



Determinants of Insulin Resistance among Non-Diabetic Indonesian Adults: A Multivariable Analysis of Metabolic, Dietary, and Lifestyle Factors

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Summary

Introduction: Insulin resistance (IR), a major precursor of type 2 diabetes affecting 44.2 % of Indonesians, was assessed using the triglyceride–glucose (TyG) index, a more practical and economical measure. Comprehensive investigations linking IR with metabolic, dietary, and lifestyle factors remain scarce in Indonesia.

Objective: To assess the metabolic, dietary, and lifestyle factors associated with insulin resistance among non-diabetic adults in Indonesia.

Materials and Methods: This cross-sectional study used baseline data from the Non-Communicable Disease Risk Factor Cohort Study in Bogor, Indonesia. From 5,329 respondents, 251 with fasting glucose ≥ 126 mg/dL and 463 with incomplete data were excluded, yielding 4,615 participants. Insulin resistance was defined by a TyG index ≥ 8.5 . Variables with $p < 0.25$ in chi-square tests were entered into multivariable logistic regression to identify independent predictors. Odds ratios (ORs) and 95 % confidence intervals (CIs) were reported.

Results: Multivariable analysis revealed several strong predictors of the TyG index among non-diabetic adults. Male sex (OR = 3.90, 95 % CI: 3.15–4.82), high total cholesterol (OR = 4.36, 95 % CI: 3.72–5.11), and low HDL cholesterol (OR = 4.24, 95 % CI: 3.62–4.97) demonstrated the highest associations. Frequent consumption of packaged beverages (>3 packs/day) showed the greatest dietary effect (OR = 5.10, 95 % CI: 1.38–18.82). Central obesity (OR = 2.39, 95 % CI: 2.01–2.84) and age ≥ 40 years (OR = 1.67, 95 % CI: 1.41–1.98) were also significant predictors.

Conclusion: Insulin resistance (TyG index ≥ 8.5) is strongly linked to metabolic, dietary, and modifiable lifestyle factors and may serve as a practical screening tool in urban populations.

Keywords: insulin resistance, TyG index, metabolic risk, dietary patterns, lifestyle risk factors, non-diabetic adults.

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Детерминанты инсулинорезистентности у взрослых индонезийцев, не страдающих диабетом: многомерный анализ факторов метаболизма, питания и образа жизни

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Резюме

Введение. Инсулинорезистентность (ИР), основной предшественник диабета второго типа, встречающаяся у 44,2 % индонезийцев, оценивалась с помощью индекса триглицеридов–глюкозы (TyG) как более практичного и экономичного показателя. В Индонезии комплексные исследования зависимости между факторами метаболизма, питания и образа жизни и ИР по-прежнему проводятся редко.

Цель: оценить факторы метаболизма, питания и образа жизни, связанные с инсулинорезистентностью, у взрослых жителей Индонезии, не страдающих диабетом.

Материалы и методы. В нашем поперечном исследовании использовались первичные данные когортного исследования факторов риска неинфекционных заболеваний, проведенного в Богоре, Индонезия. Из 5329 респондентов 251 участник с уровнем глюкозы натощак ≥ 126 мг/дл и 463 человека с неполными данными были исключены, вследствие чего итоговая выборка составила 4615 респондентов. Инсулинорезистентность определялась по индексу TyG $\geq 8,5$. Переменные с $p < 0,25$ в критериях хи-квадрат были включены в многофакторную логистическую регрессию для выявления независимых предикторов. Были получены отношения шансов (ОШ) и 95 % доверительные интервалы (ДИ).

Результаты. Многофакторный анализ выявил несколько сильных предикторов индекса TyG среди взрослых без диабета. Наибольшая корреляция с индексом триглицеридов–глюкозы была установлена для принадлежности к мужскому полу (ОШ = 3,90, 95 % ДИ: 3,15–4,82), высокого уровня общего холестерина (ОШ = 4,36, 95 % ДИ: 3,72–5,11) и низкого уровня холестерина ЛПВП (ОШ = 4,24, 95 % ДИ: 3,62–4,97). Наиболее выраженный эффект, связанный с питанием, наблюдался при частом употреблении пакетированных напитков (>3 упаковок в день) (ОШ = 5,10, 95 % ДИ: 1,38–18,82). Также значимыми предикторами оказались центральное (абдоминальное) ожирение (ОШ = 2,39, 95 % ДИ: 2,01–2,84) и возраст от 40 лет (ОШ = 1,67, 95 % ДИ: 1,41–1,98).

Заключение: инсулинорезистентность (индекс TyG $\geq 8,5$) значимо связана с метаболизмом, питанием и модифицируемыми факторами образа жизни и может служить практическим инструментом скрининга городского населения.

Ключевые слова: инсулинорезистентность, индекс TyG, метаболический риск, особенности питания, факторы риска, связанные с образом жизни, взрослые без диабета.

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Introduction. Insulin resistance (IR) is a major contributor to the development of type 2 diabetes and cardiovascular diseases. In Indonesia, it affects around 44.2 % of the population, reflecting a global upward trend and growing public health concern [1, 2]. The triglyceride–glucose (TyG) index is a validated and practical surrogate marker for insulin resistance, diabetes risk, and mortality, especially in large-scale epidemiological studies [3, 4]. The TyG index is widely used in international research as a cost-effective IR survey [5].

While Western populations have extensively studied insulin resistance, research among non-diabetic individuals in Southeast Asia—especially Indonesia—remains limited. Most Indonesian studies, particularly in rural areas like Flores, focus mainly on BMI and waist circumference. Few have explored behavioral and nutritional factors using multivariable methods, highlighting the need for comprehensive analyses to understand modifiable risk factors in the local context [6].

Understanding how modifiable lifestyle and dietary factors influence insulin resistance—particularly through accessible markers like the TyG index—has important public health implications for Indonesia and other low- and middle-income countries. Clarifying these associations in non-diabetic adults enables early detection of metabolic risk using a low-cost tool, allowing timely preventive actions such as improved diet, physical activity, and weight control. Given the high prevalence of IR among Indonesian adults, especially in culturally distinct regions like Bogor, such evidence is essential for designing targeted, context-specific interventions. This study provides a comprehensive analysis of IR determinants, offering evidence to guide national screening policies and enhance prevention strategies to delay disease onset and reduce healthcare burden.

This study focuses on insulin resistance among non-diabetic Indonesian adults, as defined by a TyG index ≥ 8.5 . It examines the influence of metabolic, dietary, and lifestyle factors on insulin resistance. The analysis **aims** to provide insights into modifiable risk factors relevant to the study population.

Materials and Methods

Respondents, Data Source, and Study Design

The Non-Communicable Disease (NCD) Risk Factor Cohort Study included adults aged 22–65 residing permanently in five urban villages (Kebon Kalapa, Babakan Pasar, Babakan, Ciwaringin, and Panaragan) of Bogor Tengah District, Bogor City. Participants were selected based on inclusion and exclusion criteria, excluding individuals who were pregnant, had mental disorders, underwent hysterectomy, or were diagnosed with NCDs (coronary heart disease, stroke, diabetes, cancer, or lung disease). Data were collected through interviews, physical examinations, and laboratory tests at the Ministry of Health's Integrated Laboratory for Applied Technology and Clinical Epidemiology.

This cross-sectional study utilized baseline data from the Bogor NCD Risk Factor Cohort Study (2011–2021), involving 5,329 adults aged 22–65 from urban and peri-urban Bogor. After excluding individuals with

fasting glucose ≥ 126 mg/dL ($n = 251$) or missing key data on diet ($n = 382$), blood pressure ($n = 7$), body weight ($n = 2$), or glucose values ($n = 72$), the final analysis included 4,615 non-diabetic adults.

Variables

The independent variables included sociodemographic factors (age, sex, education, marital status, family history of diabetes, and health insurance), anthropometrics (BMI and central obesity), clinical indicators (fasting/postprandial glucose, lipid profile, and blood pressure), dietary intake (energy, fat, meat, oil, and packaged beverages), and behavioral factors (stress, smoking, alcohol use, and physical activity). The outcome variable was the triglyceride–glucose (TyG) index, which served as a proxy indicator for insulin resistance.

Measurements

Sociodemographic data (age, sex, education, marital status, family history of diabetes, and health insurance) were collected via structured interviews. Behavioral data (smoking, alcohol use, and physical activity) were obtained using the modified WHO STEPS questionnaire, while stress was assessed with the WHO Self-Reporting Questionnaire (SRQ). Anthropometric measurements (weight, height, and waist circumference) were taken by trained health workers following WHO STEPS protocols. Blood pressure was assessed by trained staff using a sphygmomanometer.

Biochemical data—including fasting glucose, 2-hour postprandial glucose, and lipid profile (total cholesterol, triglycerides, HDL, LDL)—were collected by trained laboratory staff. Respondents fasted the day before sampling and consumed a glucose solution for postprandial measurements. Dietary intake was assessed using a 24-hour recall and food habits through the Food Frequency Questionnaire (FFQ), both conducted by trained enumerators.

Insulin resistance is defined by a TyG index ≥ 8.5 , a threshold validated in Asian populations to reflect region-specific metabolic characteristics and enhance diagnostic relevance [7]. The triglyceride–glucose (TyG) index number is obtained by the formula:

$$\text{TyG Index} = \ln \frac{\text{fasting triglycerides (mg/dL)} \times \text{fasting blood sugar (mg/dL)}}{2}$$

Statistical Analyses

Bivariate Analysis

Descriptive statistics summarized population characteristics and initial variable associations. Bivariate analysis using the chi-square test assessed relationships between categorical predictors and elevated TyG index (≥ 8.5), appropriate due to the binary outcome. Following Hosmer and Lemeshow's guidance, variables with $p < 0.25$ were included in the multivariable model to retain potentially relevant predictors [8].

Multivariable Analysis

Multivariable logistic regression was conducted using the enter method, with stepwise removal of non-significant variables. Adjusted odds ratios (ORs) and 95 % confidence intervals (CIs) were reported, with significance set at $p < 0.05$. Model fit was evaluated using the Hosmer–Lemeshow test, and multicollinearity was assessed via Variance Inflation Factors (VIF).

Results

Table 1 presents bivariate analysis results, identifying insulin resistance based on a TyG index ≥ 8.5 , as validated in Asian populations. Several sociodemographic, clinical, behavioral, dietary, and physical activity variables showed significant associations ($p < 0.05$) with insulin resistance. Sociodemographic factors like sex, age, employment, and insurance status were significantly linked to elevated TyG index. Clinically, high BMI, central obesity, hypertension, abnormal lipids, and elevated 2-hour glucose were

associated with insulin resistance. Smoking, alcohol use, and stress also showed significant associations.

Dietary factors such as inadequate intake of energy, macronutrients ($< 80\%$ RDA), low sodium, high sugar, flavor enhancers, frequent egg and packaged beverage intake, and low coffee consumption were related to higher TyG index. Low physical activity, including infrequent walking and lack of moderate or vigorous exercise, was also significantly associated. All variables with $p < 0.25$ in bivariate analysis were included in the multivariable logistic regression.

Table 1. Description of the respondents and bivariate associations with elevated triglyceride–glucose (TyG) index
Таблица 1. Описание респондентов и двумерных ассоциаций с повышенным индексом триглицеридов–глюкозы (TyG)

Variables / Переменные	Total / Всего, <i>n</i>	Insulin resistance / Инсулинорезистентность				<i>p</i>
		No / Нет TyG index < 8.5		Yes / Да TyG index ≥ 8.5		
		<i>n</i>	%	<i>n</i>	%	
1	2	3	4	5	6	7
Sex / Пол						
– Female / Женский	2995	2123	70.9	872	29.1	0.000*
– Male / Мужской	1620	892	55.1	728	44.9	
Age group, years / Возрастная группа, лет						
– < 40	1673	1289	77.0	384	23.0	0.000*
– ≥ 40	2942	1726	58.7	1216	41.3	
Family history of diabetes / Наличие диабета в семейном анамнезе						
– No / Нет	3951	2600	65.8	1351	34.2	0.098*
– Yes / Да	664	415	62.5	249	37.5	
Marital status / Семейное положение						
– Married / В браке	3894	2547	65.4	1347	34.6	0.796
– Single / Холост/не замужем	721	468	64.9	253	35.1	
Education level / Уровень образования						
– High / Высокий	1993	1324	66.4	669	33.6	0.170*
– Low / Низкий	2622	1691	64.5	931	35.5	
Employment status / Занятость						
– Yes / Да	2380	1424	59.8	956	40.2	0.000*
– No / Нет	2235	1591	71.2	644	28.8	
Health insurance ownership / Наличие полиса медицинского страхования						
– Yes / Да	1780	1126	63.3	654	36.7	0.019*
– No / Нет	2835	1889	66.6	946	33.4	
Body mass index / Индекс массы тела						
– < 25	2529	1873	74.1	656	25.9	0.000*
– > 25	2086	1142	54.7	944	45.3	
Central obesity / Центральное (абдоминальное) ожирение						
– No / Нет	2574	1888	73.3	686	26.7	0.000*
– Yes / Да	2037	1123	55.1	914	44.9	
Hypertension / Гипертония						
– No / Нет	3109	2208	71.0	901	29.0	0.000*
– Yes / Да	1506	807	53.6	699	46.4	
Total cholesterol / Общий холестерин						
– Low/Normal / Низкий/Нормальный	2348	1849	78.7	499	21.3	0.000*
– High / Высокий	2267	1166	51.4	1101	48.6	
HDL cholesterol / Холестерин ЛПВП						
– High/ Normal / Высокий/Нормальный	3043	2233	73.4	810	26.6	0.000*
– Low / Низкий	1572	782	49.7	790	50.3	
LDL cholesterol / Холестерин ЛПНП						
– Low/ Normal / Низкий/Нормальный	841	651	77.4	190	22.6	0.000*
– High / Высокий	3774	2364	62.6	1410	37.4	

Table 1 (continued) / Таблица 1 (продолжение)

1	2	3	4	5	6	7
2 hours postprandial glucose / Уровень глюкозы в крови через 2 часа после еды						
– Low/Normal / Низкий/Нормальный	3476	2439	70.2	1037	29.8	0.000*
– High / Высокий	1139	576	50.6	563	49.4	
Flavour enhancer usage / Использование усилителей вкуса						
– No / Нет	235	139	59.1	96	40.9	0.041*
– Yes / Да	4376	2874	65.7	1502	34.3	
Reuse frequency of cooking oil a day / Частота повторного использования пищевых масел для приготовления блюд в день						
– < 3	3532	2289	64.8	1243	35.2	0.174*
– > 3	1060	711	67.1	349	32.9	
Active smoking / Активное курение						
– No / Нет	3046	2107	69.2	939	30.8	0.000*
– Yes / Да	1569	908	57.9	661	42.1	
Alcohol / Употребление алкоголя						
– No / Нет	3666	2496	68.1	1170	31.9	0.000*
– Yes / Да	948	518	54.6	430	45.4	
Stress / Стресс						
– No / Нет	3635	2339	64.3	1296	35.7	0.007*
– Yes / Да	980	676	69.0	304	31.0	
Adequacy of energy intake, % RDA / Энергетическая ценность рациона питания, % от РСН						
– ≥ 80%	1901	1362	71.6	539	28.4	0.000*
– < 80%	2714	1653	60.9	1061	39.1	
Adequacy of protein intake, % RDA / Потребление белков, % от РСН						
– ≥ 80%	2543	1778	69.9	765	30.1	0.000*
– < 80%	2072	1237	59.7	835	40.3	
Adequacy of fat intake, % RDA / Потребление жиров, % от РСН						
– ≥ 80%	2117	1463	69.1	654	30.9	0.000*
– < 80%	2498	1552	62.1	946	37.9	
Adequacy of carbohydrate intake, % RDA / Потребление углеводов, % от РСН						
– ≥ 80%	1667	1187	71.2	480	28.8	0.000*
– < 80%	2948	1828	62.0	1120	38.0	
Fruit and vegetables frequency, times a day / Частота потребления фруктов и овощей в день						
– > 3	1356	870	64.2	486	35.8	0.389*
– < 3	2718	1781	65.5	937	34.5	
Adequacy of sodium intake, % RDA / Потребление соли, % от РСН						
– < 100%	1669	1012	60.6	657	39.4	0.000*
– > 100%	2946	2003	68.0	943	32.0	
Sugar intake, % of total energy / Потребление сахара, % от калорийности суточного рациона						
– < 5%	3031	2033	67.1	998	32.9	0.001*
– > 5%	1584	982	62.0	602	38.0	
Intake of oil-derived products, times a day / Частота потребления жиров и масел в день						
– < 3	2279	1508	66.2	771	33.8	0.233*
– > 3	2298	1482	64.5	816	35.5	
Intake of meat, times a day / Частота потребления мяса в день						
– < 1	3275	2168	66.2	1107	33.8	0.057*
– > 1	1314	831	63.2	483	36.8	
Intake of fresh fish, times a week / Частота потребления свежей рыбы в неделю						
– > 7	260	159	61.2	101	38.8	0.144*
– < 7	4325	2837	65.6	1488	34.4	
Intake of egg, times a week / Частота потребления яиц в неделю						
– > 4	1434	975	68.0	459	32.0	0.011*
– < 4	3151	2021	64.1	1130	35.9	
Intake of milk, times a day / Частота потребления молока в день						
– > 2	28	16	57.1	12	42.9	0.360
– < 2	4561	2983	65.4	1578	34.6	
Intake of plant-based products, times a day / Частота потребления продуктов растительного происхождения в день						
– < 3	4199	2759	65.7	1440	34.3	0.098*
– > 3	390	240	61.5	150	38.5	

Table 1 (continued) / Таблица 1 (продолжение)

1	2	3	4	5	6	7
Intake of legumes, times a day / Частота потребления бобовых в день						
– < 1	359	220	61.3	139	38.7	0.092*
– > 1	4223	2774	65.7	1449	34.3	
Intake of packaged beverages, times a day / Частота потребления упакованных напитков в день						
– < 3	4573	2993	65.4	1580	34.6	0.019*
– > 3	16	6	37.5	10	62.5	
Intake of confectionery, time a week / Частота потребления кондитерских изделий в неделю						
– < 4	2280	1466	64.3	814	35.7	0.139*
– > 4	2305	1530	66.4	775	33.6	
Intake of coffee, times a day / Частота потребления кофе в день						
– < 1	3122	2111	67.6	1011	32.4	0.000*
– > 1	1463	885	60.5	578	39.5	
Vigorous physical activity / Интенсивная физическая активность						
– Yes / Да	535	323	60.4	212	39.6	0.010*
– No / Нет	4080	2692	66.0	1388	34.0	
Days of vigorous physical activity a week / Количество дней интенсивной физической активности в неделю						
– > 3	457	273	59.7	184	40.3	0.008*
– < 3	4158	2742	65.9	1416	34.1	
Moderate physical activity / Умеренная физическая активность						
– Yes / Да	3762	2514	66.8	1248	33.2	0.000*
– No / Нет	853	501	58.7	352	41.3	
Days of moderate physical activity a week / Количество дней умеренной физической активности в неделю						
– > 5	3224	2169	67.3	1055	32.7	0.000*
– < 5	1391	846	60.8	545	39.2	
METs of physical activity, MET-min/week / МЭН для физической активности, МЭН-мин в неделю						
– > 1500	3547	2357	66.5	1190	33.5	0.004*
– < 1500	1068	658	61.6	410	38.4	
Walking for at least 10 minutes / Прогулки/ходьба в течение 10 и более минут						
– Yes / Да	3635	2396	65.9	1239	34.1	0.108*
– No / Нет	980	619	63.2	361	36.8	
Days of walking a week / Количество дней с прогулками в неделю						
– > 5	2584	1729	66.9	855	33.1	0.011*
– < 5	2031	1286	63.3	745	36.7	
High intensity training / Тренировки высокой интенсивности						
– Yes / Да	166	97	58.4	69	41.6	0.057*
– No / Нет	4449	2918	65.6	1531	34.4	
Days of high intensity training a week / Количество дней тренировок высокой интенсивности в неделю						
– > 3	45	27	60.0	18	40.0	0.450
– < 3	4570	2988	65.4	1582	34.6	
Moderate intensity training / Тренировки умеренной интенсивности						
– Yes / Да	1484	961	64.8	523	35.2	0.573
– No / Нет	3131	2054	65.6	1077	34.4	
Days of moderate intensity training a week / Количество дней тренировок умеренной интенсивности в неделю						
– > 5	228	146	64.0	82	36.0	0.673
– < 5	4387	2869	65.4	1518	34.6	
METs of training, MET-min/week / МЭН для тренировок, МЭН-мин в неделю						
– > 1500	178	108	60.7	70	39.3	0.183*
– < 1500	4437	2907	65.5	1530	34.5	
Sedentary lifestyle, hours a day / Сидячий образ жизни, часов в день						
– < 8	3821	2490	65.2	1331	34.8	0.607
– ≥ 8	794	525	66.1	269	33.9	

Abbreviations to Tables 1 and 2: HDL, high-density lipoprotein; LDL, low-density lipoprotein; RDA, recommended dietary allowance; MET, metabolic equivalent of task.

Note: Chi-square test * $p \leq 0.25$.

Аббревиатуры таблиц 1 и 2: ЛПВП, липопротеины высокой плотности; ЛПНП, липопротеины низкой плотности; РСН, рекомендуемая суточная норма потребления; МЭН, метаболический эквивалент нагрузки.

Примечание: Критерий хи-квадрат, * $p \leq 0.25$.

Based on the results of the multivariable logistic regression analysis presented in Table 2, several factors were found to be significantly associated with insulin resistance. Being male and above 40 years old showed significant associations with insulin resistance. Clinically, central obesity, hypertension, high total cholesterol, low HDL cholesterol, and elevated 2-hour postprandial glucose levels were all positively associated with insulin resistance.

Behavioral factors such as active smoking and alcohol consumption were also positively related to insulin resistance. Similarly, inadequate energy intake (<80% of RDA), frequent consumption of oil-based products (>3 times/day), frequent meat intake (>1 times/day), and high intake of packaged beverages (>3 packs/day) were positively associated with insulin resistance. In addition, walking less than 5 days/week was also positively associated with insulin resistance.

Discussion

This study examined insulin resistance determinants among non-diabetic Indonesian adults using the TyG index as a surrogate marker. Conducted within a large urban cohort, it identified significant associations between elevated TyG values (≥ 8.5) and various metabolic, sociodemographic, behavioral, and dietary factors, supporting its utility for early detection in both clinical and epidemiological contexts. Key metabolic indicators—high total cholesterol, low HDL, elevated postprandial glucose, central obesity, and hypertension—were strongly linked to increased TyG index, reflecting its relevance to lipid-glucose

interactions and visceral adiposity. For example, a high TyG index has been associated with hypertension, regardless of HDL and LDL cholesterol levels [9], and specifically associated with more severe hypertension subtypes, including isolated diastolic hypertension [10]. Furthermore, the TyG index has been validated as a predictor of visceral obesity [11], with additional evidence highlighting its synergistic effects with visceral fat in increasing cardiometabolic risk [12]. These consistent findings support the biological plausibility of lipid-glucose disruption and central adiposity in driving early insulin resistance.

For instance, an elevated TyG index has been shown to correlate significantly with indicators of central obesity, including waist circumference, even after adjusting for other anthropometric measures [13, 14]. A cross-sectional study in a Chinese population found waist circumference to be a better predictor of insulin resistance and metabolic issues than BMI. The TyG index strongly correlated with waist circumference, highlighting its value as a marker of central obesity and early metabolic dysfunction. Elevated TyG levels were also consistently associated with dyslipidemia (low HDL, high total cholesterol) and impaired glucose metabolism. Similar findings in Chinese children and adolescents further support the TyG index as a reflection of combined lipid-glucose imbalances and visceral fat accumulation [15, 16]. A large cross-sectional study in China confirmed the TyG index as a reliable marker linked to metabolic syndrome components like hypertension and low

Table 2. Multivariable logistic regression determinants of triglyceride–glucose index

Таблица 2. Детерминанты индекса триглицеридов–глюкозы по результатам многофакторной логистической регрессии

Variables / Переменные	B	SE / CO	AOR (95% CI) / СОШ (95% ДИ)	p
Male sex / Мужской пол	1.360	0.109	3.895 (3.148 – 4.820)	0.000*
Age > 40 years old / Возраст от 40 лет	0.514	0.085	1.672 (1.414 – 1.975)	0.000*
No health insurance ownership / Отсутствие полиса медицинского страхования	-0.161	0.075	0.851 (0.735 – 0.985)	0.031*
Central obesity / Центральное ожирение	0.871	0.088	2.390 (2.013 – 2.838)	0.000*
Hypertension / Гипертензия	0.419	0.082	1.521 (1.295 – 1.786)	0.000*
High total cholesterol / Высокий уровень общего холестерина	1.472	0.081	4.357 (3.718 – 5.106)	0.000*
Low HDL cholesterol / Низкий уровень холестерина ЛПВП	1.445	0.081	4.242 (3.620 – 4.971)	0.000*
High 2-hour postprandial glucose / Уровень глюкозы в крови через 2 часа после еды	0.577	0.084	1.780 (1.510 – 2.099)	0.000*
Active smoking / Активное курение	0.267	0.095	1.306 (1.084 – 1.573)	0.005*
Alcohol consumption / Употребление алкоголя	0.215	0.106	1.240 (1.008 – 1.527)	0.042*
Energy adequacy intake <80% of RDA / Энергетическая ценность рациона питания, % от РСН	0.279	0.078	1.322 (1.136 – 1.539)	0.000*
Intake of oil-derived products >3 times/day / Потребление пищевых масел от трех раз в день	0.169	0.075	1.184 (1.023 – 1.371)	0.024*
Intake of meat ≥ 1 time/day / Потребление мяса от одного раза в день	0.204	0.082	1.226 (1.044 – 1.440)	0.013*
Intake of packaged beverages > 3 packs/day / Потребление более трех упакованных напитков в день	1.629	0.666	5.098 (1.381 – 18.82)	0.015*
Days of walking <5 days/week / Меньше пяти дней ходьбы/прогулок в неделю	0.199	0.074	1.220 (1.056 – 1.409)	0.007*

Abbreviations: SE, standard error; AOR, adjusted odd ratio; CI, confidence interval.

Note: Binary logistic regression, * $p < 0.05$.

Аббревиатуры: СО, стандартная ошибка; СОШ, скорректированное отношение шансов; ДИ, доверительный интервал.

Примечание: Бинарная логистическая регрессия, * $p < 0,05$.

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HDL. These consistent findings support its role as an integrative indicator of metabolic dysfunction and early insulin resistance [17, 18].

Male sex and older age were linked to higher TyG index values, aligning with evidence of sex- and age-related differences in fat distribution and insulin sensitivity. TyG levels tend to rise with age and are generally higher in men, likely due to greater visceral fat, which is closely tied to insulin resistance. In contrast, women—especially premenopausal—store more subcutaneous fat and benefit from estrogen's protective effects, which diminish with age [16,19–21].

Participants without health insurance showed a lower risk of insulin resistance based on the TyG index, differing from previous studies that linked insurance ownership to better glucose control. This discrepancy may be due to over-reliance on insurance, leading to reduced health-conscious behavior, or reverse causality, where individuals at higher metabolic risk are more likely to obtain insurance, making the insured group appear more vulnerable [22–25].

Several lifestyle factors were linked to a higher TyG index, indicating increased insulin resistance risk. Smoking and alcohol consumption were associated with elevated TyG levels, consistent with Korean studies showing higher TyG indices among smokers and drinkers, especially co-users, even after adjusting for key health variables [26, 27]. Tobacco use increases oxidative stress, inflammation, and endothelial dysfunction, contributing to insulin resistance and higher triglycerides. Similarly, excessive alcohol intake disrupts glucose-lipid balance and promotes liver fat and inflammation, raising TyG and insulin resistance [26, 28]. In chronic smokers, nicotine disrupts insulin signaling in muscles, reducing sensitivity and promoting resistance. Conversely, quitting smoking improves insulin sensitivity. Alcohol intake impairs insulin regulation in the brain and liver and increases gluconeogenesis and lipolysis, thus worsening insulin resistance [29–32].

Physical inactivity, such as walking less than five days a week, was linked to a higher TyG index. This supports evidence that physical activity boosts insulin sensitivity by improving glucose uptake and reducing visceral fat. Meta-analyses of clinical trials show exercise enhances insulin-stimulated glucose use, especially in muscle. Studies confirm that physical activity increases muscle glucose uptake and reduces visceral fat activity, improving overall insulin sensitivity. Clustering studies also link combined unhealthy behaviors—like inactivity, smoking, alcohol use, and poor sleep—to higher insulin resistance and glucose levels, highlighting their role in raising the TyG index and contributing to metabolic dysfunction [33–36].

Consumption of meat, packaged beverages, oil-derived products, and low energy intake were positively associated with elevated TyG index. A longitudinal study in Brazil found that high red and processed meat intake raised the risk of insulin resistance and type 2 diabetes. Similarly, meta-analyses showed that high meat consumption increased the risk of metabolic syndrome, including elevated triglycerides and insulin resistance, with red meat linked to higher triglyceride levels [37–40].

Frequent intake of packaged beverages (over three servings/day) was a strong predictor of elevated TyG index. This aligns with studies showing that packaged beverages containing fructose, glucose, high-fructose corn syrup, sucrose, or aspartame reduce insulin sensitivity and increase liver fat [41].

Unhealthy fat intake from cooking oils increases insulin resistance, while replacing it with MUFA or PUFA can lower the TyG index risk. High fat intake, especially from reused oil, is linked to elevated TyG. This study also found that consuming less than 80 % of daily calorie needs increases insulin resistance. Poor calorie intake, without balanced nutrition, can impair metabolism and insulin sensitivity. Overall, both the quantity and quality of diet influence insulin sensitivity via the TyG pathway [42–45].

The study strengths include a large urban sample of non-diabetic Indonesian adults, enhancing relevance for similar settings, and the use of the TyG index as a practical marker. It also examined various metabolic, dietary, and lifestyle components. However, its cross-sectional design limited causal interpretation. Some associations weakened after adjustment, possibly due to confounding. Dietary data relied on self-report, risking bias. Lastly, while useful, the TyG index is an indirect measure and may not fully capture insulin resistance complexity.

Future studies should use longitudinal designs to clarify causality and include objective markers like inflammation, cortisol, or genetics to uncover mechanisms beyond the TyG index. Mixed-methods research may also deepen insight into behavioural and psychosocial factors influencing metabolic risk.

Conclusion

A combination of metabolic, dietary, and lifestyle factors influences insulin resistance among non-diabetic Indonesian adults. The TyG index effectively identified individuals at higher risk, highlighting the need for early screening and targeted interventions to prevent cardiometabolic complications. By prioritizing targeted interventions tailored to the unique needs of this population, the healthcare system can effectively mitigate the long-term health consequences associated with insulin resistance.

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