

Original Article

Garlic consumption and risk of diabetes mellitus in the Chinese elderly: A population-based cohort study

Jing Du MD[†], Ying Duan MD[†], Ling Yang MD, Yan Cui MD, Huaqing Liu MD

School of Public Health, Bengbu Medical University, Bengbu, China

[†]Both authors contributed equally to this manuscript

Background and Objectives: Diabetes mellitus (DM) is a major public health problem worldwide. Numerous traditional plants are used for preventing DM. However, limited evidence supports the association between garlic consumption and DM. **Methods and Study Design:** Data used in this study was from the 2008-2018 Chinese Longitudinal Healthy Longevity Survey. Data on garlic consumption was obtained by questionnaire, and DM by self-reported diagnosis. A multivariate adjusted Cox regression model was used to estimate hazard ratios (HR) and 95% confidence intervals (CI) to determine the incidence of DM. **Results:** A total of 1927 participants were included in this study, of which 24.08% consumed garlic daily and 20.08% developed DM. The HR for daily garlic consumption decreased by 42%, when compared to rare or no garlic consumption. Our subgroup analyses revealed that daily garlic consumption significantly reduced the risk of DM in older adults aged 65-79, rural, non-drinkers informal education, financial dependence, and working in agriculture (aged 65-79: HR = 0.54, 95% CI: 0.36-0.80; rural area: HR = 0.48, 95% CI: 0.29-0.77; non-drinkers: HR = 0.60, 95% CI: 0.41-0.86; informal education: HR = 0.46, 95% CI: 0.29-0.74; financial dependence: HR = 0.39, 95% CI: 0.23-0.65; agricultural work: HR = 0.49, 95% CI: 0.32-0.76). **Conclusions:** Garlic consumption can reduce the risk of DM in older Chinese adults. This benefit varies by age, current residence, drinking status, education level, occupation, and economic source. Future efforts should focus on developing dietary intervention strategies that consider demographic, educational, financial, and occupational disparities to effectively prevent diabetes in older populations.

Key Words: garlic consumption, diabetes, older adults, epidemiology, China

INTRODUCTION

Diabetes mellitus (DM) is a major public health problem. In 2021, the global prevalence of DM was 10.5% (536.6 million people), and the incidence was highest among those aged 75-79 years. The International Diabetes Federation estimated that the prevalence of DM will rise to 12.2% (783.2 million) by 2045.¹ The global prevalence of DM is skyrocketing.² China is one of the countries with the highest prevalence of DM. The prevalence of DM among Chinese adults rose from 0.67% in 1980 (WHO standards) to 10.9% in 2013 (the American Diabetes Association standards).^{3,4}

DM, a complex metabolic disorder characterized by β -cell dysfunction, hyperglycemia, and insulin resistance,⁵ causes severe complications, including myocardial infarction, stroke, diabetic foot amputation, and chronic kidney disease,⁶ all of which considerably contribute to the high DM-associated mortality rate. Furthermore, DM imposes a substantial financial burden on individuals, families, and health-care systems. The health-care cost associated with DM was US\$966 billion in 2021, in which this figure is expected to rise to US\$1054 billion by 2045.¹

The onset of DM is linked to numerous factors including lifestyle, environmental, and genetic factors.⁷ For instance, individuals with low socioeconomic status, a smoking habit, a sedentary lifestyle, rare physical activity, and poor eating habits are more likely to develop

DM.^{8,9} Despite recent scientific advancements in its management and treatment, DM is still regarded as a life-threatening disease.¹⁰ In addition, most antidiabetic drugs have side effects; these include as hypoglycemia, weight gain, nutritional disorders, allergic reactions, and liver disease.¹¹ Therefore, developing antidiabetic drugs with fewer side effects is necessary, especially for individuals who experience severe side effects from clinical drugs or individuals of low socioeconomic status.

Traditional plants and herbs are used in many parts of the world to cure common diseases.¹² Garlic (*Allium sativum*), a perennial herb species in the Amaryllidaceae family, was consumed and used in ancient civilizations worldwide, including Rome, India, Greece, Egypt, and China.¹³⁻¹⁵ Garlic is commonly used as flavoring, in functional foods, and in traditional medicine for nutritional and medical purposes.^{16,17} Garlic or its bioactive components have been associated with considerable health benefits. A population-based study reported that garlic is effective in preventing cardiovascular disease.¹⁸

Corresponding Author: Dr Huaqing Liu, School of Public Health, Bengbu Medical University, Bengbu, China

Tel: 86-552-3175226

Email: lhqbbmc@163.com

Manuscript received 09 July 2024. Initial review completed 03 August 2024. Revision accepted 25 September 2024.

doi: 10.6133/apjcn.202504_34(2).0003

Furthermore, case-control studies have indicated that garlic can protect against colorectal cancer, gastric cancer, prostate cancer, lung cancer, and head and neck cancer.^{19–22} A meta-analysis of 11 studies showed that garlic is beneficial for treating hypertension.²³ At present, research on garlic and DM are mainly focused on the animal experiments and clinical cell research of garlic and its extract and DM, DM complication or DM related index. However, the analytical epidemiological study on the relationship between garlic intake and DM is limited.^{24,25} Accordingly, we conducted this population-based cohort study with the aim of investigating the causal association between garlic consumption and DM in older Chinese adults.

METHODS

Study participants

We retrieved study data from the China Longitudinal Health and Longevity Survey (CLHLS), a nationwide prospective cohort study aimed at identifying individual, family, and social factors related to the health and longevity of older adults. This survey applied stratified multi-stage sampling in 23 of the 31 provinces of mainland China. All survey information was obtained through face-to-face interviews by specially trained interviewers from local Centers for Disease Prevention and Control. Detailed information regarding the CLHLS can be found in literature.²⁶ The survey was approved by the Ethics Committee of Peking University (IRB00001052–13074). Informed consent was obtained from all participants.

For the present study, we used CLHLS data for the period from 2008 to 2018. Among the total of 16,954 respondents in 2008, 15,799 remained after excluding those younger than 65 years of age (391), missing data on garlic consumption (10), missing data on diabetes (332), and those who already had diabetes at the 2008 baseline survey (422). In addition, we excluded 13872 respondents due to loss to follow-up during the three follow-up sur-

veys, death, and incomplete diabetes data. Therefore, 1927 individuals were included in our study, as shown in the screening process illustrated in Figure 1.

Assessment of garlic consumption

A short food frequency questionnaire—which was demonstrated to be effective in assessing functional performance²⁷—was used in the CLHLS. Garlic consumption habits were determined according to participants' responses to the question: "How often do you eat garlic at present?" Then, the frequency of garlic consumption were classified into three categories: daily, occasionally, and never or rarely.²⁸

Assessment of DM

DM was determined according to participants' responses to the following question: "Are you currently suffering from DM?" Those who had DM before death were also included in the study analysis.

Assessment of covariates

Demographic variables included sex (female or male), age group (65–79 or ≥ 80 years), marital status (married and living with spouse or others), and residence (urban and rural). We used dietary diversity scores (DDS) rather than nutritional adjustments alone to account for the potential confounding effect of dietary diversity in the association between garlic consumption and DM risk. The participants completed a food frequency questionnaire involving 12 major food groups: eggs, beans, milk or dairy products, meat, fish, mushrooms or algae, tea, nuts, sugar, fruit, preserved vegetables and fresh vegetables. The frequency of consumption was used to determine the scores for each food group.²⁹ The DDS was derived as the sum of the scores of the 12 food groups, with a higher DDS indicating higher dietary diversity. Lifestyle habits included exercise status (yes or no), drinking status (yes

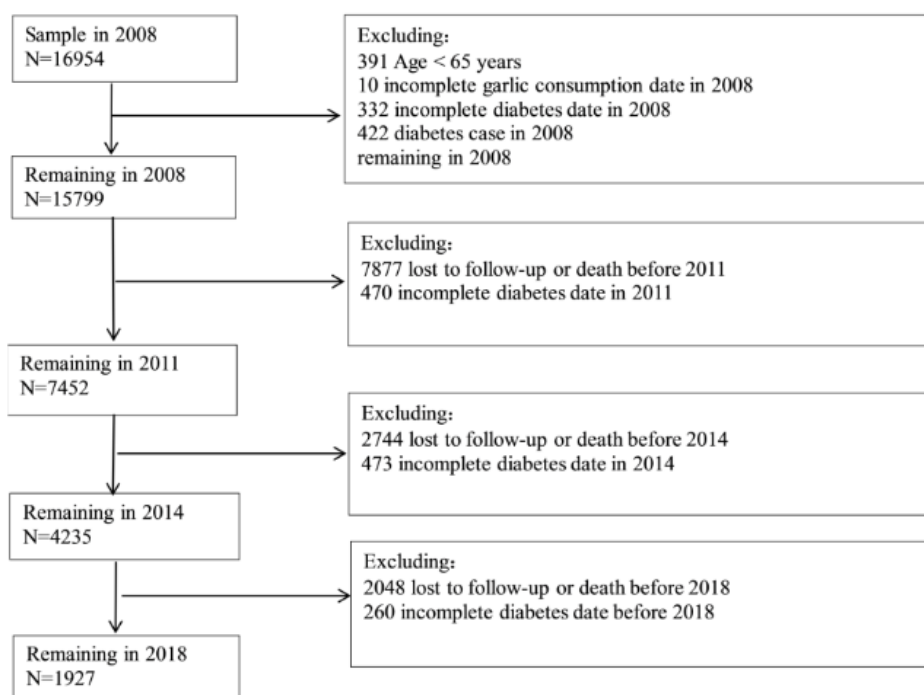


Figure 1. Flowchart of the sample selection process

or no), and smoking status (yes or no). Socioeconomic status included education level, income source, and occupation. Education level was classified as formal if the participants attended school and as informal if they did not. Income source was determined according to the participants' responses to the following question: "What are your main sources of financial support?" On the basis of the responses, income source was classified as financially dependent or financially independent. Occupation before the age of 60 was classified as non-agricultural work or agricultural work. Health conditions included a history of chronic diseases and body mass index (BMI; underweight, normal, overweight, or obese). Participants who did not report heart disease, hypertension, cancer, dyslipidemia, stroke, or cerebrovascular disease were determined to not have a history of chronic diseases (i.e., "No"); by contrast, those who reported any of the listed diseases were determined to have a history of chronic diseases (i.e., "Yes").

Statistical analysis

Categorical variables are presented as numbers and percentages; average age and DDS are presented as mean and standard deviation. The variables were compared at baseline by using a chi-square test and an analysis of variance (ANOVA). The Cox proportional hazards model was used to assess the association between garlic consumption and DM risk. This model provided estimates of hazard ratios (HR) along with 95% confidence intervals (CI). The final model was adjusted for sex, age, residence location, education level, BMI, DDS, drinking status, smoking status, exercise status, marital status, income source, occupation, and history of chronic disease. Also, we further conducted subgroup analyses by stratified by age, residence, drinking status, education level, occupation, income source and BMI to assess the association between garlic consumption and the incidence of DM. All statistical analyses were conducted using SPSS software. Statistical significance was defined as a two-sided *p* value of 0.05.

RESULTS

Participant characteristics

The basic characteristics of the participants were presented in Table 1. There were 1927 participants, of which 1328 (68.9 %) were aged 65–79 years and 898 (46.6 %) were men. Of the participants, 49.27 % had no formal education, 58.2 % were financially dependent, 26.5% worked in agriculture, 77.9 % did not smoke, 77.7% did not consume alcohol, and 63.7 % did not exercise. It was also found that 20.8 % of the participants rarely or never consumed garlic, 55.1 % consumed garlic occasionally, and 24.1 % consumed garlic every day. Participants who consumed garlic daily were younger, had a higher DDS, and were mostly economically independent with a normal BMI.

The prevalence of DM was 20.08%, and was higher in older adults who were male, lived in the urban area, were farmers, did not smoke, did not drink alcohol, exercised, were overweight or obese, and had a history of chronic disease. (Table 2)

Garlic consumption and incidence of DM

As presented in Table 3, the unadjusted model revealed that the HR for DM was 0.61 (95% CI: 0.44–0.82) for those who consumed garlic daily compared with those who never or rarely consumed garlic. The model adjusted only for age, sex and residence and adjusted for demographic characteristics, lifestyle habits, dietary habits, socioeconomic status, and health conditions showed that, the association between garlic consumption and DM risk remained (Model 2 daily garlic consumption: HR = 0.62, 95% CI: 0.45–0.84; Model 3 daily garlic consumption: HR = 0.58, 95% CI: 0.42–0.80); the HR for daily garlic consumption decreased by 42% relative to rare or no garlic consumption.

Subgroup analysis and interaction analysis

Results of subgroup analyses stratified by age, sex, residence location, smoking status, drinking status, exercise status and socioeconomic status were presented in Figure 2. Daily garlic consumption significantly reduced the risk of DM in 65–79 year old Chinese adults (HR = 0.54, 95% CI: 0.36–0.80) but not in those over 80 years of age (HR = 0.74, 95% CI: 0.41–1.32). Garlic consumption also reduced DM risk in those living in rural areas (HR = 0.48, 95% CI: 0.29–0.77) but not in those living in urban areas (HR = 0.67, 95% CI: 0.42–1.06). Furthermore, DM risk was reduced in non-drinkers (HR = 0.60, 95% CI: 0.41–0.86), those with informal education (HR = 0.46, 95% CI: 0.29–0.74), financially dependent (HR = 0.49, 95% CI: 0.32–0.76) or involved in agricultural work (HR = 0.39, 95% CI: 0.23–0.65). However, the risk was not reduced in those who are current drinkers (HR = 0.53, 95% CI: 0.24–1.16), with formal education (HR = 0.73, 95% CI: 0.45–1.17), financially independent (HR = 0.73, 95% CI: 0.46–1.16) or involved in non-agricultural work (HR = 0.62, 95% CI: 0.36–1.06). However, daily consumption of garlic reduced the risk of DM in older adults across gender, smoking status, and exercise status.

The results of the interaction showed that older adults who consumed garlic daily and were financially independent had a lower risk of DM compared with older adults who rarely consumed garlic and were financially dependent; no significant interactions were found among the other variables.

DISCUSSION

Data from this study was derived from a 10-year population-based longitudinal study, aiming to examine the effects of garlic consumption on DM risk among older Chinese adults. Findings showed that about 1 in 5 older adults in China developed DM during the 10-year follow-up and about 1 in 4 regularly consume garlic. After controlling for potential confounders and baseline DM, daily garlic consumption showed an inverse association with DM risk, suggesting that regular garlic consumption may be an effective way to reduce DM risk.

Our findings are consistent with those of previous studies, revealing beneficial effects of garlic consumption. Garlic is used clinically as a hypoglycemic drug.³⁰ In most cases, reduced insulin sensitivity and insulin secretion are associated with the development of DM.³¹ Evidence suggested that garlic may exert its hypoglycemic

Table 1. Basic characteristics of the participants with different garlic consumptions

Characteristics	N (%)	Garlic consumption, n%		
		Rarely or never	Occasionally	Daily
Total	1927 (100)	401 (20.81)	1062 (55.11)	464 (24.08)
Age group				
65-79	1328 (68.92)	253 (19.05)	733 (55.2)	342 (25.75)
≥80	599 (31.08)	148(24.71)	329 (54.92)	122 (20.37)
Sex				
Male	898 (46.60)	188 (20.94)	485 (54.01)	255 (28.4)
Female	1029 (53.40)	213 (20.70)	577 (56.07)	239 (23.23)
Residence location				
Town or city area	703 (36.48)	151 (21.48)	386 (54.91)	166 (23.61)
Rural area	1224 (63.52)	250 (20.42)	676 (55.23)	298 (24.35)
Education level				
Informal education	948 (49.27)	203 (21.41)	528 (55.7)	217 (22.89)
Formal education	976 (50.73)	198 (20.29)	532 (54.51)	246 (25.20)
Financial source				
Financial dependence	1121 (58.17)	244 (21.77)	653 (58.25)	224 (19.98)
Financial independence	806 (41.83)	157 (19.48)	409 (50.74)	240 (29.78)
Occupation				
Non-agricultural work	1352 (73.52)	277 (20.49)	770 (56.95)	305 (22.56)
Agricultural work	487 (26.48)	105 (21.56)	252 (51.75)	130 (26.69)
Marital status				
Married and living with spouse	1107 (57.45)	219 (19.78)	623 (56.28)	265 (23.94)
others	820 (42.55)	182 (22.20)	439 (53.54)	199 (24.27)
Smoking status				
No	1501 (77.89)	312 (20.79)	840 (55.96)	349 (23.25)
Yes	426 (22.11)	89 (20.89)	222 (52.11)	115 (27.00)
Drinking status				
No	1497 (77.69)	319 (21.31)	830 (55.44)	348 (23.25)
Yes	430 (22.31)	82 (19.07)	232 (53.95)	116 (26.98)
Exercise status				
No	1227 (63.67)	273 (22.25)	700 (57.05)	254 (20.70)
Yes	700 (36.33)	128 (18.29)	362 (51.71)	210 (30.00)
BMI, kg/m ²				
Underweight (< 18.5)	402 (20.98)	106 (26.37)	217 (53.98)	79 (19.65)
Normal (18.5–23.99)	1082 (56.47)	227 (20.98)	591 (54.62)	264 (24.4)
Overweight (24–27.99)	339 (17.69)	55 (16.22)	205 (60.47)	79 (23.30)
Obese (≥28)	93 (4.85)	12 (12.90)	42 (45.16)	39 (41.94)
History of chronic diseases				
No	1343 (69.69)	269 (20.03)	763 (56.81)	311 (23.16)
Yes	584 (30.31)	132 (22.6)	299 (51.2)	153 (26.2)
DDS, M (SD)	5.42 (2.43)	5.04 (2.25)	5.27 (2.44)	6.11 (2.42)

DDS: dietary diversity scores; M (SD): mean (stand deviation).

effects by influencing both mechanisms. Liu reported that garlic oil significantly increased the concentration of basal insulin in rats with DM.³² Padiya revealed that applying garlic as treatment to glucose-fed rats significantly reduced blood glucose and increased insulin sensitivity.³³ Mathew et al. reported an increase in peripheral insulin activity in alloxan-induced diabetic rabbits treated with allicin, suggesting that the most likely mechanism of allicin is its activity against insulin-inactivating sulfhydryl group compounds, which can prevent insulin inactivation.³⁴ Recent studies have proposed a new mechanism underlying the action of garlic: that is, garlic can inhibit dipeptidyl peptidase-4 (a protease-regulating glucose metabolism), thereby inhibiting the secretion of postprandial glucagon, improving the function of pancreatic cells, and promoting insulin production.³⁵ In addition, lipid metabolism disorder is one of the key factors for DM.³⁶ Garlic is used as an antidiabetic nutrient because it reduces plasma levels of triglycerides, cholesterol, and low-density lipoprotein cholesterol.³⁰

Oxidative stress plays a major role in the pathogenesis of DM. High levels of free radicals and a decrease in endogenous antioxidants may be contributing factors to the development of insulin resistance.³⁷ Garlic contains phenolic compounds, which have strong antioxidant properties.³⁸ Human studies have shown that 2 weeks of garlic powder supplementation reduced the oxidative sensitivity of apolipoprotein B by 34%.³⁹

A recent meta-analysis showed that garlic supplementation could regulate oxidative stress markers, including malondialdehyde and total antioxidant capacity.⁴⁰ In addition, inflammation can induce insulin resistance.⁴¹ Previous studies have also suggested that hyperglycemia is a proinflammatory state.⁴² Garlic enhances insulin sensitivity by activating AMP-activated protein kinase (AMPK). AMPK activation inhibits several inflammatory factors and sterol regulatory element-binding protein 1c, thereby suppressing chronic inflammation in adipocytes.⁴³ Garlic has anti-inflammatory and antioxidant properties that are helpful for both DM prevention and treatment.

Table 2. Univariate analysis of covariates and diabetes prevalence

Characteristics	N (%)	DM, n%		χ^2
		No	Yes	
Total	1927 (100)	1540 (79.92)	387 (20.08)	
Age group				0.21
65-79	1328 (68.92)	1065 (80.20)	263 (19.8)	
≥ 80	59 (31.08)	475 (79.30)	124 (20.70)	
Sex				13.59***
Male	898 (46.60)	750 (83.52)	148 (16.48)	
Female	1029 (53.40)	790 (76.77)	239 (23.23)	
Residence location				41.93***
Urban area	703 (36.48)	507 (72.12)	196 (27.88)	
Rural area	1224 (63.52)	1033 (84.40)	191 (15.60)	
Education level				0.52
Informal education	948 (49.27)	751 (79.22)	197 (20.78)	
Formal education	976 (50.73)	786 (80.53)	190 (19.47)	
Financial source				1.36
Financial dependence	1121 (58.17)	906 (80.82)	215 (19.18)	
Financial independence	806 (41.83)	634 (78.66)	172 (21.34)	
Occupation				21.07***
Non-agricultural work	1352 (73.52)	356 (73.10)	131 (9.69)	
Agricultural work	487 (26.48)	1119 (82.77)	233 (47.84)	
Marital status				0.37
Married and living with spouse	1107 (57.45)	890 (80.40)	217 (19.60)	
Others	820 (42.55)	650 (79.27)	170 (20.73)	
Smoking status				4.54*
No	1501 (77.89)	1184 (78.88)	317 (21.12)	
Yes	426 (22.11)	356 (83.57)	70 (16.43)	
Drinking status				6.99**
No	1497 (77.69)	1177 (78.62)	320 (21.38)	
Yes	430 (22.31)	363 (84.42)	67 (15.58)	
Exercise status				4.24*
No	1227 (63.67)	998 (81.34)	229 (18.66)	
Yes	700 (36.33)	542 (77.43)	158 (22.57)	
BMI, kg/m ²				30.53***
Underweight (< 18.5)	402 (20.98)	348 (86.57)	54 (13.43)	
Normal (18.5–23.99)	1082 (56.47)	874 (80.78)	208 (19.22)	
Overweight (24–27.99)	339 (17.69)	243 (71.68)	96 (28.32)	
Obese (≥ 28)	93 (4.85)	66 (70.97)	27 (29.03)	
History of chronic diseases				36.33***
No	1343 (69.69)	1122 (83.54)	221 (16.46)	
Yes	584 (30.31)	418 (71.58)	166 (28.42)	
DDS, M (SD)	5.42 (2.43)	5.40 (2.39)	5.50 (2.58)	0.54 [†]

DDS: dietary diversity scores; M (SD): mean (stand deviation).

[†] indicates the statistical value in variance analysis.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Nonenzymatic glycosylation is among the mechanisms underlying diabetic complications.⁴⁴ Several sulfur compounds in garlic can protect low-density lipoprotein from glycosylation in healthy individuals or patients with diabetes.^{45,46} Garlic's antiglycative properties may also prevent DM.

Subgroup analyses revealed that the protective effect of garlic consumption against DM varied across age, residence location, drinking status and socioeconomic status (occupation, education level, and financial source). The highest prevalence of diabetes was in 65-79 years of age group.⁴⁷ Daily consumption of garlic may be able to effectively reduce the risk of diabetes for these older people; however, the mortality rate of diabetes has also increased with age,⁴⁸ and those beyond the age of 80 had relatively good health in general. This study did not find that garlic consumption was effective in lowering the risk of diabetes mellitus in those over 80 years of age. The prevalence of DM in urban areas is significantly higher

than in rural areas,⁴⁹ but the prevalence of DM as a whole is showing a rapid growth trend.⁵⁰ DM is characterized by a high prevalence and a low rate of awareness, treatment and control⁵¹ in rural areas of China, and therefore consuming garlic daily might reduce the risk of DM effectively. On the other hand, urban areas have relatively good health care resources and clinical capacity,⁵² weakening the DM risk lowering effect of garlic. A previous study reported that up to 9 out of 10 new cases of DM can be attributed to modifiable lifestyle habits such as alcohol consumption.⁵³ Alcohol consumption is harmful to the pancreas, resulting in defective insulin secretion in animals.^{54,55} Furthermore, alcohol consumption can reduce glucose production in healthy people, engendering insulin resistance.⁵⁶ Alcohol consumption may influence the effects of garlic on DM. The present study did not reveal protective effects of garlic among older adults who were drinkers. Notably, the findings of existing studies on alcohol consumption and DM risk are inconsistent. Some

Table 3. Association between garlic consumption and incidence of DM

Characteristics	Model 1	Model 2	Model 3
	HR (95% CI)	HR (95% CI)	HR (95% CI)
Rarely or never	Reference		
Occasionally	0.86 (0.67-1.09)	0.86 (0.68-1.09)	0.88 (0.69-1.13)
Daily	0.61 (0.44-0.82)**	0.62 (0.45-0.84)**	0.58 (0.42-0.80)**

HR: hazard ratio, CI: confidence interval.

Model 1: No adjustment.

Model 2: Adjustment for age, sex and residence.

Model 3: Adjustment for age, sex, residence, education level, BMI, DDS, drinking status, smoking status, exercise status, marital status, income source, occupation, and history of chronic diseases.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

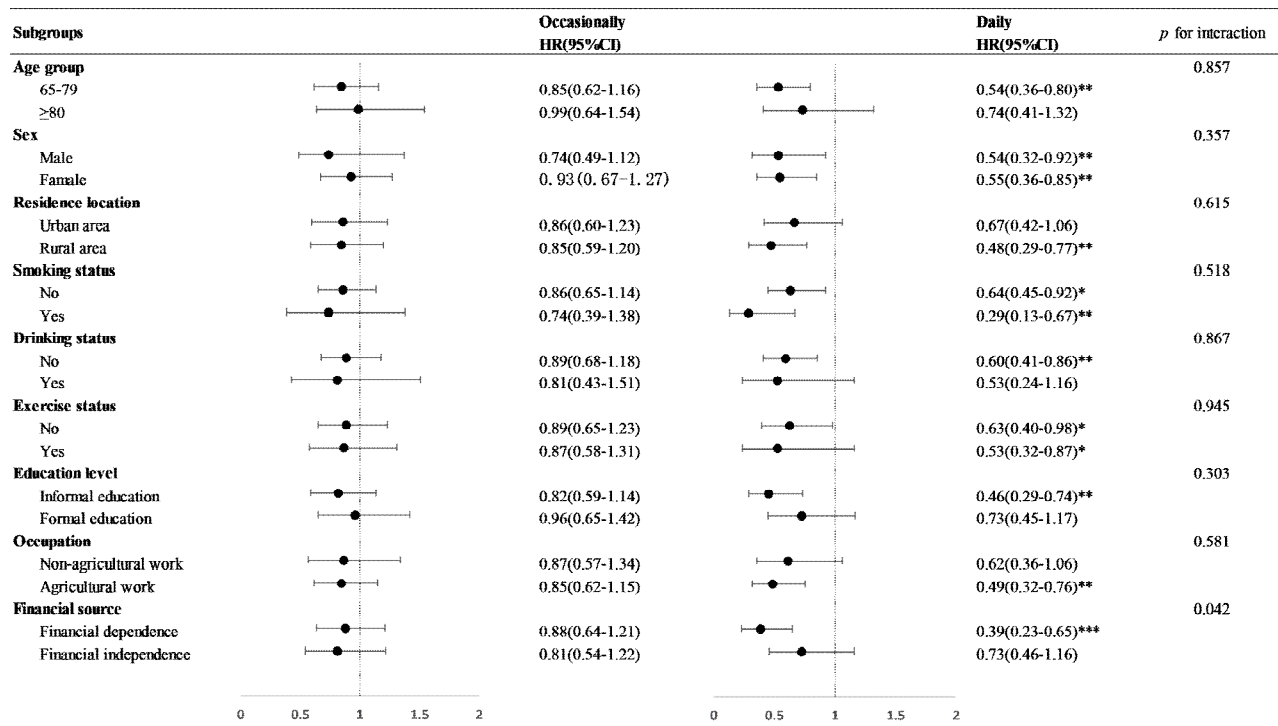


Figure 2. Association between frequency of garlic consumption and incidence of DM stratified by age, residence location, drinking status and socioeconomic status. HR: hazard ratio; CI: confidence interval. Adjusted for age, sex, residence, education level, BMI, DDS, drinking status, smoking status, exercise status, marital status, income source, occupation, and history of chronic diseases. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

studies have reported that moderate alcohol consumption can reduce the risk of DM; however, the definition of “moderate” in these studies is unclear. In addition, one of the reasons older adults choose not to drink is to maintain their health. This health awareness may encourage them to choose garlic as an affordable, healthy option. As a result, the benefits of garlic may be greater in these groups of older adults.

This study revealed that garlic consumption can significantly reduce the risk of DM in older adults who work in agriculture, receive informal education, and are financially dependent. Economic independence and daily garlic consumption synergistically reduce the risk of DM. Some epidemiological studies have shown that the prevalence of DM is higher in individuals of low socioeconomic status than in those of high socioeconomic status.^{57,58} The precise mechanism underlying the association between low socioeconomic status and an increased risk of DM is currently being researched, with key modifiable DM factors such as obesity, diet, and physical activity accounting

for 33% to 50% of the association.⁵⁹ Other factors, including hopelessness, psychosocial stress, lack of autonomy, limited access to exercise facilities, healthy food, and medical services may account for the remainder of the association.⁵⁹⁻⁶¹ Socioeconomic factors can influence dietary habits and quality.⁶² A healthy diet should include garlic. These findings corroborate our findings that older adults of relatively low socioeconomic status should consume garlic to prevent DM.

Our study is an epidemiologic study based on a representative, prospective, large-sample national sample of older adults investigating the association between garlic consumption and risk of DM. However, it has some limitations. First, our findings were based on a questionnaire on garlic consumption, which included information on garlic consumption frequency but did not include specific garlic intake information. Second, DM was self-reported by the participants, instead of being identified from medical records, which may have led to information bias. Finally, this study lacked diabetes-related information on

metabolic biochemical indicators that might affect our results.

Conclusion

The prevalence of DM is high in China, and garlic consumption is associated with a reduced risk of DM in older Chinese adults. The benefits vary by age, residence, drinking status, education, financial source, and occupation. Therefore, older adults, particularly those with limited education, financial dependence, and agricultural occupations, should consume garlic and adopt healthy lifestyle habits, such as abstaining from alcohol, to prevent DM.

ACKNOWLEDGEMENTS

The data used in this study were obtained from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), which was managed by the Peking University Center for Healthy Aging and Development Studies. This survey was jointly funded by the National Natural Science Foundation of China (No. 71233001 and 71110107025), NIH (No. R01AG023627), and United Nations Population Fund.

CONFLICT OF INTEREST AND FUNDING DISCLOSURES

The authors declare that they have no competing interests.

The work was supported by the 512 Talent training Project of Bengbu Medical College (BY51201203).

REFERENCES

- Sun H, Saeedi P, Karuranga S, Pinkepank M, Ogurtsova K, Duncan BB et al. IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. *Diabetes Res Clin Pract.* 2022;183:109119. doi: 10.1016/j.diabres.2021.109119.
- World Health Organization. *Global Report on Diabetes.* WHO; Geneva, Switzerland: 2016.
- Zhong X. Diabetes mellitus survey in China. *Chinese medical journal*, 1982, 95: 423-30. doi: 10.5555/cmj.0366-6999.95.06.p423.01
- Wang L, Gao P, Zhang M, Huang Z, Zhang D, Deng Q, et al. Prevalence and Ethnic Pattern of Diabetes and Prediabetes in China in 2013. *JAMA.* 2017;317:2515-23. doi: 10.1001/jama.2017.7596
- Wu H, Norton V, Cui K, Zhu B, Bhattacharjee S, Lu YW, et al. Diabetes and Its Cardiovascular Complications: Comprehensive Network and Systematic Analyses. *Front Cardiovasc Med.* 2022;9:841928. doi: 10.3389/fcvm.2022.841928
- Stratton IM, Adler AI, Neil HA, Matthews DR, Manley SE, Cull CA, Hadden D, Turner RC, Holman RR. Association of glycaemia with macrovascular and microvascular complications of type 2 diabetes (UKPDS 35): prospective observational study. *BMJ.* 2000;321:405-12. doi: 10.1136/bmj.321.7258.405
- Wu Y, Ding Y, Tanaka Y, Zhang W. Risk factors contributing to type 2 diabetes and recent advances in the treatment and prevention. *Int J Med Sci.* 2014 Sep 6;11:1185-200. doi: 10.7150/ijms.10001
- Kyrou I, Tsigos C, Mavrogianni C, Cardon G, Van Stappen V, Latomme J, et al; Feel4Diabetes-study Group. Socio-demographic and lifestyle-related risk factors for identifying vulnerable groups for type 2 diabetes: a narrative review with emphasis on data from Europe. *BMC Endocr Disord.* 2020;20:134. doi: 10.1186/s12902-019-0463-3
- Xia M, Liu K, Feng J, Zheng Z, Xie X. Prevalence and Risk Factors of Type 2 Diabetes and Prediabetes Among 53,288 Middle-Aged and Elderly Adults in China: A Cross-Sectional Study. *Diabetes Metab Syndr Obes.* 2021;14:1975-85. doi: 10.2147/DMSO.S305919IF
- Padiya R, Banerjee SK. Garlic as an anti-diabetic agent: recent progress and patent reviews. *Recent Pat Food Nutr Agric.* 2013;5:105-27. doi: 10.2174/18761429113059990002
- Chaudhury A, Duvoor C, Reddy Dendi VS, Kraleti S, Chada A, Ravilla R, et al. Clinical Review of Antidiabetic Drugs: Implications for Type 2 Diabetes Mellitus Management. *Front Endocrinol (Lausanne).* 2017;8:6. doi: 10.3389/fendo.2017.00006
- Nasiri A, Ziamajidi N, Behrouj H, Abbasalipourkabir R, Dehghan A. The effects of aqueous extract of chicory root on steatosis, lipid profile and liver damage enzyme markers in tamoxifen-treated rats. *Mol Biochem Diagnosis.* 2014, 1: 185-94.
- Milner JA. A historical perspective on garlic and cancer. *J Nutr.* 2001;131:1027S-31S. doi: 10.1093/jn/131.3.1027S
- Rivlin RS. Historical perspective on the use of garlic. *J Nutr.* 2001;131:951S-4S. doi: 10.1093/jn/131.3.951S
- Koch HP, Lawson LD, eds. *Garlic: the science and therapeutic application of Allium sativum L. and related species.* Lippincott Williams & Wilkins, 1996.
- Value of Agricultural Production (FAO). <http://www.fao.org/home/en/>.
- Banerjee SK, Maulik SK. Effect of garlic on cardiovascular disorders: a review. *Nutr J.* 2002;1:4. doi: 10.1186/1475-2891-1-4
- Schwingshackl L, Missbach B, Hoffmann G. An umbrella review of garlic intake and risk of cardiovascular disease. *Phytomedicine.* 2016;23:1127-33. doi: 10.1016/j.phymed.
- Myneni AA, Chang SC, Niu R, Liu L, Swanson MK, Li J, Su J, Giovino GA, Yu S, Zhang ZF, Mu L. Raw Garlic Consumption and Lung Cancer in a Chinese Population. *Cancer Epidemiol Biomarkers Prev.* 2016;25:624-33. doi: 10.1158/1055-9965.EPI-15-0760
- Turati F, Pelucchi C, Guercio V, La Vecchia C, Galeone C. Allium vegetable intake and gastric cancer: a case-control study and meta-analysis. *Mol Nutr Food Res.* 2015;59:171-9. doi: 10.1002/mnfr.201400496
- Kodali RT, Eslick GD. Meta-analysis: Does garlic intake reduce risk of gastric cancer? *Nutr Cancer.* 2015;67:1-11. doi: 10.1080/01635581.2015.967873
- Jin ZY, Wu M, Han RQ, Zhang XF, Wang XS, Liu AM, Zhou JY, Lu QY, Zhang ZF, Zhao JK. Raw garlic consumption as a protective factor for lung cancer, a population-based case-control study in a Chinese population. *Cancer Prev Res (Phila).* 2013;6:711-8. doi: 10.1158/1940-6207.CAPR-13-0015
- Ried K, Frank OR, Stocks NP, Fakler P, Sullivan T. Effect of garlic on blood pressure: a systematic review and meta-analysis. *BMC Cardiovasc Disord.* 2008;8:13. doi: 10.1186/1471-2261-8-13
- Eidi A, Eidi M, Esmaili E. Antidiabetic effect of garlic (*Allium sativum L.*) in normal and streptozotocin-induced diabetic rats. *Phytomedicine.* 2006 Nov;13:624-9. doi: 10.1016/j.phymed.2005.09.010
- Sanie-Jahromi F, Zia Z, Afarid M. A review on the effect of garlic on diabetes, BDNF, and VEGF as a potential treatment for diabetic retinopathy. *Chin Med.* 2023;18:18. doi: 10.1186/s13020-023-00725-9.
- Zeng Y. Towards Deeper Research and Better Policy for Healthy Aging --Using the Unique Data of Chinese Longitudinal Healthy Longevity Survey. *China Economic J.* 2012;5:131-49. doi: 10.1080/17538963.2013.764677.
- An R, Liu G, Khan N, Yan H, Wang Y. Dietary habits and cognitive impairment risk among oldest-old Chinese. *J.*

- Gerontol. B Psychol. Sci. Soc. Sci. 2019;74:474–83. doi: 10.1093/geronb/gbw170.
28. Feng L, Li J, Ng TP, Lee TS, Kua EH, Zeng Y. Tea drinking and cognitive function in oldest-old Chinese. *J Nutr Health Aging*. 2012;16:754–8. doi: 10.1007/s12603-012-0077-1
 29. Aihemaitijiang S, Zhang L, Ye C, Halimulati M, Huang X, Wang R, Zhang Z. Long-Term High Dietary Diversity Maintains Good Physical Function in Chinese Elderly: A Cohort Study Based on CLHLS from 2011 to 2018. *Nutrients*. 2022;14:1730. doi: 10.3390/nu14091730
 30. Shabani E, Sayemiri K, Mohammadpour M. The effect of garlic on lipid profile and glucose parameters in diabetic patients: A systematic review and meta-analysis. *Prim Care Diabetes*. 2019;13:28–42. doi:10.1016/j.pcd.2018.07.007.
 31. Liu CT, Sheen LY, Lii CK. Does garlic have a role as an antidiabetic agent?. *Mol Nutr Food Res*. 2007;51:1353–64. doi:10.1002/mnfr.200700082.
 32. Liu CT, Hse H, Lii CK, Chen PS, Sheen LY. Effects of garlic oil and diallyl trisulfide on glycemic control in diabetic rats. *Eur J Pharmacol*. 2005;516:165–73. doi:10.1016/j.ejphar.2005.04.031.
 33. Padiya R, Khatua TN, Bagul PK, Kuncha M, Banerjee SK. Garlic improves insulin sensitivity and associated metabolic syndromes in fructose fed rats. *NNutr Metab (Lond)*. 2011;8:53. doi:10.1186/1743-7075-8-53.
 34. Mathew PT, Augusti KT. Studies on the effect of allicin (diallyl disulphide-oxide) on alloxan diabetes. I. Hypoglycaemic action and enhancement of serum insulin effect and glycogen synthesis. *Indian J Biochem Biophys*. 1973;10:209–12.
 35. Kalhotra P, Chittepu V, Osorio-Revilla G, Gallardo-Velazquez T. Phytochemicals in Garlic Extract Inhibit Therapeutic Enzyme DPP-4 and Induce Skeletal Muscle Cell Proliferation: A Possible Mechanism of Action to Benefit the Treatment of Diabetes Mellitus. *Biomolecules*. 2020;10:305. doi:10.3390/biom10020305.
 36. Tripathi BK, Srivastava AK. Diabetes mellitus: complications and therapeutics. *Med Sci Monit*. 2006;12:RA130–47.
 37. Whiteman M, Gooding KM, Whatmore JL, Ball CI, Mawson D, Skinner K, Tooke JE, Shore AC. Adiposity is a major determinant of plasma levels of the novel vasodilator hydrogen sulphide. *Diabetologia*. 2010;53:1722–6. doi: 10.1007/s00125-010-1761-5
 38. Petropoulos S, Fernandes Â, Barros L, Ciric A, Sokovic M, Ferreira I. Antimicrobial and antioxidant properties of various Greek garlic genotypes. *Food Chem*. 2018;245:7–12. doi:10.1016/j.foodchem.2017.10.078.
 39. Phelps, S, Harris, WS. Garlic supplementation and lipoprotein oxidation susceptibility. *Lipids*. 1993;28:475–7. doi:10.1007/BF02535949.
 40. Moosavian SP, Arab A, Paknahad Z, Moradi S. The effects of garlic supplementation on oxidative stress markers: A systematic review and meta-analysis of randomized controlled trials. *Complement. Ther. Med*. 2020;50:102385. doi: 10.1016/j.ctim.2020.102385.
 41. Shoelson SE, Lee J, Goldfine AB. Inflammation and insulin resistance. *J Clin Invest*. 2006;116:1793–801. doi:10.1172/JCI29069.
 42. Festa A, D'Agostino R, Jr Howard G, Mykkanen L, Tracy RP, Haffner SM. Chronic subclinical inflammation as part of the insulin resistance syndrome: the Insulin Resistance Atherosclerosis Study (IRAS). *Circulation*. 2000;102:42–7. doi:10.1161/01.cir.102.1.42.
 43. Miki S, Inokuma KI, Takashima M, Nishida M, Sasaki Y, Ushijima M, Suzuki JI, Morihara N. Aged garlic extract suppresses the increase of plasma glycated albumin level and enhances the AMP-activated protein kinase in adipose tissue in TSOD mice. *Mol Nutr Food Res*. 2017;61. doi: 10.1002/mnfr.201600797
 44. Vlassara H, Brownlee M, Cerami A. Nonenzymatic glycosylation: role in the pathogenesis of diabetic complications. *Clin Chem*. 1986;32:B37–41.
 45. Ou CC, Tsao SM, Lin MC, Yin MC. Protective action on human LDL against oxidation and glycation by four organosulfur compounds derived from garlic. *Lipids*. 2003;38:219–24. doi:10.1007/s11745-003-1054-4.
 46. Huang CN, Horng JS, Yin MC. Antioxidative and anti-glycative effects of six organosulfur compounds in low-density lipoprotein and plasma. *J Agric Food Chem*. 2004;52:3674–8. doi:10.1021/jf0307292.
 47. Russo MP, Grande-Ratti MF, Burgos MA, Molaro AA, Bonella MB. Prevalence of diabetes, epidemiological characteristics and vascular complications. *Arch Cardiol Mex*. 2023;93:30–6. doi: 10.24875/ACM.21000410.
 48. Li Y, Kou C, Bai W, Hua W, Yu W, Song Y, Liu X, Li W. Trends in Diabetes Mortality by Gender in Urban and Rural Areas in China From 2003 to 2012: An Age-Period-Cohort Analysis. *Asia Pac J Public Health*. 2019;31:238–45. doi: 10.1177/1010539519841288.
 49. Zhao Y, Li HF, Wu X, Li GH, Golden AR, Cai L. Rural-urban differentials of prevalence and lifestyle determinants of pre-diabetes and diabetes among the elderly in southwest China. *BMC Public Health*. 2023;23:603. doi: 10.1186/s12889-023-15527-9.
 50. Lovic D, Piperidou A, Zografou I, Grassos H, Pittaras A, Manolis A. The Growing Epidemic of Diabetes Mellitus. *Curr Vasc Pharmacol*. 2020;18:104–9. doi: 10.2174/1570161117666190405165911.
 51. Wang Q, Zhang X, Fang L, Guan Q, Guan L, Li Q. Prevalence, awareness, treatment and control of diabetes mellitus among middle-aged and elderly people in a rural Chinese population: A cross-sectional study. *PLoS One*. 2018;13:e0198343. doi: 10.1371/journal.pone.0198343.
 52. Wang Y, Hu XJ, Wang HHX, Duan HY, Chen Y, Li YT, Luo ZL, Li X, Wang JJ, Mercer SW. Follow-up care delivery in community-based hypertension and type 2 diabetes management: a multi-centre, survey study among rural primary care physicians in China. *BMC Fam Pract*. 2021;22:224. doi: 10.1186/s12875-021-01564-z.
 53. Mozaffarian D, Kamineni A, Carnethon M, Djoussé L, Mukamal KJ, Siscovick D. Lifestyle risk factors and new-onset diabetes mellitus in older adults: the cardiovascular health study. *Arch Intern Med*. 2009;169:798–807. doi:10.1001/archinternmed.2009.21.
 54. Holley DC, Bagby GJ, Curry DL. Ethanol-insulin interrelationships in the rat studied in vitro and in vivo: evidence for direct ethanol inhibition of biphasic glucose-induced insulin secretion. *Metabolism*. 1981;30:894–9. doi:10.1016/0026-0495(81)90068-8.
 55. Tiengo A, Valerio A, Molinari M, Meneghel A, Lapolla A. Effect of ethanol, acetaldehyde, and acetate on insulin and glucagon secretion in the perfused rat pancreas. *Diabetes*. 1981;30:705–9. doi:10.2337/diab.30.9.705.
 56. Yki-Järvinen H, Nikkilä EA. Ethanol decreases glucose utilization in healthy man. *J Clin Endocrinol Metab*. 1985;61:941–5. doi:10.1210/jcem-61-5-941.
 57. Robbins JM, Vaccarino V, Zhang H, Kasl SV. Socioeconomic status and type 2 diabetes in African American and non-Hispanic white women and men: evidence from the Third National Health and Nutrition Examination Survey. *Am J Public Health*. 2001;91:76–83. doi:10.2105/ajph.91.1.76.
 58. Stelmach W, Kaczmarczyk-Chałas K, Bielecki W, Drygas W. How education, income, control over life and life style

- contribute to risk factors for cardiovascular disease among adults in a post-communist country. *Public health*. 2005;119:498–508. doi:0.1016/j.puhe.2004.09.006.
59. Spencer Bonilla G, Rodriguez-Gutierrez R, Montori VM. What we Don't talk about when we talk about preventing type 2 diabetes-addressing socioeconomic disadvantage. *JAMA Intern Med*. 2016;176:1053–4. doi:10.1001/jamainternmed.2016.2952.
60. Volaco A, Cavalcanti AM, Filho RP, Prêcoma DB. Socioeconomic status: the missing Link between obesity and diabetes mellitus? *Curr Diabetes Rev*. 2018;14:321–6. doi:10.2174/1573399813666170621123227.
61. Espelt A, Arriola L, Borrell C, Larrañaga I, Sandín M, Escolar-Pujolar A. Socioeconomic position and type 2 diabetes mellitus in Europe 1999-2009: a panorama of inequalities. *Curr Diabetes Rev*. 2011;7:148–58. doi:10.2174/157339911795843131.
62. Backholer K, Spencer E, Gearon E, Magliano DJ, McNaughton SA, Shaw JE, Peeters A. The association between socio-economic position and diet quality in Australian adults. *Public Health Nutr*. 2016;19:477-85. doi:10.1017/S136898001500147.