SHORT COMMUNICATION

Flavonoid intake is inversely associated with obesity and C-reactive protein, a marker for inflammation, in US adults

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Recent studies have demonstrated the importance of flavonoid intake and disease risk, however the association between flavonoid intake and obesity has not been evaluated in a nationally representative sample of US adults. The objective of the study was to evaluate the association between flavonoid consumption and established risk factors for obesity and obesity-related inflammation. Data from a nationally representative sample of 9551 adults who participated in the 2005–2008 National Health and Nutrition Examination Survey (NHANES) were analyzed. Flavonoid consumption was inversely associated with obesity in both men and women in multivariate models. Adults in the highest quartile of flavonoid intake had significantly lower body mass index and waist circumference than those in the lowest quartile of flavonoid intake (P < 0.03 and P < 0.04, respectively), and flavonoid intake was inversely related to C-reactive protein levels in women (p-trend, 0.01). These findings support a growing body of laboratory evidence that flavonoid consumption may be beneficial for disease prevention.

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INTRODUCTION

Over the past few decades, the rates of obesity have risen markedly.¹ Overweight and obesity have been identified as risk factors for several diseases, including cardiovascular disease, diabetes and cancer. Survey data from large, nationally representative samples of US individuals can provide insight into trends that have potentially contributed to this increase in obesity. Data from the National Health and Nutrition Examination Surveys (NHANES) have shown that although there have been no substantial changes in eating frequency, snacking behaviors or overall energy intake among US adults, there have been significant changes in macronutrient distribution and beverage consumption, suggesting that specific dietary patterns, such as increased intake of carbohydrates and sugar-sweetened beverages, may influence weight status.²⁻⁴

Flavonoid consumption has been linked to a decrease in risk for: stroke,⁵ cardiovascular disease,⁶⁻⁸ asthma,⁹⁻¹⁴ and some cancers.²⁻⁴ The majority of studies on the relationship between flavonoid intake and obesity have focused on intake of specific flavonoids subclasses and body mass index or weight gain¹⁵,¹⁶ or lipid metabolism;¹⁷ with very few assessing the relationship between overall flavonoid intake and obesity. The objective of this study was to determine the relationship between flavonoid consumption and obesity in a representative sample of 9551 US adults. Using NHANES data, the association of flavonoid consumption and multiple markers for obesity including: body mass index (BMI), waist circumference and C-reactive protein were explored.

MATERIALS AND METHODS

Data source

NHANES is a large, cross-sectional survey conducted by National Center for Health Statistics. NHANES is designed to monitor the health and nutritional status of non-institutionalized civilians in the US; nationally representative survey and physical data are collected on a continual basis and released in two-year increments. Complete details regarding the NHANES sampling methodology, data collection, and interview process are available on the NHANES website (http://www.cdc.gov/nchs/nhanes.htm). Written consent is obtained from all NHANES participants. Data from the 2005–2008 survey cycles were combined for this study. The present study was approved by the Institutional Review Board at the Pennsylvania State University.

Anthropometric and biomarker data

In both cycles of NHANES, height and weight were measured by trained examiners using standardized protocols and calibrated equipment during the physical examination component of the study. Adults were classified as lean (BMI ≤ 24.9 kg m⁻²), overweight (BMI of 25.0–29.9) or obese (BMI ≥ 30) using CDC cut points (https://www.cdc.gov/obesity/adult/defining.html). For this analysis, underweight (BMI < 18.5) participants were included in the lean category. Blood samples were collected on a smaller subset of the population. Non-fasting samples were obtained for C-reactive protein (CRP), a marker for inflammation.

Assessment of flavonoid intake

Flavonoid content of the diet was assessed using the USDA Flavonoid database version 3.0,¹⁸ which includes flavonols, flavones, flavanones, flavan-3-ols and anthocyanidins. The database contains a list of foods and the currently available flavonoid compound data by flavonoid class. The food data were aggregated where possible to match USDA National Nutrient Databank (NDB) standard reference (SR) codes.¹⁸ The SR codes were used to identify and match foods from the flavonoid database to corresponding FNDDS codes in order to identify foods that contain bioactive compounds (for example, a smoothie containing pomegranate juice). Using the FNDDS ingredient file, the gram weight of each flavonoid-containing component of a...
Few studies have evaluated or identified specific dietary patterns that are related to obesity and markers for Metabolic syndrome.\textsuperscript{19} The association between intake of a specific flavonoid-containing food (that is, tea, soy) and obesity has been previously demonstrated in a nationally representative sample of US adults,\textsuperscript{20,21} has been inversely correlated to longitudinal weight gain in larger cohort studies\textsuperscript{22} and has also been recently correlated with lower levels of inflammatory markers in a cohort sample from the Framingham Offspring Study.\textsuperscript{23} However the present study takes a novel approach to assessing the relationship between total dietary flavonoid intake and markers for obesity by applying the USDA Flavonoid database to NHANES survey data. These findings support a growing body of laboratory evidence that flavonoid consumption may be beneficial for disease prevention.

## RESULTS

Demographic characteristics are presented in Table 1. The population sample contained equal percentages of men and women; approximately half of the sample had a history of smoking, and over 90% of the population reported consumption of a flavonoid-containing foods. An inverse association between total flavonoid intake and BMI was observed (p-trend, 0.013) after adjusting for age, sex, race, education, physical activity, smoking status, poverty-income ratio, total alcohol intake, and caloric density (Figure 1). When evaluating flavonoid intake and waist circumference, a similar association was observed (p-trend 0.013, Figure 1). Table 2 demonstrates the relationship between regular consumption of flavonoid-containing foods and C-reactive protein levels, after controlling for the same cofactors. Across all food categories, it was noted that higher intake of flavonoid-containing foods was associated with lower CRP levels. When evaluating the association between overall flavonoid intake and CRP levels, an overall inverse association was observed (p-trend 0.013), but mean CRP levels did not differ between specific quartiles after controlling for relevant covariates.

## DISCUSSION AND CONCLUSION

In this nationally representative sample of US adults, intake of dietary flavonoids was inversely associated with obesity and CRP. Several studies have evaluated or identified specific dietary patterns that are related to obesity and markers for Metabolic syndrome.\textsuperscript{19} The association between intake of a specific flavonoid-containing food (that is, tea, soy) and obesity has been previously demonstrated in a nationally representative sample of US adults,\textsuperscript{20,21} has been inversely correlated to longitudinal weight gain in larger cohort studies\textsuperscript{22} and has also been recently correlated with lower levels of inflammatory markers in a cohort sample from the Framingham Offspring Study.\textsuperscript{23} However the present study takes a novel approach to assessing the relationship between total dietary flavonoid intake and markers for obesity by applying the USDA Flavonoid database to NHANES survey data. These findings support a growing body of laboratory evidence that flavonoid consumption may be beneficial for disease prevention.

### Table 1. Demographic characteristics of US Adults: NHANES 2005–2008

| Sex         | Sample n\textsuperscript{a} | Percent\textsuperscript{b} |
|-------------|------------------------------|----------------------------|
| Female      | 4587                         | 50.0                       |
| Male        | 4964                         | 50.0                       |
| Age group   |                              |                            |
| 18–30       | 2270                         | 23.5                       |
| 31–50       | 2972                         | 37.6                       |
| 51–70       | 2712                         | 27.7                       |
| > 70        | 1597                         | 11.2                       |
| Race\textsuperscript{a} |                      |                            |
| NH-White    | 4502                         | 71.0                       |
| NH-Black    | 2156                         | 11.5                       |
| Mex-Am      | 1802                         | 8.3                        |
| Other       | 1091                         | 9.3                        |
| Education   |                              |                            |
| HS or less  | 2931                         | 19.8                       |
| High School Grad/GED | 2427 | 26.5                       |
| Some College or AA degree | 2545 | 30.0                       |
| College Graduate or above | 1642 | 23.7                       |
| Income\textsuperscript{d} |                          |                            |
| PIR < 130%  | 3356                         | 24.9                       |
| 130 < PIR < 350% | 3483 | 34.4                       |
| PIR > 350%  | 2712                         | 40.7                       |
| Smoking status |                                 |                            |
| Never smoker | 4540                         | 50.9                       |
| Current smoker | 2029                        | 25.1                       |
| Ever smoker (> 100 cigarettes) | 2246 | 23.9                       |
| Weight status\textsuperscript{e} |                        |                            |
| Lean (BMI < 25) | 3259 | 36.2                       |
| Overweight (BMI 25–30) | 3183 | 32.9                       |
| Obese (BMI > 30) | 3109 | 30.9                       |
| Survey cycle |                                 |                            |
| 2005–2006   | 4296                         | 48.2                       |
| 2007–2008   | 5255                         | 51.8                       |
| Flavonoid consumer |                                |                            |
| No          | 434                          | 4.9                        |
| Yes         | 9482                         | 95.6                       |

Abbreviations: BMI, body mass index; PIR, poverty–income ratio.\textsuperscript{\textsuperscript{a}Sample n represents raw participant counts. \textsuperscript{b}Population percentages based on NHANES survey weights and represents that population of non-institutionalized US adult residents. \textsuperscript{c}Race categories: NH-White, Non-Hispanic white; NH-Black, Non-Hispanic black, Mex-Amer, Mexican American; Other. \textsuperscript{d}Adjusted income level based on poverty-income ratio adjusted for household size and "Weight status categorized by body mass index, measured in kg m\textsuperscript{-2}.}
Body mass index and waist circumference by flavonoid intake quartile. Least-squared means calculated with adjustment for sex, age, race, education, physical activity, smoking status, poverty-income ratio, total alcohol intake, total fat intake and dietary energy density.

| Consumption category | Onions  | Tofu | Apples | Grapes |
|----------------------|--------|------|--------|--------|
| Non-consumer         | 4.10   | 4.10 | 4.81   | 5.63   |
| Infrequent (< 1 x/month) | 4.37   | 3.24 | 4.16   | 3.83   |
| Monthly consumer (< 3 x/month) | 3.84   | 3.41 | 3.81   | 3.56   |
| Weekly consumer (1–2 x/week) | 3.66   | 2.65 | 3.28   | 4.09   |
| Regular consumer (3 x/week) | 3.85   | 2.80 | 2.91   | 2.78   |
| P-trend              | 0.002  | 0.004| 0.001  | 0.02   |

Table 2. Adjusted mean C-reactive protein level (mg dl⁻¹) by consumption category

**CONFLICT OF INTEREST**

The authors declare no conflict of interest.

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