nutrición clínica y Dietética Hospitalaria

Artículo Original

Nutr Clín Diet Hosp. 2024; 44(4):111-119
DOI: 10.12873/444putri

Relationship between nutritional status, physical activity, macronutrient intake and glycemic profile of prediabetic women in rural areas of Indonesia

Sefanadia PUTRI[1,3], Sri Anna MARLIYATI[2], Budi SETIAWAN[2], Rimbawan RIMBAWAN[2]

1 Graduate Program of Nutrition Science, Graduate School, IPB University, Bogor, Indonesia.
2 Department of Community Nutrition, Faculty of Human Ecology, IPB University, Bogor, Indonesia.
3 Department of Nutrition, Tanjungkarang Health Polytechnic Ministry of Health Republic of Indonesia, Bandar Lampung, Indonesia.

Recibido: 6/agosto/2024. Aceptado: 1/octubre/2024.

ABSTRACT

Prediabetes significantly raises the risk of progressing to type 2 diabetes mellitus (T2DM). In rural areas, changes in lifestyle and diet influence the prevalence of prediabetes. This study evaluated the association of nutritional status, physical activity, and macronutrient intake with glycemic profile in prediabetic women in rural areas. The cross-sectional study included 26 women aged 40-64 years with prediabetes. Location in Pesawaran Regency, Lampung Province, Indonesia in 2023. Data were collected on demographics, food consumption, physical activity, anthropometric and clinical biomarkers. Statistical analysis used Pearson and Spearman tests. Physical activity showed a positive significant correlation with BMI ($r = 0.41$, $p = 0.037$), and BMI was significantly associated with HOMA-IR ($r = 0.465$, $p = 0.021$) and QUICKI ($r = -0.429$, $p = 0.036$). However, energy, carbohydrate, protein, fat, and fiber intake were not significantly correlated with glycemic indicators or plasma insulin. There is a significant relationship between physical activity level and body mass index (BMI), with decreased physical activity associated with increased BMI values and affected insulin resistance and sensitivity. Macronutrient intake was not significantly correlated with glycemic profile. Public health interventions need to focus on increasing physical activity to prevent T2DM.

KEYWORDS

Dietary analysis, exercise habits, lifestyle, nutritional assessment, rural health, women's health.

Correspondencia:
Sri Anna Marliyati
marliyati@apps.ipb.ac.id

ABBREVIATIONS

BMI: Body Mass Index.

FPG: Fasting Plasma Glucose.

IFG: Impaired Fasting Glucose.

IGT: Impaired Glucose Tolerance.

OGTT: Oral Glucose Tolerance Test.

OGT: Oral Glucose Test.

IPAQ-SF: International Physical Activity Questionnaire-Short Form.

MET: Metabolic Equivalent.

T2DM: Type 2 Diabetes Mellitus.

INTRODUCTION

Prediabetes is a high-risk condition for developing T2DM[1] that occurs in the early stages of T2DM symptoms and The three countries with the highest rates of prediabetes globally are China (48.6 million), the United States (36.8 million), and Indonesia (27.7 million). According to the 2018 Riskesdas data, prediabetes prevalence in Indonesia is notably high, with 26.3% of the population showing impaired fasting blood glucose (IFG) and 30.8% experiencing impaired glucose tolerance (IGT). Prediabetes increases the risk of developing type 2 diabetes by 2 to 10 times[2]. The rising incidence of prediabetes on a global scale is a substantial issue of public health importance. This is a negative sign for the increasing diabetes epidemic and the problems it causes[3]. The essential aspect of this disease, insulin resistance, can be aggravated by the Indonesian diet[4].

Managing and preventing prediabetes is significantly influenced by lifestyle factors such as food, physical activity, and nutritional status. A good diet will reduce insulin workload by optimizing the work of insulin to convert glucose into glycogen. Lifestyle changes like regular physical activity, weight loss, and healthy eating can prevent prediabetes from progressing to type 2 diabetes mellitus (T2DM). Without intervention, 15% to 30% of people with prediabetes may develop T2DM within five years[5].

in the rural areas of Indonesia, the health challenges are more complex due to limited access to health services, lack of knowledge about healthy diets, and inactive lifestyles. Rapid urbanization and improved living conditions in rural areas have decreased physical activity through the use of mechanized farming tools, contributing to a higher risk of obesity and related conditions like prediabetes and type 2 diabetes mellitus (T2DM)[6].

Several studies have demonstrated the association between nutritional status and macronutrient intake with T2DM, but studies exploring this association in prediabetes are limited. This study aims to assess the relationship between nutritional status, physical activity, and macronutrient intake with the glycemic profile of prediabetic women in rural Indonesia. The findings are expected to offer valuable insights into the factors influencing prediabetes and support the creation of more effective interventions to prevent the progression to T2DM among women in these rural areas.

RESEARCH METHOD

The study utilized a cross-sectional research design, targeting women aged 40 to 64 years residing in the Bunut Health Center area, Pesawaran Regency, Lampung Province, Indonesia in 2023. The inclusion criteria specified that participants must be women within the 40 to 64 age range[7]. Participants were diagnosed with prediabetes based on the following criteria[2,8,9]: HbA1c levels between 5.7% and 6.4%, fasting plasma glucose (FPG) of 100-125 mg/dL, oral glucose tolerance test (OGTT) results of 140-199 mg/dL, and a body mass index (BMI) ranging from 20 to 40 kg/m² and stable food consumption without an increase or decrease in body weight of more than 5 kg in the last ten weeks. Exclusion criteria were: subjects undergoing insulin therapy, women who were breastfeeding, pregnant, history of impaired liver or kidney function and heart failure, alcohol consumption (>20 g/day), participation in other clinical trials in the previous three months, and unqualified as judged by the researchers.

The research protocol received approval from the Ethics Committee of Tanjung Karang Health Polytechnic, Ministry of Health (No. 432/KEPK-TJK/VIII/2023). Written informed consent was obtained from all participants. Data collection occurred over two visits. During the first visit, data on the participants' characteristics were gathered, including name, age, menstrual status, blood pressure, and socioeconomic information and to be continued collecting data on physical activity, as well as energy, protein, fat, carbohydrate, and dietary

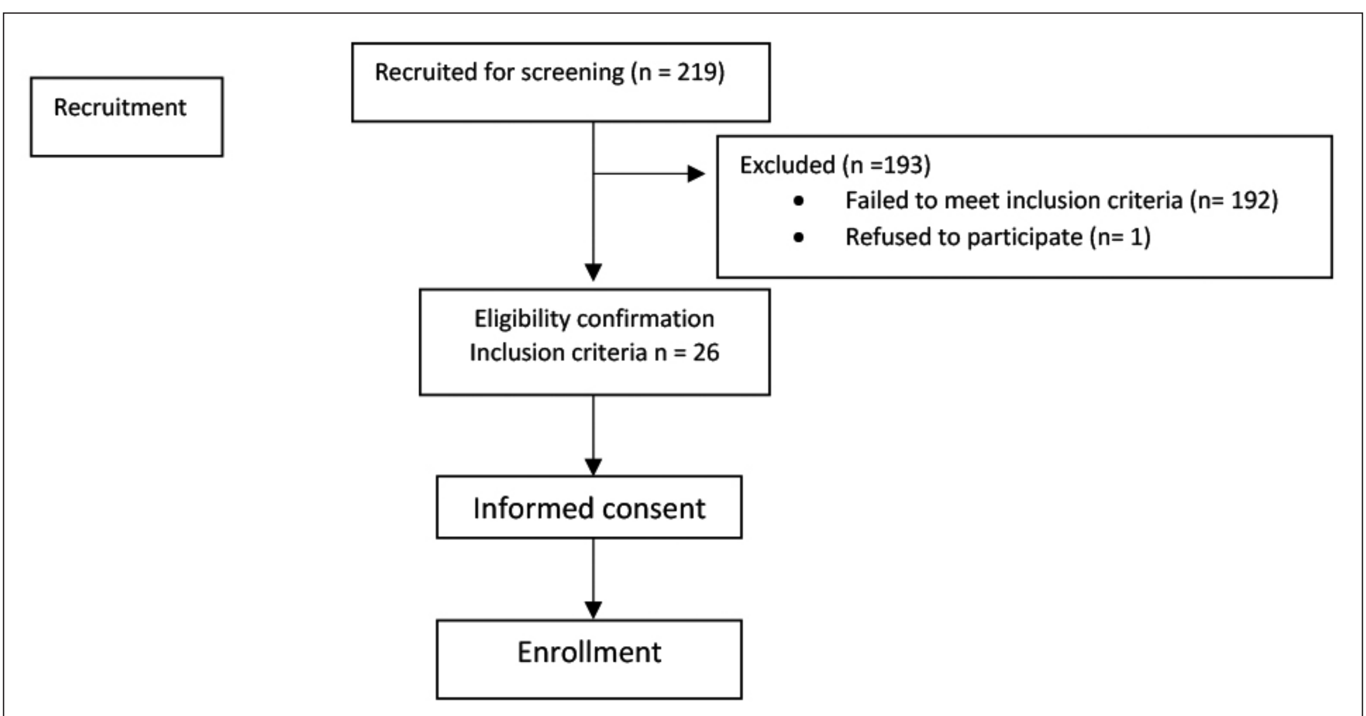

Figure 1. Flow chart of the study population

fiber intake. This information was obtained through interviews using the International Physical Activity Questionnaire Short-Form (IPAQ-SF)[10] and a 24-hour dietary recall form.

The second stage of clinical data collection included anthropometric measurements such as body weight, height, and Body Mass Index (BMI), along with blood biochemical parameters, including fasting blood glucose and oral glucose tolerance (OGT) tests, HbA1c and plasma insulin. Venous blood samples of 8 mL were taken after 10-12 hours of fasting. Data collection using a *24-hour recall form* was done twice, on weekdays and holidays. Physical activity data were obtained from the International Physical Activity Questionnaire Short-Form (IPAQ-SF) questionnaire results. This questionnaire includes physical activity performed by the subject during the last seven days, then processed using the IPAQ scoring guide with the help of IPAQ *automatic report* with the unit of *metabolic equivalents of task* (MET). Physical activity levels were categorized as follows: Low, indicating some activity but insufficient to meet the criteria for moderate or vigorous levels; Moderate, defined as 5 or more days of combined walking, moderate, or vigorous activity totaling at least 600 MET minutes per week; and Vigorous, defined as 7 or more days of combined walking, moderate, or vigorous activity reaching at least 3,000 MET minutes per week[10].

Nutritional status was measured anthropometrically at the clinical assessment stage. Body weight was weighed using a onemed digital bathroom scale Ministry of Health RI AKL 10901129864 (Zhongshan Camry Electronic Co. Ltd., China). Height measurement used a microtoise measuring instrument. Measurements were taken by one person who had been trained in anthropometric measurements. Furthermore, the respondent's BMI score was determined, which was calculated based on weight in kilograms compared to TB in square meters. Blood collection was assisted by competent medical personnel. Respondents were comfortable and without coercion, so blood pressure was measured first before taking blood. The room and equipment used were clean, sterile, and relaxed. At each stage, venous blood was taken. Blood was taken as much as 8 mL using a syringe, onemed disposable syringe 10 mL; needle 23 g and accommodated in a vacutainer with ethylenediaminetetraacetic acid (EDTA), vacutainer gel & clot activator. Blood plasma was then separated in the laboratory to analyze FPG, HbA1c and insulin.

The obtained blood samples were then put into a sterile falcon tube and centrifuged at 2500 rpm for 10 minutes at 25ºC. Three layers (plasma, buffy coat and erythrocytes) were obtained for plasma samples. The top layer was then separated to obtain plasma. The obtained plasma samples were put into several microtubes and stored at -20ºC until testing was performed—assessment of blood glucose levels during OGTT using *glucose oxidase* sensor method and glucometer. Blood was taken from the finger by cleaning the finger with alcohol, then massaged or sequenced slowly, then the tip of the finger was pierced with a needle (lancet).Fasting blood glucose was measured using the GOD-PAP method with the Kenza 240 TX Automatic Biochemistry Analyzer manufactured by BIOLABO Made in France and the Glucose Kit (GLU/GOD-PAP) reagent manufactured by Shenzen Icubio Biomedical Technology Co., Ltd. HbA1c measurement using fluorescence immunoassay method and Ichroma HbA1c Neo reagent produced by Boditech Med Incorporated Republic of Korea. Serum insulin was analyzed using Human Insulin Lipoprotein Antibody, INS BT-LAB Kit, respectively, according to the protocol described in the insert-kit (Bioassay Technology Laboratory; Shanghai Korain Biotech)[11].

The data obtained were then analyzed univariately to see the distribution of respondent characteristics and their frequency, mean, and standard deviation. Numerical data were analyzed using the Shapiro-Wilk test to determine whether the data were normally distributed (P>0.05). As a determinant of the following test in bivariate analysis, if the data were normally distributed, then the test performed in the bivariate analysis was Pearson (relationship of BMI, FPG and HbA1c with physical activity, energy, protein, carbohydrate); otherwise, if the data were not normally distributed, the Spearman test was applied for analysis (relationship of BMI, FPG and HbA1c with dietary fat and fiber; nutritional status and macronutrient intake with glycemic profile of prediabetic women).

RESULT

The average age of the respondents is approximately 49.73 years, indicating that most respondents are within an age range that is not too different from the average. The ages of individuals ranged from 37 to 64 years old. The average education level of individuals in the sample was 8, which may indicate that most individuals had completed education up to the secondary or early college level. In this survey, there were 26 respondents divided into two socio-economic groups. Income categories were grouped based on Lampung Governor Decree No. G/694/V.08/HK/ 2023, with the Lampung Provincial Minimum Wage in 2024 of Rp. 2,716,497.

The low socio-economic group consisted of 21 people, and the high socio-economic group consisted of 5 people. Income ranges from Rp 1,000,000 to Rp 7,000,000 with an average income of Rp 2,394,230.76. The mean blood pressure was 138.85/87.27 mmHg, which suggests that the mean blood pressure was within the hypertensive range.A total of 50% of individuals were menopausal, while 50% were still menstruating, indicating a balance in menstrual status among participants. Most individuals were obese (84%), with 46% being in the Obesity II category. Only 12% had normal nutritional status, and 4% were overweight. Most individuals (76.9%) had fasting blood sugar levels over 100 mg/dL, and 69.23% had HbA1c levels above 5.7%, reflecting a high prevalence of diabetes risk and inadequate glycemic control.

Table 1. Characteristics of respondents

Variable	N	Min	Max	Mean	Std. Dev
Age (year)	26	37	64	49.73	8.69
Education	26	-	-	-	-
< Senior high school	21	-	-	-	-
>Senior high school	5	-	-	-	-
Socio economic (Rp)	26	1.000.000	7.000.000	2.394.230.76	1.330.738.66
Low	21	-	-	-	-
High	5	-	-	-	-
Blood pressure (mmHg)	26				
Sistolik		110	180	138.85	10.72
Diastolik		70	110	87.27	8.89

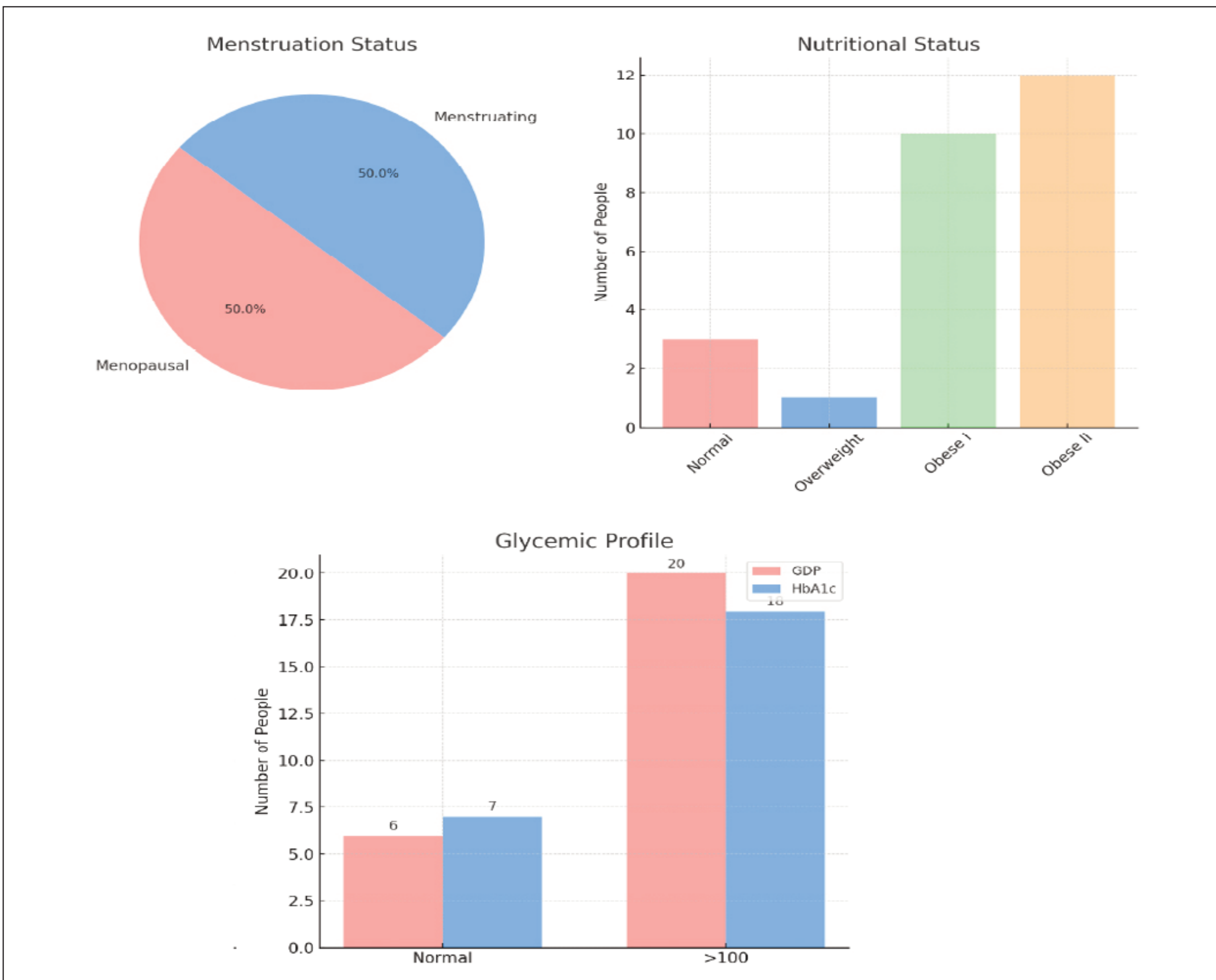

Figure 2. Characteristics Menstrual status, respondents' nutritional status, and glycemic profile

Table 2. Characteristics of the subject's medical history

Variable	n	%
History of hypertension		
Yes	19	73.00
No	5	19.00
History of other diseases (CHD, stroke)		
Yes	8	30.76
No	16	61.53
Family member with DM		
Yes	17	65.38
No	7	26.92
A family member has a history of non-communicable diseases		
Gout	5	19.23
Kidney	1	3.80
Heart	3	11.53
Liver	1	3.80
History of hospitalization in health facilities		
Yes	1	3.80
No	23	88.46

Description: Mann-Whitney t-test.

Most participants (73%) had a history of hypertension, while 30.76% had a history of coronary heart disease or stroke. The majority of participants (65.38%) had family members affected by diabetes mellitus, with 19.23% having gout, 11.53% heart disease, and 3.8% each for kidney and liver disease. Only 3.8% of participants had a history of hospitalization in a health facility, suggesting that hospitalization was relatively rare in this group.

Based on the level of nutritional adequacy, there were energy and nutritional deficiencies. A significant positive correlation was observed between physical activity and BMI (r = 0.41, p = 0.037), indicating that increased physical activity was linked to a higher BMI. However, the negative correlations between physical activity and FPG (r = -0.073, p = 0.723) and HbA1c (r = -1.112, p = 0.593) were not significant. Similarly, energy intake showed no significant correlations with BMI (r = 0.042, p = 0.838), FPG (r = 0.276, p = 0.173), or HbA1c (r = -0.018, p = 0.92). Carbohydrate intake had a positive correlation with BMI (r = 0.341, p = 0.088) and a negative correlation with FPG (r = -0.097, p = 0.63) and HbA1c (r = -0.02, p = 0.92), but not significant.

Protein intake had a negative near-significant correlation with BMI (r = -0.367, p = 0.065), indicating that an increase in protein intake tends to correlate with a decrease in BMI, but was not significant for FPG (r = 0.65, p = 0.75) and HbA1c (r = -0.11, p = 0.58). Fat intake was negatively correlated with BMI (r = -0.076, p = 0.711) and positively near significant with FPG (r = 0.347, p = 0.08) but not significant with HbA1c (r = 0.037, p = 0.86). The correlation between fiber intake and BMI (r = 0.007, p = 0.971) was very weak and insignificant, as well as with FPG (r = -0.14, p = 0.49) and HbA1c (r = -0.26, p = 0.20).

DISCUSSION

Individuals who have prediabetes are at a significantly elevated risk of acquiring diabetes, as well as a heightened risk of experiencing cardiovascular disease and kidney illness[3]. Chronic inflammation in the body can cause kidney and liver problems and increase the risk of heart disease. Most of the subjects had family members affected by diabetes mellitus, 66.67 and 75% in controls, respectively. Genetic factors play an important role in the development of prediabetes and diabetes mellitus. The majority of subjects had family members with diabetes mellitus, indicating genetic factors as one of the significant risk factors in the development of prediabetes and

Table 3. Frequency Distribution of Macronutrient Consumption (Carbohydrate, Protein, Fat, Fiber) of Respondents

Variable	Min	Max	Mean	St. Dev
Energy (cal)	970.55	1410.75	1158.99	124.11
Protein (g)	23.90	69.80	39.79	9.90
Fat (g)	25.05	67.70	40.61	12.78
Carbohydrate (g)	115.80	197.05	159.49	20.29
Dietary fiber (g)	3.60	12.75	6.66	1.96

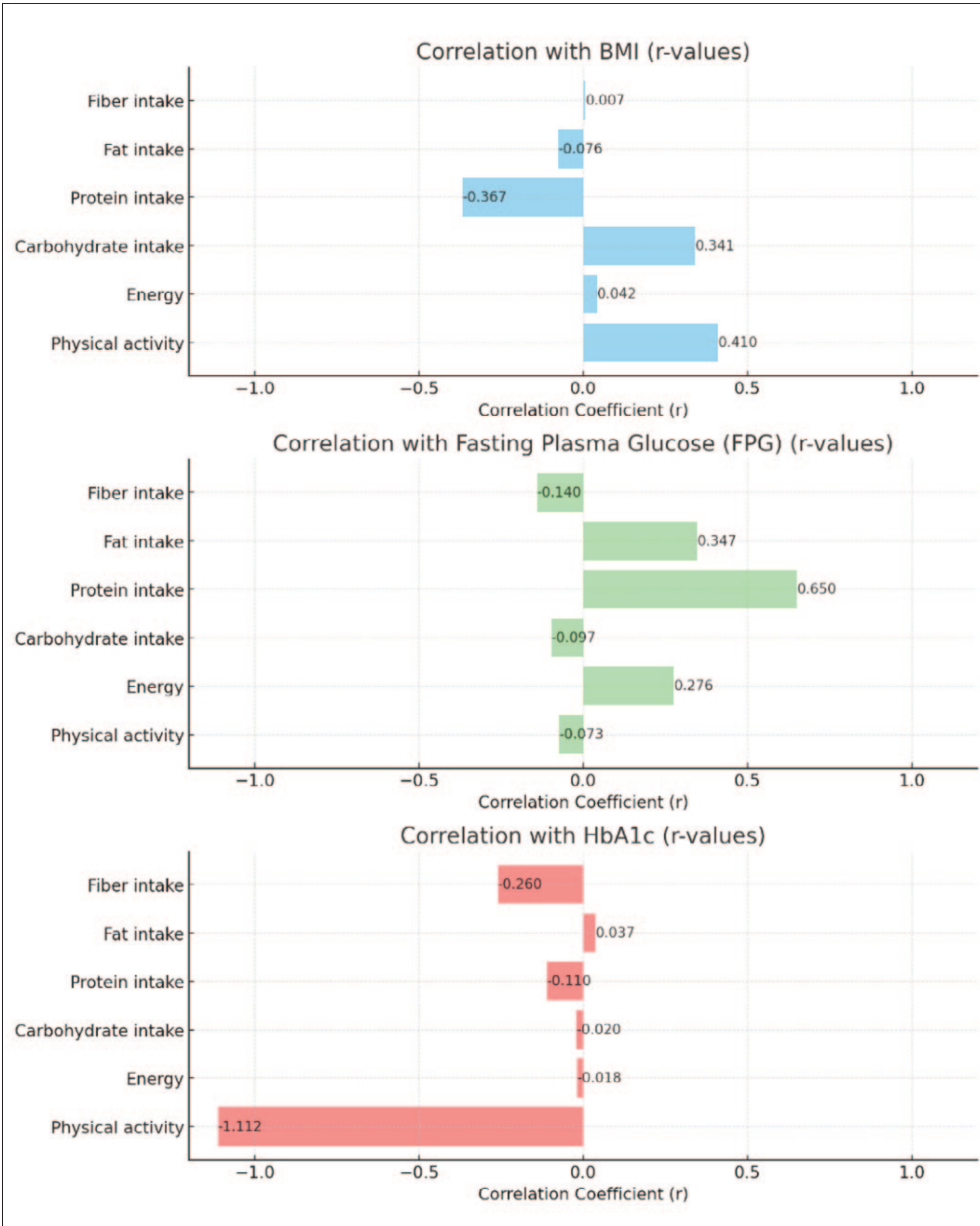

Figure 3. Relationship between physical activity and macronutrient intake with BMI and glycemic profile of prediabetic women

Table 4. Relationship between Nutritional Status and Macronutrient Intake with Glycemic Profile of Prediabetic Women

Variable	Plasma Insulin		HOMA-IR		HOMA-B		QUICKI	
	r	p-value	r	p-value	r	p-value	r	p-value
BMI	0.134	0.53	0.465	0.021*	0.131	0.54	-0.429	0.036*
Energy	-0.055	0.796	0.167	0.433	-0.25	0.236	-0.164	0.442
Carbohidrate intake	0.031	0.884	0.088	0.68	0.013	0.951	-0.044	0.836
Protein intake	0.006	0.977	0.018	0.932	-0.118	0.582	-0.006	0.974
Lemak intake	-0.096	0.653	0.063	0.768	-0.306	0.145	-0.107	0.617
Fiber intake	0.064	0.763	0.019	0.929	0.010	0.961	0.009	0.964

Data presented as mean; * = Significant P < 0.05; Spearman.

diabetes mellitus. The development of diabetes mellitus is heavily influenced by non-modifiable risk factors like ethnicity and family history, which have a strong genetic basis[12].

The study subjects had family members with a history of non-communicable diseases such as gout, kidney problems, heart disease, and liver disorders. These diseases are often associated with prediabetes and T2DM. Genetic factors that may be family-related and similar dietary and lifestyle habits may influence the likelihood of prediabetes. Based on hospitalization history, only one subject had a history of hospitalization in a health facility such as a hospital. Prediabetes is a pre-disease condition that generally does not cause severe symptoms or require intensive care as may be required in severe cases of type 1 diabetes or type 2 diabetes. The characteristic results of this study are consistent with findings from the 2018 Indonesian Basic Health Research, which observed the prevalence of prediabetes in women with low education levels and low socio-economic status.

A significant positive correlation exists between physical activity and body mass index (BMI), where physical activity, especially strength training, contributes to increased muscle mass and BMI. Research by[13] showed that physical activity can affect BMI through increasing muscle mass, while[14] found that regular physical activity was associated with significant changes in body composition and BMI. In contrast, the study by[15] reported that although physical activity can influence body weight, its effect on BMI may vary depending on the type and intensity of physical activity. In addition[16], emphasized the importance of considering other factors, such as diet and metabolism, that may affect the relationship between physical activity and BMI.

BMI significantly correlates with HOMA-IR and QUICKI, which suggests that BMI is associated with insulin resistance and sensitivity. BMI indicates body composition that affects insulin sensitivity and insulin resistance. Being overweight and obese, reflected in a high BMI, is often associated with increased insulin resistance. Excess body fat, especially visceral fat (around the internal organs), can cause inflammation and impaired insulin function, which increases HOMA-IR values. A higher BMI often indicates an accumulation of body fat, which can increase insulin resistance. Thus, BMI and HOMA-IR usually show a significant positive correlation[17]. A study on newly diagnosed type 2 diabetes patients showed that BMI was significantly correlated ($p<0.05$) with HOMA-IR and QUICKI[18].

Increased BMI may reduce insulin sensitivity, as excess body fat can interfere with insulin function through various biological mechanisms linked to adipose tissue expansion and dysfunction. As BMI increases, insulin sensitivity typically decreases, reflected in lower QUICKI values. The significant correlation between BMI and QUICKI suggests that a higher BMI is usually associated with reduced insulin sensitivity, leading to a decrease in QUICKI values[19]. Potential mechanisms linking increased BMI to decreased insulin sensitivity include: Impaired adipogenesis and increased visceral fat deposition lead to the secretion of inflammatory cytokines, which disrupt insulin signaling. High concentrations of fatty acids inhibit insulin signaling pathways in cells. Excess lipid accumulation generates reactive oxygen species, activating pathways that inhibit insulin signaling[18].

There was no significant correlation between energy, carbohydrate, protein, fat, and fiber intakes with glycemic indicators or plasma insulin levels. Different metabolic responses between individuals may influence the relationship between nutrient intake and glycemic indicators[17]. Nutrients act complexly, and interactions between different nutrients can influence effects on glycemic indicators and plasma insulin[20]. The timing of data collection and long-term dietary patterns can affect the relationship between food intake and metabolic indicators[21]. The quality and type of food consumed, such as carbohydrate and fat sources, may influence the results[17]. The relationship between macronutrient intake and profile glycemic is complex and may be influenced by factors such as macronutrient type and quality, individual characteristics, and the study design.

Strengths of this study include the use of a cross-sectional research design that allows analysis of correlations between variables at a single point in time, a relevant population of women aged 40-64 years in a rural area, comprehensive data collection including demographic characteristics, food consumption patterns, and clinical and biochemical parameters, use of valid measurement tools such as the International Physical Activity Questionnaire Short-Form (IPAQ-SF), and appropriate statistical analysis using Pearson and Spearman tests. However, study weaknesses include the cross-sectional design that only provides a picture of correlations at a single point in time and cannot demonstrate cause-and-effect relationships, variability in individual responses to nutrient intake and physical activity that may not be fully represented, self-reported measurements that are prone to bias, as well as geographical limitations that limit the generalizability of the results. The implications of this study are the importance of public health intervention programs focused on increasing physical activity and healthy eating to prevent the progression of prediabetes to type 2 diabetes, increased public and policymaker awareness of early prevention and management of prediabetes in rural areas, assistance in designing more effective health policies, the need for follow-up studies with larger samples and longitudinal designs, and the use of modern technology for more accurate measurement of physical activity and nutrient intake in the future.

CONCLUSION

This study demonstrates a notable and favorable association between physical activity and body mass index (BMI), where in higher levels of physical activity, especially strength training, contributes to increased muscle mass and BMI. BMI also significantly correlated with HOMA-IR and QUICKI, suggesting an association between BMI and insulin resistance and sensitivity. However, energy, carbohydrate, protein, fat, and fiber intake did not show significant correlations with glycemic indicators or plasma insulin, likely due to the variability of individual responses and the complexity of nutrient interactions. This study emphasizes the importance of managing prediabetes through a healthy diet and increased physical activity to prevent the onset of type 2 diabetes (T2DM). Implementing intervention programs that promote physical activity and healthy eating in rural areas can help reduce the risk of prediabetes progressing to T2DM.

Declarations

Research involving human participants requires careful attention to ethical guidelines, participant rights, and informed consent, as outlined in international declarations such as the Declaration of Helsinki.

Informed consent

The research was approved by Ethics Committee of Tanjung Karang Health Polytechnic, Health Ministry of The Republic of Indonesia No. 432/KEPK-TJK/VIII/2023.

REFERENCES

1. Dong Y, Zhang B, Sun W, Xing Y. Intervention of Prediabetes by Flavonoids From Oroxylum indicum [Internet]. 2nd ed. Bioactive Food as Dietary Interventions for Diabetes. Elsevier Inc.; 2019. 559–575 p. Available from: http://dx.doi.org/10.1016/B978-0-12-813822-9.00036-9
2. PDI dan PERKENI. Pedoman Pengelolaan dan Pencegahan Prediabetes DiIndonesia 2019. Surabaya: Airlangga University Press; 2020.
3. Echouffo-Tcheugui JB, Selvin E. Prediabetes and What It Means: The Epidemiological Evidence. Annu Rev Public Health. 2020; 42:59–77.
4. Widiana R, Bukhari A, Taslim NA, Rasyid H, Syauki Y. Effect of Nusantara diet feeding with triglyceride glucose index as a measure of insulin resistance in individuals ’ metabolic syndrome risk. 2024;44(3):142–8.
5. K.A.M White, Daneshvari S, Lilyquist J, Luo L, Steffen L., Bivin A, et al. Prediabetes: The Variation between HbA1c and Fasting Plasma Glucose. Physiol Behav. 2017;176(1):139–48.
6. Wang B, Mu X-L, Zhao J, Jiang H-P, Li S-S, Yan G, et al. Effects of lifestyle interventions on rural patients with type 2 diabetes mellitus. World J Diabetes. 2020;11(6):261–8.
7. Vatcheva KP, Fisher-Hoch SP, Reininger BM, McCormick JB. Sex and age differences in prevalence and risk factors for prediabetes in Mexican-Americans. Diabetes Res Clin Pract [Internet]. 2020;159:107950. Available from: https://doi.org/10.1016/j.diabres.2019.107950
8. World Health Organization. Definition and Diagnosis of Diabetes Mellitus and Intermediate Hyperglycemia. New Compr Biochem. 2006;1(C):161–214.
9. PERKENI. Pedoman Pengelolaan dan Pencegahan Diabetes Melitus Tipe 2 Dewasa di Indonesia 2021 [Internet]. Global Initiative for Asthma. PB. PERKENI; 2021. 104 p. Available from: www.ginasthma.org.
10. Craig C., Ainsworth B., Arvidsson D, Brown W, Ekelund U. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sport Exerc [Internet]. 2003;35(1381):95. Available from: https://sites.google.com/view/ipaq/references?authuser=0#h.yk3urvppwu41
11. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia. 1985;28(7):412–9.
12. Galicia-Garcia U, Benito-Vicente A, Jebari S, Larrea-Sebal A, Siddiqi H, Uribe KB, et al. Pathophysiology of type 2 diabetes mellitus. Int J Mol Sci. 2020;21(17):1–34.

13. Saad R, Deschamps T, Bernard P. Physical activity and body mass index: A study on the correlation between physical activity and body mass index in adults. J Phys Act Heal. 2018;15(4):310–8.

14. Zhang X, Wang Y, Chen Y. Effect of physical activity on body mass index and waist circumference: A meta-analysis. Obes Rev. 2018; 19(12):1670–81.

15. Hamasaki H. The Physical Activities in Obesity BT - Obesity: Clinical, Surgical and Practical Guide. In: Ahmad SI, editor. Cham: Springer International Publishing; 2024. p. 169–84. Available from: https://doi.org/10.1007/978-3-031-62491-9_13

16. Garcia R, Munoz L, Ruiz A. Impact of physical exercise on body composition and metabolic parameters: A review of recent evidence. Clin Nutr. 2020;39(2):377–86.

17. Kirk EP, McMahon M. Body Mass Index, Insulin Resistance, and Glucose Metabolism. J Clin Endocrinol Metab. 2022;107(4): 1237–46.

18. Wasana KGP, Attanayake AP, Weerarathna TP, Wijewardana Jayatilaka KAP. Value of simple clinical parameters to predict insulin resistance among newly diagnosed patients with type 2 diabetes in limited resource settings. PLoS One [Internet]. 2021;16(3 March 2021):1–13. Available from: http://dx.doi.org/10.1371/journal.pone.0248469

19. Zhao Y, Wu X. Association of Body Mass Index with Insulin Sensitivity and Insulin Resistance. World J Diabetes. 2016; 7(14):328–38.

20. Weyer C, Bogardus C. Obesity and insulin resistance: a review of the pathophysiology and therapeutic strategies. Clin Diabetes. 1999;17(1):10–8.

21. Katz A, Nambi SS, Mather K, Baron AD, Follmann DA, Sullivan G, et al. Quantitative insulin sensitivity check index: a simple, accurate method for assessing insulin sensitivity in humans. J Clin Endocrinol Metab. 2000;85(7):2402–10.