Nutrition Journal

RESEARCH

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Consuming spicy food and type 2 diabetes incidence in Southwestern Chinese aged 30–79: a prospective cohort study

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Abstract

Background Capsaicin is the main component of chili peppers and is believed to have antidiabetic effects. However, the association between spicy food consumption and the incidence of diabetes remains unclear.

Methods A cohort of 20,490 Han residents aged 30–79 without diabetes at baseline were followed from enrollment to June 2, 2023. The consumption of spicy food was obtained through face-to-face surveys conducted during the baseline survey from October 2018 to February 2019. The definition of type 2 diabetes onset was based on the ICD-10 code of E11 in the diabetes case reporting system and death system; Additionally, self-reported diagnosis of diabetes by a physician in active follow-ups, or a fasting blood glucose level of ≥ 7 mmol/L or a glycated hemoglobin percentage of ≥ 6.5% found on-site during the resurvey. Both Cox proportional hazard regression and competing risk regression were used to calculate hazard ratios (HRs) and confidence intervals (CIs).

Results During the follow-up period (53.5 ± 3.0 months), 182 individuals (1.1%) were newly diagnosed with T2D with an incidence rate of 246.2 per 100,000 person-years. Cox regression analyses revealed that spicy food consumers had a 34% reduced risk of developing type 2 diabetes (HR: 0.66, 95% CI: 0.48, 0.91) compared to non-consumers. The HRs (95% CIs) for participants consuming spicy food 3–5 days/week, 6–7 days/week, and with weak pungency were 0.45 (95% CI: 0.25, 0.81), 0.69 (0.49, 0.98), and 0.64 (0.46, 0.90), respectively. However, little significant protective effect was observed among those who consumed spicy food for 1–2 days/week, with moderate pungency, or with strong pungency (all $P > 0.05$).

Conclusions Consuming spicy food may lower the risk of developing type 2 diabetes, particularly at a frequency of 3–5 days/week, and with weak pungency. Further multicenter prospective studies or interventional studies are needed to confirm these findings.

Keywords Spicy food, Type 2 diabetes, Cohort study, Epidemiology, China multi-ethnic cohort

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Background

Diabetes mellitus is an escalating global health crisis in the modern era. From 1990 to 2019, the global rate of age-standardized disability-adjusted life-years (DALYs) due to type 2 diabetes (T2D) rose from 628.3 per 100,000 person-years to 801.5 per 100,000 person-years [1]. In China, the estimated prevalence of diabetes increased from 10.9% in 2013 to 12.4% in 2018 [2], accounting for nearly one-quarter of cases worldwide [3], and the economic burden of diabetes is growing faster than that of China's economy [4]. Therefore, finding effective strategies to control diabetes is highly important.

Diet is an essential segment of the lifestyle changes necessary for diabetes prevention and management [5, 6]. Spicy food, characterized by its chili pepper content, is a popular dietary choice in many regions across the globe, due to its unique flavor and abundant nutrients such as capsaicin, carotenoids, vitamins, proteins, potassium, phosphorus, and calcium [7, 8]. Research has found that spicy food has multiple beneficial effects [8, 9], including anti-thrombotic and vasodilatory effects, anti-inflammatory, antioxidant, antimicrobial, anti-tumor, anti-hypertensive, and anti-hyperglycemic effects.

The association between consuming spicy food and diabetes remains inconclusive. To date, no studies have identified a relationship between spicy food and the incidence of diabetes. Zhao et al. [10] reported a negative correlation between spicy food preference and diabetes prevalence, fasting plasma glucose, and postprandial plasma glucose. Other studies also reported a reduced risk of diabetes-related mortality [11], improved insulin resistance [12], and attenuation of postprandial hyperinsulinemia with consuming spicy food [13]. However, some studies have not found a significant association between spicy food and diabetes [14–17]. Regional differences in preferences for spicy food and the distribution of diabetes burden, as well as variations in confounding factors, may contribute to the inconsistent findings.

Therefore, investigating the association between spicy food consumption and diabetes in different regions is highly practical. In this study, we aimed to explore the relationship between spicy food consumption and the incidence of T2D using data from a prospective cohort study of Han Chinese residents in Chongqing.

Methods

Study population

This is an ongoing prospective population-based cohort study conducted in Chongqing Municipality, Southwest China, based on the China Multi-Ethnic Cohort (CMEC) study, which has been described in detail elsewhere [18, 19]. Between September 2018 and February 2019, a total of 23,308 Han Chinese participants aged 30–79 years were recruited to complete an electronic questionnaire with face-to-face interviews (e.g., sociodemographics, diet and lifestyle, medical history), medical examinations (e.g., height, body weight, and blood pressure), and clinical laboratory tests (e.g., blood and urine specimens).

To focus our analysis on individuals at risk of developing diabetes during the follow-up period, we excluded 2,818 participants with a prior diabetes diagnosis before the baseline survey, including those who had been previously diagnosed with diabetes, as well as those with a fasting blood glucose level of ≥7 mmol/L, or a glycated hemoglobin percentage of ≥6.5% at the time of enrollment. Additionally, a total of 855 individuals with incomplete data on spicy food consumption, diabetes, or other relevant covariates were excluded, along with 3041 participants who reported a history of peptic ulcer, gastroenteritis, or cancer, and 22 subjects who were pregnant or lactating. Finally, 16,572 participants were included (Fig. 1). Ethical approvals from the Medical Ethics Committee of Chongqing Center for Disease Control and Prevention (2021(006),2017(001)) and the Sichuan University Medical Ethical Review Board (K2016038) were obtained. Informed consent was obtained from all study participants.

Follow-up and outcomes assessment

The follow-up for T2D was conducted by matching with the diabetes case reporting system and death registry system of Chongqing Municipality, with a resurvey among 10% of the surviving participants in 2020, and with annual telephone follow-ups between 2019 and 2022. The definition of T2D onset was based on the ICD-10 (International Statistical Classification of Diseases and Related Health Problems (10th Revision)) code of E11 [20] in the diabetes case reporting system and death system, with the diagnosis date after the baseline survey date; Additionally, self-reported diagnosis of diabetes by a physician in active follow-ups (10% resurvey and annual telephone follow-ups), or a fasting blood glucose level of ≥7 mmol/L or a glycated hemoglobin percentage of ≥6.5% found on-site during the resurvey. Participants contributed person-months from their enrollment date until the onset of T2D, death (from any cause), loss to follow-up, or the final follow-up assessment date (June 2, 2023, for this current study), whichever came first.

Assessment of spicy food consumption

Spicy food intake refers to the consumption of any "hot" spices when cooking or eating, including fresh or dried chili pepper, chili sauce, chili oil, or other hot spices. Participants were asked about their consumption frequency (never or rarely, only occasionally, 1–2 days/week, 3–5 days/week, or 6–7 days/week) in the past month at baseline. Those individuals who chose the last 3 categories (1–2 days/week, 3–5 days/week, or 6–7 days/week) were

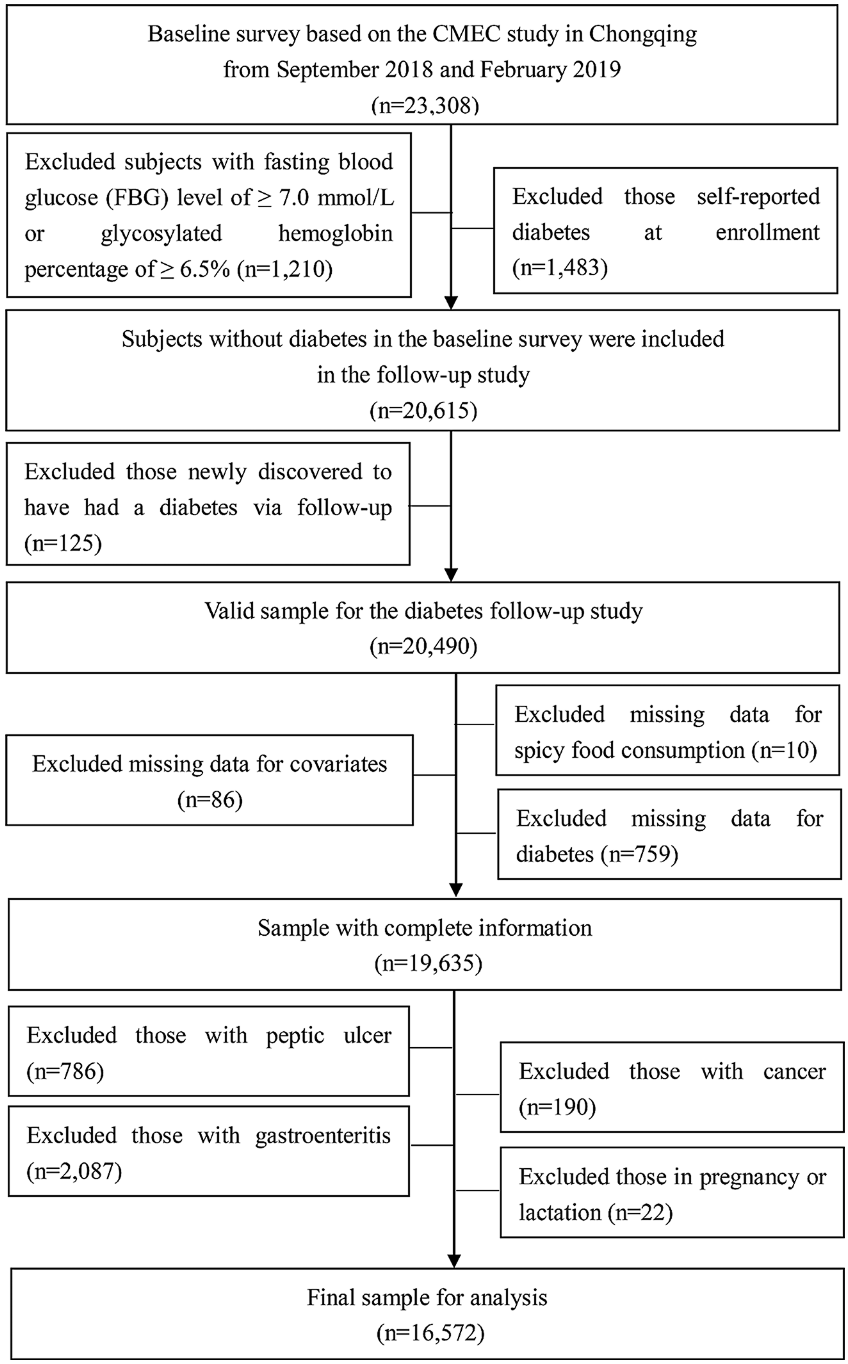

Fig. 1 Data cleaning flowchart

categorized as regular spicy food consumers and non-consumers (never or rarely, only occasionally) served as the reference group in this study. Regular spicy food consumers were further asked "What strength of spicy food do you usually eat?", with three response categories: "weak", "moderate", and "strong". The questions about spicy food consumption mentioned above were based on the China Kadoorie Biobank (a large-scale natural population standard cohort in China). For 3,782 participants who completed the baseline survey in 2018–2019 and the resurvey in 2020 (with an average interval of 21.3±1.2 months), we calculated the Spearman correlation coefficients for the frequency and strength of spicy food consumption, both of which were 0.38.

Assessment of covariates

Sociodemographic covariates included gender (male and female), age (continuous), and education level (primary school and below, middle school, high school, college or university and above). A family history of diabetes was defined as having at least one parent or sibling diagnosed with diabetes. Based on the responses to the question "Do you smoke?" participants were categorized as current nonsmokers (no) or current smokers (yes). Alcohol consumption was calculated as grams of pure alcohol per week, based on the self-reported alcohol type, amount drunk, and frequency, assuming the following alcohol content by volume (v/v) in China: beer 4%, grape wine 12%, rice wine 15%, weak spirits 38% and strong spirits 53% [21]. Harmful drinking was defined as >61 g/day for men and >41 g/day for women [22]. Physical activity was estimated by summing the corresponding metabolic equivalent values (METs) of four domains, namely, leisure, work, transportation, and housework [23]. Sleep duration was defined as the total time spent sleeping each day, including naptime.

The collection of food intake data was achieved through a quantitative food frequency questionnaire (FFQ). Its validity and reproducibility were both assessed by conducting repeated FFQ and 24-hour dietary recalls in a resurvey in 2020 [24]. Each of the seven food groups, including whole grains, fresh fruits, vegetables, beans, red meat products, dairy, and sodium, was assigned a score of 1 to 5 based on the quintile of the average food intake. For whole grains, fresh fruits, vegetables, beans, and dairy, a score of 5 was given for the highest quintile, while a score of 1 was given for the lowest quintile. For red meat products and sodium, this pattern of scoring was inverted. The sum of the seven component scores resulted in an overall DASH score ranging from 7 (minimal adherence) to 35 (maximal adherence) [24].

Hypertension was defined as systolic/diastolic blood pressure (SBP/DBP) ≥ 140/90 mmHg or a history of hypertension diagnosed by doctors [25]. Dyslipidemia was regarded as having any one of the following conditions: triacylglycerol (TG) ≥ 2.26 mmol/l; serum total cholesterol (TC) ≥ 6.22 mmol/l; low-density lipoprotein cholesterol (LDL-C) ≥ 4.14 mmol/l; high-density lipoprotein cholesterol (HDL-C) < 1.04 mmol/l; or a history of hyperlipemia diagnosed by a physician [26]. If participants had hypertension or dyslipidemia, it was defined as "hypertension or dyslipidemia".

Statistical analysis

Continuous variables were expressed as the median [interquartile range, IQR], and statistical significance was assessed by the Wilcoxon rank sum test. Categorical variables were described as numbers (percentages), and statistical significance was assessed by the chi-square test.

To assess the association between spicy food consumption and the incidence of T2D, we employed Cox proportional hazards regression for multivariable analyses. Additionally, we plotted cumulative survival curves after adjusting for potential confounding factors to visualize the survival probabilities over time. Potential confounding factors were selected based on the literature [22] and the distribution characteristics of the data from this study, and they were progressively adjusted in a series of models. Model 1 was the crude model without any adjustments; Model 2 was adjusted for gender (male and female), age (continuous), education level (primary school and below, middle school, high school, college or university and above), and family history of diabetes (no and yes); Model 3 was adjusted for Model 2 plus smoking status (no and yes), harmful drinking (no and yes), total energy intake (continuous), DASH score (continuous), physical activity (continuous), sleep duration (continuous), BMI (continuous), waist circumference (continuous); Model 4 was adjusted for Model 3 plus hypertension or dyslipidemia (no and yes).

In sensitivity analyses, we utilized a competing risk model to analyze the relationship between spicy food consumption and the incidence of T2D. Additionally, after excluding participants who self-reported a weight loss of at least 2.5 kg in the past year at the baseline survey, we conducted the Cox proportional hazards regressions again to assess the impact of weight loss on the study results.

Data analyses were performed using SPSS (Version 25.0. IBM Corp., Armonk, NY, USA) and R Statistic software (version 4.3.0, R Foundation for Statistical Computing, Vienna, Austria). A two-sided p-value < 0.05 was considered to indicate statistical significance.

Results

General characteristics

Of the 16,572 subjects, the median age at baseline was 48.0 (42.0, 58.0) years and 53.5% of them were females. 77% of them consumed spicy food. Among them, 23.4%, 17.1%, and 59.5% of the participants ate spicy food 1–2 days, 3–5 days, and 6–7 days per week, respectively. Those who consumed weak pungency, moderate pungency, or strong pungency accounted for 80.5%, 17.3%, and 2.2%, respectively. Participants who consumed spicy food more frequently were more likely to be male, younger, smokers, harmful drinkers, and to have a family history of diabetes. They also tended to have a higher level of education, a higher DASH score, higher total energy intake, greater physical activity, higher BMI, larger waist circumference, and longer sleep duration. Additionally, they exhibited a lower prevalence of hypertension or dyslipidemia (Table 1, all $P < 0.05$). Among those who regularly ate spicy food more than once per week, those who consume spicy food more often usually prefer it to be spicier ($P < 0.05$).

Table 1 Baseline characteristics of study participants by spicy food consumption

Characteristics	Overall	Frequency of spicy food consumption				
		Non-consumers	1–2 days/week	3–5 days/week	6–7 days/week	*P*
No. participants	16,572(100.0)	3803(22.9)	2994(18.1)	2182(13.2)	7593(45.8)	
Age (years)	48.0 [42.0, 58.0]	51.0 [45.0, 63.0]	47.0 [41.0, 56.0]	47.0 [39.0, 55.0]	48.0 [42.0, 56.0]	< 0.001
Gender (Males)	7701 (46.5)	1705 (44.8)	1225 (40.9)	997 (45.7)	3774 (49.7)	< 0.001
Education level						
Primary school and below	5072(30.6)	1544(40.6)	727(24.3)	450(20.6)	2351(31.0)	< 0.001
Middle school	5408(32.6)	1192(31.3)	996(33.3)	740(33.9)	2480(32.7)	
High school	3135(18.9)	537(14.1)	640(21.4)	469(21.5)	1489(19.6)	
College or university and above	2957(17.8)	530(13.9)	631(21.1)	523(24.0)	1273(16.8)	
Family history of diabetes (Yes)	2236(13.5)	407(10.7)	419(14.0)	343(15.7)	1067(14.1)	< 0.001
Smoking status (Yes)	3380(20.4)	511(13.4)	467(15.6)	438(20.1)	1964(25.9)	< 0.001
Harmful drinking (Yes)	170(1.0)	20(0.5)	17(0.6)	10(0.5)	123(1.6)	< 0.001
Total energy intake (kcal/day)	1646.5 [1316.6, 2055.6]	1535.6 [1195.0, 1919.3]	1582.9 [1268.2, 1977.8]	1655.20 [1341. 8, 2039.9]	1732.7 [1396.7, 2151.8]	< 0.001
DASH score	21.0 [18.0, 24.0]	20.0 [16.0, 24.0]	22.0 [19.0, 25.00]	22.0 [19.0, 25.0]	21.0 [18.0, 24.0]	< 0.001
Physical activity (MET-hours/day)	29.7 [19.2, 40.4]	27.9 [16.4, 39.5]	29.4 [19.0, 39.0]	29.5 [20.0, 39.2]	30.7 [20.4, 41.5]	< 0.001
Sleep duration (hours/day)	8.0 [7.0, 8.5]	8.0 [7.0, 8.5]	8.0 [7.0, 8.5]	8.0 [7.0, 8.5]	8.0 [7.0, 8.5]	0.001
BMI (kg/m^2)	24.3 [22.3, 26.5]	24.2 [22.2, 26.4]	24.0 [22.1, 26.3]	24.3 [22.3, 26.4]	24.5 [22.5, 26.8]	< 0.001
Waist circumference (cm)	82.0 [76.0, 89.0]	81.5 [76.0, 88.0]	81.0 [74.2, 88.0]	82.0 [76.0, 89.0]	83.1 [77.0, 90.0]	< 0.001
Hypertension or dyslipidemia (Yes)	7985(48.2)	1936(50.9)	1308(43.7)	1016(46.6)	3725(49.1)	< 0.001
Strength of consuming spicy food						
Non-consumers	3803(22.9)	3803(100.0)	0(0.0)	0(0.0)	0(0.0)	< 0.001
Weak	10,281(62.0)	0(0.0)	2705(90.3)	1831(83.9)	5745(75.7)	
Moderate	2206(13.3)	0(0.0)	262(8.8)	328(15.0)	1616(21.3)	
Strong	282(1.7)	0(0.0)	27(0.9)	23(1.1)	232(3.1)	

Abbreviations DASH: Dietary Approaches to Stop Hypertension; BMI: body mass index

Continuous variables were expressed as the median [interquartile range, IQR], and statistical significance was assessed by the Wilcoxon rank sum test. Categorical variables were described as numbers (percentages), and statistical significance was assessed by the chi-square test

Association between spicy food consumption and diabetes incidence

The mean follow-up time was 53.5 (3.0) months, and 182 individuals (1.1%) were diagnosed with T2D during the follow-up period, which is equivalent to an incidence rate of 246.2 per 100,000 person-years (Table 2). The incidence density of T2D among participants who consumed spicy food was lower than that among participants who did not eat spicy food (Table 2; Fig. 2). Specifically, the lowest incidence densities were observed among those who consumed spicy food 3–5 days/week and those who consumed food with moderate spiciness, with values of 143.5 (78.4-240.7) and 202.5 (123.7-312.7), respectively (Table 2; Fig. 2).

After adjusting for gender, age, education level, family history of diabetes, smoking status, harmful drinking, total energy intake, DASH score, physical activity, sleep duration, BMI, waist circumference, and hypertension or dyslipidemia, Cox regression analyses revealed that spicy food consumers had a 34% reduced risk of developing T2D (HR: 0.66, 95% CI: 0.48, 0.91) compared to those who did not consume spicy food. Compared with those who did not consume spicy food, the risk of developing diabetes can be reduced by 55% and 31% respectively for individuals who ate spicy food 3–5 days a week (HR: 0.45, 95% CI: 0.25, 0.81) or 6–7 days a week (HR: 0.69, 95% CI: 0.49, 0.98). Regarding the strength of consuming spicy food, individuals who consumed spicy food with weak pungency had a 36% lower risk of developing T2D (HR: 0.64, 95% CI: 0.46, 0.90) compared to non-consumers. Little significant protective effect was observed for those consuming spicy food 1–2 days/week, with moderate pungency, or with strong pungency (all $P>0.05$).

Sensitivity analysis

During the follow-up period, 175 individuals (1.1%) died, and the results of competing risk regression analyses were consistent with those of Cox proportional hazard

Table 2 Association between consuming spicy food and incident type 2 diabetes

Exposures	Number of Events/*N*	Incidence Density (1/100,000 Person-Years)	Model 1		Model 2		Model 3		Model 4	
			HR (95%CI)	*P*	HR (95%CI)	*P*	HR (95%CI)	*P*	HR (95%CI)	*P*
Overall	182/16572	246.2(211.7-284.6)								
Consuming spicy food										
Non-consumers	60/3803	355.8(271.5-457.9)	Ref		Ref		Ref		Ref	
Consumers	122/12769	213.8(177.5-255.2)	0.60(0.44,0.82)	0.001	0.68(0.5,0.94)	0.018	0.66(0.48,0.91)	0.011	0.66(0.48,0.91)	0.011
Frequency of consuming spicy food										
Non-consumers	60/3803	355.8(271.5-457.9)	Ref		Ref		Ref		Ref	
1–2 days/week	30/2994	224.7(151.6-320.8)	0.63(0.41,0.98)	0.040	0.72(0.46,1.13)	0.153	0.71(0.46,1.12)	0.139	0.71(0.46,1.12)	0.141
3–5 days/week	14/2182	143.5(78.4-240.7)	0.40(0.23,0.72)	0.002	0.46(0.26,0.83)	0.010	0.45(0.25,0.81)	0.008	0.45(0.25,0.81)	0.008
6–7 days/week	78/7593	229.7(181.5-286.6)	0.64(0.46,0.90)	0.010	0.73(0.52,1.02)	0.067	0.69(0.49,0.98)	0.040	0.69(0.49,0.98)	0.039
Strength of consuming spicy food										
Non-consumers	60/3803	355.8(271.5-457.9)	Ref		Ref		Ref		Ref	
Weak	95/10281	206.8(167.3-252.8)	0.58(0.42,0.80)	0.001	0.66(0.47,0.92)	0.013	0.64(0.46,0.90)	0.009	0.64(0.46,0.90)	0.009
Moderate	20/2206	202.5(123.7-312.7)	0.57(0.34,0.94)	0.028	0.65(0.39,1.09)	0.101	0.61(0.36,1.03)	0.067	0.61(0.36,1.03)	0.062
Strong	7/282	557.3(224.1-1148.3)	1.56(0.71,3.42)	0.265	1.65(0.75,3.61)	0.213	1.53(0.69,3.39)	0.299	1.50(0.68,3.34)	0.315

Model 1: without adjustment; **Model 2**: adjusted for gender (male and female), age (continuous), education level (primary school and below, middle school, high school, college or university and above), and family history of diabetes (no and yes); **Model 3**: adjusted for Model 2 plus smoking status (no and yes), harmful drinking (no and yes), total energy intake (continuous), DASH score (continuous), physical activity (continuous), sleep duration (continuous), BMI (continuous), waist circumference (continuous); **Model 4**: adjusted for Model 3 plus hypertension or dyslipidemia (no and yes)

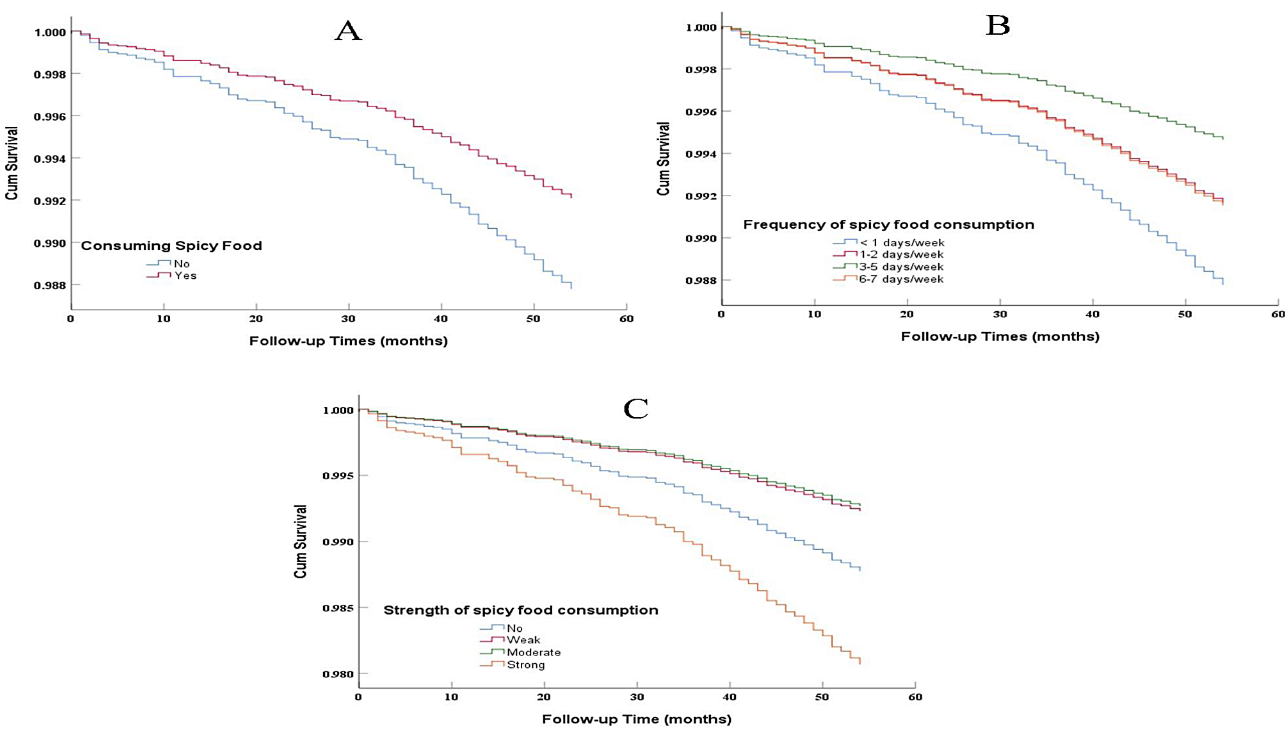

Fig. 2 The cumulative survival rate curves for spicy food consumption, adjusted for various factors including gender, age, education level, family history of diabetes, smoking status, harmful drinking, total energy intake, DASH score, physical activity, sleep duration, BMI, waist circumference, as well as the presence of hypertension or dyslipidemia. **A**: Consuming spicy food (non-consumers and consumers); **B**: Frequency of spicy food consumption (non-consumers, 1–2 days/week, 3–5 days/week, and 6–7 days/week); **C**: Strength of spicy food consumption (non-consumers, weak, moderate, and strong)

regression, with almost identical effect sizes (Table 3). After excluding participants who self-reported a weight loss of at least 2.5 kg in the past year at the baseline survey ($n=1468$), the HRs for T2D incidence associated with spicy food consumption were similar to that before excluding those with weight loss (Table 3). However, possibly due to the reduced sample size, the reduction in diabetes risk associated with consuming spicy food 6–7 days/week was no longer statistically significant (HR: 0.72, 95% CI: 0.50, 1.06)

Table 3 Sensitivity analysis on the relationship between spicy food consumption and the incidence of type 2 diabetes

Exposures	HR (95%CI)[a]	P^a	HR (95%CI)[b]	P^b
Consuming spicy food				
Non-consumers	Ref		Ref	
Consumers	0.66(0.48, 0.91)	0.011	0.70(0.50,1.00)	0.049
Frequency of consuming spicy food				
Non-consumers	Ref		Ref	
1–2 days/week	0.71(0.45, 1.12)	0.150	0.80(0.50,1.28)	0.352
3–5 days/week	0.45(0.25, 0.80)	0.007	0.49(0.26,0.91)	0.025
6–7 days/week	0.69(0.49, 0.98)	0.038	0.72(0.50,1.06)	0.096
Strength of consuming spicy food				
Non-consumers	Ref		Ref	
Weak	0.64(0.46, 0.90)	0.009	0.69(0.48,0.98)	0.041
Moderate	0.61(0.35, 1.04)	0.067	0.66(0.38,1.16)	0.147
Strong	1.51(0.69, 3.32)	0.310	1.61(0.68,3.82)	0.279

[a] Competing risk regression, adjusted for gender (male and female), age (continuous), education level (primary school and below, middle school, high school, college or university and above), family history of diabetes (no and yes), smoking status (no and yes), harmful drinking (no and yes), total energy intake (continuous), DASH score (continuous), physical activity (continuous), sleep duration (continuous), BMI (continuous), waist circumference (continuous), and hypertension or dyslipidemia

[b] Cox proportional hazard regression, excluding subjects with weight loss ($n = 1468$)

Discussion

In this study, approximately 77.0% of participants consumed spicy food, and the incidence rate of T2D was 246.2 per 100,000 person-years. Spicy food consumers were found to have a 34% lower risk of developing diabetes compared to non-consumers, which aligns with findings from previous studies, such as ecological studies [10], cross-sectional studies [12], animal studies [27], in vitro studies [28, 29], and clinical studies [30]. To our knowledge, this is the first prospective cohort study to investigate the beneficial effect of consuming spicy food on T2D incidence. Hui et al. [31] reported that administering capsaicin (the main ingredient in chili peppers) significantly enhanced glucose tolerance and insulin sensitivity by reducing gluconeogenesis and increasing glycogen synthesis in the liver. Additionally, the beneficial effects of capsaicin on glucose metabolism in db/db mice were partially mediated by the "gut microbiota-bile acid-enterohepatic farnesoid X receptor" axis. Another animal study showed that compared to using metformin alone, metformin combined with capsaicin can exert hypoglycemic and anti-inflammatory effects by modulating the abundance of microorganisms, such as Akkermansia, to alter the gut microbiota profile [32]. In a placebo-controlled, blinded, crossover experiment, a group of eight young adult males with an average age of 22 years were given a high carbohydrate meal (90 g glucose) after fasting overnight, which increased their blood glucose levels from a fasting baseline of 4.4 mg/L to 8.5 mmol/L after 45 min [33]. With capsicum supplementation, blood glucose levels returned to the normal range within 15 min, whereas it took 120 min for the blood glucose levels to normalize in the placebo group. An in vitro study revealed that capsaicin can elevate the level of Sirtuin 1 through the "transient receptor potential vanilloid subtype 1 (TRPV1)/[Ca(2+)]i/Calcium-dependent Protein Kinase II/Adenosine Monophosphate-activated Protein Kinase" pathway, inhibiting the aging of endothelial cells mediated by intermittent high glucose [34]. A critical review evaluated the available experimental and clinical evidence and concluded that the decreased mortality risk associated with CVD may be attributed to the beneficial impact of digested capsaicin on the gut microbiota. However, dietary capsaicin has no clear effect on blood glucose or lipid profiles [35]. Another meta-analysis of controlled trials showed that capsaicin supplementation seems to have no beneficial or detrimental effects on blood glucose or insulin levels [36]. Two reasons may be responsible for the inconsistent results: Firstly, the heterogeneity among different studies is large, including differences in race, ethnicity, region, health status, lifestyle, exposure dosage, exposure duration, and exposure form, all of which are closely related to the research results. Therefore, it is reasonable that the results of different studies vary. Secondly, the sample size of most clinical controlled trials is too small, which may result in insufficient study power to detect the expected positive results. In summary, further in-depth research, such as stratified analysis or multicenter analysis, is needed to understand the relationship between spicy food and diabetes, and our study results can provide some clues

Spicy food may exert an antidiabetic effect via several mechanisms including activating TRPV1 and through the non-TRPV1 pathway. Capsaicin, the main component of spicy food, can act as an exogenous agonist of TRPV1. Firstly, activation of TRPV1 promotes cation influx, which may directly regulate glucose homeostasis, increase glucagon-like peptide-1 (GLP1) secretion and insulin secretion, improve insulin resistance, and reduce serum glucose level via upregulation of the peroxisome proliferator-activated receptor-γ (*PPARγ*), PPARγ-coactivator-1α (*PGC-1α*), uncoupling protein-1 (*UCP1*) and mucin-2 (*Muc2*) genes [9, 35]. Secondly, spicy food could exert antihyperglycemic effects by inhibiting the activities of α-amylase and α-glucosidase enzymes, which can hydrolyze polysaccharides into glucose [8, 37]. Thirdly, spicy food may exert anti-glycemic and anti-inflammatory effects by modulating the gut microbiota [9, 38]. Research has shown that the use of capsaicin reduces the abundance of *Faecalibaculum* and *Marvinbryantia* while increasing the abundance of *Turicibacter*, *Odoribacter*, and *Ileibacterium* in feces [39]. Additionally, it reduces the abundance of deoxycholic acid, cholic acid, xanthine, and cholesterol in the cecal contents [39]. Moreover, spicy food could indirectly exert an antidiabetic effect by increasing satiety and energy expenditure and decreasing fat accumulation, serum lipid levels, and other bioactive properties, such as anti-inflammatory activity, anti-inflammatory activity, and antihypertensive activity [8, 39–41]

In addition, we found that the protective effect of spicy food on T2D is related to the frequency and strength of spicy food consumption. Participants who consumed spicy food for 3–5 days/week had the lowest incidence density of T2D (HR:0.45, 95% CI: 0.25, 0.81], followed by those who consumed food with weak spiciness (HR:0.64, 95% CI: 0.46, 0.90). Eating spicy food for 1–2 days/week, having moderate or strong pungency found no significant protective effect, which may be attributed to insufficient follow-up time and an inadequate number of T2D patients. These findings suggest that there may be a dose-response relationship between spicy food consumption and T2D risk. Li et al. [9] found that eating spicy food ≥ 1 day/week was associated with a reduced risk for cardiovascular events among individuals with diabetes but there was no significant difference in risk reduction with different frequencies of spicy food consumption. In our previous study [42], we found that eating spicy food for 3–5 days/week or with strong pungency had a higher beneficial effect on improving systolic blood pressure. Further research is needed to determine the optimal frequency and strength of spiciness for diabetes control and prevention

The strengths of this study include that it is the first large-scale prospective cohort study to explore the beneficial effects of spicy food on T2D incidence. In sensitivity analyses, the comparison of the results from the Cox proportional hazards regression excluding the subjects with weight loss, as well as the competing risk regression for death, indicates that the findings of this study are reliable. Thirdly, this study not only investigated the relationship between spicy food consumption and T2D but also examined the frequency and strength of spicy food intake

However, the present study has certain limitations. Firstly, the data on spicy food consumption were self-reported, and the pungency assessment was subjective, which may introduce recall bias and measurement error. Secondly, our study was conducted in a specific population who eat spicy food relatively often, and therefore, the findings may not be generalizable to other populations with different dietary habits and lifestyles. Additionally, due to the short follow-up period, the number of T2D patients may be insufficient, which could prevent the detection of the effects of consuming spicy foods 1–2 days/week, as well as moderate and strong pungency, and also preclude subgroup analysis. Furthermore, although we adjusted for various confounding factors in our regression analyses, residual confounding cannot be completely ruled out due to the observational nature of our study

Conclusions

In conclusion, our study suggested that consuming spicy food may lower the risk of developing T2D, particularly at a frequency of 3–5 days/week, and with weak pungency. Our findings provide evidence that consuming spicy food might be a potential choice for preventing and managing diabetes. However, further multicenter prospective studies or interventional studies are needed to confirm these findings and investigate dose-response relationships

Abbreviations

T2D	Type 2 diabetes
ICD-10	International Statistical Classification of Diseases and Related Health Problems (10th Revision)
HR	Hazard ratio
CI	Confidence interval
CMEC	China Multi-Ethnic Cohort
MET	Metabolic equivalent value
DASH	Dietary Approaches to Stop Hypertension
BMI	Body mass index
FFQ	Food frequency questionnaire
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
TG	Triacylglycerol
TC	Total cholesterol
LDL-C	Low-density lipoprotein cholesterol
HDL-C	High-density lipoprotein cholesterol
IQR	Interquartile range
TRPV1	Transient receptor potential vanilloid subtype 1

Acknowledgements

We are very grateful to all the participants in this study and all team members for their support of this study.

Author contributions

WT, XD, and JW designed the research. LC, WT, and XD conducted research. LC, XW, RZ, and YC analyzed data and wrote the draft manuscript. XD and JW had primary responsibility for the final content. All authors read and approved the final manuscript.

Funding

This research was funded by the Science-Health Joint Medical Scientific Research Project of Chongqing (grant number: 2024MSXM116), the Medical Scientific Research Project of Chongqing Health Commission (grant number: 2022WSJK021), and the National Key R&D Program of China (grant number: 2017YFC0907303).

Data availability

Data as well as analytical codes supporting the conclusions of this article will be made available by the authors, upon request.

Declarations

Ethics approval and consent to participate

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Medical Ethics Committee of Chongqing Center for Disease Control and Prevention (2021(006),2017(001)) and the Sichuan University Medical Ethical Review Board (K2016038). Written informed consent was obtained from all participants prior to entering the study.

Consent for publication

Not applicable.

Competing interests
The authors declare no competing interests.

Received: 19 March 2024 / Accepted: 8 August 2024
Published online: 11 November 2024

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