	3 (12.5%)	6 (25%)	0.068
Female	12 (57.1%)	21 (87.5%)	18 (75%)	
Education level				
Secondary to lower	9 (42.9%)	18 (75%)	11 (45.8%)	0.051
Upper secondary	12 (57.1%)	6 (25%)	13 (54.2%)	
Occupation				
Non-working/housewife	7 (33.3%)	16 (66.7%)	13 (54.2%)	0.080
Work and retirees	14 (66.7%)	8 (33.3%)	11 (45.8%)	
Marital status				
Unmarried+widow/widower	6 (28.6%)	5 (20.8%)	8 (33.3%)	0.620
Married	15 (71.4%)	19 (79.2%)	16 (66.7%)	
History of nutritional education and T2DM				
Ever	13 (61.9%)	19 (79.2%)	13 (54.2%)	0.178
Never	8 (38.1%)	5 (20.8%)	11 (45.8%)	
T2DM class membership				
Never	14 (66.7%)	17 (70.8%)	21 (87.5%)	0.220
Occasional+Routine	7 (33.3%)	7 (29.2%)	3 (12.5%)	
T2DM's family history				
Have a history	9 (42.9%)	10 (41.7%)	11 (45.8)	0.956
None	12 (57.1%)	14 (58.3%)	13 (54.2)	
Medication				
Without medication	4 (19%)	0 (0%)	0 (0%)	
Monotherapy	6 (28.6%)	8 (33.3%)	5 (20.8%)	
2 drugs combination	7 (33.3%)	12 (50%)	17 (70.8%)	
3 drugs combination	2 (9.5%)	0 (0%)	2 (8.3%)	
Insulin	2 (9.5%)	2 (8.3%)	0 (0%)	
Combination of oral+insulin	0 (0%)	2 (8.3%)	0 (0%)	

*Kruskal-Wallis dan Chi-square Test; Secondary to lower education: Junior high school, elementary school, not graduating from elementary school; Upper to secondary education: High school, D3 (diploma 3/associate degree), D4/S1 (bachelor's degree), postgraduate. T2DM: Type 2 Diabetes Mellitus, FBR: Food-based dietary recommendations, PE: Physical exercise.

Table 4, the intake of protein and fiber was greatly different between the FBR and FBR+PE groups when compared to the control group. Additionally, this study analyzed the adequacy of micronutrient intake that affected glycemic control. The results showed that the intake of calcium, zinc, vitamin A, and omega-3 in the two groups that received the local food-based food recommendations experienced a notable increase in comparison to the control group. The results of the analysis showed that both groups had an increase in intake.

In this study he participants' BMI was also analyzed and presented in Table 5 revealing significant differences between groups (p=0.000). In the pre-intervention measurements, the average BMI of the control group was 26.4±4.5 kg/m², the FBR group was 29.3±4.1 kg/m², and the FBR+PE group was 24.1±3.7 kg/m². After the intervention, the control group's BMI was 26.2±5.07 kg/m², the FBR group was 29.5±4.1 kg/m², and the FBR+PE group was 24.4±3.5 kg/m² (p=0.000). Analysis of BMI changes (Δ pre-post) showed that the control group decreased by -0.21±0.41 kg/m², the FBR group increased by 0.102±0.56 kg/m², and the FBR+PE group increased by 0.27±0.59 kg/m² with significant differences between groups (p=0.008).

Table 4: Average percentage of respondents' macronutrient needs fulfillment before and after 1 month of education.

Nutrient	Control group			FBR group			FBR+PE group			*P* value
	Pre	Post	ΔPre-Post	Pre	Post	ΔPre-Post	Pre	Post	ΔPre-Post	
Energy	65.4±20.6	62.8±23.1[a]	(-2.6±17.8)[a]	62.9±19.7	78.0 ±20.5[b]	15.1±25.8[b]	72.2±23.6	84±23.4[b]	11.8±20.0[b]	0.020*
Protein	92.5±35.6	89.1±33.6[a]	(-3.4±23.8)[a]	83.9±28.4	117.1±43.8[b]	33.2±50.7[b]	105.5±44	126.4±41.7[b]	20.9±44.8[b]	0.028*
Fat	88.4±38.2	80.3±37[a]	(-8.1±30.9)	93.2±39.9	110.3±41.6[b]	17.1±54.1	108.5±46.7	112.8±43.8[b]	4.3± 52	0.398
Carbohydrate	85.7±36.5	83.7±32	(-2.0±28.7)[a]	80.2±29	100.4±25	20.1±29.6[b]	90.2±29.4	110.8±36.4	20.6±28.8[b]	0.017*
Fiber	29.3±16	35.5±18.1[a]	6.1±19.3[a]	27.2±20	59.1±28[b]	31.9±33.8[b]	33.6±17.7	71.7±35.8[b]	38.1±39.5[b]	0.006*
Calcium	34.3±16.9	35.5±24.5[a]	1.2±13.4[a]	32.9±15.6	58.8±36[b]	25.9±38.1[b]	38.2±15.5	52.0±22.4[b]	13.8±25.7[a,b]	0.028*
Zinc	46±20.7	37.8±18.2	(-8.3±13.0)[a]	40.5±13.6	46.8±14.6	6.3±16.8[b]	42.3±16	47.2±13.5	5±16.7[b]	0.007*
Vitamin C	42.1±34.5	51.0±52.7[a]	8.9±35.7	61.8±3818	105.0±55.8[b]	43.2±59.0	77.4±65.7	116.6±70.4[b]	39.2±79.8	0.055
Vitamin A	175.5±111.3	172.5±128.6[a]	(3.0±140.4)[a]	148.5±62.0	256.9±108.1[b]	108.4±115.2[b]	185.4±85	263.6±136.5[b]	78.2±112.2[b]	0.011*
Vitamin E	174.1±110.8	157.7±121.5[a]	(-16.4±108.5[a]	149.5±72	230.1±79.9[b]	80.6±114.2[b]	165.6±88.5	206.2±81.2[b]	40.6±126.2[a,b]	0.026*
Omega 3	47.8±29.3	41.6±22.5[a]	(-6.1±24.7)[a]	46.8±23.2	76.3±38.8[b]	29.4±42.7[b]	52.0±29.4	68.1±31.8[b]	16.1±36.6[b]	0.004*

Post-intervention calcium control vs. FBR 0.005; control vs. FBR+PE 0.012; FBR vs. FBR+PE 0.934; Vitamin C control vs. FBR 0.000; control vs. FBR+PE 0.000; FBR vs. FBR+PE 0.550; vitamin A control vs. FBR 0.002; control vs. FBR+PE 0.003; FBR vs. FBR+PE 0.975; Omega-3 control vs. FBR 0.000; control vs. FBR+PE 0.001; FBR vs. FBR+PE 0.474; vitamin E control vs. FBR 0.004; control vs. FBR+PE 0.031; FBR vs. FBR+PE 0.312. Delta pre-post; vitamin A control vs. FBR 0.004; control vs. FBR+PE 0.023; FBR vs. FBR+PE 0.592; omega 3 control vs. FBR 0.002; control vs. FBR+PE 0.008; FBR vs. FBR+PE 0.695; vitamin E control vs. FBR 0.007; control vs. FBR+PE 0.107; FBR vs. FBR+PE 0.241; a: Not significantly different from control, b: Sgnificantly different from control, *: Significant. FBR: Food-based dietary recommendations, PE: Physical exercise.

Table 5: BMI of the respondents.

Parameter	Control group (n=21)	FBR group (n=24)	FBR+PE group (n=24)	*P* value
BMI (kg/m^2)				
Pre-intervention	26.4±5.1[a]	29.3±4.1[b]	24.1±3.7[a]	0.000*
Post-intervention	26.2±5.07[a]	29.5±4.1[b]	24.4±3.5[a]	0.000*
p value	0.03	0.377	0.035	
Δpre-post	(-0.21±0.41)	0.102±0.56	0.27±59	0.008*

a: Not significantly different from control, b: Significantly different from control. BMI: Body mass index.

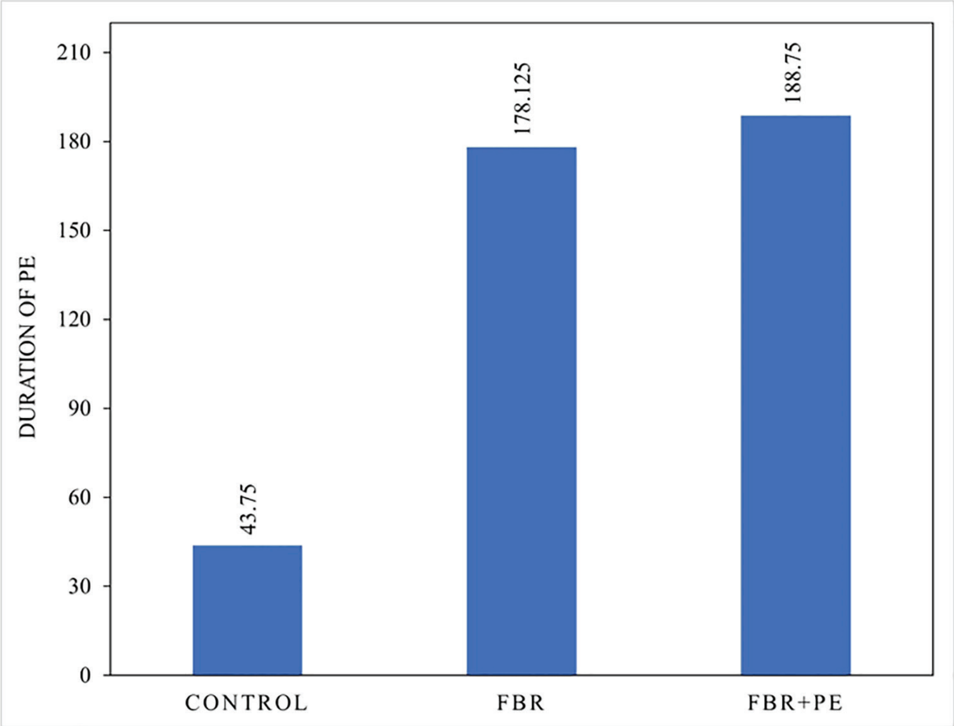

Figure 1: Median duration of physical exercise (minutes per week) during 1 month of intervention: Kruskal-Wallis test, Mann–Whitney test: Control vs. FBR (p=0.007); control vs. FBR+PE (p=0.029); FBR vs. FBR+PE (p=0.893).

After evaluating compliance with recommendations on food consumption, further assessment was carried out on changes in compliance with recommendations on PE duration. Based on the survey results using the IPAQ-S instrument, it was found that almost all groups evenly in the last week of the intervention had light+moderate or heavy physical activity; statistically, there was no significant difference. However, based on the compilation of the respondents' physical exercise records per day, the FBR and FBR+PE groups had a higher and significantly different duration of physical exercise compared to the control group (p=0.020). All treatment groups had a median duration that was in accordance with the recommendations (minimum 150 minutes/week) (Figure 1).

Based on the results of the Kruskal-Wallis's comparative test, significant differences were observed in the delta GA level between the three groups (p=0.002). Similarly, the post-hoc/Mann-Whitney test analysis indicated that a significant difference in the delta GA level occurred in the FBR+PE group when compared to the control and FBR groups. There was a difference between FPG (p=0.012) and 2-hour postprandial (p=0.003) before and after the intervention in the FBR+PE group, whereas there was no difference in the other 2 groups (Figure 2).

Discussion

T2DM can benefit from a nutritional intervention (12). According to our results, combining dietary recommendations with physical activity can greatly improve glycemic index, especially the GA level in patients with T2DM. In our study, dietary recommendations were developed on the basis of a comprehensive analysis of the participants' habitual consumption patterns and local market food availability. A previous study has also shown that food-based interventions tailored to the local context and affordability can lead to better dietary adherence (13). Moreover, a study demonstrated that personalized, culturally sensitive dietary recommendations were more likely to be accepted and adhered to by patients when they did not cause drastic changes to the traditional diet, which is crucial in improving health outcomes (14).

In addition, significant differences in BMI was noticed between groups regarding the FBR group having the highest BMI (overweight category) and the lowest FBR+PE group. A mild increase in BMI in the intervention group may indicate an improved nutritional status and glycemic control, especially if there has been previously uncontrolled weight loss due to hyperglycemia (15). BMI status has an important influence on glycemic control where overweight and obesity (BMI≥25 kg/m²) are associated with higher insulin resistance (16). The FBR+PE group with the lowest BMI and the addition of physical exercise had the potential to have the best glycemic control because the combination of diet and physical activity can improve insulin sensitivity (17).

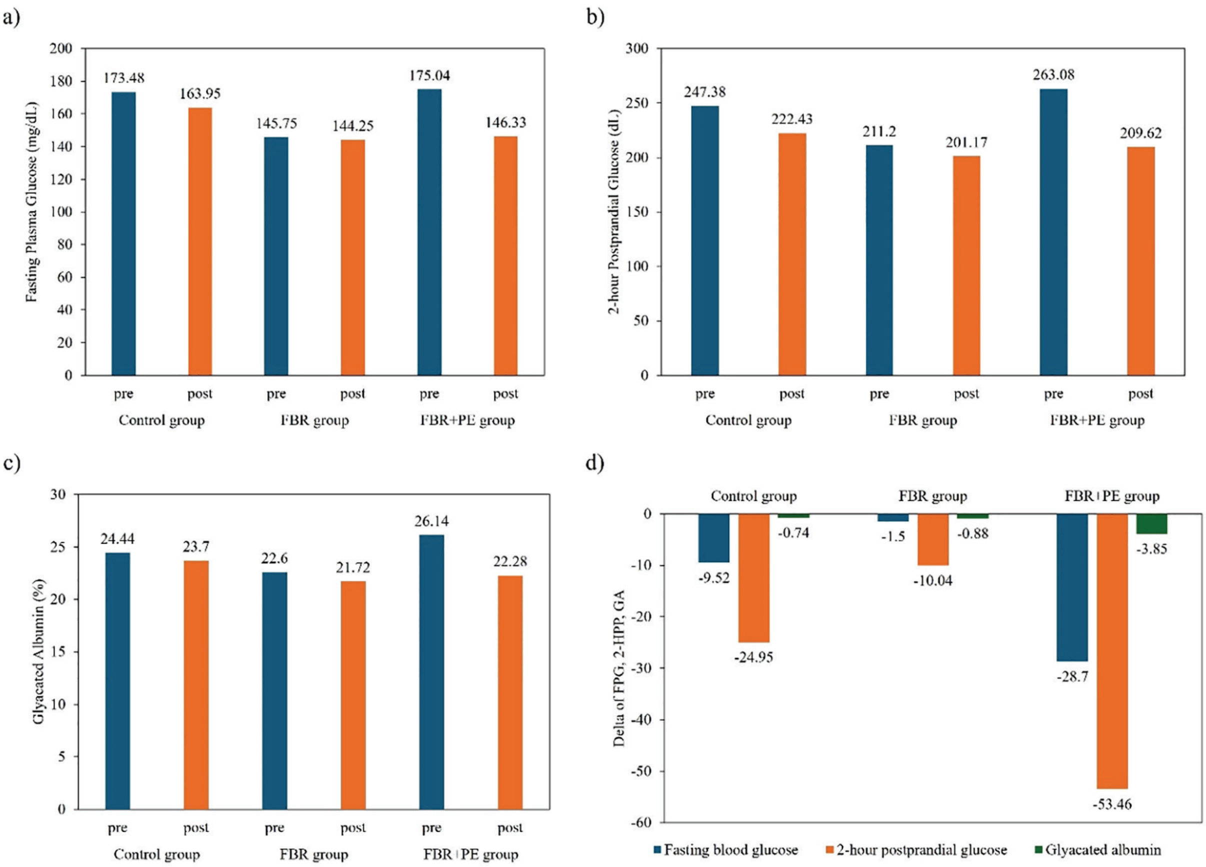

Figure 2: Glycemic control after 1 month of intervention: A: Difference in fasting blood glucose (FBG) levels before and after the intervention in each group; B: Difference in 2-hour postprandial glucose level before and after the intervention in each group; C: Difference in GA level before and after the intervention in each group; D: Differences in delta FPG, 2H PP, and GA between the groups.

Our results have also shown that compliance with local food recommendations was followed by the fulfillment of the intake of specific nutrients needed to control blood sugar level. The combination of nutrient-dense local foods, such as corn rice, fish, mackerel, tempeh, green leafy vegetables, moringa leaves, and kepok banana notably improved nutrient intake, particularly in terms of fiber, protein, omega-3 fatty acids, and vitamins A, C, and E. The findings revealed a statistically significant enhancement in dietary adherence among participants in both FBR and FBR+PE intervention when compared to the control group. The FBR+PE group exhibited higher compliance with the intake of corn rice and kepok bananas in comparison to the control group. This was also followed by the fulfillment of the highest fiber needs among the three groups, meeting >65% of the requirements (71.7%±35.8%).

Corn rice and kepok banana are primary sources of dietary fiber with low glycemic indices, playing crucial roles in the regulation of nutritional status and glycemic control. Corn rice is a local staple food derived from maize and serves as a primary alternative to conventional white rice. The fiber content in 100 g of corn rice is approximately 6.2 g, whereas that of kepok banana is 5.7 g per 100 g. The functional mechanism of dietary fiber involves the formation of viscous solutions within the small intestine, which attenuate the interaction between macronutrients and digestive enzymes, thereby delaying glucose absorption. This physiological process consequently reduces postprandial plasma glucose concentrations and insulin levels (18).

Dietary fiber influences the secretion of glucagon-like peptide-1 (GLP-1), a hormone that potentiates insulin secretion (19). Experimental research on patients with T2DM also indicated that dietary fiber could improve GA levels (20). Additionally, adherence to the local diet increased the intake of antioxidant vitamins and omega-3 fatty acids in the FBR+PE group. Omega-3 intake is known to reduce fasting glucose level, inflammatory factors, and insulin resistance (21). These findings align with those of Szczerba *et al.* who reported that dietary approaches, such as plant-based, high-protein diets and higher intake of omega-3 fatty acids can be effective in improving surrogate markers of disease and health in people with T2DM (22). Another systematic review has illustrated that evidence of culturally tailored diabetes programs can effectively control weight and have a notable impact on HbA1c in patients with T2DM (23).

Physical exercise has long been recognized as one of the main management strategies for individuals with T2DM. The role of insulin sensitivity in improving blood glucose level, reducing blood glucose level and improving overall glycemic control have been illustrated (24). Our results are in agreement with the findings of a systematic review and meta-analysis showing a notable decrease in post-intervention HbA1c in the exercise group (25). Physical exercise also has an important role in improving the quality of life (QOL) and nutritional status in diabetes patients, so it can be a safe additional therapy in the medical care of these patients (26). Improvement in blood sugar control via this combination also enhances the QOL in people with diabetes mellitus (27).

The differential effects between the FBR and FBR+PE groups suggested while dietary modifications alone might offer some benefits, the integration of physical exercise offers superior glycemic control (FBG, 2hPPG, and GA), particularly in reducing GA. The FBR+PE group had a noticeably longer duration of physical exercise per week than the control group during the 4-week intervention. In contrast, the control group, which received standard care, showed limited improvements in glycemic control. Although the control group exhibited modest changes in FBG and postprandial blood glucose levels, these changes did not reach statistical significance. This is in consistent with a previous finding which demonstrated that the combination of dietary changes and physical activity leads to a more pronounced reduction in diabetes-related complications (28) and led to superior outcomes in terms of glycemic control compared with either intervention alone (29, 30).

The FBR+PE group's greater reduction in GA level is particularly noteworthy, as GA is a much more reliable marker of long-term glycemic control than short-term glucose measures such as FBG or postprandial glucose. It is an alternative laboratory marker for glycated hemoglobin (A1c). GA does not require fasting for its measurement and reflects short- to medium-term glycemia due to the half-life of albumin, which is about 3 weeks. Compared with A1c, GA is not affected by hemoglobin metabolism or situations that falsely change A1c level (31, 32). Additionally, in conditions such as anemia, pregnancy, postprandial hyperglycemia, and T2DM requiring insulin, GA appears to be a better glycemic marker than A1c (33).

The improvements in glycemic control observed in this study suggested a synergistic interaction between structured physical exercise and dietary modification. Regular physical exercise enhances insulin sensitivity through increased translocation of GLUT4 to skeletal muscle membranes and activation of the AMPK pathway, which collectively promotes glucose uptake, fatty acid oxidation, and mitochondrial biogenesis (34, 35). These adaptations contribute to improved glucose metabolism and energy efficiency in muscle tissue. In addition, aerobic exercise also stimulates mitochondrial biogenesis, which plays an important role in improving glucose metabolism and oxidative capacity of muscle cells, thereby supporting better glycemic control (36).

In parallel, dietary modification supports glycemic control by lowering postprandial glycemic load and improving lipid profile, thereby reducing lipotoxicity and inflammation as two key factors contributing to insulin resistance. The combination of physical exercise and dietary modification produces synergistic effects that reinforce positive metabolic adaptation. Exercise-induced increased mitochondrial function has the potential to protect cells against metabolic stress and toxic lipid accumulation (37). The significant reduction in GA level in this study reflected the improved medium-term glycemic control, indicating reduced glucose fluctuations and cumulative glycemic exposure. This finding reinforces the necessity of incorporating comprehensive lifestyle interventions into T2DM management. A regulating diet and physical activity can change the gut microbiota, which in turn improves glucose metabolism.

It is supported by Silva *et al.* who found that structured physical activity not only enhanced glucose uptake but also contributed to long-term improvements in metabolic markers by reducing oxidative stress and inflammation, both of which are implicated in the pathophysiology of T2DM (38). Hashim also highlighted that standard care alone often fails to provide substantial benefits in terms of glycemic control in patients with T2DM (39). In addition, the comprehensive management of diabetes, which includes adequate diabetes education and lifestyle changes such as diet adherence and regular exercise, has the potential to achieve blood glucose control and reducing the risk of comorbidities such as cardiovascular diseases (40). These findings are in line with a broader evidence base from the Southeast Asian region and low-middle-income countries (LMICs), where combination lifestyle interventions have shown significant glycemic improvement. A systematic review of the Southeast Asian population showed that lifestyle modifications that combined diet and exercise resulted in an average HbA1c decrease of 0.56% (6.45 mmol/mol), at 3 months (41). Similarly, a systematic review across LMICs has confirmed that multicomponent self-management educational interventions to be successful in improving glycemic control compared to usual treatments (35).

This present study emphasized the potential of integrating culturally adapted dietary recommendations with structured physical activity in the clinical management of T2DM. By incorporating local food resources and culturally relevant eating patterns, primary health care providers can design interventions that are not only effective but also practical and acceptable to patients. This approach helps to enhance patient adherence, independence, and long-term sustainability in managing their condition. Moreover, combining nutrition education with the promotion of accessible physical activities offers a feasible model for community-based diabetes management programs. Such programs can empower patients to make healthier lifestyle choices using locally available and affordable food ingredients. The results of this study also highlighted the broader importance of developing context-specific interventions that consider dietary habits, cultural preferences, and local resources to improve engagement and ensure lasting glycemic control outcomes.

Although the study provided compelling evidence for the efficacy of combined dietary and exercise interventions, several limitations must be considered. This study used a relatively small sample size, which could affect the generalizability of the findings. Limited sample sizes reduced statistical power and could not fully represent the broader heterogeneity of T2DM patient population, including variation in age, disease duration, comorbidities, and socioeconomic background. Further researches into a larger and more diverse sample are needed to confirm these findings. Multi-focus studies with longer follow-up durations are also needed to evaluate the sustainability of the intervention's effects and long-term impact on clinical outcomes and patient quality of life. Additionally, the study's relatively short intervention period of four weeks may not have been sufficient to capture the full long-term effects of the interventions on glycemic control. Future researches should explore the sustainability of these effects over a longer period, ideally with follow-up assessments beyond the intervention phase. Additionally, the study's reliance on self-reported dietary adherence and physical activity may introduce biases, particularly regarding the accuracy of meal diaries and exercise logs. Future studies could benefit from more objective measures of dietary intake and physical activity, such as biomarkers of nutrient status and wearable technology like accelerometer-based physical activity tracking.

Conclusion

This study provided strong evidences that combining culturally tailored, local FBR with structured physical exercise notably improves glycemic control in patients with T2DM, with the FBR+PE group showing the greatest reduction in GA level. The combined intervention was more effective than dietary modification alone or standard care, highlighting the synergistic benefits of integrating diet and physical activity. To the best of our knowledge, this is one of the first studies to implement affordable, locally relevant interventions tailored to the Indonesian context to support both metabolic outcomes and patient adherence. Future researches should assess the long-term sustainability of such interventions through extended follow-up and objective compliance measures.

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Authors' Contribution

KPT: Conceptualization, Methodology (nutritional and dietary intervention design), Data Curation, Formal Analysis, Investigation, Writing – Original Draft Preparation, Writing – Review & Editing. US: Conceptualization (clinical and biomarker framework), Methodology (biomarker assessment), Validation, Resources (clinical setting and patient recruitment), Supervision, Writing – Review & Editing. MH: Methodology (physical activity intervention design), Validation, Supervision, Writing – Review & Editing. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of Interest

The authors declare no conflict of interest.

References

1 International Diabetes Federation. IDF Diabetes Atlas (11th ed.). International Diabetes Federation: Belgium; 2025.

2 Masoumi SJ, Nekooeian AA, Tanideh N, et al. Effect of allium porrum on streptozotocin-induced diabetes mellitus hyperglycemia and insulin resistance in male Sprague Dawley rats. *Onl J Vet Res*. 2020;24:573-577. DOI: 10.5555/20203531172.
3 Sagastume D, Siero I, Mertens E, et al. The effectiveness of lifestyle interventions on type 2 diabetes and gestational diabetes incidence and cardiometabolic outcomes: A systematic review and meta-analysis of evidence from low- and middle-income countries. *EClinicalMedicine*. 2022;53:101650. DOI: 10.1016/j.eclinm.2022.101650. PMID: 36119561.
4 Al Mhanna SB, Rocha Rodriguesc S, Mohamed M, et al. Effects of combined aerobic exercise and diet on cardiometabolic health in patients with obesity and type 2 diabetes: A systematic review and meta-analysis. *BMC Sports Sci Med Rehabil*. 2023;15:165. DOI: 10.1186/s13102-023-00766-5. PMID: 38049873.
5 Bitew ZW, Alemu A, Jember DA, et al. Prevalence of glycemic control and factors associated with poor glycemic control: A systematic review and meta-analysis. *Inquiry*. 2023;60:469580231155716. DOI: 10.1177/00469580231155716. PMID: 36852627.
6 Hosseini SE, Mehrabani D, Ghaedi HR. The effect of pomegranate juice on hemogram and weight profile in streptozotocin-induced diabetic adult male rats. *Damghan J Zool*. 2013;6:1-8.
7 Mohammed AS, Adem F, Tadiwos Y, et al. Level of adherence to the dietary recommendation and glycemic control among patients with type 2 diabetes mellitus in eastern Ethiopia: A cross-sectional study. *Diabetes Metab Syndr Obes*. 2020;13:2605-2612. DOI: 10.2147/DMSO.S256738. PMID: 32801812.
8 Zhao X, He Q, Zeng Y, et al. Effectiveness of combined exercise in people with type 2 diabetes and concurrent overweight/obesity: A systematic review and meta-analysis. *BMJ Open*. 2021;11:e046252. DOI: 10.1136/bmjopen-2020-046252. PMID: 34615674.
9 Hosseini SE, Mehrabani D, Rezaei E. Effects of pomegranate juice on liver enzymes (ALT, ALP, AST) in diabetic and non-diabetic rats. *J Anim Physiol Develop*. 2014;24:59-64.
10 Indonesian Endocrinology Association. Pedoman pengelolaan dan pencegahan diabetes melitus tipe 2 dewasa [Guidelines for the management and prevention of type 2 diabetes mellitus in adults]. Indonesia: Perkeni; 2021.
11 Tritisari KP, Sukorini U, Penggalih MHST, et al. Incorporating locally available food using linear programming to improve food-based recommendation for preelderly diabetic patients. *Nutr Health*. 2025:2601060251401258. DOI:10.1177/02601060251401258. PMID: 41342732.
12 Rezaei E, Hosseini SE, Mehrabani D. Effects of pomegranate juice on insulin and glucose in diabetic and non-diabetic male rats. *J Birjand Univ Med Sci*. 2013;20:1-8.
13 Baral J, Karki KB, Thapa P, et al. Adherence to dietary recommendation and its associated factors among people with type 2 diabetes: A cross-sectional study in Nepal. *J Diabetes Res*. 2022;2022:6136059. DOI: 10.1155/2022/6136059. PMID: 36313817.
14 Farhat G. Culturally tailored dietary interventions for improving glycemic control and preventing complications in South Asians with type 2 diabetes: Success and future implications. *Healthcare*. 2023;11:1123. DOI: 10.3390/healthcare11081123. PMID: 37107956.
15 American Diabetes Association. Standards of medical care in diabetes—2021. *Diabetes Care*. 2021;44:S1-S233. DOI: 10.2337/dc21-S002. PMID: 33298413.
16 Ganz ML, Wintfeld N, Li Q, et al. The association of body mass index with the risk of type 2 diabetes: a case–control study nested in an electronic health records system in the United States. *Diabetol Metab Syndr*. 2014;6:50. DOI:10.1186/1758-5996-6-50. PMID: 24694251.
17 Colberg SR, Sigal RJ, Yardley JE, et al. Physical activity/exercise and diabetes: A position statement of the american diabetes association. *Diabetes Care*. 2016;39:2065-2079. DOI: 10.2337/dc16-1728. PMID: 27926890.
18 McRae MP. Dietary fiber intake and type 2 diabetes mellitus: An umbrella review of meta-analyses. *J Chiropr Med*. 2018;17:44-53. DOI: 10.1016/j.jcm.2017.11.002. PMID: 29628808.
19 Giuntini EB, Sardá FAH, de Menezes EW. The effects of soluble dietary fibers on glycemic response: An overview and futures perspectives. *Foods*. 2022;11:3934. DOI: 10.3390/foods11233934. PMID: 36496742.
20 Adyarini DD, Sinorita H, Ikhsan MR. The effect of providing food made from resistant starch fiber (Dioscorea Esculenta, Maranta Arundinaceae L, Cucurbita Moschata, Manihot Utilissma) on the improvement of glycated albumin in type 2 diabetes mellitus patients at Dr. Sardjito General Hospit. *Acta Interna J Intern Med*. 2019;9:1-7. DOI: 10.22146/actainterna.51364.
21 Liu W, Gao M, Yang S, et al. Effects of omega-3 supplementation on glucose and lipid metabolism in patients with gestational diabetes: A meta-

analysis of randomized controlled trials. *J Diabetes Complications.* 2023;37:108451. DOI: 10.1016/j.jdiacomp.2023.108451. PMID: 36913875.
22 Szczerba E, Barbaresko J, Schiemann T, et al. Diet in the management of type 2 diabetes: Umbrella review of systematic reviews with meta-analyses of randomized controlled trials. *BMJ Medicine*. 2023;2:e000664. DOI: 10.1136/bmjmed-2023-000664. PMID: 38027413.
23 Joo JY, Liu MF. Experience of culturally-tailored diabetes interventions for ethnic minorities: A qualitative systematic review. *Clin Nurs Res*. 2021;30:253-262. DOI: 10.1177/1054773819885952. PMID: 31690114.
24 Syedaa USA, Battillo D, Visariac A, et al. The importance of exercise for glycemic control in type 2 diabetes. *Am J Med Open*. 2023;9:100031. DOI: 10.1016/j.ajmo.2023.100031. PMID: 39035065.
25 Qadir R, Sculthorpe NF, Todd T, et al. Effectiveness of resistance training and associated program characteristics in patients at risk for type 2 diabetes: A systematic review and meta-analysis. *Sports Med Open*. 2021;7:38. DOI: 10.1186/s40798-021-00321-x. PMID: 34050828.
26 Shah SZA, Karam JA, Zeb A, et al. Movement is improvement: The therapeutic effects of exercise and general physical activity on glycemic control in patients with type 2 diabetes mellitus: A systematic review and meta-analysis of randomized controlled trials. *Diabetes Ther*. 2021;12:707-732. DOI: 10.1007/s13300-021-01005-1. PMID: 33547579.
27 Paradise S, Maidin A, Razak A, et al. Effect of diet, medication, physical activity on glycemic control of type-2 diabetes mellitus patients in Makassar City. *Phcog J*. 2024;16:1110-1113. DOI: 10.5530/pj.2024.16.180.
28 Bianco A, Franco I, Curci R, et al. Diet and exercise exert a differential effect on glucose metabolism markers according to the degree of NAFLD severity. *Nutrients*. 2023;15:2252. DOI: 10.3390/nu15102252. PMID: 37242135.
29 Yeh YK, Yen F, Hwu C. Diet and exercise are a fundamental part of comprehensive care for type 2 diabetes. *J Diabetes Investig.* 2023;14:936-939. DOI: 10.1111/jdi.14043. PMID: 37337794.
30 Amerkamp J, Benli S, Isenmann E, et al. Optimizing the lifestyle of patients with type 2 diabetes mellitus - Systematic review on the effects of combined diet-and-exercise interventions. *Nutr Metab Cardiovasc Dis*. 2025;35:103746. DOI: 10.1016/j.numecd.2024.09.016. PMID: 39490277.
31 Hosseini SE, Rezaei E, Mehrabani D, Tavakoli F. Effect of pomegranate juice on lipid profile in streptozotocin-induced diabetic adult male rats. *J Exp Anim Biol*. 2013;2:13-20.
32 Ciobanu DM, Bogdan F, Pătruţ CI, et al. Glycated albumin is correlated with glycated hemoglobin in type 2 diabetes. *Med Pharm Rep*. 2019;92:134-138. DOI: 10.15386/mpr-1247. PMID: 31086840.
33 Koga M, Kasayama, S. Clinical impact of glycated albumin as another glycemic control marker. *Endocr J*. 2010;57:751-762. DOI: 10.1507/endocrj.k10e-138. PMID: 20724796.
34 Stanford KI, Goodyear LJ. Exercise and type 2 diabetes: molecular mechanisms regulating glucose uptake in skeletal muscle. *Adv Physiol Educ*. 2014;38:308-314. DOI:10.1152/advan.00080.2014. PMID: 25434013.
35 O'Donoghue G, O'Sullivan C, Corridan I, et al. Lifestyle interventions to improve glycemic control in adults with type 2 diabetes living in Low-and-middle income countries: A systematic review and meta-analysis of randomized controlled trials (RCTs). *Int J Environ Res Public Health*. 2021;18:6273. DOI:10.3390/ijerph18126273. PMID: 34200592.
36 Sheikhani Shahin H, Koushkie Jaromi M, Kardeh E, et al. The effect of aerobic exercise on bone mineral density and bone mineral content in female athlete patients following kidney transplantation in Shiraz, southern Iran. *World Appl Sci J*. 2013;27:23-27. DOI: 10.5829/idosi.wasj.2013.27.01.7566.
37 Lemos GO, Torrinhas RS, Waitzberg DL. Nutrients, Physical Activity, and Mitochondrial Dysfunction in the Setting of Metabolic Syndrome. *Nutrients*. 2023;15:1217. DOI:10.3390/nu15051217. PMID: 36904216.
38 Silva FM, Duarte Mendes P, Teixeira AM, et al. The effects of combined exercise training on glucose metabolism and inflammatory markers in sedentary adults: A systematic review and meta-analysis. *Sci Rep*. 2024;14:1936. DOI: 10.1038/s41598-024-51832-y. PMID: 38253590.
39 Hashim SA, Yusof BNM, Saad HA, et al. Effectiveness of simplified diabetes nutrition education on glycemic control and other diabetes-related outcomes in patients with type 2 diabetes mellitus. *Clin Nutr ESPEN*. 2021;45:141-149. DOI: 10.1016/j.clnesp.2021.07.024. PMID: 34620310.
40 Reyes-García R, Moreno-Pérez Ó, Tejera-Pérez C, et al. Documento de abordaje integral de la diabetes tipo 2. *Endocrinol Diabetes Nutr*. 2019;66:443-458. DOI: 10.1016/j.endinu.2018.10.010. PMID: 30827909.
41 Htoo ZW, Hsu WW, Rosenkranz R. Systematic review and meta-analysis: Is lifestyle modification effective for glycemic control among adults with type II diabetes in Southeast Asia? *Diabetes Res Clin Pract*. 2016;122:148-153. DOI:10.1016/j.diabres.2016.10.008. PMID: 27855340.