The longitudinal associations between sweet potato intake and the risk of non-alcoholic fatty liver disease: the TCLSIH cohort study

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ABSTRACT
This study aimed to evaluate the longitudinal association between sweet potato intake and risk of NAFLD in the general adult population. In total, the number of 15,787 participants (males, 42.4%) was included in this prospective cohort study. Sweet potato intake was assessed by using a validated food frequency questionnaire. NAFLD was diagnosed by transabdominal sonography during an annual health examination. Cox proportional hazards regression models were fitted to assess the hazard ratios (HRs) and 95% confidence intervals (CIs) across categories of energy-adjusted sweet potato intake. Compared to participants with the lowest tertile of sweet potato intake, the finally adjusted HRs (95% CIs) of incident NAFLD for those with the highest tertile were 0.87 (0.78, 0.97) in males (p for trend = 0.009); and 1.05 (0.92, 1.21) in females (p for trend = 0.52). Our study revealed that sweet potato intake was inversely associated with the risk of NAFLD in males.

Introduction
Non-alcoholic fatty liver disease (NAFLD) is a pathologic condition characterised by excessive fat accumulation in the hepatocytes, in the absence of significant alcohol consumption, and other reasons for secondary hepatic fat accumulation, including usage of medicine and parenteral nutrition (Chalasani et al. 2018). It encompasses a spectrum of chronic liver disease, ranging from simple fatty liver to non-alcoholic steatohepatitis (NASH), liver fibrosis, cirrhosis, and even hepatocellular carcinoma (Younossi 2019), and is strongly associated with metabolic diseases, including obesity and diabetes (Bellentani et al. 2010). The prevalence of NAFLD has been rising rapidly in the past few years, with an estimated approximately 25% of the global population suffering from NAFLD (McKay et al. 2018; Younossi et al. 2019). Recently, a meta-analysis reported that 29.2% of the Chinese adult population is suffering from NAFLD (Zhou et al. 2019). Thus, the prevention of NAFLD is necessary for public health. In the absence of approved therapies for NAFLD, life modifications, especially dietary regimen, has been a main clinical recommendation for the management and improvement of NAFLD (Mundi et al. 2020).

Sweet potato is an extremely versatile and delicious vegetable (Wang et al. 2016). Originated in Central America, it is now widely cultivated and consumed in more than 100 countries (Bach et al. 2021). The storage roots are usually the most common edible part of sweet potato. They are a valuable source of carbohydrates, dietary fibre, vitamins (C and E), and...
phytochemicals, including flavonoids, phenolic acids, and carotenoids; however, contain no cholesterol and saturated fat (Kurata et al. 2019; Mariano et al. 2019). Compare to ordinary potatoes, the sweet potato has a better nutritional composition with a lower glycemic index, a higher proportion of complex carbohydrates, more vitamin C and dietary fibre, and has been regarded as part of traditional medicine in many Asican countries (Ozaki et al. 2010; Mohanraj and Sivasankar 2014).

The sweet potato contains resistance starch (Senanayake et al. 2013), the consumption of which may prevent NAFLD by improving insulin resistance and reducing the accumulation of adipose tissue (Harazaki et al. 2014; Bindels et al. 2015). In addition, sweet potatoes have a high content of bioactive compounds, including dietary fibre, anthocyanin, phenolic acids, carotenoid, and water-soluble polysaccharides (Mariano et al. 2019), all of which have shown protective effects against NAFLD (Naowaboot et al. 2016; Sun et al. 2018; Christensen et al. 2019; Perez-Montes de Oca et al. 2020; Salomone et al. 2020; Zhu et al. 2022). Many studies have demonstrated that sweet potato consumption is associated with a lower risk of metabolic diseases, including diabetes and obesity (Ludvik et al. 2003; 2008; Shih et al. 2019), both of which play an important role in the pathogenesis of NAFLD (Bellentani et al. 2010). Notably, NAFLD has been commonly considered as the hepatic manifestation of metabolic diseases. Therefore, we hypothesised that sweet potato consumption might have protective effects on the onset and development of NAFLD.

To date, no studies were found to focus on the association between sweet potato intake and NAFLD. Therefore, we designed this large-scale prospective study to evaluate the association between sweet potato intake and risk of NAFLD among the general adult population.

**Material and methods**

**Study participants**

All participants were recruited from the Tianjin Chronic Low-grade Systemic Inflammation and Health (TCLSIH) Cohort Study, which is a large-scale population-based prospective dynamic study focussing on the relationships between the health status of a population living in Tianjin, China. The city is located in northern China, with a 15 million resident population. Briefly, the TCLSIH started on January 1, 2007. Participants were randomly recruited when they had their annual health examination in centres for health management and community centres. More details of this cohort study were described previously (Gu et al. 2017).

In this study, all participants received at least twice health examinations. And they were instructed to fill out a structured and self-reported questionnaire for health status, which consisted of a validated food frequency questionnaire (FFQ) and diverse information on lifestyles and socioeconomic characteristics since May 2013. All participants have been living in Tianjin for at least 5 years. And they were all adults aged from 18 years old to older. The present study almost covered all occupations. Besides, we also recruited retired individuals who lived in residential communities. As a result, the sample of this study was convincing enough to be representative of the general adult populations living in Tianjin. We then followed up on eligible participants from the data they finished the FFQ to December 2019. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Institutional Review Board of Tianjin Medical University (number: TMUhMEC 201430). And all participants gave written informed consent prior to participate in the study. This study was registered at UMIN Clinical Trials Registry as UMIN000027174.

From May 2013 to December 2019, the total number of 37,291 participants who underwent an abdominal ultrasound and finished the FFQ were included in our study. We exclude the people diagnosed with NAFLD at baseline (n = 7,489), first enrolled in this cohort in 2019 (n = 6,351), or had missing data on dietary consumption (n = 1,853). In addition, participants who had a history of cancer (n = 226), cardiovascular disease (n = 1,419), other liver disease (n = 185), or excessive alcohol consumption (n = 1,195) were also excluded. Furthermore, participants were excluded if lost in following up (n = 2,786, retention rate: 85.0%). Finally, the number of 15,787 participants were brought into the assessment. A flowchart is presented in Figure 1.

**The diagnosis of NAFLD and other liver diseases**

Abdominal ultrasonography was used to detect liver steatosis when participants undertook their annual health examinations, which was performed by a trained and experienced sonographer on TOSHIBA SSA-660A 87 ultrasound machine (Toshiba, Tokyo,
Diagnosis of NAFLD requires at least two of the following abnormal findings: increased liver echo texture compared with the kidneys, brightness of liver, and a diffusely echogenic change in the liver parenchyma, and hepatauxe and vascular blurring (Farrell et al. 2007; Koplay et al. 2015). Participants who had fatty liver were diagnosed with NAFLD after excluding those who had a history of chronic hepatitis B or C, long-term use of steatogenic medication, significant alcohol consumption (> 210 g/week and > 140 g/week in men and women respectively). The diagnosis of other liver diseases was acquired via the self-reported history of illness and the results of their health examination.

Dietary assessment

Dietary intake was assessed via a food frequency questionnaire (FFQ) with specified serving sizes described as natural portions or standard weight and volume measures of the servings commonly consumed. The FFQ consisted of 100 items (the initial version of FFQ comprised 81 food items), which were categorised into 7 frequencies varying from “never eat” to “two or more times/day” for foods and 8 frequencies ranging from “never drink” to “four or more cups/day” for beverages. Participants were asked to choose the average consumption frequency of each food and beverage during the previous month. The mean daily intake of nutrients and energy was calculated by an ad hoc computer program. The database of nutrients and

Figure 1. Flow diagram showing the selection of the study population.

Participants who provided informed content (n = 37,291)

- Participants who had NAFLD at baseline were excluded (n = 7,498)
- Participants who were firstly enrolled into this cohort in 2019 (n = 6,351)
- Participants who had missing data on dietary consumption were excluded (n = 1,853)
- Participants with a history of cancer were excluded (n = 226)
- Participants with a history of CVD were excluded (n = 1,419)
- Participants with other liver diseases were excluded (n = 185)
- Participants who had excessive alcohol consumption were excluded (n = 1,195)

Follow-up participants (n = 18,573)

- Participants who did not undergo health examinations during follow-up were excluded (n = 2,786, retention rate: 85.0%)

Participants included in the final follow-up analysis (n = 15,787)
energy in foods was based on the Chinese Food Consumption Tables (Yang 2009). Sweet potato consumption was collected by the question: ‘how often do you eat sweet potato?’. Participants were asked to select from one of the seven frequencies: never eat, 1 time/week, 2–3 times/week, 4–6 times/week, 1 time/day, and ≥ 2 times/day. Intake of food items (g/day), including sweet potato, was calculated by multiplying the portion size (g/time) by the frequency of each food item consumed per day. To correct for potential measurement error, total sweet potato consumption was adjusted for total energy intake according to the nutrient density method and expressed as (g/ (1000 kcal ∙ d)) (Willett et al. 1997). For further analysis, we categorised the energy-adjusted sweet potato intake into tertiles (medians [g/(1000 kcal ∙ d)]: the lowest tertile: 0.00, the middle tertile: 7.31, the highest tertile: 20.2).

To assess the overall diet quality, factor analysis was used to generate major dietary patterns and factor loadings for each food item (gram). To enhance interpretability, varimax rotation was used. Three factors were set via combining criteria of the eigenvalue, the interpretability, and the scree plot test. Food with factor loading ≥ 0.30 is the main factor that affects the dietary patterns and represents the characteristics of each pattern. Factors were named descriptively according to the food items showing high loading (absolute value) concerning each dietary pattern as follows: “Sweets pattern,” “Healthy pattern,” and “Animal foods pattern” (Zhang et al. 2019).

The validity and reproducibility of the FFQ were assessed by 4-day weighed diet records (WDRs) performed on 150 participants and more details were described previously (Xia et al. 2019). In brief, Spearman correlation coefficients between the weighted diet records and FFQ were 0.49 for total energy and 0.35–0.54 for nutrients (n-3 fatty acid, fat, and carbohydrate). Spearman’s rank correlation coefficients between the two FFQs were 0.68 for total energy and 0.62–0.79 for the food group (fruits, vegetables, and beverages).

**Assessment of other variables**

All participants in this study had taken a series of physical examinations, which consisted of both physical measurements and physiochemical tests. The anthropometric variables (height, body weight, and waist) were measured with a standard protocol. Body mass index (BMI) was calculated as weight in kilograms (kg) divided by height in squared metres (m²). Venous blood samples for analysis were collected in vacuum plastic tubes. Total cholesterol (TC) and triglycerides (TG) were measured via an enzymatic method, low-density lipoprotein (LDL) cholesterol was measured by the polystyrene sulphate acid precipitation method, high-density lipoprotein cholesterol (HDL-C) was measured by the chemical precipitation method using appropriate kits on a Cobas 8000 analyser, and alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were measured by International Federation of Clinical Chemists (IFCC) method using reagents from Roche Diagnostics on an automatic biochemistry analyser. Blood pressure (BP) was assessed at least twice by using the TM-2655 oscillometric device (A&D, Tokyo, Japan) after a 5-minute break in a seated position. The average of two recordings was determined as the BP value. Hypertension was defined as diastolic BP (DBP) ≥ 90 mmHg and/or systolic BP (SBP) ≥ 140 mmHg or having a self-reported history of hypertension.

Information on sociodemographic and lifestyles was also collected by the health questionnaire, such as household income, education level, smoking and drinking status, history of family and personal disease, and personal usage of medicine. Education level was divided into two classifications: < College graduate or ≥ College graduate. Family disease history was comprised of five illnesses, including cancer, hypertension, hyperlipemia, diabetes, and cardiovascular disease. The assessment of physical activity (PA) in the most recent week was acquired by using the validated Chinese version of the International Physical Activity Questionnaire (IPAQ) (Craig et al. 2003). Participants were asked about the duration and frequency of each sport, including light activity, moderate activity, heavy activity, and walking solely. And weekly PA of different activities was calculated by metabolic equivalent (MET) hours per week (MET ∙ hour/week). The total amount of PA was the summation of all activities.

**Statistical analysis**

On the background of the significantly different prevalence of NAFLD in males and females, all analysis was undertaken to stratify by sex. Geometric means (95% confidence interval (CI)) and percentages were respectively presented for continuous variables and categorical variables. The baseline characteristics of participants were compared using analysis of covariance for continuous variables and logistic regression analysis for categorical variables. Follow-up time was calculated from the date when participants...
completed the baseline FFQ survey to date of the first diagnosis of NAFLD, the ending of follow-up (31 December 2019), or loss to follow-up, whichever was earliest. Participants were categorised into tertiles according to energy-adjusted sweet potato consumption. Four Cox proportional hazards regression models were fitted to assess the association between sweet potato intake and risk of NAFLD. The hazard ratios (HRs) and 95% confidence intervals (CIs) were calculated by using the lowest tertile as the reference. The first model was a crude model. The second model was further adjusted for BMI (kg/m²), continuous and age (years, continuous). The third model was further adjusted for many confounding factors, including smoking status (current, former, or never) and drinking status (current, sometime, former, or never), family history of diseases (including hypertension [yes or no], diabetes [yes or no], hyperlipemia [yes or no], and cardiovascular disease [yes or no]), education level (college graduate or not), occupation (managers, professionals, or others), household income (< 10,000 or ≥ 10,000 Yuan), PA (MET-h/wk, continuous), hyperlipemia (yes or no), hypertension (yes or no), diabetes (yes or no), scores of Self-Rating Depression Scale (SDS) (< 45 or ≥ 45), total energy intake (kilocalories per day, continuous), "Health" pattern score,
To examine the robustness of our results, we performed several sensitivity analyses: 1) we repeated the main analysis by removing participants who developed NAFLD within the first follow-up year \((n = 1,159)\); 2) we included participants with cancer and cardiovascular disease (CVD); 3) we excluded participants with hypertension, diabetes, hyperlipidaemia, and obesity \((\text{BMI} \geq 30 \text{kg/m}^2)\) because they could have changed their dietary habits after diagnosis; 4) we repeated the final models by replacing BMI with waist; 5) the final multivariable model was rerun by adjusting for metabolic syndrome instead of diabetes, hypertension, and hyperlipidaemia; 6) because we didn’t know the precise time of occurrence for NAFLD, logistic models were used to assess the association between sweet potato intake and the prevalence of NAFLD. A two-tailed \(P\) value of less than 0.05 was considered statistically. And all statistical analyses were calculated by using SAS version 9.3 (SAS Institute, Inc.).

**Results**

From May 2013 to December 2019, a total number of 15,787 participants (males, 42.4%) who completed the follow-up were concluded into this study. The mean \((\text{SD})\) age of males was 41.1 ± (12.4) years, while the mean age of females was 38.7 ± (10.7) years. During a median follow-up year of 3.5 years (range 1.0 to 5.5 years), the number of 3,656 (males, 61.9%) participating developed NAFLD. The prevalence of NAFLD was 33.8% and 15.3% in males and females, respectively.

The baseline characteristics of participants were shown in Table 1. Compared to the lowest tertile of sweet potato intake group, participants who had the

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**Table 2.** The association between energy-adjusted sweet potato intake and risk of NAFLD according to sex \((n = 15,787)\).

| Categories of energy-adjusted sweet potato intake | Tertile 1 | Tertile 2 | Tertile 3 | \(P\) for trend
|---------------------------------------------------|----------|----------|----------|-----------------|
| Men, \(n\)                                        | 2,177    | 2,333    | 2,150    |                 |
| Cases, \(n\)                                      | 809      | 762      | 692      |                 |
| Person-years                                     | 7,211    | 7,559    | 7,111    |                 |
| Model 1 \(^a\) (reference) \(^d\)                 | 1.00     | 0.90     | 0.87     | 0.006           |
| Model 2                                           | 1.00     | 0.92     | 0.86     | 0.005           |
| Model 3                                           | 1.00     | 0.92     | 0.86     | 0.006           |
| Model 4                                           | 1.00     | 0.92     | 0.87     | 0.009           |
| Women, \(n\)                                      | 2,760    | 3,082    | 3,245    |                 |
| Cases, \(n\)                                      | 411      | 464      | 518      |                 |
| Person-years                                     | 10,147   | 11,434   | 12,179   |                 |
| Model 1 \(^a\) (reference) \(^d\)                 | 1.00     | 1.00     | 1.05     | 0.44            |
| Model 2                                           | 1.00     | 1.06     | 1.05     | 0.45            |
| Model 3                                           | 1.00     | 1.08     | 1.05     | 0.49            |
| Model 4                                           | 1.00     | 1.08     | 1.05     | 0.52            |

\(^a\)NAFLD, non-alcohol fatty liver disease; BMI, body mass index; SDS, self-rating depression scale; ALT, alanine aminotransferase; Hs-CRP, hypersensitive C-reactive protein.

\(^b\)Obtained by using multivariable Cox proportional regression analysis. The \(P\) values for trend were calculated by using the categories of sweet potato intake as an ordinal variable.

\(^c\)Model 1 was a crude model.

Model 2 was further adjusted for age (years, continuous) and BMI (kg/m\(^2\), continuous).

Model 3 was further adjusted for smoking status (current, former, or never), drinking status (everyday drinker, sometime drinker, ex-drinker, or non-drinker), education level (college graduate or lower), occupation (managers, professionals, or other), household income (< 10,000 Yuan), total energy intake (kcal/d), physical activity (MET-h/wk), individual and family history of disease (including hypertension [yes or no], hyperlipidaemia [yes or no], and diabetes [yes or no]), SDS scores (< or ≥ 45), family history of disease (including cardiovascular disease [yes or no], hypertension [yes or no], hyperlipidaemia [yes or no], and diabetes [yes or no]), and three dietary patterns (including “sweet” dietary pattern score, “vegetable” dietary pattern score, and “animal food” dietary pattern score).

Model 4 was further adjusted Hs-CRP (mg/dl, continuous) and ALT (IU/L, continuous).

\(^d\)Hazard ratio (95% confidence interval) (all such values).
Table 3. Hazard ratios (95% confidence intervals) for NAFLD according to categories of energy-adjusted sweet potato intake in males stratified by main risk factors (n = 6,700).a

| Categories of energy-adjusted sweet potato intake | Tertile 1 | Tertile 2 | Tertile 3 | P for trendb | P for interactionc |
|--------------------------------------------------|----------|----------|----------|--------------|---------------------|
| Age (years)                                       |          |          |          |              |                     |
| ≥ 40 (n = 3,077)                                  | 1.00 (reference)d | 0.98 (0.84, 1.13) | 0.91 (0.78, 1.06) | 0.22 | 0.53 |
| < 40 (n = 3,623)                                  | 1.00 (reference) | 0.86 (0.74, 0.99) | 0.83 (0.71, 0.97) | 0.02 |         |
| BMI (kg/m²)                                       |          |          |          |              |                     |
| ≥ 24 (n = 3,488)                                  | 1.00 (reference) | 0.98 (0.86, 1.10) | 0.86 (0.75, 0.98) | 0.03 | 0.97 |
| < 24 (n = 3,212)                                  | 1.00 (reference) | 0.79 (0.67, 0.95) | 0.89 (0.74, 1.09) | 0.20 |         |
| PA (MET-h/wk)                                     |          |          |          |              |                     |
| ≥ 23 (n = 4,328)                                  | 1.00 (reference) | 0.86 (0.72, 1.02) | 0.82 (0.68, 0.99) | 0.03 | 0.08 |
| < 23 (n = 4,382)                                  | 1.00 (reference) | 0.94 (0.83, 1.07) | 0.90 (0.78, 1.03) | 0.11 |         |
| Hypertension                                      |          |          |          |              |                     |
| Yes (n = 1,485)                                   | 1.00 (reference) | 0.91 (0.74, 1.11) | 0.91 (0.74, 1.12) | 0.37 | 0.33 |
| No (n = 5,215)                                    | 1.00 (reference) | 0.92 (0.82, 1.04) | 0.84 (0.74, 0.96) | 0.009 |      |
| Hyperlipidaemia                                   |          |          |          |              |                     |
| Yes (n = 2,548)                                   | 1.00 (reference) | 0.89 (0.77, 1.03) | 0.85 (0.72, 0.99) | 0.04 | 0.78 |
| No (n = 4,152)                                    | 1.00 (reference) | 0.95 (0.82, 1.09) | 0.89 (0.76, 1.03) | 0.12 |      |
| Diabetes                                          |          |          |          |              |                     |
| Yes (n = 282)                                     | 1.00 (reference) | 0.90 (0.55, 1.48) | 0.75 (0.46, 1.24) | 0.27 | 0.91 |
| No (n = 6,418)                                    | 1.00 (reference) | 0.92 (0.83, 1.02) | 0.87 (0.78, 0.97) | 0.01 |      |

aMultivariable Cox proportional regression was adjusted for age (years, continuous), BMI (kg/m², continuous), smoking status (current, former, or never), drinking status (everyday drinker, sometime drinker, ex-drinker, or non-drinker), education level (college graduate or lower), occupation (managers, professionals, or other), household income (< or ≥ 10,000 Yuan), total energy intake (kcal/d), physical activity (MET-h/wk), individual history of disease (including hypertension [yes or no], hyperlipidaemia [yes or no], and diabetes [yes or no]), SDS scores (< or ≥ 43), family history of disease (including cardiovascular disease [yes or no], hypertension [yes or no], hyperlipidaemia [yes or no], and diabetes [yes or no]), three dietary patterns (“sweet” dietary pattern score, “vegetable” dietary pattern score, “animal food” dietary pattern score), Hs-CRP (mg/dl, continuous), and ALT (IU/L, continuous). BMI, body mass index; MET, metabolic equivalent; ALT, alanine aminotransferase; Hs-CRP, hypersensitive C-reactive protein.

bBased on categories of energy-adjusted sweet potato consumption as a continuous variable.

cHazard ratio (95% confidence interval) (all such values).

The association between energy-adjusted sweet potato intake and the risk of NAFLD was shown in Table 2. In males, after adjusting for demographic and socioeconomic characteristics, lifestyle factors, dietary intake, and inflammatory biomarkers, the final HRs (95% CI) for NAFLD across sweet potato intake were 1.00 (reference) for the lowest tertile, 0.92 (0.83, 1.02) for the middle tertile, and 0.87 (0.78, 0.97) for the highest tertile (p for trend = 0.009). In females, the final HRs (95% CI) for NAFLD across sweet potato intake were 1.00 (reference) for the lowest tertile, 1.08 (0.94, 1.24) for the middle tertile, and 1.05 (0.92, 1.21) for the highest tertile (p for trend = 0.52).

Table 3 showed that no statistical interaction existed between sweet potato intake and age (p for interaction = 0.53), BMI (p for interaction = 0.97), PA (p for interaction = 0.08), hypertension (p for interaction = 0.33), hyperlipidaemia (p for interaction = 0.78), or diabetes (p for interaction = 0.91) in males. In females, no significant interaction was found between sweet potato intake and age (p for interaction = 0.44), PA (p for interaction 0.78), hypertension (p for interaction = 0.15), or diabetes (p for interaction = 0.08), except BMI (p for interaction < 0.0001) and hyperlipidaemia (p for interaction = 0.04) (Table 4). We then performed stratified analysis, and the association was not substantially changed (Table 4).

In sensitivity analyses, a similar association was observed in both sexes when we removed participants who developed NAFLD within the first follow-up year (Supplemental Table 1). In addition, the results were not substantially changed when we included participants with CVD and cancer (Supplemental Table 2). Moreover, the inverse association was still observed in males when we excluded participants with diabetes, hypertension, hyperlipidaemia, and obesity (Supplemental Table 3). The association remained sustained after replacing BMI with waist circumference (WC) (Supplemental Figure 1) or metabolic syndrome with diabetes, hypertension, and hyperlipidaemia (Supplemental Figure 2). When logistic models were used, a similar association was observed in both sexes (Figure 2).
Discussion

The results of this prospective study showed that the highest tertile of sweet potato intake was inversely associated with the risk of NAFLD in males but not in females. To the best of our knowledge, this is the first study to investigate the association of sweet potato intake with NAFLD in the general population.

In this study, we adjusted for many confounding factors. First, age and BMI were well-established
confounders. Thus, we performed adjustments for age and BMI. However, adjustments for these factors didn’t change the observed association in both sexes. Second, we adjusted for potential confounders, including smoking status, drinking status, education level, occupation, household income, total energy intake, physical activity, individual history of disease (including hypertension, hyperlipidaemia, and diabetes), SDS scores, family history of disease (including cardiovascular disease, hypertension, hyperlipidaemia, and diabetes), and three main dietary patterns. However, a similar association was observed. Third, previous studies have demonstrated that serum hs-CRP and ALT are associated with the risk of NAFLD (De Silva et al. 2019). We therefore adjusted for hs-CRP and ALT. However, the association remained sustained in both sexes.

The NAFLD incidence rate in our study was 65.7 cases per 1,000 person-years. A recent meta-analysis consisting of Asian studies reported similar results, the incidence of which was 63.0 cases per 1,000 person-years in mainland China (Ye et al. 2020). Many studies have demonstrated that sweet potato consumption was beneficial for metabolic diseases. One clinical trial conducted in 58 overweight white-collar workers proved that the sweet potato used as meal replacement was useful for weight loss (Shih et al. 2019), which was one of the main cornerstones for improving NAFLD. In patients with diabetes, consumption of sweet potatoes was found to effectively reduce insulin resistance (Ludvik et al. 2003; 2008).

NAFLD has been regarded as the hepatic manifestation of metabolic diseases. However, no epidemiological study related to the association between sweet potato consumption and NAFLD was found. Two clinical trials showed that the intake of purple sweet potato beverages decreased the levels of serum hepatic markers in healthy adults with borderline hepatitis, including AST and ALT (Suda et al. 2008; Oki et al. 2017), both of which are released from the damaged hepatocytes into the blood and are useful surrogates for NAFLD (De Silva et al. 2019). An animal study reported that purple sweet potato colour, which is a class of naturally occurring anthocyanins in sweet potato, exhibited beneficial effects on hepatic steatosis in rats (Wang et al. 2017). These studies support the idea that sweet potato intake may play a protective role for NAFLD. Our results indicated that sweet potato intake was inversely associated with the risk of NAFLD in males, providing new insight into the treatment for NAFLD. More clinical trials are needed to verify our findings.

The underlying mechanism behind the inverse association between the highest category of sweet potato intake and NAFLD in males may be plausibly explained as follows. First, sweet potato contains resistance starch, which is characterised as an indigestible starch (Keenan et al. 2015). A relevant study reported that the content of resistance starch ranged from 13.2% to 17.2% in flours from four types of sweet potato roots (Senanayake et al. 2013). Compelling evidence has shown that the intake of resistant starch is related to improvements in insulin resistance, reduced accumulation of adipose tissue, and decreased risk for metabolic diseases (Tomomi et al. 2014; Bindels et al. 2015), all of which play a prominent role in the pathogenesis of NAFLD (Chalasani et al. 2018). Moreover, sweet potatoes contain dietary fibre, which has been regarded as prebiotics that could positively modulate host intestinal microbiota (Mariano et al. 2019; Perez-Montes de Oca et al. 2020). This prebiotic may prevent NAFLD by lowering hepatic triglyceride and attenuating hepatic steatosis mediated by host intestinal microbiota (Esposito et al. 2009; Ye et al. 2017). In addition, the sweet potato is high in bioactive compounds, including anthocyanin, phenolic acids, carotenoids, and soluble polysaccharides (Mohanraj and Sivasankar 2014; Kurata et al. 2019; Mariano et al. 2019). Compelling evidence shows that they can prevent insulin resistance and liver steatosis (Ahn et al. 2012; Naowaboot et al. 2016; Wang et al. 2017) and have strongly antioxidative and anti-inflammatory activity (Panchal et al. 2013; Sun et al. 2018; Zhu et al. 2022). Thus, may ameliorate NAFLD by improving lipid and glucose metabolism and attenuating the hepatic damage induced by antioxidative stress and inflammation (Christensen et al. 2019; Salomone et al. 2020; Abenavoli et al. 2021; Zhu et al. 2022). Nevertheless, future mechanistic studies are needed to examine the exact mechanism underlying the inverse association between sweet potato intake and NAFLD.

Interestingly, there was no significant association between sweet potato intake and NAFLD in females. We can only speculate on potential explanations. First, the benefic effect of sweet potato consumption might be better discernible because of the higher prevalence of NAFLD in males (Lazo et al. 2013). In addition, males have a higher proportion of central obesity in our population (25.4% vs. 9.1% for males vs. females, \( p < 0.0001 \)), and they might have a larger visceral fat mass, related to a more pro-inflammatory profile (Ballestri et al. 2017), which might directly release free fatty acids into the portal vein, therefore
promoting hepatic steatosis (Nielsen et al. 2004). Second, females usually have a healthier awareness of nutrition (Kiefer et al. 2005), which was also indicated by a higher proportion of females in more sweet potato consumption groups in the present study. As a result, the effect of the sweet potato might be mitigated by other healthy diets. Finally, females are at especially higher risk for developing NAFLD following menopause because of the loss of protection conferred by oestrogen and combining with sub-clinical disturbances in metabolic parameters prior to menopause (DiStefano 2020). Thus, the plausibly protective effect of oestrogen might influence the effects of sweet potato consumption in females.

The main strength of the present study includes the large sample size, prospective cohort design, elaborate information on socioeconomic characteristics and lifestyle, and usage of a validated food frequency questionnaire (FFQ) for the assessment of dietary intake. Additionally, we adjusted for many confounding factors which might affect the association between sweet potato consumption and NAFLD. Nonetheless, there are some limitations to this study. First, the diagnosis of NAFLD was conducted by abdominal ultrasound instead of liver biopsy, which is the gold diagnostic standard for NAFLD. However, abdominal ultrasound is not invasive and easy to accept by participants. Moreover, with a sensitivity and specificity of 89% and 93% respectively, this non-invasive method is widely used in large-scale population-based studies (Saadeh et al. 2002). Second, sweet potato consists of elements, which varied from diversity (Mohanraj and Sivasankar 2014). Yet, different types of sweet potato were not assessed in our study. Therefore, we may have difficulty in finding out the effect of specific sweet potato on NAFLD. Third, the baseline characteristics of participants in this study (Table 1) showed that participants with higher sweet potato intake had many healthier lifestyles and dietary habits, such as more physically active, less smoking and drinking, and higher vegetables and fruits consumption. Higher sweet potato intake may be a marker of other healthy lifestyle factors. However, the results were not substantially changed when we adjusted for these factors. Nevertheless, although we made adjustments for a considerable number of confounding factors, we cannot rule out the possibility that unmeasured factors might contribute to the associations observed. Forth, even though the population of the present study was composed of general adults in Tianjin, China, our findings may apply to other parallel populations.

**Conclusion**

In conclusion, results of this study demonstrated that the highest category of sweet potato intake was significantly associated with a lower risk of NAFLD in males. No significant association between sweet potato intake and risk of NAFLD was found in females. Our findings suggest that higher sweet potato intake might play a protective role in the development of NAFLD in males. However, because of the observational study design, we cannot infer the causality between sweet potato intake and risk of NAFLD. Further randomised controlled trials with full consideration of more factors related to NAFLD and inter-groups variation in the study population are required to clarify the causality.

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**Author contributions**

The authors’ responsibilities were as follows: H.Y. analysed the data and wrote the paper. H.Y., T.Z., S.R., A.T., W.D., G.M., Q.Z., L.L., H.W., Y.G., S.Z., X.W., H.L., J.Z., J.D., X.Z., Z.C., X.Z., X.D., S.S., X.W., M.Z., Q.J., and K.S. conducted research. K.N. designed the research and had primary responsibility for the final content. All authors had full access to all the data in the study and read and approved the final manuscript.

**Ethics approval**

This study was approved by the Institution Review Board of Tianjin Medical University (Ethics Approval Number: TMUhMEC 201430), and written informed consent was obtained from all participants.

**Consent to participate**

Written informed consent was obtained from each participant prior to enrolment.

**Disclosure statement**

None of the authors has any potential conflict of interest.

**Data availability statement**

Data of the present research is available from the corresponding authors on reasonable request.
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