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Refined food consumption and the triglyceride-glucose index in adults with type 2 diabetes: Associations across food categories

Consumo de alimentos refinados e índice triglicéridos-glucosa en adultos con diabetes tipo 2: asociaciones según categorías de alimentos

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ABSTRACT

Introduction: Evidence on the association between refined foods and metabolic outcomes is inconsistent, particularly in type 2 diabetes mellitus (T2DM). This study evaluated the associations of added sugars, industrial pastries, and refined cereals with the triglyceride-glucose (TyG) index in Peruvian adults with T2DM.

Methods: This secondary analysis included 80 adults with T2DM from the baseline assessment of a quasi-experimental study conducted at a primary healthcare center in Peru. The exposures were added sugars, industrial pastries, and refined cereals, assessed using a validated food frequency questionnaire. The outcome was the TyG index. Linear regression models estimated β coefficients and 95% confidence intervals (95% CI). Model 1 adjusted for sex, age, education, diabetes knowledge, abdominal obesity, and physical activity; Model 2 additionally adjusted for diabetes medication use.

Results: The mean age was 50.3 years, and 67.5% of participants were women. In model 2, any consumption of added sugars (β = 0.74; 95% CI: 0.39–1.09; p < 0.001) and industrial pastries (β = 0.52; 95% CI: 0.14–0.89; p = 0.007), compared with no consumption, was associated with a higher TyG index. For refined cereals, consumption ≥1 time/day compared with <1 time/day showed a smaller and less precise association (β = 0.29; 95% CI: −0.01 to 0.60; p = 0.056).

Conclusions: Any consumption of added sugars and industrial pastries was associated with a higher TyG index compared with no consumption, whereas a weaker association was observed for refined cereal consumption.

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Keywords: Diabetes Mellitus, Type 2; Dietary Carbohydrates; Dietary Sugars; Insulin Resistance; Peru

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ESUMEN

Introducción: La evidencia sobre la asociación entre el consumo de alimentos refinados y los desenlaces metabólicos es inconsistente, particularmente en personas con diabetes mellitus tipo 2 (DM2). Este estudio evaluó las asociaciones del consumo de azúcares añadidos, productos de pastelería industrial y cereales refinados con el índice triglicéridos-glucosa (TyG) en adultos peruanos con DM2.

Metodología: Este análisis secundario incluyó a 80 adultos con DM2 provenientes de la evaluación basal de un estudio cuasiexperimental realizado en un centro de atención primaria de salud en Perú. Las exposiciones fueron el consumo de azúcares añadidos, productos de pastelería industrial y cereales refinados, evaluados mediante un cuestionario de frecuencia de consumo de alimentos validado. El desenlace fue el índice TyG. Se utilizaron modelos de regresión lineal para estimar los coeficientes β ajustados y sus intervalos de confianza del 95% (IC 95%). El modelo 1 se ajustó por sexo, edad, nivel educativo, conocimientos sobre diabetes, obesidad abdominal y actividad física; el modelo 2 incluyó adicionalmente el uso de medicamentos para la diabetes.

Resultados: La edad media fue de 50,3 años y el 67,5% de los participantes fueron mujeres. En el modelo 2, cualquier consumo de azúcares añadidos (β = 0,74; IC 95%: 0,39–1,09; p < 0,001) y de productos de pastelería industrial (β = 0,52; IC 95%: 0,14–0,89; p = 0,007), en comparación con ningún consumo, se asoció con un mayor índice TyG. Para los cereales refinados, el consumo ≥1 vez/día en comparación con <1 vez/día mostró una asociación de menor magnitud y menor precisión (β = 0,29; IC 95%: −0,01 a 0,60; p = 0,056).

Conclusiones: Cualquier consumo de azúcares añadidos y de productos de pastelería industrial se asoció con un mayor índice TyG en comparación con ningún consumo, mientras que se observó una asociación de menor magnitud para el consumo de cereales refinados.

Financiación: Los autores declaran que no se recibió financiamiento para la realización de este estudio.

Palabras clave: Diabetes Mellitus Tipo 2; Carbohidratos de la Dieta; Azúcares de la Dieta; Resistencia a la Insulina; Perú

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HIGHLIGHTS

- Evidence on the associations between refined foods and metabolic outcomes remains inconsistent, particularly across specific refined food categories among adults with type 2 diabetes.
- Any consumption of added sugars and industrial pastries was associated with a higher triglyceride-glucose (TyG) index compared with no consumption, whereas the association with refined cereals was weaker and less precise.
- Refined food categories may show different patterns of association with the TyG index, highlighting the value of evaluating them separately.

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INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a major public health challenge and one of the leading causes of morbidity and premature mortality worldwide[1–3]. In South and Central America, more than 35 million adults are currently living with diabetes, and this number is projected to increase substantially over the coming decades[1]. Because insulin resistance is a central feature of T2DM pathophysiology and a key determinant of disease progression, understanding modifiable determinants of this metabolic dysfunction remains a priority for improving metabolic management[4]. The triglyceride-glucose (TyG) index, derived from fasting triglyceride and glucose concentrations, has emerged as a simple and validated surrogate marker of insulin resistance, demonstrating good agreement with the euglycemic–hyperinsulinemic clamp, including among individuals with T2DM[5]. Beyond its role as a surrogate marker of insulin resistance, the TyG index has also shown clinical utility in patients with T2DM by correlating with glycemic control, predicting fasting plasma glucose and diabetes remission after metabolic surgery, and providing prognostic information for selected clinical outcomes[4].

Among the modifiable determinants of insulin resistance, diet plays a fundamental role in the management of T2DM and is recognized as a cornerstone of medical nutrition therapy[6,7], with refined foods constituting an important component of dietary patterns in many populations[8]. Although refined foods are frequently considered as a single dietary category in nutritional epidemiology, they comprise heterogeneous food groups that differ substantially in their nutritional composition, particularly regarding added sugar, dietary fiber, and glycemic characteristics[8,9]. Consequently, different categories of refined foods may not exert equivalent metabolic effects[8,9]. These nutritional differences may influence postprandial glycemic responses, insulin demand, and overall metabolic control. Although higher consumption of some refined foods has been associated with adverse metabolic outcomes, the available evidence remains inconsistent across specific food categories[8,10–13].

Despite growing interest in the relationship between diet and insulin resistance, few studies have evaluated specific categories of refined foods in adults with established T2DM[14–16]. Furthermore, most investigations have examined refined carbohydrate-rich foods as a single dietary group or have focused on diabetes incidence rather than markers of insulin resistance among individuals

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with existing disease[11,14–16]. This knowledge gap is particularly relevant in Peru, where added sugar consumption exceeds dietary recommendations and whole-grain intake remains below recommended levels[17], highlighting the need to better understand how different refined food categories relate to metabolic health.

Therefore, this study aimed to evaluate the association between the consumption of added sugars, industrial pastries, and refined cereals and the TyG index among adults with T2DM in Peru.

METHODOLOGY

Study design

A secondary cross-sectional analysis of baseline data collected in 2024 from a quasi-experimental nutritional intervention study originally designed to evaluate the effects of a nutritional education program on diabetes-related knowledge, food consumption, anthropometric, and biochemical outcomes among adults with type 2 diabetes in Peru[18].

Population and sample

The primary study included adults with type 2 diabetes mellitus (T2DM) attending the Non-Communicable Diseases Program at a primary healthcare center in Villa El Salvador, an urban district of Lima, Peru. Participants were 30–59 years of age and had been diagnosed with T2DM during 2023. A non-probability convenience sampling strategy was used to recruit eligible participants. Individuals with diabetes-related complications or other major comorbidities, those receiving insulin therapy or presenting with sensory, psychological, or physical impairments were excluded.

The present secondary analysis included baseline data from 80 participants collected before the nutritional intervention. No additional eligibility criteria or exclusions were applied.

Variables and measures

Outcome variable

The outcome variable was the triglyceride-glucose (TyG) index, calculated using the following formula:

$$\text{TyG index} = ln\left(\frac{fasting\ triglycerides\ [\frac{mg}{dL}] \times fasting\ glucose[\frac{mg}{dL}]}{2}\right)$$

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as originally proposed by Guerrero-Romero et al[5]. Venous blood samples (6 mL) were collected by a trained laboratory professional after a 12-hour overnight fast. Plasma glucose, total cholesterol, HDL-C, LDL-C, and triglyceride concentrations were measured using a colorimetric method with a semi-automated biochemical analyzer (Mindray BA-88A, Mindray, Shenzhen, China).

Exposure variable

The exposure variable was refined food consumption, assessed using a validated Food Groups Frequency Questionnaire (FGFQ) based on a food exchange system. The questionnaire comprises 19 food groups representing approximately 470 individual foods with similar nutritional characteristics within each group. The FGFQ was previously validated against a 7-day weighed food record in healthy adults. Correlation coefficients for estimates of energy and nutrient intakes ranged from 0.33 to 0.62, while intraclass correlation coefficients ranged from 0.16 to 0.61[19].

The questionnaire was self-completed by participants with guidance from trained research personnel. Food groups were reviewed sequentially, and standardized examples of foods belonging to each group were provided to facilitate their identification. These examples were used during administration of the FGFQ in the original intervention study and were not part of the originally published questionnaire. The examples provided for the three food groups analyzed in the present study are detailed in Supplementary Table S1. Participants reported their usual frequency of consumption during the previous year using predefined response categories: never or almost never; 1, 2, or 3 times per month; 1 to 6 times per week; or 1 to ≥6 times per day.

For the present study, refined food consumption was operationalized using three food groups available in the questionnaire: added sugars, industrial pastries, and refined cereals. Added sugars and industrial pastries were classified as no consumption (never or almost never) or any consumption (any reported consumption), as current dietary recommendations encourage minimizing the consumption of foods containing added sugars rather than defining acceptable intake thresholds[20]. Accordingly, this classification was intended to distinguish the absence from the presence of reported consumption rather than to represent a nutritional intake threshold.

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Refined cereal intake was classified as <1 time/day or ≥1 time/day, with the latter category intended to identify habitual daily refined cereal consumption. This cutoff represented an operational definition of consumption frequency rather than a nutritional threshold. This approach is consistent with the use of frequency- and intake-based categorizations in epidemiological studies evaluating refined grain intake and with dietary recommendations favoring whole-grain alternatives[11,20]. For refined cereals, an alternative cutoff of ≥4 times/week was also prespecified to represent habitual consumption without requiring daily intake and to assess the robustness of the findings to the operational definition of consumption frequency. The use of a frequency-based alternative definition was also consistent with categorizations used in previous epidemiological studies of refined grain intake[11].

Covariates

The following variables were considered as covariates based on their potential association with dietary habits and insulin resistance: age (30–51/52–59 years), sex (female/male), educational level (none/primary, secondary, or higher education), diabetes knowledge (<14/≥14 points) assessed using the Diabetes Knowledge Questionnaire (DKQ-24)[21], abdominal obesity (yes/no) defined according to the Adult Treatment Panel III (ATP III) waist circumference cut-offs (≥102 cm for men and ≥88 cm for women)[22], regular physical exercise (yes/no) defined as engaging in physical exercise at least three times per week, and diabetes medication use (yes/no).

Statistical analysis

Statistical analyses were performed using Stata version 17.0 (StataCorp, College Station, TX, USA). Categorical variables are presented as frequencies and percentages, whereas continuous variables are summarized as mean and standard deviation or median and interquartile range, according to their distribution. Baseline characteristics were compared using the chi-square test for categorical variables, the Student's t test for normally distributed continuous variables, and the Mann–Whitney U test for non-normally distributed continuous variables.

Linear regression models were fitted to evaluate the associations between added sugar consumption, industrial pastry consumption, and refined cereal consumption and the triglyceride-glucose (TyG) index. Crude and adjusted regression coefficients (β) with their corresponding 95% confidence intervals (95% CI) were reported. Two adjusted models were

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fitted. Adjusted model 1 included sex, age group (30–51/52–59 years), educational level, diabetes knowledge, abdominal obesity, and regular physical activity as prespecified covariates based on their potential relationships with dietary habits and insulin resistance and informed by adjustment strategies used in previous epidemiological studies evaluating refined grain intake and metabolic outcomes[11]. Adjusted model 2 additionally included diabetes medication use, which may reflect disease severity related to dietary habits while also affecting the metabolic parameters that comprise the TyG index. For refined cereals, a prespecified sensitivity analysis was performed using an alternative cutoff for refined cereal consumption (≥4 times/week) to evaluate the robustness of the findings to the operational definition of consumption frequency.

Normality of residuals was assessed using quantile–quantile (Q–Q) plots and the Shapiro–Wilk test, implemented using the *swilk* command in Stata. Homoscedasticity was evaluated through visual inspection of residual-versus-fitted plots and the Breusch–Pagan test. Multicollinearity was assessed using the variance inflation factor (VIF), with values <5 considered indicative of no relevant multicollinearity. Results of these diagnostic assessments are presented in Supplementary Table S2.

Given the limited sample size and unequal distribution across some exposure categories, bootstrap resampling with 5 000 replications was performed to assess the stability and precision of the exposure estimates. Bias-corrected and accelerated (BCa) 95% confidence intervals were estimated.

Statistical significance was defined as a two-sided p value <0.05.

Ethical considerations

The original study was approved by the Research Ethics Committee of Universidad Privada del Norte (Approval No. 0006-2024/ID-CIEI). Written informed consent was obtained from all participants prior to enrollment. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki[23]. The present study consisted of a secondary analysis of anonymized baseline data from the original study and did not involve additional participant contact or data collection.

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RESULTS

A total of 80 participants were included in the analysis. The mean (SD) age was 50.3 (5.7) years, and 67.5% were female. Overall, 60.0% had completed secondary education, 70.0% reported a family history of diabetes, and 77.5% were receiving diabetes medication. Only 31.3% engaged in regular physical exercise at least three times per week, whereas 53.8% scored <14 points on the DKQ-24. Most participants were overweight (37.5%) or had obesity (47.5%), and 72.5% had abdominal obesity. The median fasting glucose concentration was 127.5 mg/dL (IQR: 100.0–170.5), and the mean (SD) of the TyG index was 9.39 (0.65). Any consumption of added sugars, industrial pastries, and ≥1 time/day consumption of refined cereals was reported by 81.3%, 81.3%, and 45.0% of participants, respectively (Table 1).

Table 1. Sample characteristics of participants (n=80).

Characteristics	n (%)
Age (years), mean (SD)	50.3 (5.7)
Sex	
Female	54 (67.50)
Male	26 (32.50)
Educational level	
Primary	32 (40.00)
Secondary	48 (60.00)
Family history of diabetes	
No	24 (30.00)
Yes	56 (70.00)
Use of diabetes medication	
No	18 (22.50)
Yes	62 (77.50)
Regular physical exercise (≥3 times/week)	
No	55 (68.75)
Yes	25 (31.25)
DM knowledge ¶	
<14 points	43 (53.75)
≥14 points	37 (46.25)
BMI category	
Normal	12 (15.00)
Overweight	30 (37.50)

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Obesity	38 (47.50)
Abdominal obesity	
No	22 (27.50)
Yes	58 (72.50)
Biochemical measurements, median (p25; p75)	
Glucose (mg/dL)	127.5 (100; 170.5)
Total cholesterol (mg/dL)	180 (163; 220)
HDL cholesterol (mg/dL)	53 (44.3; 59.8)
LDL cholesterol (mg/dL)	95 (72; 122.8)
Triglycerides (mg/dL)	185.5 (123.8; 270)
TyG index, mean (SD)	9.39 (0.65)
Added sugar consumption	
No consumption	15 (18.75)
Any consumption	65 (81.25)
Industrial pastry consumption	
No consumption	15 (18.75)
Any consumption	65 (81.25)
Refined cereal consumption	
<1 time/day	44 (55.00)
≥1 time/day	36 (45.00)

SD: Standard deviation. ¶ Diabetes Mellitus knowledge measured with 24-item Diabetes Knowledge Questionnaire (DKQ-24). BMI: Body mass index. TyG index: Triglyceride-glucose index.

Bivariate comparisons of participant characteristics according to added sugar, industrial pastry, and refined cereal consumption showed that median fasting glucose (p = 0.002) and triglyceride (p = 0.002) concentrations were significantly higher among participants with any added sugar consumption than among those with no consumption. For industrial pastry consumption, this difference was observed only for triglyceride concentrations (p = 0.008). Likewise, the mean TyG index was higher among participants with any added sugar (p < 0.001) and industrial pastry consumption (p = 0.003) than among their counterparts with no consumption. No significant differences in the TyG index were observed according to refined cereal consumption (p = 0.060) (Table 2).

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Table 2. Participant characteristics according to added sugar, industrial pastry, and refined cereal consumption.

Characteristics	Added sugar consumption		*p**	Industrial pastry consumption		*p**	Refined cereal consumption		*p**
	No n (%)	Any n (%)		No n (%)	Any n (%)		<1 time/day n (%)	≥1 time/day n (%)	
Age (years), mean (SD)	51.13 (5.49)	50.09 (5.77)	0.527	52.27 (4.25)	49.83 (5.92)	0.137	50.75 (5.43)	49.72 (6.03)	0.425
Sex									
Female	9 (16.67)	45 (83.33)	0.547ª	12 (22.22)	42 (77.78)	0.363ª	31 (57.41)	23 (42.59)	0.533
Male	6 (23.08)	20 (76.92)		3 (11.54)	23 (88.46)		13 (50.00)	13 (50.00)	
Educational level									
Primary	7 (21.88)	25 (78.13)	0.559	6 (18.75)	26 (81.25)	1.00	16 (50.00)	16 (50.00)	0.463
Secondary	8 (16.67)	40 (83.33)		9 (18.75)	39 (81.25)		28 (58.33)	20 (41.67)	
Family history of diabetes									
No	6 (25.00)	18 (75.00)	0.348ª	4 (16.67)	20 (83.33)	1.00ª	13 (54.17)	11 (45.83)	0.922
Yes	9 (16.07)	47 (83.93)		11 (19.64)	45 (80.36)		31 (55.36)	25 (44.64)	
Use of diabetes medication									
No	4 (22.22)	14 (77.78)	0.734ª	3 (16.67)	15 (83.33)	1.00ª	11 (61.11)	7 (38.89)	0.554
Yes	11 (17.74)	51 (82.26)		12 (19.35)	50 (80.65)		33 (53.23)	29 (46.77)	
Regular physical exercise (≥3 times/week)									
No	9 (16.36)	46 (83.64)	0.538	10 (18.18)	45 (81.82)	1.00ª	29 (52.73)	26 (47.27)	0.544
Yes	6 (24.00)	19 (76.00)		5 (20.00)	20 (80.00)		15 (60.00)	10 (40.00)	
DM knowledge ¶									
<14	9 (20.93)	34 (79.07)	0.590	6 (13.95)	37 (86.05)	0.236	25 (58.14)	18 (41.86)	0.543
≥14	6 (16.22)	31 (83.78)		9 (24.32)	28 (75.68)		19 (51.35)	18 (48.65)	

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BMI category									
Normal	4 (33.33)	8 (66.67)	0.324	5 (41.67)	7 (58.33)	0.085	6 (50.00)	6 (50.00)	0.925
Overweight	4 (13.33)	26 (86.67)		4 (13.33)	26 (86.67)		17 (56.67)	13 (43.33)	
Obesity	7 (18.42)	31 (81.58)		6 (15.79)	32 (84.21)		21 (55.26)	17 (44.74)	
Abdominal obesity									
No	4 (18.18)	18 (81.82)	1.00ª	4 (18.18)	18 (81.82)	1.00ª	10 (45.45)	12 (54.55)	0.291
Yes	11 (18.97)	47 (81.03)		11 (18.97)	47 (81.03)		34 (58.62)	24 (41.38)	
Biochemical measurements, median (p25; p75)									
Glucose (mg/dL)	93 (87; 121)	136 (103.5; 177.5)	0.002	102 (90; 147)	128 (100.5; 174)	0.114	122.5 (93.8; 155)	138.5 (100; 185.8)	0.179
Total cholesterol (mg/dL)	176 (152; 193)	180 (169; 224)	0.141	176 (130; 205)	180 (169; 221.5)	0.311	180 (161.5; 203.8)	182.5 (164.3; 221.8)	0.311
HDL cholesterol (mg/dL)	55 (48; 67)	52 (42; 59)	0.183	49 (44; 62)	53 (45.5; 59)	0.707	52 (44.5; 59)	54 (44.3; 60)	0.742
LDL cholesterol (mg/dL)	78 (72; 112)	96 (72; 124.5)	0.323	102 (65; 123)	92 (73; 121.5)	0.958	94.5 (74.5; 127)	95 (66; 120.5)	0.635
Triglycerides (mg/dL)	119 (78; 170)	190 (154.5; 270)	0.002	130 (99; 190)	190 (154.5; 227.5)	0.008	178 (125.3; 254.3)	189.5 (145.5; 277.5)	0.252
TyG index, mean (SD)	8.79 (0.65)	9.53 (0.57)	<0.001	8.95 (0.73)	9.49 (0.59)	0.003	9.27 (0.65)	9.54 (0.63)	0.060

SD: Standard deviation. P25: percentile 25th. P75: percentile 75th. ¶ Diabetes mellitus knowledge measured with 24-item Diabetes Knowledge Questionnaire (DKQ-24). BMI: Body mass index. TyG index: Triglyceride-glucose index. *Analyzed using the Chi-square test. ªAnalyzed with Fisher's exact test. Differences in age and triglyceride-glucose index were analyzed using Student's t test. Differences in biochemical measurements were analyzed using the Mann–Whitney U test.

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In adjusted model 1, any added sugar consumption (β = 0.74, 95% CI: 0.39 to 1.08; p < 0.001) and any industrial pastry consumption (β = 0.52, 95% CI: 0.15 to 0.89; p = 0.007) were associated with a higher TyG index, compared with no consumption. Refined cereal consumption of ≥1 time/day showed a positive coefficient for the TyG index, although this association did not reach statistical significance (β = 0.28, 95% CI: −0.01 to 0.58; p = 0.064). Results were similar after additional adjustment for diabetes medication use (Table 3).

In a prespecified sensitivity analysis using an alternative cutoff for refined cereal consumption (≥4 times/week), the estimated association remained similar in magnitude and direction to the primary analysis (adjusted β = 0.32, 95% CI: 0.02 to 0.62; p = 0.037), with similar results after additional adjustment for diabetes medication use.

Bootstrap estimates and BCa 95% confidence intervals were broadly consistent with the main results (Supplementary Table S3).

Table 3. Crude and adjusted associations between added sugar, industrial pastry, and refined cereal consumption and the triglyceride-glucose (TyG) index

Refined food consumption	Crude model		Adjusted model 1		Adjusted model 2	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
Added sugars						
No consumption	Reference		Reference		Reference	
Any consumption	0.74 (0.41; 1.07)	<0.001	0.74 (0.39; 1.08)	<0.001	0.74 (0.39; 1.09)	<0.001
Industrial pastries						
No consumption	Reference		Reference		Reference	
Any consumption	0.54 (0.19; 0.89)	0.003	0.52 (0.15; 0.89)	0.007	0.52 (0.14; 0.89)	0.007
Refined cereals						
<1 time/day	Reference		Reference		Reference	
≥1 time/day	0.28 (-0.01; 0.56)	0.060	0.28 (-0.01; 0.58)	0.064	0.29 (-0.01; 0.60)	0.056

Adjusted model 1 included sex, age group (30–51/52–59 years), educational level, diabetes knowledge (<14/≥14 points), abdominal obesity, and regular physical exercise (≥3 times/week). Adjusted model 2 additionally included use of diabetes medication. β, regression coefficient; CI, confidence interval.

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DISCUSSION

The present study evaluated the association between refined food consumption and the TyG index among adults with type 2 diabetes mellitus in Peru. After adjustment for potential confounders, any consumption of added sugars and industrial pastries was associated with a higher TyG index. Although the association between refined cereal consumption and the TyG index did not reach statistical significance in the primary analysis, the prespecified sensitivity analysis using an alternative cutoff showed an estimate of similar magnitude and direction. Overall, these findings suggest that specific refined food categories may show different patterns of association with insulin resistance among adults with T2DM.

Our findings are consistent with evidence linking the consumption of added sugars, industrial pastries, and foods rich in refined grains to adverse metabolic outcomes. Among individuals without diabetes, a systematic review and meta-analyses of prospective cohort studies have reported that higher consumption of these foods is associated with an increased risk of developing T2DM[13], although the evidence for refined grain intake has been less consistent, with no overall association observed for total refined grains but positive associations reported for specific foods such as white rice[11]. Among individuals with established T2DM, a systematic review and meta-analysis of randomized controlled trials found that replacing refined grains with whole grains improved postprandial glycemia and insulinemia[15]. Likewise, cross-sectional studies in patients with T2DM have shown that added sugar consumption is associated with poorer glycemic control[16], whereas higher bread intake, but not rice intake alone, was associated with higher fasting blood glucose[14]. Together, these findings support the observed associations between added sugars and industrial pastries and the TyG index while also suggesting that treating refined foods as a homogeneous dietary category may obscure variation in their associations with metabolic outcomes. This interpretation is consistent with previous nutritional epidemiology studies showing that even different presentations of the same food, such as whole fruit and fruit juice, may exhibit distinct associations with metabolic outcomes, highlighting the importance of considering food-specific characteristics rather than broad dietary categories[24].

The comparatively weaker association observed for refined cereal consumption should be interpreted with caution. The sensitivity analysis using an alternative definition for refined cereal

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consumption (≥4 times/week) yielded an estimate of similar magnitude and direction, although with different precision. Differences in the nutritional characteristics of refined grain-based foods, including fiber content, glycemic index, and glycemic load, may partly explain this finding and contribute to the heterogeneous associations reported across studies[8,9]. These observations are consistent with the concept that carbohydrate quality and food matrix, rather than the degree of refinement alone, may be relevant to metabolic outcomes.

These findings suggest that refined food categories may show different patterns of association with the TyG index among adults with T2DM. From a clinical perspective, distinguishing between added sugars, industrial pastries, and refined cereal foods may provide a more informative approach when evaluating dietary factors associated with insulin resistance using the TyG index, a validated surrogate marker of insulin resistance with emerging utility for assessing glycemic control and prognosis in individuals with T2DM[5]. From a public health perspective, these findings are particularly relevant in Peru, where added sugar consumption exceeds recommended levels and whole-grain intake remains below dietary recommendations[17], while important socioeconomic and geographic inequalities persist in access to routine blood glucose testing and other preventive diabetes services, potentially limiting opportunities for timely metabolic evaluation[25]. In this context, identifying dietary factors associated with clinically informative markers such as the TyG index may complement strategies aimed at improving metabolic monitoring, nutritional counseling, and diabetes management, particularly in resource-constrained settings.

This study has several strengths. First, it evaluated distinct categories of refined foods rather than treating them as a homogeneous dietary group. Second, it focused on adults with established T2DM, a population in which the associations between refined food consumption and metabolic outcomes have been less extensively investigated than the risk of developing T2DM. Finally, the TyG index, a surrogate marker of insulin resistance, was derived from objectively measured fasting glucose and triglyceride concentrations, strengthening the assessment of the metabolic outcome.

Nevertheless, several limitations should be acknowledged. First, its cross-sectional design precludes establishing temporal or causal relationships between refined food consumption and

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the TyG index. Reverse causation cannot be excluded, as participants may have modified their dietary habits in response to their diabetes, metabolic status, or dietary counseling. Second, dietary intake was assessed using a food frequency questionnaire and was therefore subject to recall bias and potential exposure misclassification. Although the FGFQ was previously validated for estimating energy and nutrient intake, validation metrics were not reported separately for the food groups examined in this study. Furthermore, consumption was assessed at the food-group rather than individual-food level, which may have introduced additional exposure misclassification. This potential limitation was partly mitigated by providing standardized food examples during questionnaire completion to facilitate consistent identification of foods within each group. In addition, the questionnaire captured consumption frequency but not portion sizes. Accordingly, the exposure categories should be interpreted as operational definitions of consumption frequency rather than nutritional targets or recommended intake thresholds. Furthermore, the dichotomization of consumption frequency precluded the assessment of dose–response relationships, potentially obscuring more complex patterns of association, including nonlinear relationships or threshold effects. Third, although the analyses were adjusted for several relevant sociodemographic, behavioral, and clinical covariates, including regular physical exercise, abdominal obesity, and diabetes medication use, residual confounding from unmeasured or incompletely measured factors cannot be excluded. In particular, information on total energy intake and other dietary factors was unavailable. Fourth, the limited sample size may have reduced the precision of the estimated associations, particularly for exposure categories with fewer participants, resulting in greater uncertainty around some estimates. Although bootstrap resampling was used to assess the variability of the estimates, this approach does not overcome the limited statistical power associated with the small sample size, particularly when evaluating the association between refined cereal consumption and the TyG index. Finally, participants were recruited using a non-probability sampling strategy from a single healthcare center, which may have introduced selection bias and limits the generalizability of the findings to adults with T2DM receiving care in other healthcare settings and to the broader population with T2DM in Peru.

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CONCLUSIONS

This study showed that any consumption of added sugars and industrial pastries was associated with a higher TyG index among adults with T2DM compared with no consumption, whereas a weaker association was observed for refined cereal consumption. These findings suggest that refined food categories may show different patterns of association with the TyG index and support their separate consideration when evaluating dietary factors associated with insulin resistance in this population. Prospective studies are needed to confirm these findings and further clarify their clinical implications.

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AUTHORS' CONTRIBUTIONS

MPPM, MF-F, JR-D, YYGR, and JGV contributed to the conception and design of the study. MPPM, and MF-F conducted the investigation. MPPM, MF-F, JR-D, and YYGR coordinated the study, and drafted the original manuscript. MPPM and MF-F provided resources and supervised the study. JGV developed the methodology, curated and analyzed the data, prepared the visualizations, and contributed to drafting, reviewing, and editing the manuscript. All authors critically reviewed this and previous versions of the manuscript and approved the final version.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY

The data supporting the findings of this study are not publicly available.

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DECLARATION OF ARTIFICIAL INTELLIGENCE USE

The authors declare that no artificial intelligence tools were used in the preparation, writing, or development of this manuscript.

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