



## OPEN ACCESS

## EDITED BY

Mainul Haque,  
National Defense University of  
Malaysia, Malaysia

## REVIEWED BY

Maria Morales Suare-Varela,  
University of Valencia, Spain  
Rahnuma Ahmad,  
Medical College for Women and  
Hospital, Bangladesh  
Susmita Sinha,  
Khulna City Medical College and  
Hospital, Bangladesh  
Kona Chowdhury,  
Gonoshathaya Samaj Vittik Medical  
College, Bangladesh

## \*CORRESPONDENCE

Zhihui Li  
zhihui.li@mail.tsinghua.edu.cn  
Ai Zhao  
aizhao18@tsinghua.edu.cn

## SPECIALTY SECTION

This article was submitted to  
Nutritional Epidemiology,  
a section of the journal  
Frontiers in Nutrition

RECEIVED 19 July 2022

ACCEPTED 31 August 2022

PUBLISHED 26 September 2022

## CITATION

Yang Y, Na X, Xi Y, Xi M, Yang H, Li Z  
and Zhao A (2022) Association  
between dairy consumption and the  
risk of diabetes: A prospective cohort  
study from the China Health and  
Nutrition Survey. *Front. Nutr.* 9:997636.  
doi: 10.3389/fnut.2022.997636

## COPYRIGHT

© 2022 Yang, Na, Xi, Xi, Yang, Li and  
Zhao. This is an open-access article  
distributed under the terms of the  
[Creative Commons Attribution License  
\(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or  
reproduction in other forums is  
permitted, provided the original  
author(s) and the copyright owner(s)  
are credited and that the original  
publication in this journal is cited, in  
accordance with accepted academic  
practice. No use, distribution or  
reproduction is permitted which does  
not comply with these terms.

# Association between dairy consumption and the risk of diabetes: A prospective cohort study from the China Health and Nutrition Survey

Yucheng Yang<sup>1,2</sup>, Xiaona Na<sup>1,2</sup>, Yuandi Xi<sup>3</sup>, Menglu Xi<sup>1,2</sup>,  
Haibing Yang<sup>1,2</sup>, Zhihui Li<sup>1,2\*</sup> and Ai Zhao<sup>1,2\*</sup>

<sup>1</sup>Vanke School of Public Health, Tsinghua University, Beijing, China, <sup>2</sup>Institute for Healthy China, Tsinghua University, Beijing, China, <sup>3</sup>School of Public Health, Capital Medical University, Beijing, China

Diet is closely related to the risk of diabetes; yet the relationship between dairy consumption and the risk of diabetes is unclear with conflicting evidence from previous studies. This study used data from the China Health and Nutrition Survey to investigate the association between dairy consumption and diabetes. A total of 15,512 adults were included; dairy consumption at each survey was assessed by the 3-day 24-h recall and weighed food record methods, and diabetes occurrence was derived from self-reported information. The association between dairy consumption and diabetes was explored using Cox regression and further stratified with BMI and energy intake. Results indicated that 12,368 (79.7%) participants had no dairy consumption, while 2,179 (14.0%) and 947 (6.1%) consumed dairy at 0.1–100 and >100 g/day, respectively. After adjusting for potential confounders, dairy consumption of 0.1–100 g/day was associated with lower risk of diabetes in all participants (HR 0.53, 95% CI: 0.38–0.74;  $P < 0.001$ ) and males (HR 0.50, 95% CI: 0.31–0.80;  $P = 0.004$ ). According to the restricted cubic splines (RCS), the protective effect on diabetes was significant in the total population with dairy consumption ranging from 25 to 65 g/day (HR  $< 1$ ,  $P = 0.025$ ). In the stratified analysis, consuming 30–80 g/day was associated with reduced diabetes risk among the  $\leq 2,000$  kcal/day energy intake group (HR  $< 1$ ,  $P = 0.023$ ). In conclusion, dairy consumption was inversely associated with a reduced diabetes risk in Chinese population. Further studies are required to examine the optimal level of dairy consumption for preventing diabetes in the Chinese population.

## KEYWORDS

dairy consumption, milk, BMI, energy intake, diabetes

## Introduction

Diabetes affected the health of approximately 425 million people worldwide in 2015, and it is estimated that this number will increase to 629 million by 2040 (1). In China, the total number of diabetic patients was about 109.6 million, accounting for 10.6% of China's total population (2). The risk factors for diabetes are complex, including obesity, family genetics, lifestyle, and diet (3, 4). Growing evidence has suggested that dietary and nutritional factors, including dairy consumption, may play an important role in the development of diabetes (5, 6).

Dairy is a source of human nutrition and plays an important role in a balanced diet (7, 8). Several epidemiological studies have shown that high consumption of dairy may have protective effects against cancer, coronary heart disease, and all-cause mortality (9–12). Previous studies revealed that dairy can promote weight loss and improve body composition in adults, and it likely contributes to reducing the risk of diabetes (13, 14). However, recent epidemiologic studies on the association between dairy consumption and diabetes have shown conflicting results. A systematic review and meta-analysis showed that higher consumption of dairy was positively associated with diabetes, but this association was found only in Asian and Australian populations, not American and European populations (6). Nevertheless, a study that followed 3,454 middle-aged and elderly Spanish populations found that high consumption of dairy products, especially yogurt, was beneficial in preventing diabetes (15). A study of three large prospective cohort studies in the US evaluated the relationship between dairy consumption and diabetes found that yogurt was associated with a lower risk of diabetes, whereas cheese had the opposite effect (16). Another study on Dutch adults showed that dairy consumption was not associated with diabetes (17).

Different from western countries, dairy products are rarely included in traditional Chinese diets. With the rapid advancement of urbanization, the consumption of dairy products by Chinese residents has been increasing. We hypothesized there is a benefit of dairy consumption on diabetes prevention in the Chinese population. To test this hypothesis, data from a nationwide, prospective cohort study with long-term follow-up was used to explore the associations between dairy consumption and diabetes in the Chinese population. In addition, whether BMI and energy intake affect the relationship between dairy consumption and diabetes or not was further examined.

## Materials and methods

### Study design and participants

This study was a secondary analysis of data collected from an ongoing prospective cohort study named China Health

and Nutrition Survey (CHNS) (18), which completed ten rounds from 1989 to 2015. All data for this study are publicly available on the website <http://www.cpc.unc.edu/projects/china>. All participants signed informed consent before enrolling in the study. This study was approved by the National Institute of Nutrition and Food Safety (China) and the institutional review committees of the University of North Carolina (USA).

Since the dietary data codes for 1989 and 1993 were not identifiable from the CHNS database, in this study, we used the data collected from this longitudinal open cohort study in 1997, 2000, 2004, 2006, 2009, 2011, and 2015. Because the year of participants entering the cohort was varied, the time each participant entered the cohort was the individual's baseline. By the end of 2015, there were 26,896 available participants in the CHNS, who had not been diagnosed with diabetes at baseline. We excluded participants younger than 18 years old at baseline ( $n = 7,165$ ), participants with missing complete dietary data ( $n = 33$ ), participants who had a total energy intake  $<500$  or  $>4,500$  kcal/day ( $n = 30$ ), participants with a body mass index (BMI)  $> 40\text{kg/m}^2$  ( $n = 459$ ), and participants with fewer than two visits in this study ( $n = 3,697$ ). Finally, we included 15,512 adults in our study from 1997 to 2015 (Figure 1).

### Definition of diabetes

In our study, the outcome variable was primarily defined as self-reported diabetes. Diabetes was identified by one question in the questionnaire: 'Has your doctor ever told you that you have diabetes?' If the participant answered: 'Yes,' then proceeded to ask: 'How old were you when you were diagnosed with diabetes?'

### Covariates at baseline

The baseline questionnaire included questions on socio-demographic, lifestyle factors, and health-related information. Socio-demographic characteristics were specifically included as follows: age, gender, income, education level, and living area; lifestyle factors including smoking status and physical activity; health-related information including BMI and disease history. BMI was calculated as weight divided by height squared ( $\text{kg/m}^2$ ). Physical activity included occupational physical activity, transportation physical activity, leisure time physical activity, and housework physical activity (19). Each participant's metabolic equivalent time of physical activity (MET hours/week) was calculated in weeks based on the allocation of metabolic equivalents (MET). Disease history was defined as having at least one of the following diseases: hypertension, myocardial infarction, stroke, and cancer.

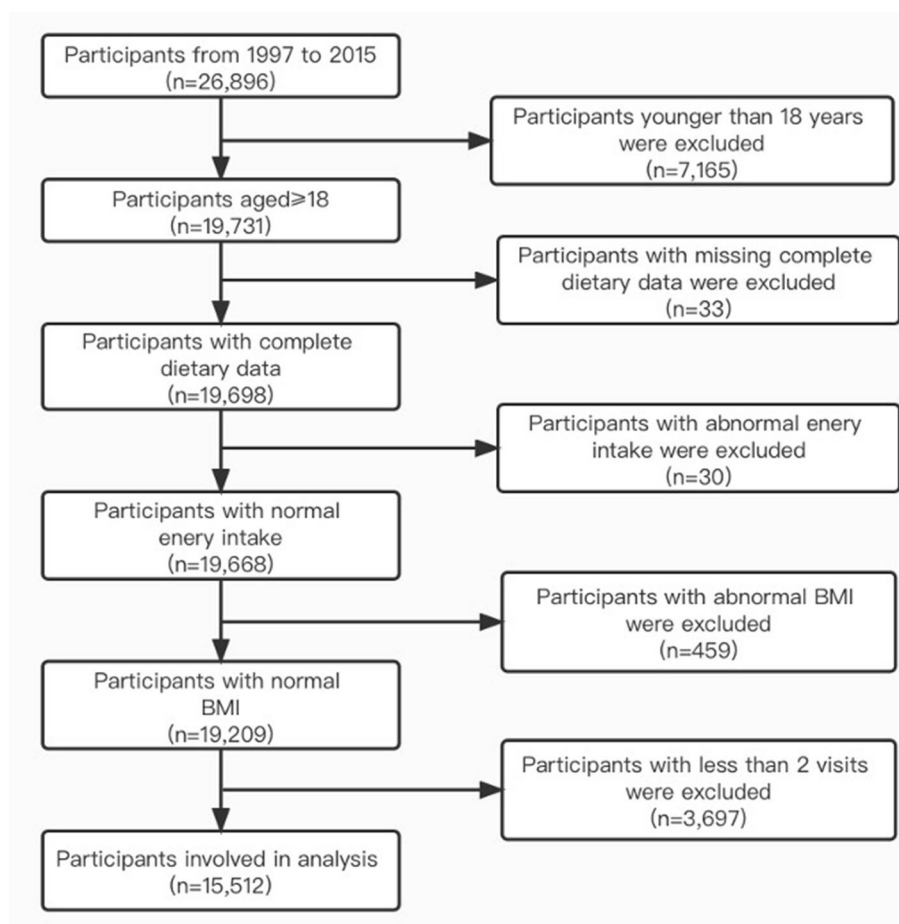


FIGURE 1  
Flow chart of participant selection.

## Dietary consumption information

The three-day (including two working days and one weekend day) 24-h recall was used to collect dietary data at the individual level. Participants were required to recall food intake except for oil, salt, and condiments within 24 h before the survey. The consumption of oil, salt, and condiments were investigated at the household level by weighing accounting method and further divided into individuals according to the person to family energy consumption ratio (20). The Chinese Food Composition Table (1991 (21), 2004 (22), and 2009 (23) editions) was referenced to calculate the energy and nutrient intake of individuals. Dairy consumption was defined as the total consumption of liquid milk, powdered milk, yogurt, and other dairy products such as cream and cheese. In this study, the average consumption of dairy from 1997 to 2015 was calculated based on a 3-day 24-h recall. Dairy consumption was divided into three groups: no consumption, 0.1–100 g/day, and >100 g/day.

## Statistical analysis

Statistical analyses were performed using R version 4.1.1, a two side  $P$ -value < 0.05 considered to be statistically significant. The median and 25th and 75th quartiles were used to describe the non-normally distributed numerical variables, and frequency and percentage were used to describe the categorical variables. Chi-squares ( $\chi^2$ ) tests and one-way analysis of variance (ANOVA) were used to compare baseline characteristics of the total study population according to the dairy consumption level. The association between dairy consumption and diabetes was explored using Cox proportion hazard regression and further stratified by gender. The Cox proportion hazard regression included three models: Model 1 didn't adjust for any confounder; Model 2 adjusted for age, gender, education level, living area, income, smoking status, BMI, disease history, and physical activity; Model 3 further adjusted for intake of vegetables, fruit, meat, alcohol, carbohydrate, and energy based on Model 2. The non-linear

association between dairy consumption and diabetes was also evaluated using Cox models with restricted cubic splines (RCS). We further examined the stratified analysis to identify the potential effects among participants with different BMI and energy intake levels. To verify the robustness of our research data, we did a sensitivity analysis to exclude participants who died within 2 years of the baseline survey.

## Result

### Baseline characteristics of the participants

Table 1 shows the baseline characteristics of the participants. Among the 15,512 participants included in this study, the mean age of participants was 43.4 years; 7,376 (47.6%) were males. In total, 12,368 (79.7%) of the participants had no dairy consumption in eight rounds of the survey from 1997 to 2015. Of participants with dairy consumption, 2,179 (14.0%) and 947 (6.1%) consumed 0.1–100 g/day and >100 g/day dairy, respectively. Participants with higher consumption were older, had smoked, and had lower levels of education and income; meanwhile, BMI and physical activity levels tended to increase with dairy consumption. In addition, statistical differences in age, gender, living area, and disease history were also significant.

### Dietary intake characteristics of the participants

Table 2 shows the dietary intake characteristics of the participants. Foods and nutrients consumption among the three groups were statistically significant. Compared with the no consumption group, participants with the highest dairy consumption had a higher intake of meat, eggs, protein, and calcium, but lower consumption of cereals, carbohydrates, and energy. Furthermore, participants with higher dairy consumption generally had a lower intake of fruits, fats, and dairy calcium, but a higher intake of vegetables.

### Association between dairy consumption and risk of diabetes

Table 3 shows the associations between dairy consumption and diabetes. During a median follow-up of 9.0 years, a total of 390 (2.5%) diabetes cases were newly diagnosed. No association was found between dairy consumption and diabetes in the crude model. After multivariable adjustment (Model 2), an inverse association was observed between consuming 0.1–100 g/day of dairy and diabetes (HR 0.53, 95% CI: 0.38–0.74;  $P < 0.001$ ); a similar relationship was observed in Model 3 (HR 0.60, 95% CI:

0.43–0.86;  $P = 0.005$ ) in which food and nutrient consumption was further adjusted. However, among those who consumed >100 g/day of dairy, dairy consumption was not associated with the risk of diabetes.

In the gender stratified analysis, there were no associations between dairy consumption and diabetes in females. However, after multivariable adjustment (Model 2), consuming 0.1–100 g/day of dairy was related to a lower risk of diabetes in comparison to no dairy consumption in males (HR 0.50, 95% CI: 0.31–0.80;  $P = 0.004$ ), and the similar relationship was observed in Model 3 (HR 0.61, 95% CI: 0.37–0.98;  $P = 0.044$ ).

### Non-linear association between dairy consumption and risk of diabetes

The non-linear relationships between dairy consumption and diabetes among the overall population and certain populations are shown in Figure 2. Among the total participants, dairy consumption of about 25–65 g/day was associated with a decreased risk of diabetes (HR < 1,  $P = 0.025$ ), then the risk of diabetes increased with increasing consumption. In the subgroup analysis, there was no association between dairy consumption and the incidence of type 2 diabetes at different BMI levels. Among those with an energy intake of  $\leq 2,000$  kcal/day, dairy consumption of about 30–80 g/day was associated with a decreased risk of diabetes (HR < 1,  $P = 0.023$ ), but no association was observed in the higher energy intake groups.

### Sensitivity analysis

In the sensitivity analysis (Supplementary Table 1), we excluded participants who died within 2 years of the baseline survey. Among all participants and male participants, the associations between dairy consumption on average and diabetes were similar to the results shown in Table 3. However, for female participants, compared with the no consumption group, there was an additional positive association between consuming 0.1–100 g/day of dairy and diabetes (HR 0.55, 95% CI: 0.34–0.88;  $P = 0.013$ ) in Model 2.

## Discussion

In the current study, we investigated the association between dairy consumption and diabetes among Chinese adults. We found that, in 15,512 individuals, there was a non-linear association between dairy consumption and diabetes. Those who consumed 0.1–100 g/day of dairy were positively associated with diabetes compared to the no dairy consumption group.

TABLE 1 Baseline characteristics of the participants by levels of dairy consumption.

	Dairy consumption			P
	No consumption N = 12,386	0.1–100g/day N = 2,179	>100g/day N = 947	
Age, M (P25, P75)	41.0 [31.0,53.0]	43.0 [33.0,54.0]	50.0 [37.0,61.0]	<0.001
Gender, n (%)				<0.001
Male	6,008 (81.5%)	976(13.2%)	392 (5.31%)	
Female	6,378 (78.4%)	1203 (14.8%)	555 (6.82%)	
Education level, n (%)				<0.001
Junior high school or below	9,820 (86.7%)	1,134 (10.0%)	372 (3.28%)	
Senior high school or vocational school	2,071 (65.9%)	747 (23.8%)	325 (10.3%)	
University or above	484 (46.9%)	298 (28.9%)	250 (24.2%)	
Living area, n (%)				<0.001
East	4,022 (68.2%)	1,152 (19.5%)	725 (12.3%)	
Central	4,937 (85.6%)	746 (12.9%)	85 (1.47%)	
West	3,427 (89.1%)	281 (7.31%)	137 (3.56%)	
Income, yuan, n (%)				<0.001
<30,000	10,834 (81.2%)	1,871 (14.0%)	631 (4.73%)	
≥30,000	706 (61.3%)	216 (17.4%)	264 (21.3%)	
Smoking status, n (%)				<0.001
Never	8,305 (78.5%)	1,538 (14.5%)	736 (6.96%)	
Yes	4,079 (82.8%)	640 (13.0%)	2,110(4.26%)	
BMI, kg/m <sup>2</sup> , M (P25, P75)	22.3 [20.4,24.7]	23.0 [21.0,25.3]	23.4 [21.2,25.6]	<0.001
Physical activity, MET-hour/week, M (P25, P75)	130 [0.00,613]	180 [11.6,577]	501 [120,1,293]	<0.001
Disease history a, n (%)				<0.001
No	9,530 (81.0%)	12,569 (13.3%)	672 (5.71%)	
Yes	2,856 (76.3%)	610 (16.3%)	275 (7.35%)	

<sup>a</sup>Disease history included hypertension, myocardial infarction, stroke, and cancer.

The protective effect on diabetes was most significant in the population with dairy consumption ranging from 25 to 65 g/day.

Our finding on the positive association between dairy consumption and risk of diabetes was supported by previous studies in Western populations, such as European Prospective Investigation into Cancer and Nutrition (EPIC) and Mediterranean populations (24–26). However, several studies have reported that higher dairy consumption can reduce the risk of diabetes (27, 28), this is contrary to our findings. This inconsistency may be attributed to differences in Chinese and Western dietary habits. Among the Chinese population, dairy consumption is generally low, and limited types of dairy are consumed. In this study, dairy products mainly included liquid milk, milk powder, yogurt, and other dairy products. But in the above studies, the definitions of dairy products were different: some included milk beverages or cream and ice cream (24, 26). On the other hand, the inconsistent results may be because of the potential confounders considered in different studies. In the current study, after further adjusting the baseline and dietary variables (model 3), the protective associations we expected were not observed, which may support the notion that the nutrients

in dairy are the key protective factor regarding diabetes. In addition, it is generally believed that dairy consumption is associated with a healthier diet and a better lifestyle (29); the disappearance of the protective effect of dairy consumption on diabetes after adjusting for dietary factors may also be related.

The protective mechanism of dairy consumption on diabetes can be explained from the following aspects (Figure 3) (30–42). Firstly, dairy contains high amounts of essential micronutrients for our body, such as vitamin D, calcium, and magnesium, which can affect insulin sensitivity. Vitamin D may benefit pancreatic  $\beta$  cell function, and calcium and magnesium could both improve insulin sensitivity, thereby helping to improve insulin secretion, which is conducive to the control of blood glucose levels (30, 31). Secondly, whey protein and casein are the two most abundant proteins in dairy, of which whey protein can increase the concentration of amino acids after digestion and promote insulin secretion (32). Whey protein can also improve energy intake balance and promote weight loss, thereby affecting the development of diabetes (33, 34). Furthermore, leucine is an essential amino acid in protein, recent evidence points to the possibility that mitochondrial dysfunction may lead

TABLE 2 Dietary intake characteristics of the participants by levels of dairy consumption. Median (P25, P75).

	No consumption N = 12,368	0.1–100g/day N = 2,179	> 100g/day N = 947	P
<b>Food consumption</b>				
Vegetables intake, g/day	215 [138,300]	205 [144,279]	240 [171,327]	<0.001
Fruit intake, g/day	0.00 [0.00,37.2]	46.7 [4.44,100]	100 [33.3,180]	<0.001
Meat intake, g/day	38.3 [10.0,74.4]	56.7 [31.5,91.6]	70.0 [36.7,110]	<0.001
Cereal intake, g/day	275 [192,367]	245 [185,314]	250 [193,327]	<0.001
Egg intake, g/day	13.3 [0.67,26.7]	25.7 [12.8,40.7]	36.8 [20.0,60.0]	<0.001
Alcohol intake, g/week	0.00 [0.00,579]	0.00 [0.00,600]	0.00 [0.00,181]	<0.001
<b>Energy and nutrient consumption</b>				
Carbohydrate intake, g/day	300 [242,361]	258 [216,300]	223 [174,275]	<0.001
Fat intake, g/day	65.5 [49.6,83.9]	77.1 [61.8,94.7]	75.2 [57.8,95.4]	<0.001
Protein intake, g/day	63.4 [53.2,74.6]	67.8 [57.9,79.5]	71.6 [58.5,85.2]	<0.001
Energy intake, kcal/day	2,098 [1,772, 2,444]	2,037 [1,751, 2,337]	1,904 [1,577, 2,216]	<0.001
Total calcium intake, g/day	343 [273,435]	414 [338,505]	579 [470,731]	<0.001
Dairy calcium intake, g/day	0.00 [0.00,0.00]	39.3 [16.3,68.8]	173 [136,236]	<0.001

TABLE 3 HRs (95% CIs) of diabetes risk according to dairy consumption.

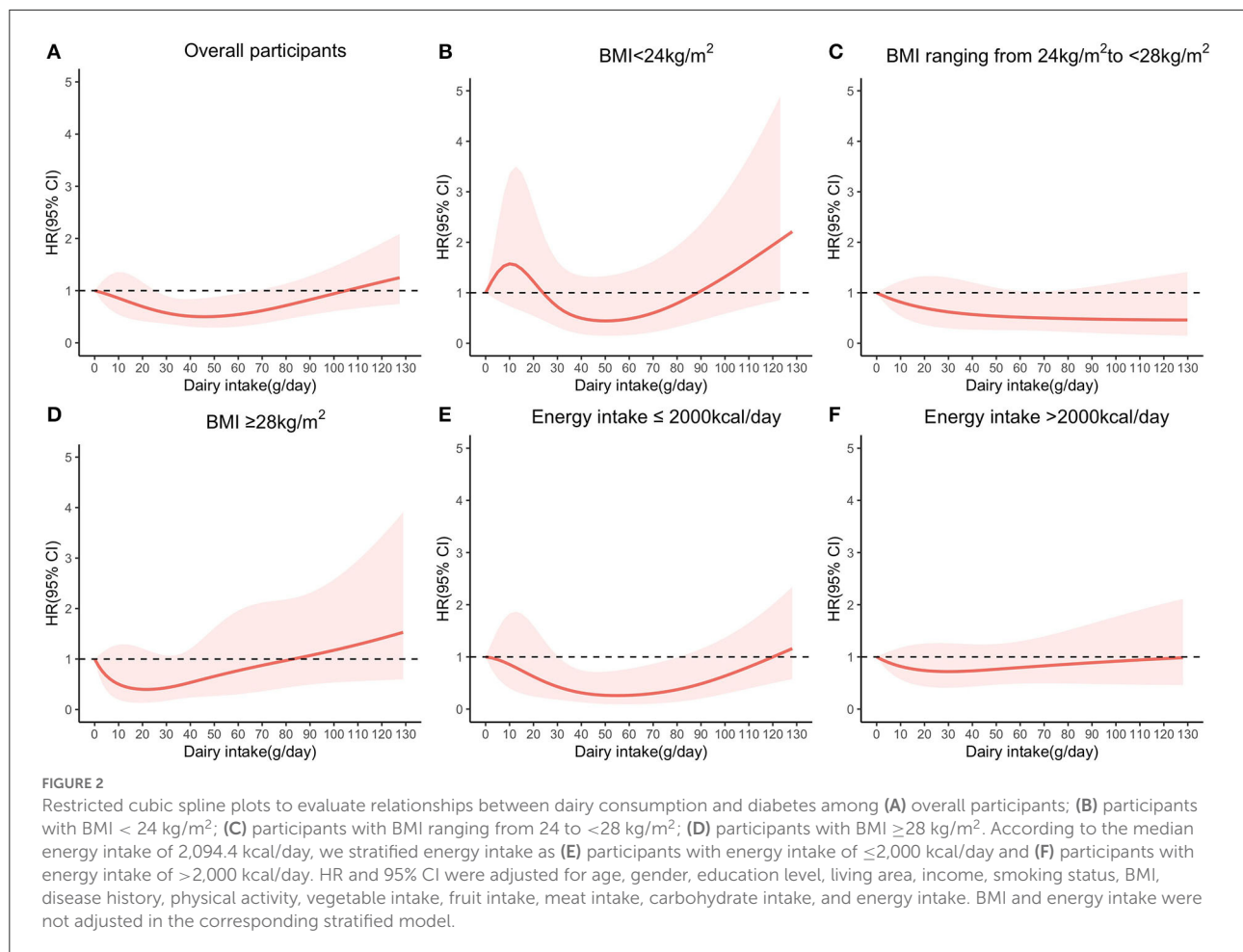
	No consumption	0.1–100g/day	P	> 100g/day	P
<b>All participants</b>					
Case/n	327/12,386	44/2,179		19/947	
Model 1	1.00 (Reference)	0.76 [0.56, 1.05]	0.095	1.52 [0.96, 2.43]	0.076
Model 2	1.00 (Reference)	0.53 [0.38, 0.74]	<0.001	0.96 [0.57, 1.57]	0.865
Model 3	1.00 (Reference)	0.62 [0.44, 0.88]	0.008	1.516 [0.88, 2.61]	0.132
<b>Male</b>					
Case/n	164/6,008	22/976		8/392	
Model 1	1.00 (Reference)	0.82 [0.52, 1.28]	0.376	1.47 [0.72, 3.01]	0.289
Model 2	1.00 (Reference)	0.50 [0.31, 0.80]	0.004	0.82 [0.39, 1.75]	0.610
Model 3	1.00 (Reference)	0.61 [0.37, 0.98]	0.044	1.32 [0.60, 2.93]	0.488
<b>Female</b>					
Case/n	163/6,378	22/1,203		11/555	
Model 1	1.00 (Reference)	0.72 [0.46, 1.12]	0.149	1.58 [0.85, 2.93]	0.146
Model 2	1.00 (Reference)	0.55 [0.34, 0.89]	0.146	1.10 [0.55, 2.18]	0.791
Model 3	1.00 (Reference)	0.66 [0.11, 1.09]	0.109	1.57 [0.74, 3.37]	0.290

Model 1 had no adjustment for confounders; Model 2 adjusted for age, gender, education level, living area, income, smoking status, BMI, disease history, and physical activity; Model 3 was based on Model 2 and further adjusted for intake of vegetables, fruit, meat, alcohol, carbohydrate, and energy.

to insulin resistance, and the leucine of dairy could promote mitochondrial production and increase the body’s antioxidant capacity, which provides a possible way to relieve insulin resistance (35–38). Thirdly, the oligosaccharides contained in dairy can promote the growth of bifidobacterium growth in the gut, and bifidobacterium has the effect of inhibiting obesity (39), which is an important cause of diabetes. Additionally, in a rodent study, mice fed a high-dairy diet reduced the number of obesity-causing bacteria such as *Desulfovibrio* and *Bacteroidetes* (40), which can affect the development of diabetes. Consumption

of dairy products can also increase the number of butyrate-producing bacteria in the Firmicutes phylum. Butyrate is an anti-inflammatory short-chain fatty acid that regulates gut health and improves beta cell function, thereby reducing insulin resistance (41, 42).

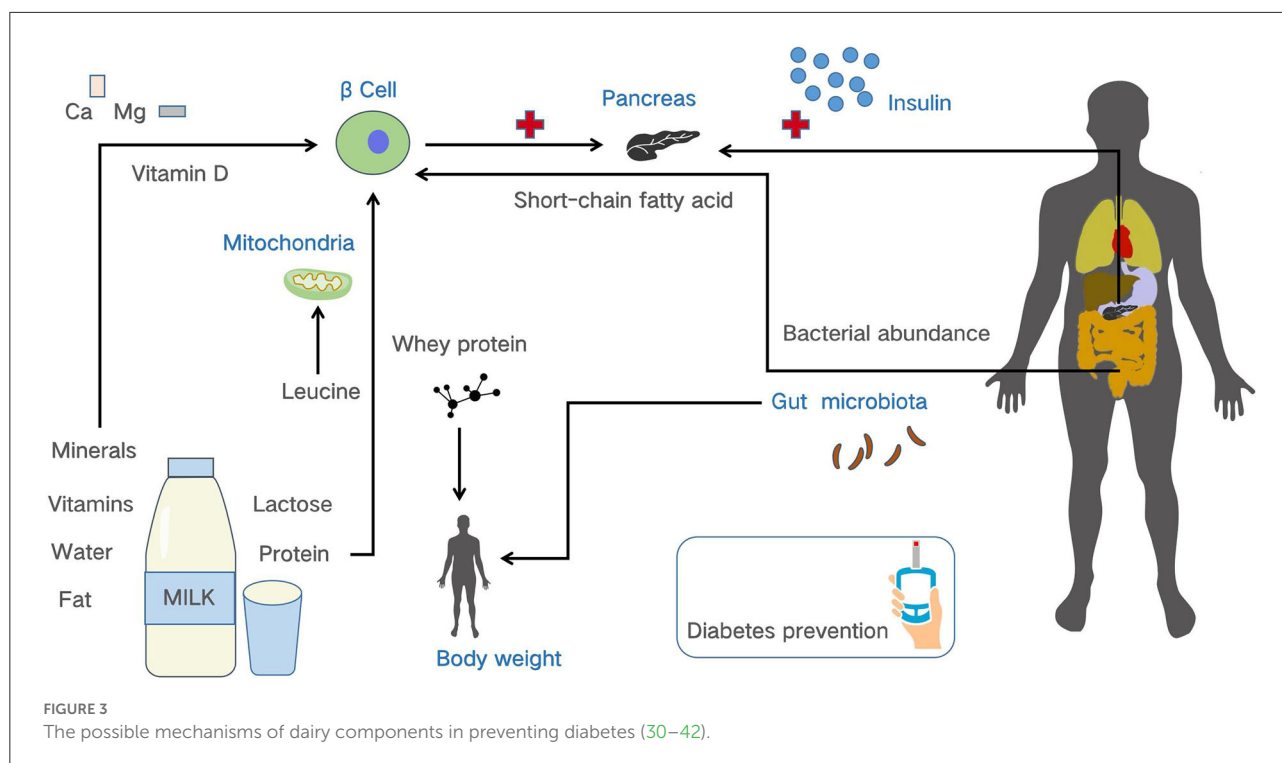
A dose-response meta-analysis suggested a linear inverse association between low-fat dairy and diabetes (43). However, in our study, we found a non-linear relationship between dairy consumption and diabetes. The protective effect was only observed in those who consumed 0.1–100 g/day of dairy



in adjusted Model 2; when participants' dairy consumption exceeded 100 g/day, no association was observed. More particularly, the RCS Cox regression in the current study further revealed that the consumption of 25–65 g/day of dairy might be associated with reduced diabetes risk. Previous research has pointed out that dairy may have adverse health effects when consumed in excess (12, 44, 45). This association may be due to the increased risk of hormone-dependent diseases caused by animal oestrogens in dairy (45, 46). A previous study in India also demonstrated that ingestion of excessive dairy could reduce the insulin sensitivity of individuals, thereby affecting the risk of diabetes (47). Moreover, higher dairy consumption is accompanied by greater energy intake, which increases body weight and therefore may increase the risk of developing diabetes (48). In the stratified analysis, we also found a significant inverse association between dairy consumption and diabetes risk in the ≤ 2,000 kcal/day energy intake group, which supports the previous view that there is a close relationship among dairy consumption, energy intake, and the risk of diabetes (49).

It should be noted that the recommended amounts for dairy consumption in the dietary guidelines of the US and Australia are 710 ml and 500 g, respectively (50, 51). According to the Chinese Dietary Guidelines (2016) (52), the recommended consumption of dairy products is 300 g/day, while the latest Chinese Dietary Guidelines (2022) revised the recommended consumption of dairy products to 300–500 g (53). According to the RCS analysis, the risk of diabetes was reduced only with 25–65 g/day of dairy consumption in the total population. Similar to the results of a previous study conducted in a Chinese population, higher dairy consumption was not necessarily better (12). Although according to the current Chinese study, there is still a great gap between dairy consumption (average consumption is 12 g/d) and recommendation (53), it is time to seriously consider the most optimal consumption level of dairy for varied populations. The recommended consumption of dairy for the Chinese population may require further verification.

In the stratified analyses, we found that the association between dairy consumption and diabetes also differed by gender. Among males, those who consumed 0.1–100 g/day of dairy had a significantly lower risk of diabetes in adjusted Models, which was



similar results to the Health Examinees (HEXA) study among Korean adults (54). However, a study of 2,375 males aged 45–59 years found no association between the consumption of dairy and the risk of diabetes (55). Interestingly, a cross-sectional study in Qingdao, China found that an inverse relationship between diabetes prevalence and dairy consumption in females (56), but not in males, which is the exact opposite of our findings. Prolactin is involved in regulating glucose homeostasis and insulin sensitivity (57). For females under the action of body hormones, the hormonal effects of dairy may not be significant; however, this active substance may affect the risk of diabetes in males. The gender differences due to different socio-cultural characteristics and dietary structures also differ between males and females. A prospective study among black women in the U.S. found no link between yogurt and diabetes because the association was attenuated after controlling for healthy eating behaviors associated with yogurt consumption (58). However, our study did not measure hormone levels in each participant and dairy, and there is insufficient evidence to determine whether dairy consumption changed insulin levels. In conclusion, further research is needed to clarify the distinctive effect of dairy consumption on the risk of diabetes in different genders.

Obesity is closely related to chronic non-communicable diseases, including diabetes (48, 59). Several studies have revealed the certain role of obesity in the chain of association between dairy consumption and obesity. Recent studies has found that neither whole milk nor low-fat milk was associated

with weight change, and cheese consumption may be beneficial for lowering BMI (60). A prospective cohort study of postmenopausal women found an inverse relationship between low dairy consumption and diabetes; this relationship was more pronounced in the high BMI group (61). One animal study revealed the possible mechanism that dairy products can modulate the gut microbiota and circulate metabolites, resulting in weight loss (40). However, there is no evidence in our study that dairy consumption was associated with the risk of diabetes in different BMI categories (<24, from 24 to <28,  $\geq 28$  kg/m<sup>2</sup>), which could necessitate further investigation to verify.

## Limitation

To our knowledge, this is the first report that there is a non-linear association between dairy consumption and diabetes in the Chinese population. However, several limitations of the current study should be noted. First, the determination of the outcome variable was based on self-reported diabetes rather than biochemical indicators. In CHNS, the blood samples of the participants were only collected in 2009 and limited biomarkers were measured, which does not allow us to diagnose diabetes, hence the incidence of diabetes among the overall population may be underestimated. Moreover, we did not distinguish between types of diabetes, and the incidence of specific types of diabetes and its association with dairy consumption could not be observed. Second, due to the low consumption of dairy in the



Chinese population, we did not distinguish between dairy types when analyzing the relationship between dairy consumption and diabetes, which may lead to inconsistencies between our findings and those of previous studies. Previous research pointed out that the relationship between dairy and diabetes appears to be related to dairy type (60). Besides, the proportions of micronutrients in different processed dairy products are varied (8, 62), therefore the mis-classification bias may not be ruled out in the current study. Third, dietary intake in this study was estimated from three dietary recall questionnaires, which may not represent long-term intake well and may suffer from recall bias. Furthermore, with the development of the economy, the consumption of dairy increases, and the dynamic changes of dairy consumption with age may also contribute to the development of diabetes. Finally, although our models adjusted for many covariates and the sensitivity analysis showed that the results were stable, the relationship between dairy consumption and diabetes might be ascribed to other potential residual confounding bias, such as genetic backgrounds of diabetes and other environmental factors.

## Conclusion

In conclusion, we found that moderate consumption of dairy can help reduce the risk of diabetes in the Chinese population. As the effects of dairy consumption on the health of different populations are not uniform, our study provides new insights that require careful consideration of the optimal consumption amount of dairy for diabetes prevention.

## Recommendation

In view of the findings of this current study and the dietary habits of the Chinese population, we suggest that moderate consumption of dairy in daily life in the Chinese population may be an effective lifestyle intervention for the prevention of diabetes. In addition, the energy from dairy should be taken into consideration, and balanced energy in the daily diet should be achieved.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/[Supplementary material](#).

## Ethics statement

The studies involving human participants were reviewed and approved by the National Institute

of Nutrition and Food Safety (China) and the institutional review committees of the University of North Carolina (USA). The patients/participants provided their written informed consent to participate in this study.

## Author contributions

YY: conceived the idea. YY and XN: performed the statistical analyses and designed the study. YY, ZL, and AZ: wrote the manuscript. YX, MX, and HY: participated in the discussion and revised the manuscript. All authors read and approved the final manuscript. All authors contributed to the article and approved the submitted version.

## Funding

The CHNS project was funded by many organizations. Major funding for the survey and data dissemination from 1991 to 2004 came from the (NIH) (P01-HD28076 and HD30880). Additional funding was from the NIH (HD39183), the Carolina Population Center, the Ford Foundation, the National Science Foundation (INT-9215399), the National Institute of Nutrition and Food Safety, and the Chinese Center for Disease Control and Prevention. In addition, the current study was supported by the Sanming Project of Medicine in Shenzhen (SZSM202111001).

## Acknowledgments

We are grateful to thank the National Institute for Nutrition and Health, China Center for Disease Control and Prevention, Carolina Population Center (P2C-HD-050924, T32-HD-007168); the University of North Carolina, Chapel Hill; the National Institutes of Health (R01-HD-30880, DK-056350, R24-HD-050924, R01-HD-38700); and the National Institutes of Health Fogarty International Center (D43-TW-009077, D43-TW-007709) for financial support for the CHNS data collection and analysis files from 1989 to 2015 and future surveys and the China-Japan Friendship Hospital, Ministry of Health, for support for CHNS 2009; Chinese National Human Genome Center at Shanghai since 2009; and Beijing Municipal Center for Disease Prevention and Control since 2011.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships

that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or

claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2022.997636/full#supplementary-material>

## References

- Ogurtsova K, da Rocha Fernandes JD, Huang Y, Linnenkamp U, Guariguata L, Cho NH, et al. IDF diabetes Atlas: global estimates for the prevalence of diabetes for 2015 and 2040. *Diabetes Res Clin Pract.* (2017) 128:40–50. doi: 10.1016/j.diabres.2017.03.024
- 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
- Arrieta F, Iglesias P, Pedro-Botet J, Becerra A, Ortega E, Obaya JC, et al. Diabetes mellitus and cardiovascular risk: update of the recommendations of the diabetes and cardiovascular disease working group of the Spanish diabetes society (SED, 2018). *Clin Investig Arterioscler.* (2018) 30:137–53. doi: 10.1016/j.artere.2018.05.002
- 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) 11:1185–200. doi: 10.7150/ijms.10001
- Schrezenmeir J, Jagla A. Milk and diabetes. *J Am Coll Nutr.* (2000) 19:176S–90S. doi: 10.1080/07315724.2000.10718087
- Schwingshackl L, Hoffmann G, Lampousi AM, Knuppel S, Iqbal K, Schwedhelm C, et al. Food groups and risk of type 2 diabetes mellitus: a systematic review and meta-analysis of prospective studies. *Eur J Epidemiol.* (2017) 32:363–75. doi: 10.1007/s10654-017-0246-y
- Pereira PC. Milk nutritional composition and its role in human health. *Nutrition.* (2014) 30:619–27. doi: 10.1016/j.nut.2013.10.011
- Kliem KE, Givens DI. Dairy products in the food chain: their impact on health. *Annu Rev Food Sci Technol.* (2011) 2:21–36. doi: 10.1146/annurev-food-022510-133734
- Abid Z, Cross AJ, Sinha R. Meat, dairy, and cancer. *Am J Clin Nutr.* (2014) 100:386S–93S. doi: 10.3945/ajcn.113.071597
- Lordan R, Tsoupras A, Mitra B, Zabetakis I. Dairy fats and cardiovascular disease: do we really need to be concerned? *Foods.* (2018) 7:29. doi: 10.3390/foods703029
- van Aerde MA, Soedamah-Muthu SS, Geleijnse JM, Snijder MB, Nijpels G, Stehouwer CD, et al. Dairy intake in relation to cardiovascular disease mortality and all-cause mortality: the Hoorn Study. *Eur J Nutr.* (2013) 52:609–16. doi: 10.1007/s00394-012-0363-z
- Na X, Lan H, Wang Y, Tan Y, Zhang J, Zhao A. Association between milk intake and all-cause mortality among chinese adults: a prospective study. *Nutrients.* (2022) 14:292. doi: 10.3390/nu14020292
- Thorning TK, Raben A, Tholstrup T, Soedamah-Muthu SS, Givens I, Astrup A. Milk and dairy products: good or bad for human health? An assessment of the totality of scientific evidence. *Food Nutr Res.* (2016) 60:32527. doi: 10.3402/fnr.v60.32527
- Abargouei AS, Janghorbani M, Salehi-Marzjafari M, Esmailzadeh A. Effect of dairy consumption on weight and body composition in adults: a systematic review and meta-analysis of randomized controlled clinical trials. *Int J Obes.* (2012) 36:1485–93. doi: 10.1038/ijo.2011.269
- Diaz-Lopez A, Bullo M, Martinez-Gonzalez MA, Corella D, Estruch R, Fito M, et al. Dairy product consumption and risk of type 2 diabetes in an elderly Spanish Mediterranean population at high cardiovascular risk. *Eur J Nutr.* (2016) 55:349–60. doi: 10.1007/s00394-015-0855-8
- Drouin-Chartier JP, Li Y, Ardisson Korat AV, Ding M, Lamarche B, Manson JE, et al. Changes in dairy product consumption and risk of type 2 diabetes: results from 3 large prospective cohorts of US men and women. *Am J Clin Nutr.* (2019) 110:1201–12. doi: 10.1093/ajcn/nqz180
- Brouwer-Brolsma EM, van Woudenberg GJ, Oude Elferink SJ, Singh-Povel CM, Hofman A, Dehghan A, et al. Intake of different types of dairy and its prospective association with risk of type 2 diabetes: the rotterdam study. *Nutr Metab Cardiovasc Dis.* (2016) 26:987–95. doi: 10.1016/j.numecd.2016.08.003
- Popkin BM, Du S, Zhai F, Zhang B. Cohort profile: the china health and nutrition survey—monitoring and understanding socio-economic and health change in China, 1989–2011. *Int J Epidemiol.* (2010) 39:1435–40. doi: 10.1093/ije/dyp322
- Ng SW, Howard AG, Wang HJ, Su C, Zhang B. The physical activity transition among adults in China: 1991–2011. *Obes Rev.* (2014) 15:27–36. doi: 10.1111/obr.12127
- Zhai FY, Du SF, Wang ZH, Zhang JG, Du WW, Popkin BM. Dynamics of the Chinese diet and the role of urbanicity, 1991–2011. *Obes Rev.* (2014) 1:16–26. doi: 10.1111/obr.12124
- Chinese Academy of Preventive Medicine IoNaFH. *Food Composition Table.* Beijing: People's Health Publishing House (1991).
- Yang YX. *Chinese Food Composition Table.* Beijing: Peking University Medical Press (2004).
- Yang YX. *Chinese Food Composition Table.* Beijing: Peking University Medical Press (2009).
- Guasch-Ferre M, Becerra-Tomas N, Ruiz-Canela M, Corella D, Schroder H, Estruch R, et al. Total and subtypes of dietary fat intake and risk of type 2 diabetes mellitus in the Prevencion con Dieta Mediterranea (PREDIMED) study. *Am J Clin Nutr.* (2017) 105:723–35. doi: 10.3945/ajcn.116.142034
- Fumeron F, Lamri A, Abi Khalil C, Jaziri R, Porchay-Balderelli I, Lantieri O, et al. Dairy consumption and the incidence of hyperglycemia and the metabolic syndrome: results from a french prospective study, data from the Epidemiological Study on the Insulin Resistance Syndrome (DESIR). *Diabetes Care.* (2011) 34:813–7. doi: 10.2337/dc10-1772
- Stuber JM, Vissers LET, Verschuren WMM, Boer JMA, van der Schouw YT, Sluijs I. Substitution among milk and yogurt products and the risk of incident type 2 diabetes in the EPIC-NL cohort. *J Hum Nutr Diet.* (2021) 34:54–63. doi: 10.1111/jhn.12767
- Bhavadharini B, Dehghan M, Mente A, Rangarajan S, Sheridan P, Mohan V, et al. Association of dairy consumption with metabolic syndrome, hypertension and diabetes in 147 812 individuals from 21 countries. *BMJ Open Diabetes Res Care.* (2020) 8:e000826. doi: 10.1136/bmjdr-2019-000826
- Slurink IAL, den Braver NR, Rutters F, Kupper N, Smeets T, Elders PJM, et al. Dairy product consumption and incident prediabetes in Dutch middle-aged adults: the Hoorn Studies prospective cohort. *Eur J Nutr.* (2022) 61:183–96. doi: 10.1007/s00394-021-02626-9
- Winkleby MA, Kraemer HC, Ahn DK, Varady AN. Ethnic and socioeconomic differences in cardiovascular disease risk factors: findings for women from the third national health and nutrition examination survey, 1988–1994. *JAMA.* (1998) 280:356–62. doi: 10.1001/jama.280.4.356
- Munoz-Garach A, Garcia-Fontana B, Munoz-Torres M. Vitamin D status, calcium intake and risk of developing type 2 diabetes: an unresolved issue. *Nutrients.* (2019) 11:642. doi: 10.3390/nu11030642
- Shah IU, Sameen A, Manzoor MF, Ahmed Z, Gao J, Farooq U, et al. Association of dietary calcium, magnesium, and vitamin D with type 2 diabetes

among US adults: National health and nutrition examination survey 2007–2014-A cross-sectional study. *Food Sci Nutr.* (2021) 9:1480–90. doi: 10.1002/fsn3.2118

32. Toffolon A, de Rocco-Ponce M, Vettore M, Iori E, Lante A, Tessari P. Effect of reversal of whey-protein to casein ratio of cow milk, on insulin, incretin, and amino acid responses in humans. *Mol Nutr Food Res.* (2021) 65:e2100069. doi: 10.1002/mnfr.202100069

33. Zapata RC, Singh A, Pezeshki A, Nibber T, Chelikani PK. Whey protein components—lactalbumin and lactoferrin - improve energy balance and metabolism. *Sci Rep.* (2017) 7:9917. doi: 10.1038/s41598-017-09781-2

34. Feng J, Wang H, Jing Z, Wang Y, Cheng Y, Wang W, et al. Role of magnesium in type 2 diabetes mellitus. *Biol Trace Elem Res.* (2020) 196:74–85. doi: 10.1007/s12011-019-01922-0

35. Hirahatake KM, Slavin JL, Maki KC, Adams SH. Associations between dairy foods, diabetes, and metabolic health: potential mechanisms and future directions. *Metabolism.* (2014) 63:618–27. doi: 10.1016/j.metabol.2014.02.009

36. Liu R, Li H, Fan W, Jin Q, Chao T, Wu Y, et al. Leucine supplementation differently modulates branched-chain amino acid catabolism, mitochondrial function and metabolic profiles at the different stage of insulin resistance in rats on high-fat diet. *Nutrients.* (2017) 9:565. doi: 10.3390/nu9060565

37. Chartrand D, Da Silva MS, Julien P, Rudkowska I. Influence of amino acids in dairy products on glucose homeostasis: the clinical evidence. *Can J Diabetes.* (2017) 41:329–37. doi: 10.1016/j.jcjd.2016.10.009

38. Hidayat K, Du X, Shi BM. Milk in the prevention and management of type 2 diabetes: the potential role of milk proteins. *Diabetes Metab Res Rev.* (2019) 35:e3187. doi: 10.1002/dmrr.3187

39. Ben Othman M, Sakamoto K. Effect of inactivated bifidobacterium longum intake on obese diabetes model mice (TSOD). *Food Res Int.* (2020) 129:108792. doi: 10.1016/j.foodres.2019.108792

40. Mayengbam S, Mickiewicz B, Trottier SK, Mu C, Wright DC, Reimer RA, et al. Distinct gut microbiota and serum metabolites in response to weight loss induced by either dairy or exercise in a rodent model of obesity. *J Proteome Res.* (2019) 18:3867–75. doi: 10.1021/acs.jproteome.9b00304

41. Khorraminezhad L, Leclercq M, O'Connor S, Julien P, Weisnagel SJ, Gagnon C, et al. Dairy product intake modifies gut microbiota composition among hyperinsulinemic individuals. *Eur J Nutr.* (2021) 60(1):159–67. doi: 10.1007/s00394-020-02226-z

42. Hidalgo-Cantabrana C, Delgado S, Ruiz L, Ruas-Madiedo P, Sanchez B, Margolles A. Bifidobacteria and their health-promoting effects. *Microbiol Spectr.* (2017) 5:73–98. doi: 10.1128/microbiolspec.BAD-0010-2016

43. Gijsbers L, Ding EL, Malik VS, de Goede J, Geleijnse JM, Soedamah-Muthu SS. Consumption of dairy foods and diabetes incidence: a dose-response meta-analysis of observational studies. *Am J Clin Nutr.* (2016) 103:1111–24. doi: 10.3945/ajcn.115.123216

44. Lu W, Chen H, Niu Y, Wu H, Xia D, Wu Y. Dairy products intake and cancer mortality risk: a meta-analysis of 11 population-based cohort studies. *Nutr J.* (2016) 15:91. doi: 10.1186/s12937-016-0210-9

45. Kazemi A, Barati-Boldaji R, Soltani S, Mohammadipoor N, Esmaeilinezhad Z, Clark CCT, et al. Intake of various food groups and risk of breast cancer: a systematic review and dose-response meta-analysis of prospective studies. *Adv Nutr.* (2021) 12:809–49. doi: 10.1093/advances/nmaa147

46. Ganmaa D, Sato A. The possible role of female sex hormones in milk from pregnant cows in the development of breast, ovarian and corpus uteri cancers. *Med Hypotheses.* (2005) 65:1028–37. doi: 10.1016/j.mehy.2005.06.026

47. Nagarathna R, Anand A, Nanda S, Patil SS, Singh A, Rajesh SK, et al. Is the Indian dietary pattern associated with type 2 diabetes? A Pan-India randomized cluster sample study. *Ann Neurosci.* (2020) 27:175–82. doi: 10.1177/09727531211005226

48. Berkey CS, Rockett HR, Willett WC, Colditz GA. Milk, dairy fat, dietary calcium, and weight gain: a longitudinal study of adolescents. *Arch Pediatr Adolesc Med.* (2005) 159:543–50. doi: 10.1001/archpedi.159.6.543

49. Ren X, Gao J, Han T, Sun C. Association between risk of type 2 diabetes and changes in energy intake at breakfast and dinner over 14 years: a latent class trajectory analysis from the China health and nutrition Survey, 1997–2011. *BMJ Open.* (2021) 11:e046183. doi: 10.1136/bmjopen-2020-046183

50. Agriculture USDo. *Dietary Guidelines for Americans, 2020–2025* Available online at: <https://www.dietaryguidelines.gov/>.

51. Margolis KL, Wei F, de Boer IH, Howard BV, Liu S, Manson JE, et al. A diet high in low-fat dairy products lowers diabetes risk in postmenopausal women. *J Nutr.* (2011) 141:1969–74. doi: 10.3945/jn.111.143339

52. Gaucheron F. Milk and dairy products: a unique micronutrient combination. *J Am Coll Nutr.* (2011) 30:400S–9S. doi: 10.1080/07315724.2011.10719983

53. Canada Go. *Eating Well with Canada's Food Guide 2007 2011.* Available online at: <https://www.canada.ca/en/health-canada/services/canada-food-guide/about/history-food-guide/eating-well-with-canada-food-guide-2007.html>.

54. Wang SS, Lay S, Yu HN, Shen SR. Dietary Guidelines for Chinese Residents (2016): comments and comparisons. *J Zhejiang Univ Sci B.* (2016) 17:649–56. doi: 10.1631/jzus.B1600341

55. Society CN. *Chinese Dietary Guideline 2022.* Beijing: People's Medical Publishing House. (2022).

56. Zhang J, Lim K, Shin S. Dairy product consumption and type 2 diabetes among Korean adults: a prospective cohort study based on the Health Examinees (HEXA) study. *Epidemiol Health.* (2022) 44:e2022019. doi: 10.4178/epih.e2022019

57. Elwood PC, Pickering JE, Fehily AM. Milk and dairy consumption, diabetes and the metabolic syndrome: the Caerphilly prospective study. *J Epidemiol Community Health.* (2007) 61:695–8. doi: 10.1136/jech.2006.053157

58. Liang J, Zhang Y, Xue A, Sun J, Song X, Xue B, et al. Association between fruit, vegetable, seafood, and dairy intake and a reduction in the prevalence of type 2 diabetes in Qingdao, China. *Asia Pac J Clin Nutr.* (2017) 26:255–61. doi: 10.6133/apjcn.012016.03

59. Li J, Rice MS, Huang T, Hankinson SE, Clevenger CV, Hu FB, et al. Circulating prolactin concentrations and risk of type 2 diabetes in US women. *Diabetologia.* (2018) 61:2549–60. doi: 10.1007/s00125-018-4733-9

60. Rosenberg L, Robles YP, Li S, Ruiz-Narvaez EA, Palmer JR. A prospective study of yogurt and other dairy consumption in relation to incidence of type 2 diabetes among black women in the USA. *Am J Clin Nutr.* (2020) 112:512–8. doi: 10.1093/ajcn/nqaa143

61. Maggio CA, Pi-Sunyer FX. Obesity and type 2 diabetes. *Endocrinol Metab Clin North Am.* (2003) 32:805–22. doi: 10.1016/S0889-8529(03)00071-9

62. Mozaffarian D. Dairy foods, obesity, and metabolic health: the role of the food matrix compared with single nutrients. *Adv Nutr.* (2019) 10:917S–23S. doi: 10.1093/advances/nmz053