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Daily consumption of specific categories of fruit and vegetables negatively correlated with frailty: findings from the US National Health and Nutrition Examination Survey

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ABSTRACT

BACKGROUND/OBJECTIVES: The specific impact of different fruit and vegetable consumption categories on frailty is not completely understood. This study examined the relationships between the daily consumption of fruit and vegetables and frailty in a large general population.
SUBJECTS/METHODS: This study used the data from the US National Health and Nutrition Examination Survey (2005–2020). Two intermittent 24-h dietary recalls were used to evaluate fruit and vegetable consumption. Frailty was assessed using the frailty index. Logistic regression, stratified analyses, and restricted cubic spline models were used to examine these associations.
RESULTS: A higher daily intake of citrus, melons, and berries (odds ratio [OR], 0.77; 95% confidence interval [CI], 0.65–0.92), other fruit (OR, 0.74; 95% CI, 0.62–0.88), intact fruit (OR, 0.71; 95% CI, 0.60–0.84), dark-green vegetables (OR, 0.71; 95% CI, 0.60–0.83), and total vegetables (OR, 0.80; 95% CI, 0.66–0.96), along with a lower fruit juice intake (OR, 0.81; 95% CI, 0.69–0.96), were associated with a reduced risk of frailty in adults aged 18 yrs and older. Further analysis showed that the daily consumption of citrus melons and berries, other fruit, intact fruit, fruit juice, and tomatoes and tomato products were inversely associated with frailty in adults under 60 yrs and females. Dark green vegetables were inversely correlated with frailty in individuals aged 40–60 yrs and over 60 yrs, regardless of sex.
CONCLUSION: The daily consumption of most types of fruit, dark green vegetables, and tomatoes and tomato products may reduce the risk of frailty in American adults, particularly for individuals under 60 yrs of age and females.

Keywords: Frailty; nutrients; fruit; vegetable; nutrition surveys

INTRODUCTION

Frailty is marked by a deterioration of physiological performance and heightened susceptibility to stressors, predisposing individuals to negative health consequences, such as falls, disability [1], cognitive decline [2], and reduced quality of life [3]. The estimated prevalence of frailty

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Conflict of Interest
The authors declare no potential conflicts of interests.

Author Contributions
Conceptualization: Zhang X; Data curation: Lai J, Jin Z, Wu Y; Formal analysis: Lai J, Jin Z, Wu Y; Methodology: Zhang X; Writing - original draft: Zhang X; Writing - review & editing: Zhang X, Lai J, Jin Z, Wu Y, Zhao K.

among community-dwelling adults aged 65 yrs and older is approximately 10%, increasing to more than 50% in those 80 yrs and older [4]. The prevalence among adults younger than 65 yrs is lower but still significant, with estimates ranging from 5.3% to 6.9% in those aged 18–64 yrs using the Fried Model and from 1.8% to 11.6% using the Accumulation of Deficits Model [5,6]. Frailty has a significant impact on society, including increased healthcare costs [7], hospitalization rates [8], and mortality [9].

The mechanisms of frailty are complex, but malnutrition is a well-recognized predisposing factor for frailty. The Mediterranean diet, characterized by the high consumption of fruit and vegetables, grains, and unsaturated fats, can ameliorate frailty and muscle atrophy [10]. Fruit and vegetables are an important component of the Mediterranean diet and provide numerous nutrients necessary for good health. Evidence suggests that incorporating fruit and vegetables into the diet regularly can lower the likelihood of developing many diseases, including chronic obstructive pulmonary disease [11], hypertension [12], and cardiovascular disease [13]. Meta-analysis showed that each additional daily serving of fruit and vegetables consumed was associated with a 14% lower risk of developing frailty [14]. The presence of macro-and micronutrients contained in fruit and vegetables, such as carotenoids [15], vitamins [13], and polyphenols [16], has a negative correlation with frailty. This may be one of the reasons why fruit and vegetable consumption is beneficial for slowing the progression of frailty. Fruit and vegetables contain a diverse range of nutrients. Thus, the effects of different categories of fruit and vegetables on frailty may be unequal, highlighting the need to explore these relationships according to the type. Several studies have evaluated the associations between frailty and vegetable or fruit intake individually, but they were limited to specific populations and the findings were inconclusive [17-19].

This study examined the association between the risk of frailty in adults and fruit and vegetable consumption. In addition, this study examined the dose-response association between fruit and vegetable consumption and frailty.

SUBJECTS AND METHODS

Study design and study population

This study used data from the National Health and Nutrition Examination Survey (NHANES), a cross-sectional survey by the Centers for Disease Control and Prevention (CDC) assessing the wellness and nutritional status of individuals in the United States. The NHANES participants were interviewed at home. They then underwent a medical examination, physical examination, and urine and blood collection at a mobile examination center (MEC).

Between 2005 and 2020, 85,750 participants were sampled by the National Health and Health Administration. After excluding those under 18 yrs old (n = 33,914), those with missing frailty data (n = 0), and those with missing data on fruit and vegetable intake (n = 12,119), 39,717 participants remained for analysis (**Fig. 1**).

Dietary fruits and vegetables assessment

Dietary information was obtained from 2 nonconsecutive 24-h dietary recall interviews. The initial interview occurred face-to-face at the MEC, while the subsequent one was conducted via phone within 3 to 10 days. The specific varieties of fruit analyzed in this study included the following: (1) citrus, melons, and berries; (2) other fruit excluding citrus, melons,

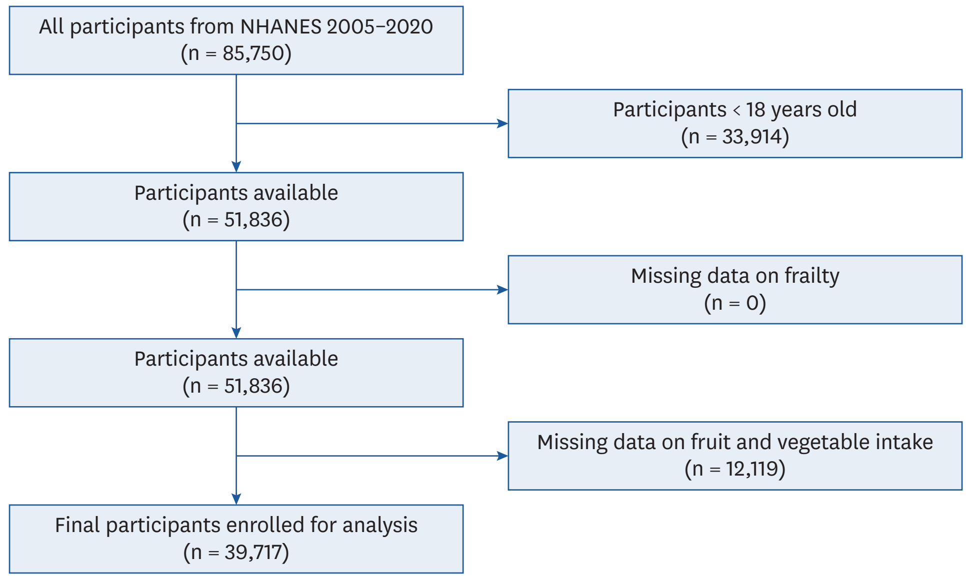

Fig. 1. Flowchart of participant selection.
NHANES, National Health and Nutrition Examination Survey.

and berries; (3) intact fruit, which is whole or cut into pieces but not further processed, encompassing fruits from categories (1) and (2); (4) fruit juice; and (5) total fruit intake, which includes total intact fruit and fruit juice according to the guidelines provided by the Food Patterns Equivalents Database. The vegetables analyzed were (1) dark green vegetables, (2) tomatoes and tomato products, (3) other red and orange vegetables, excluding tomatoes and tomato products, (4) potatoes, (5) other starchy vegetables, (6) other vegetables not listed above, (7) beans and peas, and (8) total vegetables, combining all the aforementioned vegetables except beans and peas [20]. The mean daily intake of fruits and vegetables was derived from two 24-h dietary interviews.

Frailty index assessment

The frailty index is a comprehensive health assessment encompassing cognitive function, dependence, mental health, medical conditions, hospital usage, overall health, physical performance, anthropometry, and laboratory results. The index comprised 49 factors accessible in the NHANES database [21]. The frailty index is calculated as the number of acquired deficits by the participant divided by the total number of potential deficits. The frailty index spans from 0 to 1, with higher values corresponding to increased frailty levels. Frailty was characterized by a frailty index exceeding 0.21 [22]. Detailed information on the specific variables included in the frailty index is provided in the **Supplementary Table 1**.

Covariates

This study assessed several covariates as potential confounders for each participant, including the following: (1) sociodemographic information, such as sex (male or female), age (years), race (Mexican American, non-Hispanic Black, non-Hispanic White, or others), marital status (married/living with a partner, never married, divorced/separated, or widowed), education (under high school, high school, or above high school), poverty income ratio levels (< 1.3, 1.3–3.49, or ≥ 3.5); (2) body measurements, including body mass index (BMI, kg/m^2); (3) lifestyle information, which included smoking status, drinking, physical activity, coffee consumption [23], and total daily energy intake; (4) common co-morbid conditions, including hypertension, hyperlipidemia, diabetes mellitus (DM), stroke, and coronary heart disease.

The BMI categories were divided into 4 groups: underweight (BMI < 18.5), normal weight (18.5 ≤ BMI < 25), overweight (25 ≤ BMI < 30), and obesity (BMI ≥ 30). The smoking status was divided into 3 groups: never smokers (individuals who had smoked less than 100 cigarettes in their lifespan), former smokers (individuals who had smoked more than 100 cigarettes in their lifespan but were not currently smoking), and current smokers. Alcohol consumption was divided into 5 categories: never drinkers (those who had consumed fewer than 12 times in their lifetime), former drinkers (those who had consumed more than 12 times in a year but were not currently drinking), mild drinkers (those who consumed 1–2 drinks per day for women and 1–3 drinks per day for men), moderate drinkers (those who drank 2–3 drinks per day for women and 3–4 drinks per day for men), and heavy drinkers (those who drank more than 3 drinks per day for women and 4 drinks per day for men). The physical activity was divided into 4 groups based on their weekly metabolic equivalents (METs) minutes: inactive (0 MET-min/week), low (1–499 MET-min/week), moderate (500–1,000 MET-min/week), and high (>1,000 MET-min/week).

Hypertension was diagnosed when (1) an individual had been told by a physician or other health care provider that they had the condition, (2) had a history of using antihypertensive medication, or (3) had 3 separate measurements of systolic and diastolic blood pressure equal to or exceeding 140 mm Hg and 90 mm Hg, respectively. The diagnostic criteria for hyperlipidemia consist of a triglyceride concentration ≥ 150 mg/dL, a serum total cholesterol concentration ≥ 200 mg/dL, a low-density lipoprotein level ≥ 130 mg/dL, a high-density lipoprotein level < 40 mg/dL in males or < 50 mg/dL in females, or the utilization of lipid-lowering medications.

The diagnostic criteria for diabetes include being told by a medical professional that one has the condition, having a glycosylated hemoglobin level ≥ 6.5 mmol/L, a fasting blood glucose level ≥ 7.0 mmol/L, or a history of taking anti-diabetic drugs. The diagnostic criteria for coronary heart disease and stroke are based on whether the patient has ever been diagnosed with either condition.

Statistical analyses

The participants were divided into frailty and non-frailty groups based on the frailty index. The overall fruit and vegetable consumption was evaluated by dividing the participants into 3 tertiles. Each specific fruit or vegetable intake type was divided into 3 groups. Non-consumers, those with intake below the median, and those at or above the median were placed in groups 1, 2, and 3, respectively. The continuous variables were expressed as mean ± SE and assessed using the *t*-test for normally distributed variables. Categorical variables were represented as percentages and analyzed using a χ^2 test.

Binary logistic regression analyses were used to calculate the odds ratios (ORs) and 95% confidence intervals (CIs) to determine the relationship between frailty and fruit and vegetable consumption. The crude model was unadjusted. Model 1 adjusted for age, sex, and race. Model 2 added adjustments for education, marital status, poverty-income ratio, BMI, drinking status, smoking, caffeine consumption, total dietary energy intake, and physical activity. Model 3 was further adjusted for hypertension, hyperlipidemia, diabetes, coronary heart disease, and stroke. In addition, a restricted cubic spline curve with 4 knots at the 5th,

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35th, 65th, and 90th percentiles of fruit and vegetable consumption was used in model 3 to assess the dose-response relationship with the frailty risk.

Dietary weights were used in the current study to generate the nationally representative estimation. Subgroup analysis was performed, categorizing individuals according to age and sex to examine the consistency of the association between fruit and vegetable consumption and frailty risk across different demographics. All statistical analyses were conducted using the R software (version 4.4.1; R Foundation, Vienna, Austria). A 2-sided *P*-value of ≤ 0.05 was considered statistically significant.

Ethics statement

The NHANES III study was approved by the National Center for Health Statistics (NCHS) Institutional Review Board (IRB). The participants provided informed consent prior to data collection. Subsequent NHANES studies (2005–2020) were also approved by the NCHS IRB or Research Ethics Review Board (ERB), as indicated by specific protocols for each study period. More details on NHANES studies can be found at https://wwwn.cdc.gov/nchs/nhanes/Default.aspx.

RESULTS

Characteristics of the participants at baseline

Table 1 lists the characteristics of the participants according to their frailty index. This study included 39,717 eligible participants with an average age of 46.72 yrs, of which 47.85% were male. Among the participants, 30,331 were classified as non-frail, while 9,386 were identified as frail, indicating a 23.63% prevalence of frailty. Frail individuals were generally older, female, non-Hispanic white, and more likely to be married or living with a partner, better educated, and have a lower poverty income ratio. They also engaged in more physical activity, were more often non-smokers and non-drinkers, and were frequently overweight or obese. Furthermore, they consumed more coffee and had higher rates of hypertension and hyperlipidemia, but lower rates of diabetes, stroke, and coronary heart disease.

Table 1. Baseline characteristic of the participants according to frailty status

Characteristic	Non-frailty (n = 30,331)	Frailty (n = 9,386)	*P*-value[1)]
Age (yrs)	44.42 ± 0.24	56.66 ± 0.37	**< 0.001**
Sex			**< 0.001**
Female	50.17 (0.39)	60.68 (0.94)	
Male	49.83 (0.39)	39.32 (0.94)	
Race			**< 0.001**
Mexican American	9.22 (0.61)	6.79 (0.63)	
Non-Hispanic Black	10.54 (0.63)	15.81 (0.88)	
Non-Hispanic White	66.14 (1.16)	64.07 (1.50)	
Other Race	14.11 (0.57)	13.33 (0.78)	
Marital status			**< 0.001**
Married/living with partner	59.64 (0.69)	51.20 (1.07)	
Never married	22.84 (0.60)	14.83 (0.70)	
Divorced/separated	10.37 (0.32)	17.38 (0.70)	
Widowed	3.72 (0.15)	12.44 (0.62)	
Unknown	3.43 (0.16)	4.16 (0.33)	

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Table 1. (Continued) Baseline characteristic of the participants according to frailty status

Characteristic	Non-frailty (n = 30,331)	Frailty (n = 9,386)	*P*-value[1)]
Educational level			**< 0.001**
Below high school	3.55 (0.19)	7.48 (0.45)	
High school	31.94 (0.70)	43.28 (0.97)	
Above high school	63.93 (0.75)	48.46 (1.01)	
Unknown	0.57 (0.07)	0.78 (0.12)	
Poverty-income ratio			**< 0.001**
≤ 1.3	17.43 (0.52)	30.60 (0.80)	
> 1.3 to ≤ 3.5	31.87 (0.69)	34.99 (1.09)	
> 3.5	43.52 (0.89)	26.36 (0.89)	
Unknown	7.18 (0.31)	8.05 (0.48)	
Physical activity			**< 0.001**
Low	14.21 (0.36)	14.87 (0.60)	
Moderate	11.10 (0.33)	9.52 (0.56)	
High	58.23 (0.56)	37.09 (0.93)	
Unknown	16.47 (0.39)	38.52 (0.87)	
Smoking status			**< 0.001**
Never	59.29 (0.56)	43.03 (0.95)	
Former	22.53 (0.45)	30.60 (0.71)	
Current	16.65 (0.42)	25.04 (0.82)	
Unknown	1.53 (0.10)	1.34 (0.14)	
Drinking status			**< 0.001**
No drinker	67.59 (0.53)	78.34 (0.70)	
Moderate drinker	16.18 (0.34)	11.34 (0.59)	
Heavy drinker	16.23 (0.45)	10.32 (0.48)	
Body mass index			**< 0.001**
Normal	30.51 (0.57)	16.04 (0.62)	
Underweight	1.53 (0.11)	1.56 (0.19)	
Overweight	32.63 (0.53)	27.76 (0.72)	
Obese	34.99 (0.61)	51.70 (0.96)	
Unknown	0.34 (0.04)	2.95 (0.29)	
Caffeinated coffee (g)	231.30 ± 5.29	230.08 ± 9.73	0.900
Decaffeinated coffee (g)	26.13 ± 1.58	35.30 ± 3.60	**0.020**
Hypertension			**< 0.001**
Yes	29.29 (0.52)	69.66 (0.71)	
No	70.71 (0.52)	30.32 (0.71)	
Unknown	0.00 (0.00)	0.01 (0.01)	
Hyperlipidemia			**< 0.001**
Yes	64.02 (0.62)	80.30 (0.75)	
No	35.98 (0.62)	19.69 (0.75)	
Unknown	0.00 (0.00)	0.01 (0.00)	
Diabetes			**< 0.001**
Yes	5.63 (0.21)	31.56 (0.66)	
No	93.11 (0.22)	67.57 (0.68)	
Unknown	1.26 (0.09)	0.87 (0.14)	
Stroke			**< 0.001**
Yes	1.04 (0.07)	11.62 (0.50)	
No	95.56 (0.15)	84.48 (0.55)	
Unknown	3.40 (0.14)	3.90 (0.29)	
Coronary heart disease			**< 0.001**
Yes	1.39 (0.13)	12.85 (0.65)	
No	95.12 (0.17)	83.03 (0.69)	
Unknown	3.48 (0.14)	4.12 (0.26)	

The data were analyzed using the complex sample module. Values are presented as mean ± SE or weighted % (SE). Values in bold indicate statistical significance with $P \leq 0.05$.

[1)]*P*-values from the t-test for continuous variables and *P*-values from χ^2 test for categorical variables.

Table 2. Relationship between the consumption of specific fruits and frailty in adults ≥ 18 yrs old

Characteristic (cup/day)	Crude model	Model 1[1)]	Model 2[2)]	Model 3[3)]
Citrus, melons, and berries[4)]				
Group1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.32)	0.80 (0.71–0.90)***	0.63 (0.55–0.71)***	0.72 (0.61–0.85)***	0.70 (0.58–0.84)***
Group 3 (≥ 0.32)	0.89 (0.80–0.99)***	0.66 (0.59–0.74)***	0.77 (0.67–0.90)***	0.77 (0.65–0.92)**
P-trend	0.003	< 0.001	< 0.001	< 0.001
Other fruits[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.54)	0.88 (0.80–0.97)**	0.65 (0.59–0.72)***	0.82 (0.68–0.98)**	0.80 (0.66–0.98)*
Group 3 (≥ 0.54)	0.80 (0.74–0.87)***	0.55 (0.50–0.60)***	0.74 (0.64–0.86)***	0.74 (0.62–0.88)***
P-trend	< 0.001	< 0.001	< 0.001	< 0.001
Intact fruits[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.72)	0.94 (0.86–1.03)	0.67 (0.61–0.74)***	0.84 (0.70–1.02)	0.82 (0.67–1.00)*
Group 3 (≥ 0.72)	0.85 (0.78–0.93)***	0.53 (0.48–0.59)***	0.73 (0.63–0.84)***	0.71 (0.60–0.84)***
P-trend	< 0.001	< 0.001	< 0.001	< 0.001
Fruit juice[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.36)	0.82 (0.74–0.91)***	0.72 (0.65–0.80)***	0.80 (0.69–0.94)*	0.81 (0.69–0.96)**
Group 3 (≥ 0.36)	0.88 (0.80–0.96)**	0.78 (0.71–0.86)***	0.87 (0.71–1.03)	0.94 (0.79–1.11)
P-trend	0.002	< 0.001	0.059	0.257
Total fruits[5)]				
Group 1 (0.00–0.30)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (0.31–1.17)	1.01 (0.91–1.13)	0.85 (0.76–0.95)**	0.83 (0.69–0.98)*	0.81 (0.68–0.97)*
Group 3 (1.18–20.61)	0.86 (0.76–0.96)**	0.68 (0.60–0.77)***	0.78 (0.63–0.95)*	0.77 (0.62–0.96)*
P-trend	< 0.001	< 0.001	0.21	0.026

Values are presented as odds ratio (95% confidence interval).
BMI, body mass index.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
[1)]Model 1 was adjusted for age, sex (male and female), and race (Mexican American, non-Hispanic black, non-Hispanic white, other races).
[2)]Model 2 was also adjusted for education (below high school, high school, and above high school), marital status (married/living with partner, never married, divorced/separated, and widowed), poverty-income ratio (continuous), BMI (< 18.5, 18.5 ≤ BMI < 25, 25 ≤ BMI < 30, and ≥ 30 kg/m^2), drinking status (no drinker, moderate drinker, and heavy drinker), smoking (never, former, and now), caffeine consumption(continuous, gram), total dietary energy intake(continuous, kcal/d), and physical activity(low, moderate, and high).
[3)]Model 3 was further adjusted for hypertension, hyperlipidemia, diabetes, coronary heart disease, and stroke.
[4)]The consumption of each type of fruit was divided into 3 categories: Group 1 included individuals with zero consumption, Group 2 included those with intake below the median, and Group 3 included those with intake at or above the median.
[5)]The total fruit consumption was divided into 3 groups based on the tertiles of its distribution in the whole study population.

Association between fruit and vegetable consumption and frailty

Table 2 lists the logistic regression model analyzing the relationship between frailty and various categories of fruit consumption, including the total fruit intake. In both the crude model and model 1, which only adjusted for age, sex, and race, all fruit types were significantly and inversely correlated with frailty. On the other hand, after adjusting for additional confounders in models 2 and 3, a higher fruit juice intake was no longer significantly associated with frailty (OR, 0.94; 95% CI, 0.79–1.11). In contrast, the associations between frailty and higher consumption of citrus, melons, and berries; other fruits; intact fruits; and total fruit with frailty remained significant. The ORs for the highest category were 0.77 (95% CI, 0.65–0.92) for citrus, melons, and berries, 0.74 (95% CI, 0.62–0.88) for other fruits, 0.71 (95% CI, 0.60–0.84) for intact fruits, and 0.77 (95% CI, 0.62–0.96) for total fruit.

Table 3 lists the logistic regression model analyzing the relationship between frailty and various types of vegetable consumption, including the overall vegetable intake. The consumption of dark green vegetables and total vegetables showed a strong and adverse correlation with the odds ratio of frailty in all models. Compared to no consumption, the ORs for dark green vegetable intake of more than 0.26 cup/day were 0.59 (95% CI, 0.54–0.65) in the crude model, 0.51 (95% CI, 0.46–0.57) in model 1, 0.71 (95% CI, 0.61–0.84) in model 2, and 0.71 (95% CI,

Table 3. Relationship between specific vegetable consumption and frailty in adults ≥ 18 yrs old

Characteristic (cup/day)	Crude model	Model 1[1)]	Model 2[2)]	Model 3[3)]
Dark green vegetables[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.26)	0.78 (0.70–0.88)***	0.72 (0.63–0.81)***	0.95 (0.80–1.13)	0.93 (0.76–1.13)
Group 3 (≥ 0.26)	0.59 (0.54–0.65)***	0.51 (0.46–0.57)***	0.71 (0.61–0.84)***	0.71 (0.60–0.83)***
P-trend	< 0.001	< 0.001	< 0.001	< 0.001
Tomatoes and tomato products[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.23)	0.70 (0.62–0.80)***	0.82 (0.72–0.93)**	0.99 (0.80–1.22)	0.96 (0.77–1.19)
Group 3 (≥ 0.23)	0.52 (0.47–0.58)***	0.63 (0.57–0.70)***	0.84 (0.69–1.03)	0.80 (0.64–1.00)
P-trend	< 0.001	< 0.001	0.041	0.018
Other red and orange vegetable[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.11)	0.94 (0.86–1.04)	0.84 (0.75–0.93)***	0.99 (0.78–1.20)	1.04 (0.88–1.23)
Group 3 (≥ 0.11)	0.84 (0.77–0.91)***	0.69 (0.63–0.75)***	0.94 (0.82–1.08)	0.91 (0.77–1.07)
P-trend	< 0.001	< 0.001	0.444	0.343
Potato[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.41)	1.13 (1.03–1.24)**	1.07 (0.96–1.19)	1.06 (0.88–1.28)	0.98 (0.80–1.18)
Group 3 (≥ 0.41)	1.16 (1.04–1.28)*	1.19 (1.07–1.32)**	1.13 (0.95–1.33)	1.09 (0.91–1.30)
P-trend	0.007	0.002	0.163	0.362
Other starchy vegetables[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.17)	0.97 (0.86–1.09)	0.83 (0.73–0.93)**	0.89 (0.75–1.05)	0.85 (0.71–1.02)
Group 3 (≥ 0.17)	1.13 (1.04–1.24)**	0.93 (0.84–1.02)	0.88 (0.76–1.02)	0.81 (0.69–0.95)*
P-trend	0.040	0.020	0.056	0.005
Other vegetables[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.42)	0.80 (0.69–0.92)**	0.71 (0.61–0.83)***	0.97 (0.74–1.29)	0.93 (0.71–1.22)
Group 3 (≥ 0.42)	0.56 (0.49–0.65)***	0.46 (0.40–0.54)***	0.83 (0.65–1.07)	0.78 (0.60–1.01)
P-trend	< 0.001	< 0.001	0.012	0.003
Total vegetables[5)]				
Group 1 (0.00–0.15)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (0.16–0.40)	0.74 (0.67–0.82)***	0.77 (0.69–0.85)***	0.94 (0.80–1.11)	0.94 (0.78–1.12)
Group 3 (0.41–9.06)	0.64 (0.58–0.70)***	0.65 (0.60–0.72)***	0.82 (0.68–0.98)*	0.80 (0.66–0.96)**
P-trend	< 0.001	< 0.001	0.025	0.017
Legumes[4)]				
Group 1 (= 0)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Group 2 (< 0.285)	0.78 (0.69–0.87)***	0.80 (0.71–0.89)***	0.99 (0.79–1.23)	0.97 (0.78–1.20)
Group 3 (≥ 0.285)	0.85 (0.77–0.94)**	0.94 (0.84–1.04)	1.20 (1.02–1.42)*	1.12 (0.92–1.37)
P-trend	0.014	0.014	0.088	0.397

Values are presented as odds ratio (95% confidence interval).
BMI, body mass index.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
1)Model 1 was adjusted for age, sex (male and female), and race (Mexican American, non-Hispanic black, non-Hispanic white, and other races).
2)Model 2 was also adjusted for education (below high school, high school, and above high school), marital status (married/living with a partner, never married, divorced/separated, and widowed), poverty-income ratio (continuous), BMI (< 18.5, 18.5 ≤ BMI < 25, 25 ≤ BMI < 30, and ≥ 30 kg/m^2), drinking status (no drinker, moderate drinker, and heavy drinker), smoking (never, former, and now), caffeine consumption(continuous, gram), total dietary energy intake(continuous, kcal/d), and physical activity(low, moderate, and high).
3)Model 3 was further adjusted for hypertension, hyperlipidemia, diabetes, coronary heart disease, and stroke.
4)The consumption of each type of vegetable was divided into 3 categories: Group 1 included individuals with zero consumption, Group 2 included those with intake below the median, and Group 3 included those with intake at or above the median.
5)The total vegetable consumption was divided into 3 groups based on the tertiles of its distribution in the whole study population.

0.60–0.83) in model 3. For a total vegetable intake of more than 0.41 cup/day, the ORs were 0.64 (95% CI, 0.58–0.70) in the crude model, 0.65 (95% CI, 0.60–0.72) in model 1, 0.82 (95% CI, 0.68–0.98) in model 2, and 0.80 (95% CI, 0.66–0.96) in model 3. Other vegetable types were not significantly associated with frailty in models 2 and 3 but showed significance in the crude model and model 1.

Nutrition Research and Practice

Stratified analyses of the association between specific categories of fruit and vegetable consumption and frailty

Table 4 lists the stratified analyses of the associations between fruit and vegetable consumption and frailty based on age groups. Compared with no consumption of citrus, melon, and berries, the groups consuming more than the median amount showed an inverse association with frailty in the 18–40 yrs (OR, 0.74; 95% CI, 0.55–0.98) and 41–60 yrs groups (OR, 0.75; 95% CI, 0.62–0.90). Similarly, the consumption of other fruit, intact fruit, and total fruit were significantly associated with a lower odd of frailty in adults aged 41–60 yrs. Fruit juice consumption was only negatively related to frailty in the 18–40 yrs age group, regardless of the amount consumed. A higher intake of dark green vegetables (OR 0.70, 95% CI 0.58–0.84 and OR 0.66, 95% CI 0.54–0.80) was inversely associated with frailty in the 41–60 and over 60 years old groups. Similarly, higher consumption of tomatoes and tomato products (OR 0.72,

Table 4. Stratified analyses of the association between the consumption of specific fruits and vegetables and frailty according to the age group

Variables	Age (yrs)	Group 1	Group 2	Group 3	*P* trend
Citrus, melons, and berries[1)]	18–40	Reference	0.84 (0.65–1.08)	**0.74 (0.55–0.98)**	**0.022**
	41–60	Reference	**0.65 (0.54–0.78)**	**0.75 (0.62–0.90)**	**< 0.001**
	≥ 60	Reference	0.92 (0.76–1.10)	0.93 (0.78–1.11)	0.380
Other fruits[1)]	18–40	Reference	0.84 (0.68–1.05)	0.86 (0.67–1.10)	0.153
	41–60	Reference	**0.82 (0.69–0.96)**	**0.76 (0.64–0.91)**	**0.002**
	≥ 60	Reference	0.94 (0.78–1.14)	0.85 (0.70–1.02)	0.075
Intact fruits[1)]	18–40	Reference	0.84 (0.68–1.04)	0.83 (0.65–1.06)	0.104
	41–60	Reference	**0.78 (0.65–0.91)**	**0.71 (0.59–0.85)**	**< 0.001**
	≥ 60	Reference	1.00 (0.81–1.23)	0.86 (0.69–1.06)	0.075
Fruit juice[1)]	18–40	Reference	**0.83 (0.66–1.03)**	**0.78 (0.62–0.99)**	**0.028**
	41–60	Reference	0.95 (0.80–1.11)	0.88 (0.75–1.05)	0.157
	≥ 60	Reference	0.91 (0.77–1.09)	0.96 (0.81–1.14)	0.548
Total fruit[2)]	18–40	Reference	0.87 (0.68–1.12)	0.77 (0.58–1.01)	0.063
	41–60	Reference	**0.89 (0.74–1.08)**	**0.74 (0.60–0.90)**	**0.002**
	≥ 60	Reference	0.90 (0.72–1.12)	0.84 (0.67–1.06)	0.141
Dark green vegetables[1)]	18–40	Reference	0.91 (0.70–1.17)	0.82 (0.63–1.08)	0.138
	41–60	Reference	**0.82 (0.68–0.98)**	**0.70 (0.58–0.84)**	**0.003**
	≥ 60	Reference	0.94 (0.77–1.14)	**0.66 (0.54–0.80)**	0.064
Tomatoes and tomato products[1)]	18–40	Reference	0.78 (0.60–1.02)	**0.72 (0.55–0.96)**	**0.041**
	41–60	Reference	0.95 (0.78–1.17)	**0.73 (0.59–0.90)**	**< 0.001**
	≥ 60	Reference	1.04 (0.85–1.28)	1.03 (0.84–1.27)	0.822
Other red and orange vegetables[1)]	18–40	Reference	0.89 (0.71–1.12)	0.91 (0.72–1.17)	0.368
	41–60	Reference	0.89 (0.750–1.05)	0.89 (0.75–1.05)	0.131
	≥ 60	Reference	1.14 (0.96–1.36)	1.04 (0.88–1.23)	0.580
Potatoes[1)]	18–40	Reference	0.90 (0.72–1.13)	0.96 (0.77–1.21)	0.727
	41–60	Reference	1.05 (0.89–1.24)	1.18 (1.00–1.39)	0.054
	≥ 60	Reference	1.00 (0.84–1.19)	1.17 (0.98–1.40)	0.087
Other starchy vegetables[1)]	18–40	Reference	0.95 (0.73–1.25)	1.23 (0.95–1.60)	0.197
	41–60	Reference	**0.79 (0.65–0.97)**	0.94 (0.78–1.12)	0.201
	≥ 60	Reference	1.02 (0.85–1.23)	0.93 (0.78–1.12)	0.533
Other vegetables[1)]	18–40	Reference	0.82 (0.61–1.12)	0.75 (0.54–1.03)	0.086
	41–60	Reference	1.08 (0.84–1.40)	0.87 (0.67–1.13)	**0.017**
	≥ 60	Reference	1.03 (0.77–1.34)	0.96 (0.72–1.28)	0.470
Total vegetables[2)]	18–40	Reference	0.98 (0.77–1.25)	1.05 (0.81–1.35)	0.734
	41–60	Reference	0.93 (0.78–1.11)	**0.74 (0.62–0.89)**	**0.001**
	≥ 60	Reference	1.12 (0.93–1.35)	0.88 (0.73–1.07)	0.150
Legumes[1)]	18–40	Reference	0.85 (0.66–1.10)	0.89 (0.67–1.18)	0.253
	41–60	Reference	1.10 (0.92–1.33)	0.99 (0.82–1.20)	0.801
	≥ 60	Reference	1.03 (0.85–1.26)	0.95 (0.77–1.16)	0.711

Values are presented as odds ratio (95% confidence interval). Values in bold indicate statistical significance with $P \leq 0.05$.
[1)]The consumption of specific fruits and vegetables was divided into 3 categories: Group 1 included individuals with zero consumption; Group 2 included those with intake below the median; Group 3 included those with intake at or above the median.
[2)]The total fruit and vegetable consumption was divided into 3 groups based on the tertiles of its distribution in the whole study population.

95% CI 0.55–0.96 and OR 0.73, 95% CI 0.59–0.90) was inversely associated with frailty in the 18–40 and 41–60 years old groups.

Table 5 lists the stratified analyses of the associations between fruit and vegetable consumption based on sex. The present study found that the intake of most types of fruit was significantly associated with lower odds of frailty in female participants. Compared with non-consumption, fruit intake (citrus, melons, and berries; other fruit; intact fruit; fruit juice; and total fruit) was inversely associated with frailty in females consuming above and below the median amount, but not in the male participants. Regarding vegetables, the consumption of tomatoes and tomato products, other red and orange vegetables, and total vegetables were associated with a lower risk of frailty in female participants. In addition, a higher intake of other starchy vegetables and other vegetables was associated with a lower risk of frailty in female participants. Dark green vegetables were the only vegetables negatively associated with frailty in males and females. The relationship between frailty and potatoes and legume intake was not significant in the male and female participants.

Dose-response relationships between fruit and vegetable intake and frailty

Restricted cubic spline analyses revealed nonlinear inverse (U-shaped) relationships between frailty and fruit (intact fruits; citrus, melons, and berries; other fruit; total fruits; fruit juice) and total vegetable intake (all *P* for nonlinearity < 0.05, **Fig. 2**). On the other hand, the nonlinear inverse association between dark green vegetable intake and frailty was not significant (*P* = 0.207). The risk of frailty declined rapidly with increasing intake of intact

Table 5. Stratified analyses of the association between the consumption of specific fruits and vegetables and frailty according to sex

Variables	Sex	Group 1	Group 2	Group 3	*P* trend
Citrus, melons, and berries[1)]	Female	Reference	**0.73 (0.63–0.85)**	**0.75 (0.64–0.87)**	**< 0.001**
	Male	Reference	0.86 (0.72–1.03)	0.93 (0.78–1.10)	0.236
Other fruits[1)]	Female	Reference	**0.80 (0.69–0.93)**	**0.73 (0.63–0.85)**	**< 0.001**
	Male	Reference	0.94 (0.80–1.10)	0.93 (0.79–1.09)	0.372
Intact fruits[1)]	Female	Reference	**0.81 (0.70–0.94)**	**0.68 (0.57–0.79)**	**< 0.001**
	Male	Reference	0.87 (0.74–1.02)	0.91 (0.77–1.08)	0.317
Fruit juice[1)]	Female	Reference	**0.88 (0.77–1.01)**	**0.87 (0.75–1.01)**	**0.045**
	Male	Reference	0.94 (0.80–1.10)	0.90 (0.77–1.06)	0.190
Total fruits[2)]	Female	Reference	**0.77 (0.66–0.91)**	**0.68 (0.57–0.81)**	**< 0.001**
	Male	Reference	1.08 (0.89–1.31)	0.95 (0.78–1.15)	0.402
Dark green vegetables[1)]	Female	Reference	**0.89 (0.77–1.04)**	**0.71 (0.61–0.84)**	**< 0.001**
	Male	Reference	**0.90 (0.75–1.09)**	**0.71 (0.59–0.85)**	**< 0.001**
Tomatoes and tomato products[1)]	Female	Reference	**0.95 (0.80–1.12)**	**0.82 (0.69–0.98)**	**0.014**
	Male	Reference	1.02 (0.84–1.24)	0.89 (0.73–1.08)	0.093
Other red and orange vegetables[1)]	Female	Reference	**0.90 (0.78–1.03)**	**0.87 (0.75–1.00)**	**0.037**
	Male	Reference	1.11 (0.94–1.30)	1.06 (0.91–1.24)	0.367
Potatoes[1)]	Female	Reference	1,060 (0.92–1.21)	1.14 (0.98–1.32)	0.088
	Male	Reference	0.91 (0.77–1.07)	1.11 (0.95–1.29)	0.171
Other starchy vegetables[1)]	Female	Reference	0.89 (0.76–1.04)	**0.83 (0.70–0.97)**	**0.012**
	Male	Reference	0.92 (0.77–1.11)	1.15 (0.98–1.36)	0.183
Other vegetables[1)]	Female	Reference	0.89 (0.71–1.11)	**0.77 (0.62–0.97)**	**0.007**
	Male	Reference	1.13 (0.89–1.43)	1.00 (0.78–1.28)	0.357
Total vegetables[2)]	Female	Reference	**0.94 (0.81–1.09)**	**0.78 (0.67–0.91)**	**0.002**
	Male	Reference	1.08 (0.91–1.28)	0.91 (0.77–1.09)	0.224
Legumes[1)]	Female	Reference	1.00 (0.85–1.16)	0.99 (0.83–1.19)	0.933
	Male	Reference	1.07 (0.89–1.29)	0.93 (0.78–1.10)	0.536

Values are presented as odds ratio (95% confidence interval). Values in bold indicate statistical significance with $P \leq 0.05$.

[1)]The consumption of specific fruits and vegetables was divided into 3 categories: Group 1 included individuals with zero consumption; Group 2 included those with intake below the median; Group 3 included those with intake at or above the median.

[2)]The total fruit and vegetable consumption was divided into 3 groups based on the tertiles of its distribution in the whole study population.

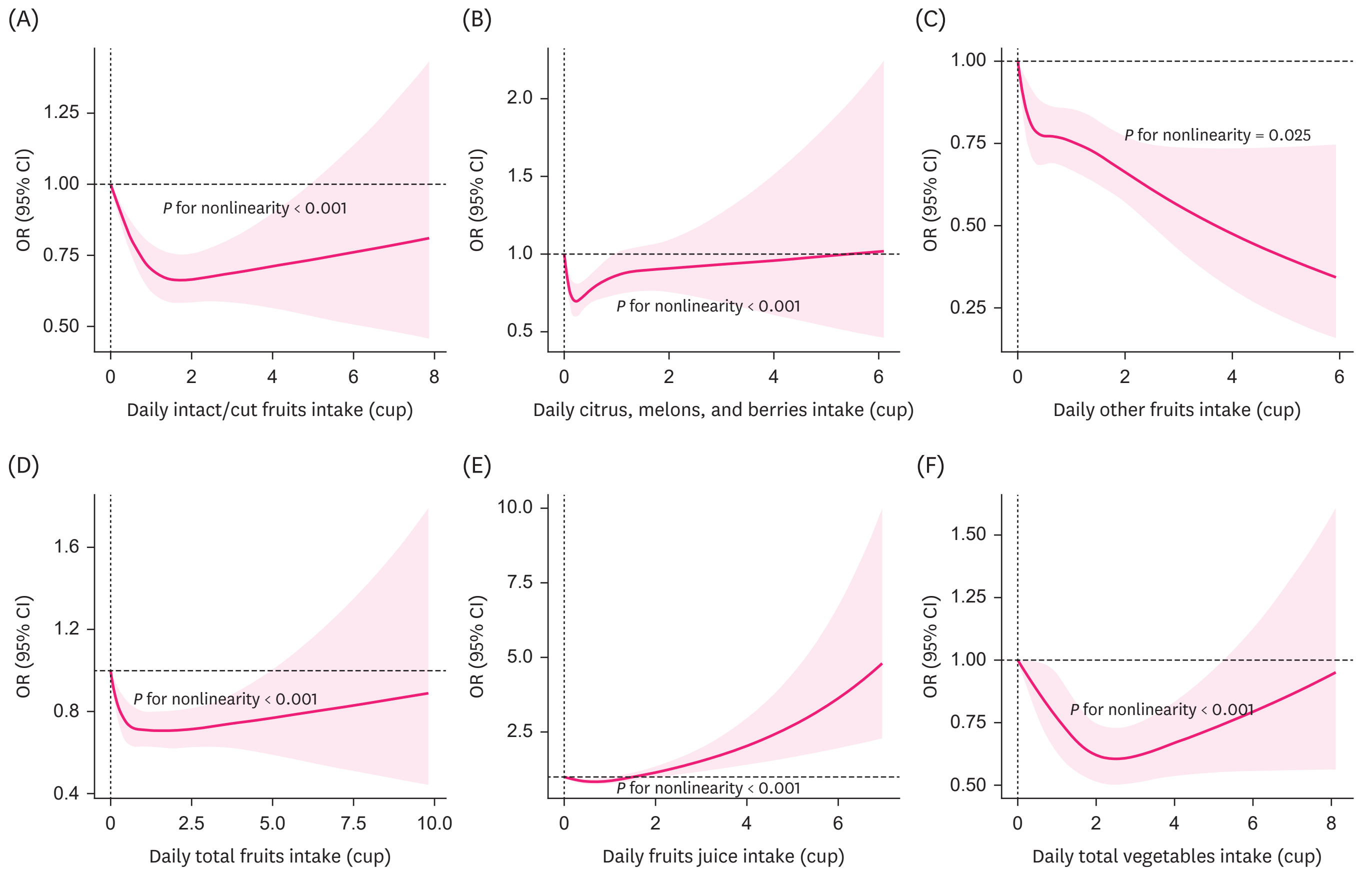

Fig. 2. Restricted cubic spline model of the association between (A) intact fruit intake and frailty; (B) citrus, melons, and berries intake and frailty; (C) other fruits intake and frailty; (D) total fruit intake and frailty; (E) fruit juice intake and frailty, (F) total vegetables intake and frailty. The red line and shaded area represent the estimated log ORs and their 95% CIs, respectively. The lowest level of daily intake was used as the reference.
OR, odds ratio; CI, confidence interval.

fruit up to 1.74 cups per day (OR, 0.66; 95% CI, 0.58–0.75; **Fig. 2A**), beyond which the trend plateaued. The total fruit consumption followed a similar pattern, with the lowest odds ratio of frailty observed at 1.58 cups per day (OR, 0.71; 95% CI, 0.62–0.80; **Fig. 2D**), after which the trend gradually reversed. The consumption of citrus, melons, and berries (OR, 0.70; 95% CI, 0.60–0.81; **Fig. 2B**) and fruit juice (OR, 0.84; 95% CI, 0.75–0.95; **Fig. 2E**) showed the lowest odds ratios for frailty at approximately 0.21 cups and 0.66 cups per day, respectively. On the other hand, the trend reversed beyond these consumption levels, with higher intake associated with an increased risk of frailty. Similarly, the risk of frailty declined rapidly as total vegetable consumption increased to 2.49 cups per day (OR, 0.61; 95% CI, 0.50–0.73, **Fig. 2F**), beyond which the trend gradually reversed. The relationship between the daily consumption of other fruit and frailty followed an inverse pattern (**Fig. 2C**).

DISCUSSION

This study showed that fruit consumption among adults ≥ 18 yrs old was associated with a reduced susceptibility to frailty, whereas higher fruit juice consumption does not lower this risk. Dark green vegetables and total vegetables are the only vegetable types inversely associated with frailty. Stratified analyses based on age groups and sex revealed a clear negative correlation between fruit and vegetable intake and the likelihood of frailty among adults below 60 yrs old and in females.

Several epidemiological studies explored the relationship between frailty and the total vegetable and fruit intake. Among these, a meta-analysis showed that consuming sufficient quantities of fruits and vegetables can lower the risk of frailty in older adults [24]. Another meta-analysis also showed that the highest category of fruit and vegetable consumption was inversely associated with the risk of frailty, aligning with the current findings [14]. On the other hand, the relationship between the consumption of specific fruits and vegetables and frailty still requires further investigation.

The correlation between fruit consumption and frailty is unclear. A meta-analysis found no statistically significant correlation between fruit consumption and the likelihood of developing frailty [14]. Kojima *et al.* [24] also found no correlation between fruit consumption alone and frailty in older individuals. Few studies have investigated the correlation between fruit consumption and frailty. Ruangsuriya *et al.* [25] revealed a significant correlation between guava consumption and reduced frailty in elderly individuals in Northern Thailand. The present study revealed a significant negative correlation between frailty and a higher intake of nearly all types of intact fruit. On the other hand, a significant relationship was found between a lower risk of frailty and lower levels of fruit juice consumption rather than higher levels.

The discrepancy between these findings and prior meta-analyses could be due to several factors. First, the definition of frailty might play a role. Most studies used the cardiovascular health study criteria for frailty, while this study used the frailty index. Second, the difference in mean age may also play a role. Adults ≥ 18 yrs old were included, whereas other studies primarily included individuals over 60 yrs of age. This study found a notable negative correlation between fruit consumption and frailty in adults under 60 yrs, but this relationship was insignificant in participants over 60 yrs, which is consistent with previous studies [14]. Third, gender might influence the relationship between specific fruit consumption and frailty. Stratified analysis revealed a significant inverse relationship between the consumption of most fruit and frailty in women but not men. The underlying cause of this gender difference is unclear, but it may be related to the different nutritional requirements between women and men.

Existing research on the correlation between vegetable consumption and frailty risk is inconclusive. Although one meta-analysis reported a negative correlation between vegetable intake and frailty [14], another did support this finding [24]. A prospective cohort study reported that individuals in the highest quintile of a healthful plant-based diet index had a hazard ratio for frailty of 0.77 (95% CI, 0.72–0.81) compared to those in the lowest quintile [26]. On the other hand, studies focusing on specific vegetables and frailty are limited. One study from Thailand showed that Acacia pennata intake reduced the frailty risk in older adults (OR, 0.42; 95% CI, 0.21–0.83) [25].

Our results indicated that the consumption of dark green vegetables, total vegetables, tomatoes, and tomato products was associated with a lower risk of frailty, particularly in adults under 60 yrs. Furthermore, the protective effects of vegetable consumption against frailty were observed mainly in women. The underlying mechanisms of these associations are unclear, highlighting the need for further research to explore how this relationship varies across age groups and sexes and to identify the mechanisms involved.

The mechanisms underlying the effects of specific fruits and vegetables on frailty are unclear, and the evidence in this area is limited. One potential reason could be changes in the gut microbiota. For example, lemon polyphenols have been shown to increase the lifespan of mice by 3 weeks and slow Lactobacillus growth, demonstrating anti-aging effects on the intestinal environment [27]. Previous studies reported a positive correlation between frailty and elevated levels of inflammatory markers [28] and anti-oxidative markers [29,30]. Fruit and vegetables contain an abundance of substances that can inhibit inflammation and oxidative stress throughout the body, such as β-carotene [31], flavonoids [32], selenium and magnesium [33], and vitamin C [34]. Reducing inflammation and oxidative stress, which contribute to the development of frailty, might be another fundamental mechanism against frailty.

The primary nutritional components of fruit and vegetables vary, which may explain the differing odds ratios of frailty associated with different fruits and vegetables [35]. The high sugar content of fruit juice, predominantly fructose, may have adverse health effects and diminish the beneficial effects of 100% fruit juice [36]. This may help explain the inverse relationship between lower, rather than higher, levels of fruit juice consumption and frailty. Despite being an excellent source of health-promoting components, legumes contain bioactive compounds that can act as antinutrients, such as phytic acid, covicine, protease, and amylase inhibitors [37]. These antinutrients disrupt the digestion and assimilation of specific dietary components, resulting in detrimental physiological effects and impeding the frailty-reducing benefits of legumes [38].

The optimal consumption of fruits and vegetables is crucial because low and high intake can lead to nutritional imbalances. Insufficient fruit and vegetable intake can result in a lack of essential nutrients, while excessive consumption can hinder the intake of sufficient calories and other crucial nutrients like protein, leading to a poor-quality, unbalanced diet and an increased risk of frailty. Despite their richness in micronutrients, fruit and vegetables are not dense in calories or proteins, and a deficiency of these nutrients can increase the risk of frailty [39]. This study also showed that consuming fruit and vegetables does not appear to mitigate frailty in individuals aged 60 yrs and older. One explanation for this observation is the excessive number of free radicals and inflammation markers, which may overwhelm the antioxidant and anti-inflammation capacity of fruit and vegetables [40]. Therefore, supplementing the diet with fruit and vegetables before reaching an advanced age is advisable to improve physical performance and guard against the development of frailty.

This study had several strengths. First, this study is the first to examine the correlation between fruit and vegetable consumption and frailty in the overall population, evaluating how different types of fruit and vegetables affect frailty among various age groups and genders in general adults. This provides valuable information for guiding public health recommendations on specific dietary choices. Second, the study used the dose-response and subgroup analyses to assess the associations, allowing for a more nuanced understanding of the relationships and identifying subgroups that may particularly benefit from consuming specific fruits and vegetables. Third, it examined a large and nationally representative sample of American adults, which enhances the statistical power and reliability of the results. Fourth, numerous potential confounding variables that could have influenced these associations were considered. Furthermore, this study used the frailty index to measure the degree of frailty. The frailty index is a continuous measure, making it suitable for longitudinal studies because it can quantify the progression of health status more precisely over time.

Nevertheless, the present investigation had several limitations. First, it was a cross-sectional study, which calls for caution regarding the conclusions. Cross-sectional evidence may not show the causal effects of nutrition on frailty because some studies suggested that frailty could change eating behaviors rather than being caused by a poor diet [41]. Second, the dietary data came from 2 nonconsecutive 24-h dietary recalls. Such recalls may be subject to recall bias and random error and may not accurately reflect the typical dietary intake of individuals. On the other hand, a validation study showed that 24-h dietary recalls exhibited fewer systematic errors than food frequency questionnaires [42]. Furthermore, repeated 24-h dietary recalls were the most effective approach for estimating the average and distribution of the true dietary intake within a population [43]. Finally, the generalizability of these findings to other countries or regions is uncertain because of the reliance on a database derived from a demographic survey conducted in the United States.

In conclusion, this study found that higher intake of fruit (excluding fruit juice) and vegetables, particularly dark green vegetables, is inversely related to frailty in American adults. The recommended daily intake is 0.21 serving of citrus, melons, and berries, 1.58 serving of total fruit, 0.66 serving of fruit juice, and 2.49 serving of total vegetables. These results suggest that advocating for the intake of recommended quantities of fruit and vegetables may mitigate the likelihood of frailty, with a particular emphasis on females and people below 60 yrs of age. Additional research will be needed to substantiate these findings by implementing extensive prospective cohort studies.

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SUPPLEMENTARY MATERIAL

Supplementary Table 1

Variables in the 49-item frailty index and their respective scorings

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