

# Longitudinal Association Between Carbohydrate Quality and Impaired Fasting Glucose in Chinese Older Adults: A Case-Control Study

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## Abstract

**Background:** Most studies have focused on carbohydrate quantity in glycemic regulation, while evidence linking carbohydrate quality to impaired fasting glucose (IFG), particularly among community-dwelling older adults in northern China, remains scarce. The carbohydrate quality index (CQI) is an integrated indicator that incorporates dietary fiber, whole-grain proportion, glycemic index (GI), and carbohydrate food sources to evaluate overall carbohydrate quality. This 1:2 individually age- ( $\pm 2$  years) and sex-matched case-control study within the Tianjin Elderly Nutrition and Cognition (TENC) cohort was conducted to examine the association between CQI and incident IFG in older adults in northern China and to provide evidence for carbohydrate-targeted dietary guidance to maintain glycemic health. **Methods:** Participants were recruited from the TENC prospective cohort (Clinical Trial Registration: ChiCTR2000034348), with a baseline population of 5918 adults aged  $\geq 60$  years. After sequential baseline and follow-up exclusions, 149 cases with newly onset IFG were individually matched to 298 normoglycemic controls, forming a final analytical sample of 447 participants. Dietary CQI, calculated from food frequency questionnaire (FFQ) data, served as the exposure, and incident IFG ( $6.1 \text{ mmol/L} \leq \text{fasting blood glucose (FBG)} < 7.0 \text{ mmol/L}$ ) was defined as the study outcome. **Results:** The total sample had a mean age of  $68.15 \pm 4.37$  years, with 49% female participants. Matching covariates (age and sex) were balanced between groups, and no intergroup differences were observed in body mass index (BMI) ( $p > 0.05$ ). Controls exhibited significantly higher CQI scores than cases ( $p = 0.002$ ). Compared with IFG cases, controls consumed more whole grains, fruits, eggs, and dietary fiber, had lower dietary GI levels, and reported less alcohol consumption (all  $p < 0.05$ ). After adjustment for potential confounders, including marital status, BMI, smoking, alcohol consumption, physical activity, and total energy intake, CQI was independently and inversely associated with incident IFG. Relative to participants in the lowest CQI quartile (Q1), those in the highest quartile (Q4) had a 76.3% lower IFG risk (odds ratio (OR) = 0.237, 95% confidence interval (CI): 0.097–0.579). **Conclusion:** Higher CQI is independently associated with the risk of incident IFG among community-dwelling older adults in northern China. Hence, optimizing the quality of dietary carbohydrates may be as a feasible nutritional strategy to mitigate glycemic dysregulation and prevent IFG in older populations.

**Keywords:** carbohydrate quality index; impaired fasting glucose; northern Chinese older adults; case-control study

## 1. Introduction

The International Diabetes Federation (IDF) released the latest Global Diabetes Atlas in April 2025, which reported that the number of adults aged 20–79 with diabetes worldwide reached 589 million in 2024 and is projected to rise to 853 million by 2050 [1]. China bears the heaviest burden, 148 million adults aged 20–79 in China had diabetes in 2024 (ranking first globally), with a projected increase to 168 million by 2050 [2]. Notably, diabetes prevalence is positively associated with age, with the highest rate

observed in adults  $\geq 65$  years. This age-related trend highlights that diabetes prevention in the elderly has become an urgent public health priority.

Diet is a pivotal modifiable lifestyle determinant of diabetes, with suboptimal dietary patterns contributing to 70.3% of global new-onset diabetes cases [3]. As the only macronutrient directly modulating blood glucose and insulin homeostasis, carbohydrates constitute the core nutritional target for the prevention and control of glycemic dysregulation [4]. Dietary interventions have been well doc-

umented to delay the progression of prediabetes to clinical diabetes, alongside reducing cardiovascular adverse events and mortality [5]. Notably, impaired fasting glucose (IFG) represents a distinct prediabetic phenotype with unique metabolic characteristics. Although lifestyle modification serves as the first-line management for IFG (with adjunct metformin therapy for high-risk individuals) [6,7], robust evidence confirming the long-term metabolic benefits of targeted early intervention for IFG remains inadequate [6,8].

Traditional clinical and nutritional guidelines for diabetes management have long focused on restricting total carbohydrate intake as a primary intervention strategy [9,10,11]. However, contemporary nutritional epidemiology has undergone a critical paradigm shift, with accumulating evidence demonstrating that carbohydrate quality, rather than total carbohydrate quantity, is the key driver of glycemic health and diabetes risk [12,13,14]. Specifically, higher intake of high-quality carbohydrates (e.g., dietary fiber and whole grains) was significantly inversely associated with susceptibility to IFG among this population [15,16], whereas low-quality carbohydrate sources (e.g., refined grains, predominantly white rice, and sugar-sweetened beverages) exacerbate disease risk [17,18].

The Carbohydrate Quality Index (CQI), an integrated composite metric for evaluating carbohydrate quality, was originally developed in the Seguimiento Universidad de Navarra (SUN) cohort to explore carbohydrate intake and micronutrient status [19]. It quantifies carbohydrate quality by combining dietary fiber, whole-grain ratio, glycemic index and carbohydrate food sources, offering a holistic assessment of carbohydrate-related diabetes risk [19,20]. Observational studies report inverse associations between elevated CQI and type 2 diabetes risk. A Chinese cohort found high CQI conferred diabetes protection, especially for adults under 60 and those with higher education [21]. The Tehran cohort similarly showed a 29% lower diabetes risk among participants with the highest CQI, while a high-volume, high-quality carbohydrate diet was linked to a 34% risk reduction [22]. Systematic reviews further support favorable correlations between CQI and healthy glucose metabolism and body composition [23]. The European BISCUITS project is conducting mechanistic explorations using multi-omics approaches to elucidate the underlying biological pathways linking dietary carbohydrate quality to the risk of chronic diseases (CORDIS, Grant Agreement No. 101154245). A growing body of evidence from metabolomics and multi-omics studies further supports the exploration of these pathways [23,24,25].

Based on the existing research evidence, the evidence regarding the association between dietary carbohydrate quality and glycemic disturbances in older adults, particularly among northern Chinese populations, remains insufficient and inconclusive. Epidemiological studies focusing on the CQI have reported conflicting findings, and tar-

geted evidence for older adults in northern China is still lacking, which hinders the comprehensive understanding of the nutritional determinants of IFG in this specific elderly population [21,26,27]. Against this research gap, we performed a 1:2 age- ( $\pm 2$  years) and sex-matched case-control study. The primary objective of this study was to systematically examine the relationship between dietary CQI and the risk of incident IFG, and to clarify the predictive value of dietary carbohydrate quality for glycemic metabolic abnormalities in northern Chinese older adults, so as to provide targeted nutritional evidence for the prevention and early intervention of elderly glycemic disorders in northern China.

## 2. Materials and Methods

### 2.1 Study Design and Participant Involvement

This study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for case-control studies.

This study employed a 1:2 individually matched case-control design based on the prospective Tianjin Elderly Nutrition and Cognition (TENC) Cohort (Clinical Trial Registration: ChiCTR2000034348). Established in 2018 in northern China, the TENC Cohort primarily aimed to investigate the associations between nutritional status and cognitive function among community-dwelling older adults aged  $\geq 60$  years. Participants were randomly recruited from two villages and one community in Baodi District, Tianjin City, using a multistage stratified cluster random sampling strategy. Standardized face-to-face interviews and clinical examinations were performed at baseline, and follow-up visits were conducted every 1–2 years intervals after baseline enrollment.

A total of 5918 participants were initially registered in the TENC Cohort. For the present case-control study, participants with the following baseline conditions were excluded prior to follow-up: individuals taking hypoglycemic agents ( $n = 1276$ ), those with baseline hyperglycemia (fasting blood glucose (FBG)  $\geq 7.0$  mmol/L) [28], participants with missing baseline FBG data ( $n = 158$ ), and those with incomplete food frequency questionnaire (FFQ) records ( $n = 1105$ ). After rigorous baseline screening, 1689 eligible participants with normal fasting glucose levels and complete core data were retained for subsequent follow-up analysis. The median follow-up duration from baseline to the last follow-up was 3 years.

During the follow-up period, participants who were lost to follow-up ( $n = 364$ ) or newly diagnosed with diabetes (FBG  $\geq 7.0$  mmol/L,  $n = 467$ ) were further excluded. Among the remaining participants, a total of 278 individuals presented with newly diagnosed IFG ( $6.1$  mmol/L  $\leq$  FBG  $< 7.0$  mmol/L), constituting the overall at-risk case population. A random sample of 149 participants was selected from these IFG patients to serve as the final case group for the case-control analysis.

According to the 1:2 individually matched case-control study design, two control participants with persistent normal fasting glucose levels during follow-up were randomly matched to each case participant. Matching covariates included age ( $\pm 2$  years) and sex. Among the 278 eligible IFG cases, 149 cases were randomly selected using a computer-generated random number sequence to achieve the required sample size while ensuring representativeness. Ultimately, a total of 447 participants (149 cases and 298 matched controls) were included in the final statistical analysis.

To minimize selection bias, both the case group and the control group were selected from the same baseline TENC cohort to ensure comparability of the source populations. Bias was addressed by using a standardized protocol, trained interviewers, and a validated FFQ to collect dietary data, and by adjusting for confounding factors—including marital status, body mass index (BMI), smoking, alcohol consumption, physical activity levels, and total energy intake—in the statistical analysis.

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The study protocol was approved by the institutional ethics committee. All participants provided written informed consent prior to enrollment. For participants with low literacy or illiterate individuals, informed consent was obtained from their legal guardians.

## 2.2 Diagnostic Criteria

In this study, normal fasting glucose was defined as FBG  $< 6.1$  mmol/L. Consistent with the World Health Organization (WHO) diagnostic criteria, IFG was defined as FBG ranging from 6.1 mmol/L to 7.0 mmol/L [28].

## 2.3 Inclusion and Exclusion Criteria

### 2.3.1 Inclusion Criteria

All eligible participants were drawn from the Tianjin Elderly Nutrition and Cognition (TENC) prospective cohort with complete baseline data and sustained follow-up until 2022.

**Case group:** Participants with newly incident IFG ( $6.1 \text{ mmol/L} \leq \text{FBG} < 7.0 \text{ mmol/L}$ ) identified during follow-up;

**Control group:** Participants who maintained persistently normal FBG ( $< 6.1 \text{ mmol/L}$ ) throughout follow-up, matched to cases at a 1:2 ratio by sex, age ( $\pm 2$  years), and baseline enrollment year.

### 2.3.2 Exclusion Criteria

Participants satisfying any of the following conditions were excluded at baseline or during follow-up: baseline use of hypoglycemic agents; baseline hyperglycemia ( $\text{FBG} \geq 7.0 \text{ mmol/L}$ ); missing baseline FBG laboratory measurements; incomplete FFQ data at baseline; loss to follow-up or missing glycemic outcome data at follow-up; new-onset diabetes ( $\text{FBG} \geq 7.0 \text{ mmol/L}$ ) detected during follow-up.

## 2.4 Sample Size Calculation

The following is the formula for calculating the sample size for a 1:r matched case-control study.

$$N = [Z_{1-\alpha/2} \sqrt{\left(1 + \frac{1}{r}\right) \bar{P}(1 - \bar{P})} + Z_{\beta} \sqrt{\frac{P_1(1 - P_1)}{r} + P_0(1 - P_0)}]^2 / (P_1 - P_0)^2$$

among which,  $P_1 = (OR \times P_0) / (1 - P_0 + OR \times P_0)$ ,  $\bar{P} = (P_1 + r P_0) / (1 + r)$ ,  $\alpha = 0.05$ ,  $\beta = 0.1$ ,  $Z_{1-\alpha/2} = 1.96$ ,  $Z_{\beta} = 1.28$ .

Referring to previous relevant cohort and case-control studies [21,29,30], we assumed the exposure prevalence of carbohydrate quality indicators among control participants ( $P_0$ ) to be 0.45 and expected an odds ratio (OR) of 0.50 for the association with incident IFG, and  $\alpha = 0.05$ ,  $\beta = 0.1$  (90% power) and  $r = 2$ . Formal sample size calculation determined that at least 149 cases were needed. Given the predefined 1:2 matching strategy based on age ( $\pm 2$  years) and sex, 298 matched controls were recruited accordingly.

## 2.5 Dietary Assessment

Dietary intake was assessed using a validated 36-semi-quantitative food frequency questionnaire (SQ-FFQ) [31], administered via one-on-one face-to-face interviews by research investigators who had completed standardized professional training to ensure consistency in data collection.

A dietary analysis database (DAD) was constructed using nutrient composition data from successive editions of the China Food Composition Table (2002–2011) [32,33,34], with adjustments made to align with local residents' daily dietary patterns and common cooking practices—this optimization ensured the database's applicability to the study population.

For each food and beverage group, standardized response options were predefined to capture two key variables: (1) consumption frequency (stratified as daily, weekly, or monthly) and (2) average serving size per consumption event. Post-interview, raw data on frequency and serving size were systematically collated and converted to estimates of daily intake (expressed in grams) for each individual food item. These daily intake values were then imported into the DAD, where nutrient matching and calculation were performed to derive the study participants' daily total energy intake and intakes of individual nutrients.

## 2.6 Calculation of CQI and Its Components

The specific components and calculation method of CQI are as follows:

(1) Whole grains as a percentage of total grains = daily intake of whole grains (g) / [daily intake of whole grains (g) + refined grains intake daily (g)];

(2) Dietary GI =  $\sum_{i=1}^n [GI_i * \text{Amount of carbohydrates available in food}_i \text{ (g)}] / \text{Total grams of carbohydrates daily meal (g)}$ ;

(3) Solid carbohydrates as a proportion of total carbohydrates = amount of solid carbohydrates / (amount of solid carbohydrates + amount of liquid carbohydrates);

(4) Amount of liquid carbohydrates = amount of carbohydrates from (sugar-sweetened beverages + alcoholic beverages) (g);

(5) Dietary fiber.

For each of the first three components—dietary fiber intake, whole grains as a proportion of total grains, and solid carbohydrates as a proportion of total carbohydrates—participants were assigned scores from 1 to 5 based on their quintile rankings (Q1–Q5). In contrast, the glycemic index (GI) component was inversely scored, with participants in the highest quintile (Q5) receiving 1 point and those in the lowest quintile (Q1) receiving 5 points. The total CQI score, ranging from 4 to 20, was calculated by summing the scores of these four subscales.

## 2.7 Other Variables

General demographic characteristics included sex, age, education level, employment status, marital status and so on. Dietary habits were assessed using the FFQ. Lifestyle factors encompassed smoking status, alcohol consumption, and physical activity level, with the latter measured using a simplified Chinese version of the International Physical Activity Questionnaire (IPAQ) [35]. Anthropometric and clinical measurements included height, weight, BMI [calculated as weight/height<sup>2</sup> (kg/m<sup>2</sup>)], waist circumference, and blood pressure. Blood biochemistry analyses involved the assessment of fasting blood glucose, which was determined by the glucose oxidase method.

## 2.8 Statistical Methods

All data analyses were conducted using statistical software packages SPSS 24.0 (IBM Corporation, Armonk, NY, USA), Microsoft Visio 2021 (Microsoft Corporation, Redmond, WA, USA), R Studio version 4.3.2 (Posit Software, PBC, Boston, MA, USA), and GraphPad Prism 9.5.0 (GraphPad Software, Boston, MA, USA) for statistical processing and graphical representation. For variables with a normal distribution, pairwise *t*-tests were used for between-group comparisons; for variables with a non-normal distribution, the Wilcoxon signed-rank test was used for between-group comparisons. All results are expressed as mean ± standard deviation (SD). Categorical variables underwent McNemar's tests to compare baseline characteristics and dietary intake between groups. Conditional logistic regression analysis was used to account for matching design. The analysis examined the association between CQI scores and the risk of developing IFG, and calculated the OR and 95% confidence interval (CI). CQI scores as continuous variables and quartiles into regression models

to establish adjusted models examining their relationship with IFG, to explore potential nonlinear patterns and facilitate clinical interpretation. Restricted Cubic Spline (RCS) analysis was employed to evaluate the dose-response association between dietary fiber intake and GI, and the risk of incident IFG. Participants with missing data on key baseline variables (e.g., FFQ records, FBG measurements) were excluded from the analysis. No imputation methods were applied.

## 3. Results

### 3.1 Sociodemographic Characteristics of Participants

This study was conducted based on the TENC cohort with an initial enrollment of 5918 participants. After baseline screening, 1689 individuals with normal fasting glucose and complete baseline data were eligible for longitudinal follow-up. During a median follow-up of 3 years, we excluded 364 participants who were lost to follow-up and 467 participants who progressed to new-onset diabetes. Among the remaining population, 278 individuals developed incident IFG. To ensure rigorous case-control matching, 149 IFG cases were randomly selected and further matched at a 1:2 ratio with 298 healthy controls by age (±2 years) and sex for the final statistical analysis (Fig. 1).

A total of 447 participants were included in the final analysis, comprising 149 cases and 298 controls (Table 1). There were no missing data in this study. The overall mean age was 68.15 ± 4.37 years, and 219 participants (49.0%) were female. Intergroup comparisons showed no statistically significant differences in key sociodemographic and lifestyle characteristics between the case and control groups, including age, sex, BMI, education level, smoking status, drinking prevalence, and physical activity (all *p* > 0.05). However, marital status exhibited a significant intergroup difference, indicating an imbalance in this variable.

During follow-up, the outcome of interest, IFG was confirmed based on fasting blood glucose levels. The mean fasting glucose level in the case group was 6.57 ± 0.27 mmol/L, significantly higher than that in the control group (5.31 ± 0.43 mmol/L; *p* < 0.001).

### 3.2 Dietary Intake Categories of the Case and Control Groups

Dietary intake was assessed using the FFQ, and the comparisons across various food categories between the case and control groups are presented in Table 2. Significant differences were observed in the intake of whole grains, fruits, eggs, alcohol and total energy (all *p* < 0.05). Specifically, the control group had significantly higher consumption of whole grains, fruits, and eggs compared to the case group, alongside lower alcohol consumption. In addition, total energy intake was higher in the control group than in the case group. No statistically significant differences were found in the intake of refined grains, legumes, tubers,

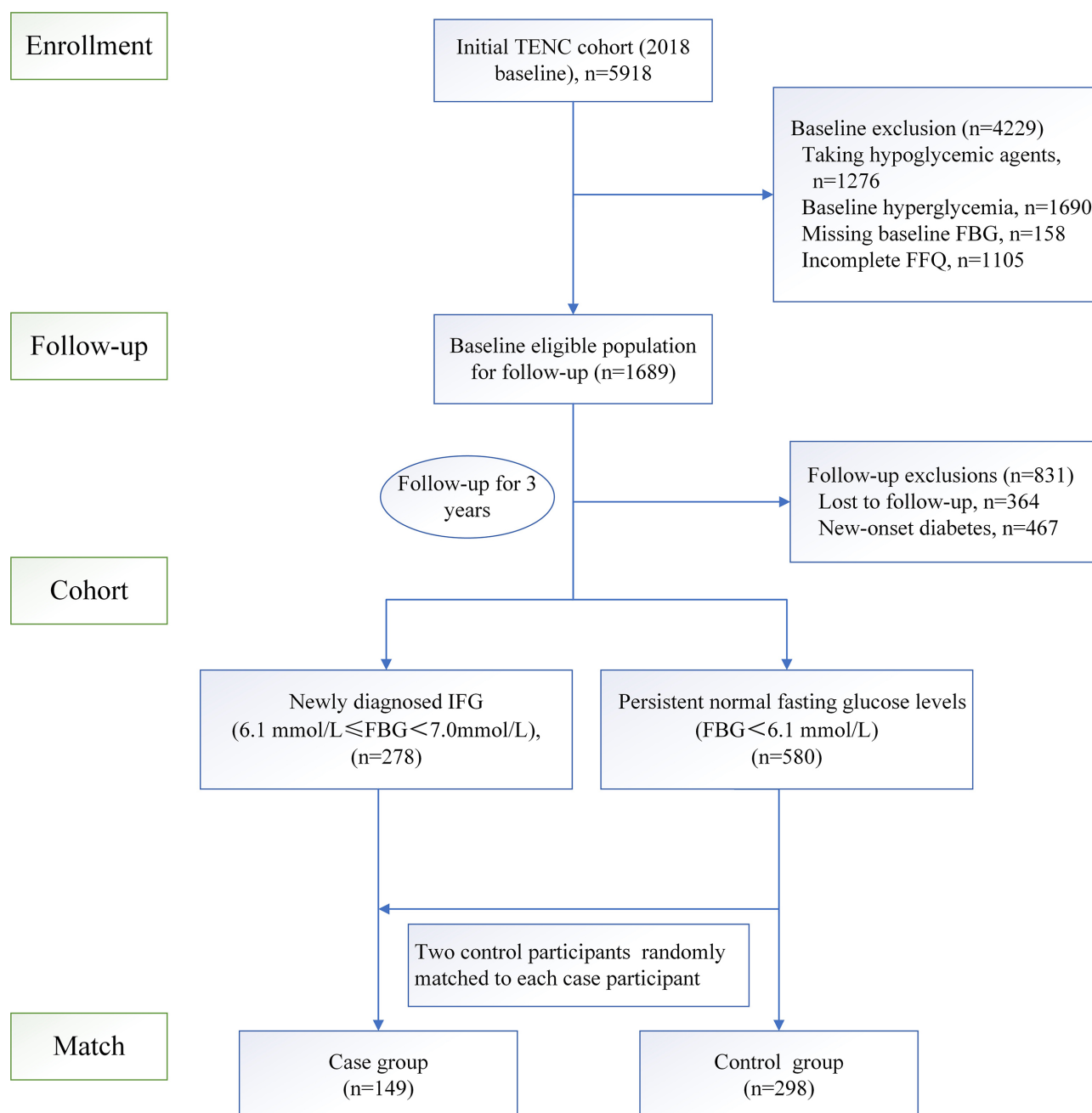


**Fig. 1. Flowchart of study participants.**

vegetables, aquatic products, poultry, livestock meat, animal viscera, dairy products, soybeans and products, nuts, snacks, sugar-sweetened beverages, or added sugar (all  $p > 0.05$ ).

### 3.3 Characteristics of the CQI of the Case and Control Groups

Comparisons of CQI components between groups (Table 3) revealed differences between the case group and the control group. Specifically, the control group exhibited higher dietary fiber intake ( $p = 0.004$ ), higher total CQI value ( $p = 0.002$ ), and lower dietary GI values ( $p < 0.001$ ). However, no statistically significant differences were ob-

served in whole grains as a proportion of total grains ( $p = 0.209$ ), solid carbohydrates as a proportion of total carbohydrates ( $p = 0.198$ ), or energy-adjusted dietary fiber ( $p = 0.197$ ).

### 3.4 Association Between CQI and Its Components With the Risk of Incident IFG

Conditional logistic regression analyses was performed to evaluate the association between CQI and its significant components and the risk of incident IFG (Fig. 2).

First, the CQI score was categorized into quartiles (Q1–Q4), with Q1 (the lowest quartile) serving as the reference. The quartile cut-offs were: Q1:  $\leq 9$ , Q2: 10–12, Q3:

**Table 1. Characteristics of the study participants (N = 447).**

| Characteristics                             | Control group (N = 298) | Case group (N = 149) | <i>p</i> value |
|---------------------------------------------|-------------------------|----------------------|----------------|
| Age <sup>#</sup> (years)                    | 68.14 ± 4.40            | 68.17 ± 4.38         | 0.945          |
| Sex, <i>n</i> (%)                           |                         |                      |                |
| Male                                        | 152 (51.0)              | 76 (51.0)            | 1.000          |
| Female                                      | 146 (49.0)              | 73 (49.0)            |                |
| BMI <sup>#</sup> (kg/m <sup>2</sup> )       | 25.53 ± 3.37            | 25.55 ± 3.06         | 0.951          |
| Education level (years) <i>n</i> (%)        |                         |                      |                |
| Person with low literacy skills             | 43 (14.4)               | 24 (16.1)            | 0.959          |
| Primary or below                            | 116 (38.9)              | 56 (37.6)            |                |
| Junior and Senior High School               | 139 (46.7)              | 69 (46.3)            |                |
| Marital status <i>n</i> (%)                 |                         |                      |                |
| Married/Cohabiting                          | 274 (91.9)              | 127 (85.2)           | 0.028          |
| Living alone                                | 24 (8.1)                | 22 (14.7)            |                |
| Smoking <i>n</i> (%)                        |                         |                      |                |
| None                                        | 174 (58.4)              | 88 (59.1)            | 0.934          |
| Used to smoke                               | 25 (8.4)                | 11 (7.4)             |                |
| Always                                      | 99 (33.2)               | 50 (33.6)            |                |
| Alcohol <i>n</i> (%)                        |                         |                      |                |
| None                                        | 230 (77.2)              | 105 (70.5)           | 0.123          |
| Yes                                         | 68 (22.8)               | 44 (29.5)            |                |
| Physical activities*                        | 1830 (693, 3612)        | 2226 (693, 4053)     | 0.964          |
| Fasting blood glucose (mmol/L) <sup>#</sup> | 5.31 ± 0.43             | 6.57 ± 0.27          | <0.001         |

\*Data for non-normally distributed variables are presented as median (P25, P75); <sup>#</sup>Values are expressed as mean ± standard deviation; BMI, body mass index.

**Table 2. Characteristics of the food type and intake.**

| Characteristics                   | Control group<br>( <i>n</i> = 298) | Case group<br>( <i>n</i> = 149) | <i>p</i> value |
|-----------------------------------|------------------------------------|---------------------------------|----------------|
| Refined grains (g/d)              | 238 ± 76.8                         | 237 ± 77.4                      | 0.879          |
| Whole grain (g/d)                 | 77.3 ± 26.5                        | 71.0 ± 26.1                     | 0.018          |
| Legumes (g/d)                     | 6.52 ± 14.0                        | 6.54 ± 13.7                     | 0.986          |
| Tubers (g/d)                      | 30.4 ± 40.1                        | 27.2 ± 34.7                     | 0.402          |
| Fruits (g/d)                      | 119 ± 90.0                         | 79.3 ± 86.2                     | <0.001         |
| Vegetables (g/d)                  | 248 ± 141                          | 223 ± 146                       | 0.081          |
| Aquatic products (g/d)            | 46.6 ± 53.9                        | 38.4 ± 41.2                     | 0.103          |
| Poultry meat (g/d)                | 11.5 ± 19.4                        | 11.1 ± 20.1                     | 0.841          |
| Livestock meat (g/d)              | 35.5 ± 47.9                        | 43.1 ± 57.4                     | 0.138          |
| Animal viscera* (g/d)             | 2.00 ± 12.3                        | 2.32 ± 10.1                     | 0.771          |
| Egg (g/d)                         | 70.0 ± 53.9                        | 58.5 ± 44.1                     | 0.031          |
| Dairy products (mL/d)             | 50.2 ± 82.4                        | 36.0 ± 68.9                     | 0.072          |
| Soybeans and products (g/d)       | 70.0 ± 72.4                        | 61.5 ± 70.5                     | 0.239          |
| Nuts (g/d)                        | 15.5 ± 23.8                        | 11.5 ± 19.6                     | 0.079          |
| Snacks (g/d)                      | 18.0 ± 40.2                        | 16.4 ± 32.3                     | 0.662          |
| Sugar-sweetened beverages* (mL/d) | 4.15 ± 19.8                        | 2.24 ± 9.56                     | 0.266          |
| Alcohol (g/d)                     | 0.23 ± 0.42                        | 0.30 ± 0.46                     | 0.003          |
| Added sugar* (g/d)                | 2.63 ± 8.95                        | 3.54 ± 11.1                     | 0.352          |
| Total energy (kcal/d)             | 2054 ± 506                         | 1914 ± 503                      | 0.006          |

Note: For ease of readability, non-normally distributed continuous variables were described as mean ± standard deviation.

\* denotes non-normally distributed data.

13–15, and Q4: ≥16. This categorization was chosen to explore potential nonlinear patterns and facilitate clinical

interpretation. In the crude model, higher quartiles (Q2–Q4) were significantly associated with a lower risk of in-

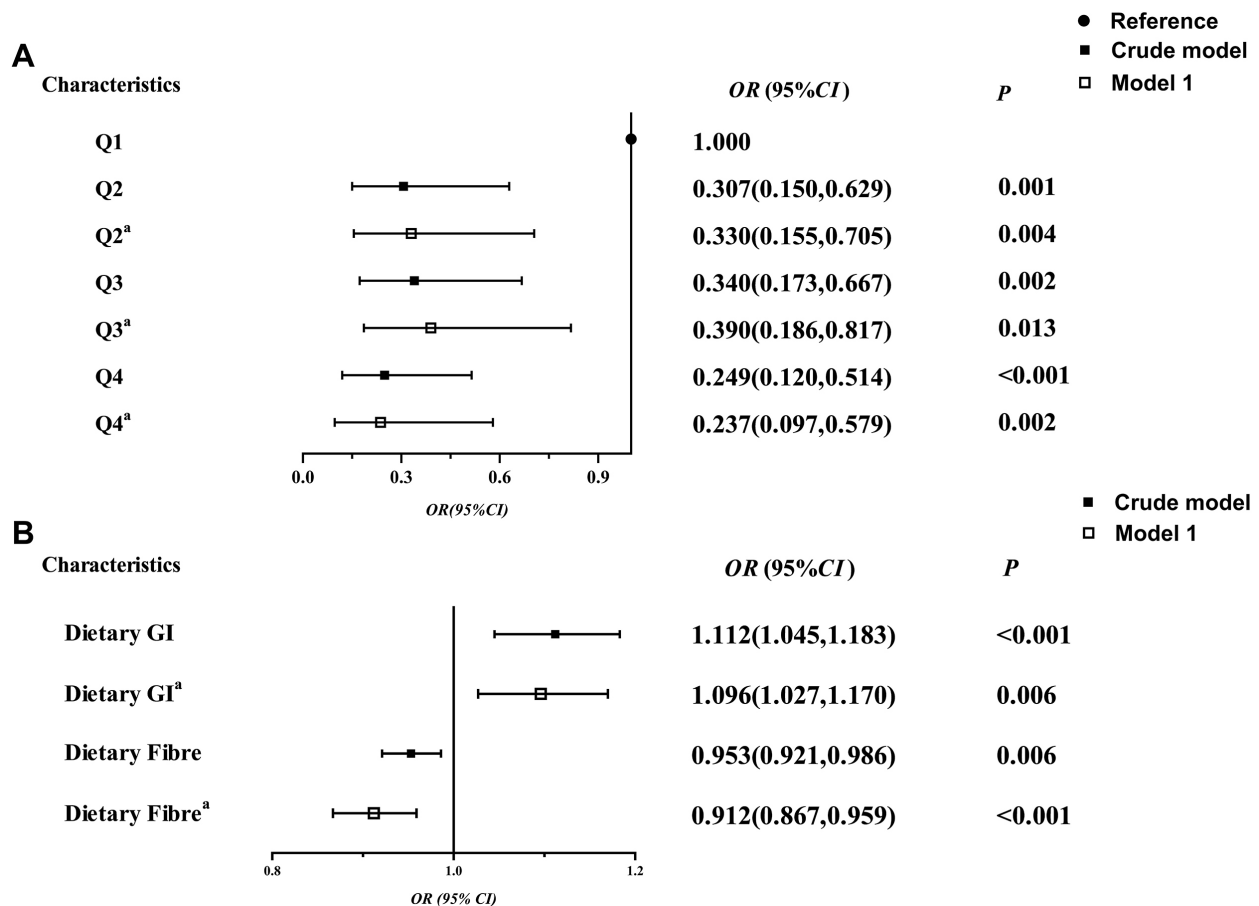


**Fig. 2. Forest plot of odds ratios (ORs) for the association between CQI components, overall CQI score, and incident IFG in crude and adjusted models.** (A) Overall CQI score (quartile 4 vs. quartile 1). (B) Individual CQI components (per SD increase). Each bar represents the estimated OR and 95% confidence interval (95% CI). Results are shown for both crude and adjusted models. Model 1 was adjusted for marital status (married/cohabiting vs. living alone), body mass index (BMI), smoking status, alcohol consumption, physical activity level, and total energy intake (kcal/d). Dietary fiber was energy-adjusted using the residual method and entered into the model as fiber density (g/1000 kcal), while total energy intake was retained as a separate covariate. ORs for continuous variables are presented per standard deviation (SD) increase, unless otherwise specified. The reference category for quartile analyses is the lowest quartile (Q1).

**Table 3. Characteristics of the CQI Grade.**

| Characteristics                                            | Control group<br>(n = 298) | Case group<br>(n = 149) | p value |
|------------------------------------------------------------|----------------------------|-------------------------|---------|
| Total CQI value                                            | 12.201 ± 3.612             | 11.047 ± 3.769          | 0.002   |
| Dietary GI                                                 | 64.986 ± 4.024             | 66.523 ± 4.684          | <0.001  |
| Whole grains as a proportion of total grains               | 0.241 ± 0.159              | 0.221 ± 0.174           | 0.209   |
| Solid carbohydrates as a proportion of total carbohydrates | 0.998 ± 0.009              | 0.999 ± 0.003           | 0.198   |
| Dietary fiber (g/d)                                        | 22.803 ± 7.916             | 20.519 ± 7.809          | 0.004   |
| Energy-adjusted dietary fiber (g/1000 kcal)                | 11.148 ± 2.831             | 10.762 ± 3.245          | 0.197   |

Dietary fiber was energy-adjusted using the residual method and is presented as g/1000 kcal; Values are expressed as mean ± standard deviation.

cident IFG compared with the lowest quartile (Q1), with the most pronounced effect observed in the highest-quality group (Q4: OR = 0.249; 95% CI: 0.120–0.514). After adjusting for marital status, BMI, smoking, alcohol consumption, physical activity levels, and total energy intake (Model

1), the inverse association persisted, albeit slightly attenuated (Q4: OR = 0.237; 95% CI: 0.097–0.579). This suggest that a higher overall CQI score is a significant protective factor against IFG.

Regarding the individual components (Fig. 2), both dietary GI and dietary fiber were significantly associated with IFG risk in the crude model. Specifically, a higher dietary GI was positively associated with increased risk (OR = 1.112; 95% CI: 1.045–1.183;  $p < 0.001$ ), whereas higher dietary fiber intake was inversely associated with risk (OR = 0.953; 95% CI: 0.921–0.986;  $p = 0.006$ ), indicating a protective effect.

In the adjusted model, dietary GI remained positively associated with IFG risk (OR = 1.096; 95% CI: 1.027–1.170;  $p = 0.006$ ). For energy-adjusted dietary fiber density (per g/1000 kcal), the inverse association remained statistically significant (OR = 0.912; 95% CI: 0.867–0.959;  $p < 0.001$ ), indicating that the protective effect of higher dietary fiber density was independent of total energy intake and other lifestyle-related factors.

Taken together, these findings suggest that a higher CQI, a lower dietary GI, and a higher energy-adjusted dietary fiber density are all independently associated with a reduced risk of IFG among community-dwelling older adults, highlighting the significant impact of optimizing carbohydrate quality on glycemic dysregulation.

### 3.5 Dose-Response Relationship

Restricted cubic spline (RCS) analysis was conducted to evaluate the dose-response relationships between dietary fiber intake, dietary GI, and the risk of incident IFG (Fig. 3).

For dietary fiber, a negative association with IFG risk was observed, with the OR curve declining steadily across the intake range. The test for nonlinearity yielded a  $p$  value of 0.055, which is above the conventional significance threshold, indicating that the nonlinear trend was not statistically significant. Therefore, while a strictly linear model cannot be formally rejected, the data indicate a possible curvilinear relationship that warrants cautious interpretation. The OR curve crossed the null value (OR = 1) at an intake of 20.73 g/day, hinting at a potential protective threshold; however, given the marginal significance, this point should be viewed as an exploratory reference rather than a definitive cut-off.

In contrast, dietary GI exhibited a highly significant positive nonlinear association with IFG risk (overall  $p < 0.001$ ; nonlinear  $p = 0.004$ ). The OR curve remained near 1 until a GI value of 66.11, beyond which the risk escalated sharply, demonstrating a clear risk-enhancing threshold effect.

These findings suggest that while dietary GI confers a robust threshold-based risk pattern, the protective effect of dietary fiber may follow a marginally nonlinear dose-response, with potential risk reduction becoming more evident above ~20.73 g/day [36,37,38]. These quantitative reference points provide useful, though provisional, targets for future dietary intervention studies.

## 4. Discussion

This individually matched case-control study within the TENC cohort investigated the association between carbohydrate quality, assessed by the CQI, and the risk of incident IFG among older adults in Northern China. We found that higher CQI scores were significantly and independently associated with a lower risk of IFG. Specifically, the highest quartile of CQI was significantly associated with a lower risk of incident IFG compared with the lowest quartile. Furthermore, the control group exhibited a more favorable dietary pattern characterized by higher consumption of whole grains, fruits, eggs and dietary fiber, alongside a lower dietary GI, compared to the case group.

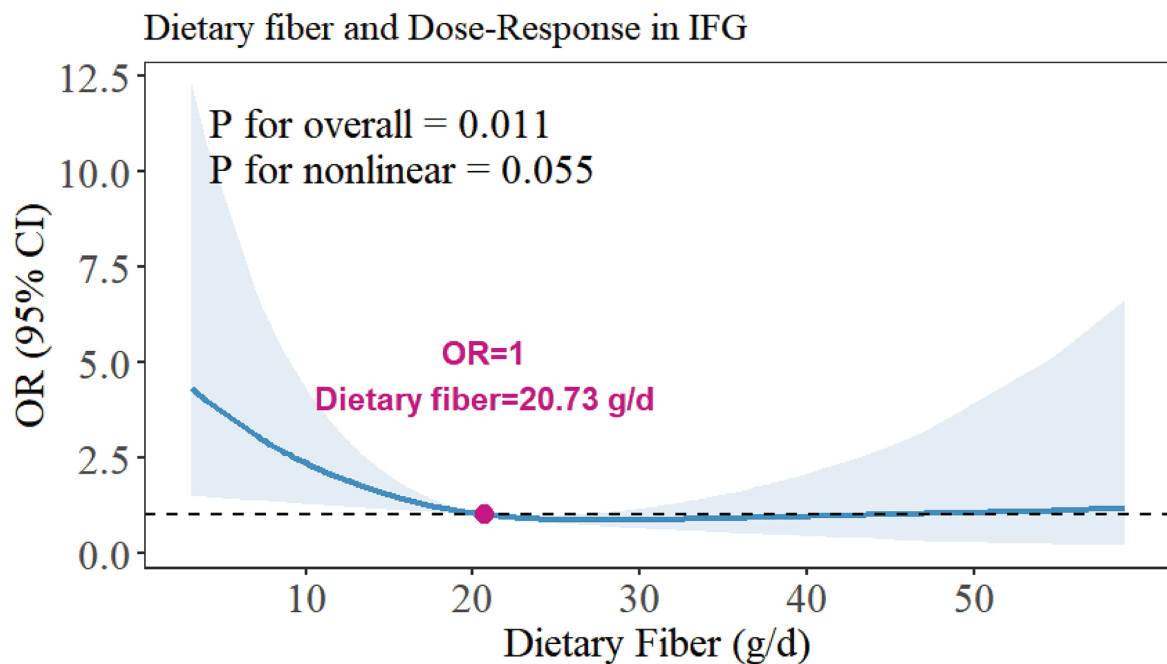
We explored the roles of core CQI components: GI and dietary fiber. High-GI diets are known to induce rapid postprandial glycemic and insulin surges. Chronic exposure to these fluctuations can impair glucose tolerance and promote pancreatic  $\beta$ -cell dysfunction, key precursors to Type 2 Diabetes Mellitus (T2DM) [39,40]. Our finding of a lower dietary GI in the control group supports the protective role of low-GI diets in minimizing metabolic stress.

Conversely, dietary fiber exerts protective effects largely through the gut microbiota. Insufficient fiber intake disrupts the abundance of short-chain fatty acids (SCFAs)-producing bacteria [41]. In line with previous evidence, we posit that the higher fiber intake observed in our control group likely enhanced SCFA synthesis. SCFAs improve glycemic control by strengthening the intestinal barrier (reducing inflammation), stimulating GLP-1 secretion (promoting insulin release), and reducing insulin resistance [42,43]. This “fiber-microbiota-SCFA” axis likely mediates the beneficial associations observed with the CQI.

Interestingly, dietary GI was independently associated with IFG risk in both unadjusted and adjusted models. After adjustment for total energy intake and BMI, the protective association of dietary fiber remained significant with modestly attenuated effect sizes. This attenuation implies that fiber-related benefits may partly operate through shared pathways of energy homeostasis and body-weight regulation in this population [44,45]. The robust inverse association of CQI, a metric heavily weighted toward fiber, further highlights the merit of holistic carbohydrate-quality assessment over single-nutrient analyses. Notably, controls reported higher energy intake than cases despite similar BMI, a paradox that could reflect greater diet-induced thermogenesis from fiber-rich foods and higher physical activity among controls.

Our results align with both regional and international evidence, while also highlighting the importance of dietary context. The protective associations of high fiber and low GI are consistent with studies in Asian populations (China, Japan, Indonesia) [36,46,47,48,49], suggesting these are universal principles of carbohydrate metabolism. However, a notable divergence from Western studies was observed regarding the solid-to-total carbohydrate ratio [20,50], which

A



B

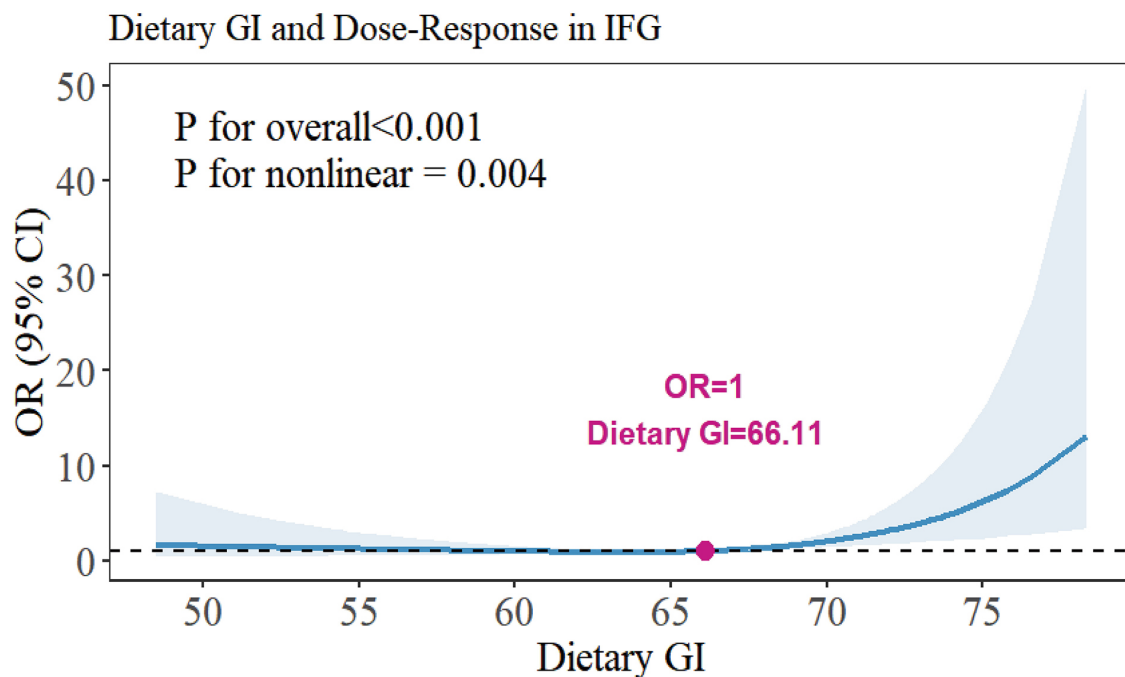


**Fig. 3. Dose-response relationship between dietary fiber intake, dietary GI, and the risk of incident IFG.** (A) Dose-response relationship between dietary fiber and IFG. (B) Dose-response relationship between dietary glycemic index (GI) and IFG. Solid lines represent estimated odds ratios (ORs) for IFG, with shaded areas indicating 95% confidence intervals (95% CIs). Dose-response curves were derived using restricted cubic splines in a multivariate-adjusted conditional logistic regression model (Model 1), which was adjusted for marital status (married/cohabiting vs. living alone), body mass index (BMI, kg/m<sup>2</sup>), smoking status, alcohol consumption, physical activity level, and total energy intake (kcal/d). Dietary fiber was energy-adjusted using the residual method and entered into the model as fiber density (g/1000 kcal). For dietary fiber, the test for nonlinearity was marginally significant (overall  $p = 0.011$ , nonlinear  $p = 0.055$ ), indicating a generally linear protective trend. In contrast, dietary GI showed a highly significant nonlinear association (overall  $p < 0.001$ , nonlinear  $p = 0.004$ ).

showed no significant difference between our case and control groups. We attribute this to the distinct dietary culture of Northern China, where traditional diets are naturally low in liquid carbohydrates (e.g., sugary beverages) [46]. This suggests that while the CQI framework is valid, the relevance of specific components may vary culturally.

The quantitative thresholds identified in this study provide practical guidance for public health recommendations. We observed that the OR curves crossed the null value ( $OR = 1$ ) at a dietary fiber intake of approximately 20.73 g/day and a dietary GI of around 66.11. For dietary fiber, this indicates a protective threshold above which the risk begins to fall below the reference level; for dietary GI, this marks a risk-enhancing threshold beyond which the risk escalates sharply. Thus, these values should be interpreted as reference-crossing points rather than the exact points of minimum or maximum risk. Notably, the optimal fiber intake observed in our study approaches the lower limit of the Acceptable Macronutrient Distribution Range (AMDR) and is slightly below the 25 g/day recommendation for chronic disease prevention in China [51,52]. This suggests that even modest increases in fiber intake, achievable within typical energy requirements, can yield significant metabolic benefits for older adults. Similarly, maintaining a dietary GI below 66–70 aligns with the “low-to-moderate” range advocated by dietary guidelines, offering a concrete target for IFG prevention [53].

Our findings carry explicit clinical and public health implications for the aging population in northern China. Firstly, the identified thresholds—approximately 20.7 g/day of dietary fiber and a dietary GI below 66—offer easily communicable targets for dietitians and geriatricians. For elderly patients with pre-diabetes, a practical strategy could involve replacing half of the refined wheat staples (e.g., white steamed buns) with whole-grain alternatives [52], and ensuring at least two servings of low-GI fruits (e.g., apples and pears) daily. Secondly, given that the protective effect of the total CQI persisted independently of BMI and energy intake, clinicians should prioritize carbohydrate quality evaluation even for non-obese elderly individuals who are often overlooked in routine metabolic management [21,54]. Future pragmatic clinical trials should randomize high-risk elderly populations to a ‘CQI-guided menu’ versus standard care to validate the efficacy and adherence in real-world settings, potentially integrating continuous glucose monitoring (CGM) to capture postprandial excursions that fasting glucose alone might miss [55].

Despite these insights, several limitations warrant consideration. First, this study used a single self-administered FFQ to assess dietary exposure. Due to recall bias and errors in portion estimation, this approach may result in non-differential misclassification of intake, thereby undermining the effect estimates of true associations. Furthermore, the lack of 24-hour dietary recalls or repeated measurements limits the ability to account for

within-individual variability; future studies should combine the use of FFQs with multiple 24-hour dietary recalls to improve the reliability of dietary assessment. Second, the CQI adaptation used a fixed fat value (30 g), which may not capture individual variations in fat intake. Third, the use of fasting glucose alone as the outcome may have missed cases of isolated postprandial hyperglycemia. Thirdly, the CQI was developed in Western populations; its components may not fully capture the nuances of the Northern Chinese diet. Future research should focus on developing and validating a culturally adapted CQI for the Chinese population. Prospective intervention trials randomizing elderly individuals to high-CQI versus conventional diets are needed to establish causality. Furthermore, exploring the interaction between CQI, the gut microbiome, and metabolites like SCFAs could unveil novel mechanisms. Finally, all participants were from Baodi District, Tianjin, a specific region within the North China Plain. The local dietary pattern there, which is dominated by wheat-based foods, differs fundamentally from that of the rice-growing regions in southern China, the pastoral areas in the west, and populations in other countries. Additionally, the study participants were all community-dwelling older adults aged 60 years or older; the metabolic characteristics and dietary habits of this population differ from those of middle-aged and young adults, limiting the generalizability of the findings to other age groups.

## 5. Conclusions

In conclusion, higher carbohydrate quality (higher fiber intake and lower dietary GI) is independently linked to lower incident IFG risk among northern Chinese older adults. Our region-specific evidence supports integrating carbohydrate quality indicators into dietary guidelines for glycemic disease prevention. The CQI is a viable indicator for nutritional education to promote healthy carbohydrate selections in seniors. Clinical dietary interventions targeting carbohydrate quality are promising, yet interventional trials are required to confirm these associations and formulate personalized dietary advice.

## Availability of Data and Materials

All data reported in this paper will also be shared by the corresponding author upon request.

## Author Contributions

WL and CS: Conceptualization, Methodology, Supervision and Writing-Review & Editing. JZ and LZ: Writing-Original Draft, Formal analysis and Data Curation. TW, HY, GH and YW: Investigation. HD: Validation and Analysis. ZL, JY: Software and Analysis. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

## Ethics Approval and Consent to Participate

The ethics approval was obtained by the Ethics Committee of Tianjin Medical University, China (Approval No. TMUhmEC2018013).

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## Conflicts of Interest

The authors declare no conflicts of interest. Guowei Huang is serving as one of the Editorial Board members of this journal. We declare that Guowei Huang had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Torsten Bohn.

## Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used DeepSeek in order to check spelling and grammar. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

## Supplementary Material

Supplementary material associated with this article can be found, in the online version, at <https://doi.org/10.31083/IJVN52938>.

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