Published in final edited form as:
Nutr Res. 2012 April ; 32(4): 251–259. doi:10.1016/j.nutres.2012.03.005.

Candidate measures of whole plant food intake are related to biomarkers of nutrition and health in the US population (NHANES 1999–2002)

Leah M. Lipsky[1], **Kyeongmi Cheon**[1], **Tonja R. Nansel**[1], and **Paul S. Albert**[1]
[1]*Eunice Kennedy Shriver* National Institute of Child Health and Human Development, Bethesda MD.

Abstract

Indices of overall dietary patterns are used in epidemiologic research to examine the relationship between nutrition and health. The objective of this study was to develop and validate an interpretable summary measure of dietary intake of whole plant foods (WPF-whole grains, vegetables, whole fruit, legumes, nuts, seeds) due to their similar nutritional characteristics and health effects. Six candidate WPF measures were calculated using data from subjects (age≥6y) participating in the 1999–2000 and 2001–2002 National Health and Nutrition Examination Survey (NHANES). Measures differed by the inclusion or exclusion of potatoes and whether they were expressed as total intake or as a proportion of energy (1000 kcal) or mass (kg) consumed. Both standard and non-truncated (allowed to vary proportionally with intake) Health Eating Index-2005 (HEI-2005) scores were calculated. Regression analysis examined associations between WPF and HEI-2005 measures, and between all diet measures and serum carotenoid concentration, serum lipids, fasting glucose, insulin, c-peptide and c-reactive protein. Mean total WPF intake was 3.6 cup/oz equivalents, or 1.7 cup/oz equivalents per 1000 kcal and per kg. The largest R^2 between WPF and HEI-2005 measures was found for energy-adjusted WPF including potatoes and non-truncated HEI-2005 (R^2 =0.50). All diet measures were positively related to serum carotenoids ($p<0.001$) and were similarly related with health indicators (R^2 range from 0.003–0.16, $p<0.045$ for regressions indicating significant associations between WPF measures and health indicators). WPF measures are interpretable indicators of dietary intake that are significantly related to nutrition and health biomarkers, and may be of public health utility.

Keywords/phrases

Human; Nutrition Indices; National Health and Nutrition Examination Survey; Food Plants; Biomarkers

1. Introduction

In pursuit of understanding the relationship between diet and health, researchers have developed a number of indices to indicate quality of dietary intake, created on the basis of a

Corresponding author: Leah Lipsky, 6100 Executive Blvd Suite 7B13, Bethesda MD 20852. Phone: 301-435-6932 Fax: 301-402-2084 lipskylm@mail.nih.gov.

The authors declare no conflicts of interest.

priori knowledge of the importance of various dietary components to health outcomes [1]. Indices have been constructed to reflect dietary guidance, patterns, and/or nutrient content, and represent an alternative approach for classifying dietary exposure, rather than focusing on specific foods or nutrients in isolation [1–3]. Measures of diet quality or patterns are intended to give a more realistic measure of dietary behavior, given that nutrients and foods are not consumed in isolation, as well as to address the interrelationships among nutrients of dietary components [2,4]. The utility of such measures may be evaluated with respect to their relationships with other indicators of dietary intake and health status, their interpretability, and their potential applications for research and policy.

The Healthy Eating Index-2005 (HEI-2005) [5] is an index of overall dietary quality that was developed in 2008 by a governmental interagency working group to assess adherence to the 2005 Dietary Guidelines for America (DGA). The HEI-2005 total score is comprised of 12 component scores, which are calculated from dietary intakes of various foods or nutrients per 1000 kilocalories (kcal) consumed, and represent different elements of the 2005 DGA. Total scores resulting from the summation of the 12 components range from 0 to 100, with higher scores indicating better adherence to dietary guidelines. The primary improvement in this index over its predecessors is that scores are determined on the basis of intake standardized to 1000 kcal, allowing for comparisons across individuals with different energy requirements. Previous studies have reported relationships between the HEI-2005 and health biomarkers [6] as well as with long-term health outcomes [7]. However, the complexity of the index’s calculation limits the measure’s implementation in many research settings and the interpretation of any observed associations with outcomes. Since the HEI-2005 overall score reflects a variety of dietary components with differential nutritional profiles and health effects, relations observed between the overall score and outcomes related to nutrition and health are difficult to interpret [1,2]. Conversely, utilizing the individual components of the HEI-2005 as the exposure may limit the ability to detect relationships with diet and health outcomes since multiple food groups with similar nutritional characteristics and health effects would be examined individually rather than collectively [1,2].

Findings from numerous studies have indicated the primary health importance of dietary intake of whole plant foods (WPF), including whole fruit, vegetables, whole grains, legumes, nuts and seeds. Shared nutritional characteristics of WPF include their low energy and high micronutrient and fiber content [8], and the absence of added sugars, animal fats, sodium, and other chemicals, preservatives and additives associated with food processing (e.g., juicing and refining). Foods with these nutritional attributes have been associated with health benefits including prevention of type 2 diabetes [9–12], improvement in glycemic control and cardiovascular disease risk factors and events [13–18], and reduced cancer risk [19–21] and overall mortality [22]. However, we are not aware of the existence of any measure representing this aspect of dietary quality, which may complement and enhance analytic methods for studying the relationship between diet and health. The objective of this paper was to develop and evaluate a measure of WPF intake. Validity was assessed by examining associations with the HEI-2005 as well as with biomarkers of dietary intake and health status. The candidate measures were designed for simplicity of calculation to facilitate application in a variety of settings and interpretability in order to assist translation from research to policy and practice. We used data from the National Health and Nutrition Examination Survey (NHANES) to evaluate alternative measures of WPF intake in a proof-of-concept manner.

2. Methods and materials

2. 1. Sample

This study used data from individuals aged 6 years and older with a complete and reliable dietary recall (n=7794) participating in the 1999–2000 and 2001–2002 NHANES. Data from these two release cycles were used to provide a sufficient sample size for addressing the stated research objectives. Preschool-aged children were excluded due to the increased difficulty associated with assessing dietary intake in this age group [23]. The survey is a multistage stratified probability sample of the non-institutionalized, civilian population in the US at least 2 months of age [24] Information on smoking, physical activity, supplement use, age, sex and race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican American, other including multi-racial, other Hispanic) was obtained during subject interviews. Exclusions were made for women who were pregnant (n = 623) or nursing (n = 72). Details on the study design, procedures and methods rates are described elsewhere [25].

2.2. Dietary data collection

Dietary information was obtained using a single interviewer-assisted 24-hour dietary recall during an examination in a mobile examination center (MEC). Dietary data for children 6–11 years of age were assisted by an adult. Descriptions of the dietary interview methods, including pictures of the Computer-Assisted Dietary Interview system screens, measurement guides, and charts used to collect dietary information are provided in the NHANES Dietary Interviewer's Training Manual [26].

2.3. Healthy Eating Index-2005

The HEI-2005 total score was calculated based on instructions provided by the USDA [27,27] using the MyPyramid Equivalents Database (MPED) for USDA Survey Food Codes, version 1, and the CNPP MyPyramid Equivalents Database for Whole Fruit and Fruit Juice, version 1, which enable calculation of intakes for the food group components of the HEI-2005 for NHANES data collected up to 2002 [28]. The HEI-2005 total score is comprised of twelve dietary components (total fruit, whole fruit, total vegetables, dark green/orange vegetables and legumes, total grains, whole grains, milk, meat and beans, oils, saturated fat, sodium, and solid fat/alcohol/added sugars) reflecting the recommendations of the 2005 Dietary Guidelines for Americans [5]. The index is calculated on a scale of 0 to100, such that scores are truncated once intakes exceed minimum or maximum recommendations. For example, the maximum score for whole fruit is assigned for intakes either at or above 0.4 cup equivalents per 1000 kcal [27], thus eliminating variation at the tails of the intake distributions. In order to enable more direct comparisons with WPF measures described below (which are non-truncated), we further calculated non-truncated HEI-2005 scores (HEI_NT) to allow total and component scores to vary directly with intake amounts regardless of exceeding maximum or minimum thresholds that apply for standard HEI-2005 scoring.

2.4. Whole Plant Food Intake Measures

WPF candidate measures were constructed using a food-based approach to represent overall dietary intake of whole plant foods, which included whole fruit, vegetables, whole grains, legumes, nuts and seeds (plant-based foods excluding juice and refined grains). Food category information was obtained by merging NHANES dietary data with the MyPyramid Equivalents Databases and the CNPP Fruit and Fruit Juice Equivalents Database, as described above [28] (for applications in other nutrition analysis software, any standard measure of serving size would suffice). Six measures were calculated, each representing the number of cup/oz equivalents of WPF intake, but varying in terms of representing either total or proportional intake. Measures also varied by whether WPF intake included or excluded potatoes, given some evidence of adverse or differing effects on health indicators and outcomes [29,30]. Both total and proportional measures of WPF intake were calculated in order to enable comparison of these approaches. Two total intake measures represented the total number of cup/oz equivalents of WPF intake, either with (WPFP_TOT) or without (WPFNP_TOT) potatoes. For the proportional diet approach, we conceptualized the "whole diet" as being represented by either the quantity of energy or mass of food and beverage consumed. WPF intake density measures were calculated as total WPF intake as described above, standardized per 1000 kcal or per kg (as indicated by a _kc and _kg suffix, respectively) in order to facilitate comparisons across individuals with differing food and nutrient requirements, and to compare the relevance of dietary energetic value versus physical mass. Thus, these measures increase in value with increasing proportion (per 1000 kcal or per kg) of WPF in the diet, and decrease with increasing proportion of the diet attributed to foods other than WPF including animal-derived foods, added sugars and fats. The resulting four proportional measures differ with respect to whether they include white potatoes in the numerator, and whether the whole diet is conceptualized in terms of energy (kcal) or mass (kg). The names and definitions of the measures are presented in Table 1.

2.4. Biomarkers

Data on indicators of diet and health were obtained from collection of blood samples in the MEC exam. The Laboratory Procedures Manual used in the 1999–2000 and 2001–2002 NHANES gives detailed information regarding materials and methods for measuring biomarkers [25]. Total plasma carotenoids (ug/dL, available for NHANES 2001–2002 only), calculated as the sum of a-carotene, trans-b-carotene, cis-b-carotene, b-cryptoxanthin, and combined lutein/zeaxanthin, was examined as a biomarker for intake of plant foods [31]. Biomarkers for diabetes [fasting blood glucose (mg/dL), fasting insulin (uU/mL), glycohemoglobin (HbA1c, %), c-peptide (nmol/L)], inflammation (c-reactive protein, mg/dL) and cardiovascular disease [serum total cholesterol (TC, mg/dL), high density lipoprotein cholesterol (HDL-C, mg/dL), low density lipoprotein cholesterol (LDL-C, mg/dL), and triglycerides (TG, mg/dL)] were also evaluated. Per instructions in the NHANES laboratory documentation [25], at least 9 hours of fasting were required for obtaining serum TG, plasma glucose, c-peptide and insulin.

2.5. Statistical analyses

The associations between WPF and HEI-2005 measures, and between diet quality measures and nutrition and health biomarkers, were examined using regression analysis with SAS SURVEYREG procedure (SAS version 9.2, SAS Institute Inc., NC). In order to account for non-response and the unequal probability of selection due to oversampling of certain population subgroups, 4-year weights for 1999–2002 provided by National Center for Health Statistics (NCHS) were applied for all regression analyses. All regression models examining the relationships between diet and health biomarkers were adjusted either for total energy intake in order to provide estimates of the independent contribution of diet composition to the outcomes, and in order to account for potential confounding resulting from relationships of total energy intake with both intake of specific dietary components and with outcomes of interest. Extended models additionally adjusted for age, sex, race/ethnicity, physical activity (number of times per week of vigorous physical activity), smoking (currently smoking or not), and current supplement use. Relationships between WPF and HEI-2005 measures were examined graphically by plotting lowess smoothed curves, constructed in R (free software offered at http://www.r-project. org).

3. Results

3.1 Sample characteristics

Mean total intake of WPF including potatoes was 3.6 cup/oz equivalents (2.7 excluding potatoes) (Table 2). The sample consumed a mean 1.7 cup/oz equivalents of WPF including potatoes per 1000 kcal and per kg of food, and approximately half a cup/oz equivalent less potatoes were excluded.

3.2 Relationships between WPF and HEI-2005 measures

All WPF measures were significantly related to both HEI-2005 measures ($p < 0.001$), with the coefficients of determination ranging from 0.15– 0.50. The largest coefficient of determination was found between WPFP_KC and HEI2005_NT (R^2=0.50) (Table 3). These findings are reflected in lowess plots, which further indicate positive relationships between the measures, with a strong linear relationship at the higher ranges of nutritional exposure and a weak association at the lower ranges (Figure 1A–1D). A larger proportion of variance was explained for the relationships between WPF measures and non-truncated as compared with the standard HEI-2005 measure, and for energy-adjusted WPF measures as compared with total intake or food mass-adjusted WPF measures. The magnitudes of the differences in coefficients of determination according to inclusion or exclusion of potatoes were small (< 0.03).

3.3. Relationships between diet quality measures and serum carotenoids

All diet quality measures in the base models were positively related to serum carotenoid concentration ($p < 0.001$) (Table 4). The total and energy-adjusted WPF measures including potatoes explained the largest proportion of variance in serum carotenoids as compared with all other indices. Truncated HEI-2005 and mass-adjusted WPF measures explained the smallest proportion of the variance in serum carotenoids as compared with other intake measures. Results were similar for the fully adjusted models (Table 5).

3.4. Biomarkers for cardiovascular disease

We found no significant relationships between diet quality measures and LDL-C in the base models (Table 4). However, in the extended models there were inverse relationships between LDL-C and all diet quality measures except WPFP_TOT and WPFNP_TOT, and between TG and WPFP_KC (Table 5).

WPFP_TOT and energy-adjusted WPF measures were positively related to TC in base models, though R^2 values were <0.01. However, in extended models, only HEI-2005 measures were significantly inversely related to TC ($p<0.05$). All intake measures were positively related to HDL-C in the base models (Table 4). The proportion of shared variance in health biomarkers was the similar across intake measures. Results were similar in extended models, except for a non-significant relationship between the food mass-adjusted WPF measures and HDL-C (Table 5).

3.5 Biomarkers for diabetes and inflammation

In base models, there were positive correlations of A1c with non-truncated HEI-2005 and WPF measures expressed as total intake and as a proportion of energy consumed (both with and without potatoes) (Table 4). In extended models, only standard HEI-2005 was significantly inversely associated with A1c, though the beta coefficient estimate was small. Plasma glucose was positively related to WPFP_TOT and WPFP_kc in base models, though the coefficients of determination were less than 1%. No diet quality measures were found to have significant statistical correlation with blood glucose level in extended models (Table 5).

There were negative relationships of insulin levels with all diet quality indices except non-truncated HEI-2005 in both the base and extended models (Tables 4 and 5). R^2 values in extended models did not differ by diet quality measure. Insulin was significantly correlated with all diet measures except non-truncated HEI-2005 in extended models (Table 5). Additionally, c-peptide was inversely associated with all diet quality indices in base models, with the exception of non-truncated HEI-2005 (Table 4); c-peptide was inversely related to all diet measures in extended models, except non-truncated HEI-2005 (Table 5). CRP was inversely associated with all diet quality indices in both the base and extended models, except for a small positive association with HEI-2005 measures in the base model (Tables 4 and 5).

4. Discussion

The study calculated six alternative summary measures of unprocessed whole plant food (WPF) intake, and compared relationships with biomarkers of nutrient intake and health against both the standard Healthy Eating Index-2005 (HEI-2005) and a non-truncated HEI-2005 measure. Energy-adjusted WPF intake in this population (1.7 cup/oz equivalents) was approximately half the combined amount of whole fruit, vegetables and whole grains recommended in the 2005 Dietary Guidelines for Americans (3.0 cup/oz equivalents), or approximately a third of the recommended combined amount of total fruit, vegetables and total grains [32,32,32] (these guidelines were not in effect at the time of data collection). Measures of WPF intake were positively related both to the standard (HEI2005_ST) and non-truncated (HEI2005_NT) HEI-2005 measures, and explained up to a quarter of the variance in HEI2005_ST and half of the variance in HEI2005_NT. Results further indicated that associations of WPF with HEI-2005 measures were more linear in the upper HEI-2005 ranges, suggesting that WPF intake is more relevant for differentiating diet quality among individuals already meeting guidelines for other components of the HEI-2005.

The association between WPF measures and health biomarkers were generally statistically significant, though the proportion of variance explained was small. All diet quality measures were significantly and positively related to serum carotenoid concentration, an indicator of fruit and vegetable intake [31]. Energy-adjusted WPF measures explained more of the variance in serum carotenoids than HEI2005_ST, while results were similar for HEI2005_ST as with mass-adjusted WPF measures. Total and energy-adjusted WPF measures including potatoes were significantly correlated with more health biomarkers as compared with other diet quality measures in the base models adjusted only for total energy intake. In the extended models additionally adjusted for demographic covariates, HEI2005_ST was related to the greatest number of diet and health biomarkers, followed by non-truncated HEI2005_NT and energy-adjusted WPF measures. Although differences between the base and extended models were generally modest, we found significant relationships between most diet quality measures and LDL-C in the fully extended model, whereas none were significant in the base models, likely due to the improvement in precision achieved by controlling for covariates. Additionally, TC was significantly related only to select WPF measures in the base models, but only to HEI-2005 measures in the extended models. These findings may be attributed to the increased relative importance to TC of dietary components (e.g., fat) explicitly included in the HEI-2005 but not in WPF measures. Significant associations of diet quality measures with biomarkers for diet and health were in the expected direction in extended models.

As expected given the similarities in the calculation of these variables, our analysis showed that energy-adjusted WPF measures shared the greatest variation with HEI-2005 measures as compared with other measures of WPF intake. We found few differences across dietary quality measures in relationships with diet and health biomarkers. The WPF total intake and energy-adjusted measures also explained more of the variance in serum carotenoids as compared with HEI2005_ST and mass-adjusted WPF measures. Although some research findings have questioned the role of potatoes in chronic disease risk [29,30], our findings did not indicate substantial differences according to inclusion or exclusion of potatoes in WPF measures.

Two of the chief purposes of diet quality indices are to reflect dietary intake and to predict nutrition-related health outcomes. Previous studies of relationships of HEI-2005 with health outcomes have found modest associations with colorectal cancer risk [7] lipid profile [6] and inflammation [33] but no association with incident diabetes [34]. Such research has revealed important weaknesses of the HEI-2005 that may obscure associations, including the large number of dietary factors contributing to the overall score that may have differing effects [3] and the truncation of component scores outside pre-specified ranges of intakes [1]. For example, both refined and whole grains contribute to a higher HEI-2005, despite evidence of different biologic and health effects [35–37] of these foods. In addition, WPF intake in excess of dietary recommendations may offer greater disease protection than merely meeting minimum guidelines; however, these differences would not be captured in the standard HEI-2005 or other diet quality measures that similarly truncate scores related to intake of these foods. Further, due to the multifactorial calculation of the HEI-2005, while very high and very low HEI-2005 scores are considered indicative of very high and low diet quality, respectively, scores within the middle range are more difficult to interpret since they can reflect dissimilar patterns of dietary intake [33]. These disadvantages may be less applicable for WPF measures, which include foods with shared nutritional attributes that are expected to have similar relationships with health outcomes, and are allowed to vary linearly with intake amount. Additionally, the limited number of foods contributing to increased WPF values facilitates the interpretation of associations with health outcomes, which is further enhanced by the use of a food-based rather than nutrient-based approach. Moreover, the use of WPF measures would not preclude the assessment and analysis of other dimensions of dietary quality (e.g., an overall intake measure of beneficial animal-derived foods or of nutrient-poor dietary components). The WPF measures, then, may represent the middle ground in nutritional exposure classification within the spectrum of individual nutrients or foods on one end and overall dietary patterns on the other.

Interpretation of these findings must consider the study’s limitations. These results are based on a single 24-hour dietary recall, which may not reflect long-term dietary patterns and are susceptible to subject’s memory and tendencies for misreporting intake. In addition, NHANES is a cross-sectional study, which precludes determination of causality from these findings. These limitations may attenuate observed relations.

In accordance with our stated objective, we developed alternate measures of unprocessed, whole plant food intake and examined their validity with respect to the HEI-2005 and biomarkers for nutrition and health. WPF summary measures calculated as the sum of cup or ounce equivalents of whole fruit, vegetables, whole grains, legumes, nuts and seeds per 1000 kcal of food consumed explained more of the variance in biomarkers for whole plant food intake than the standard truncated HEI-2005, and were significantly related to a similar number of health biomarkers, though the proportion of explained variance observed was small. WPF measures may be useful in future longitudinal research of relationships of plant food intake with health outcomes by providing a measure of one aspect of dietary quality. The simplicity of the calculation of these measures is an advantage that enhances the measures' utility for research and analysis, and for the interpretability of findings among the general public.

Acknowledgments

This research was funded by the intramural research program of the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development.

Abbreviations

HEI-2005	Healthy Eating Index-2005
NHANES	National Health and Nutrition Examination Survey
HEI2005_ST	Standard, truncated HEI-2005
HEI2005_NT	Non-truncated HEI-2005
WPF	Whole plant food
WPFP_TOT	Total whole plant food intake, including potatoes
WPFPNP_TOT	Total whole plant food intake, excluding potatoes
WPFP_KC	Energy-adjusted whole plant food intake, including potatoes
WPFNP_KC	Energy-adjusted whole plant food intake, excluding potatoes
WPFP_KG	Food mass-adjusted whole plant food intake, including potatoes
WPFNP_KG	Food mass-adjusted whole plant food intake, excluding potatoes
HDL-C	High density lipoprotein cholesterol
LDL-C	Low density lipoprotein cholesterol
TC	Total cholesterol
TG	Triglycerides
A1C	Glycohemoglobin
CRP	C-reactive protein

Reference List

1. Waijers PM, Feskens EJ, Ocke MC. A critical review of predefined diet quality scores. Br J Nutr. 2007; 97(2):219–231. [PubMed: 17298689]
2. Arvaniti F, Panagiotakos DB. Healthy indexes in public health practice and research: a review. Crit Rev Food Sci Nutr. 2008; 48(4):317–327. [PubMed: 18409114]
3. Kourlaba G, Panagiotakos DB. Dietary quality indices and human health: a review. Maturitas. 2009; 62(1):1–8. [PubMed: 19128905]
4. Messina M, Lampe JW, Birt DF, Appel LJ, Pivonka E, Berry B, Jacobs DR Jr. Reductionism and the narrowing nutrition perspective: time for reevaluation and emphasis on food synergy. Journal of the American Dietetic Association. 2001; 101(12):1416–1419. [PubMed: 11762736]
5. Guenther PM, Reedy J, Krebs-Smith SM. Development of the Healthy Eating Index-2005. J Am Diet Assoc. 2008; 108(11):1896–1901. [PubMed: 18954580]
6. Shah BS, Freeland-Graves JH, Cahill JM, Lu H, Graves GR. Diet quality as measured by the healthy eating index and the association with lipid profile in low-income women in early postpartum. J Am Diet Assoc. 2010; 110(2):274–279. [PubMed: 20102856]
7. Reedy J, Mitrou PN, Krebs-Smith SM, Wirfalt E, Flood A, Kipnis V, Leitzmann M, Mouw T, Hollenbeck A, Schatzkin A, Subar AF. Index-based Dietary Patterns and Risk of Colorectal Cancer. American Journal of Epidemiology. 2008; 168(1):38–48. [PubMed: 18525082]

8. Kennedy E, Racsa P, Dallal G, Lichtenstein AH, Goldberg J, Jacques P, Hyatt R. Alternative approaches to the calculation of nutrient density. Nutr Rev. 2008; 66(12):703–709. [PubMed: 19019039]
9. Priebe M, van Binsbergen J, de Vos R, Vonk RJ. Whole grain foods for the prevention of type 2 diabetes. The Cochrane Collaboration. 2009; (1):1–33.
10. Sun Q, Spiegelman D, van Dam RM, Holmes MD, Malik VS, Willett WC, Hu FB. White rice, brown rice, and risk of type 2 diabetes in US men and women. Arch Intern Med. 2010; 170(11): 961–969. [PubMed: 20548009]
11. Trapp CB, Barnard ND. Usefulness of vegetarian and vegan diets for treating type 2 diabetes. Curr Diab Rep. 2010; 10(2):152–158. [PubMed: 20425575]
12. Venn BJ, Mann JI. Cereal grains, legumes and diabetes. Eur J Clin Nutr. 2004; 58(11):1443–1461. [PubMed: 15162131]
13. Bazzano LA, He J, Ogden LG, Loria CM, Vupputuri S, Myers L, Whelton PK. Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first National Health and Nutrition Examination Survey Epidemiologic Follow-up Study. Am J Clin Nutr. 2002; 76(1):93–99. [PubMed: 12081821]
14. Ferdowsian HR, Barnard ND. Effects of plant-based diets on plasma lipids. Am J Cardiol. 2009; 104(7):947–956. [PubMed: 19766762]
15. Heidemann C, Scheidt-Nave C, Richter A, Mensink GB. Dietary patterns are associated with cardiometabolic risk factors in a representative study population of German adults. Br J Nutr. 2011; 106(8):1253–1262. [PubMed: 21736839]
16. Hu FB. Plant-based foods and prevention of cardiovascular disease: an overview. Am J Clin Nutr. 2003; 78(3 Suppl):544S–551S. [PubMed: 12936948]
17. Mente A, de KL, Shannon HS, Anand SS. A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease. Arch Intern Med. 2009; 169(7):659–669. [PubMed: 19364995]
18. Tighe P, Duthie G, Vaughan N, Brittenden J, Simpson WG, Duthie S, Mutch W, Wahle K, Horgan G, Thies F. Effect of increased consumption of whole-grain foods on blood pressure and other cardiovascular risk markers in healthy middle-aged persons: a randomized controlled trial. Am J Clin Nutr. 2010; 92(4):733–740. [PubMed: 20685951]
19. Pelucchi C, Bosetti C, Rossi M, Negri E, La VC. Selected aspects of Mediterranean diet and cancer risk. Nutr Cancer. 2009; 61(6):756–766. [PubMed: 20155613]
20. Temple NJ, Gladwin KK. Fruit, vegetables, and the prevention of cancer: research challenges. Nutrition. 2003; 19(5):467–470. [PubMed: 12714102]
21. Williams MT, Hord NG. The role of dietary factors in cancer prevention: beyond fruits and vegetables. Nutr Clin Pract. 2005; 20(4):451–459. [PubMed: 16207684]
22. Park Y, Subar AF, Hollenbeck A, Schatzkin A. Dietary fiber intake and mortality in the NIH-AARP diet and health study. Arch Intern Med. 2011; 171(12):1061–1068. [PubMed: 21321288]
23. Potischman N, Cohen BE, Picciano MF. Dietary recommendations and identified research needs for The National Children's Study. J Nutr. 2006; 136(3):686–689. [PubMed: 16484543]
24. Centers for Disease Control and Prevention National Center for Health Statistics. [Accessed 9-1-2011] Analytic and reporting guidelines, The National Health and Nutrition Examination Survey (NHANES). 2005. http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/nhanes_analytic_guidelines_dec_2005.pdf.
25. Centers for Disease Control and Prevention (CDC) and National Center for Health Statistics (NCHS). [Accessed 2-1-2012] NHANES-National Health and Nutrition Examination Survey questionnaires, datasets and related documentation. www.cdc.gov/nchs/nhanes.htm. 4-29-2011.
26. National Health and Nutrition Examination. [Accessed 9-1-2011] Mec In-Pearson Dietary Interviewers Procedures Manual. 2002. http://www.cdc.gov/nchs/data/nhanes/nhanes_01_02/dietary_year_3.pdf.
27. Center for Nutrition Policy and Promotion, U.S. Department of Agriculture. [Accessed 9-1-2011] Development and Evaluation of the Healthy Eating Index-2005 Technical Report. http://www.cnpp.usda.gov/HealthyEatingIndex-2005report.htm. 10-21-2011.

28. Friday, JE.; Bowman, SA. MyPyramid Equivalents Database for USDA Survey Food Codes, 1994–2002 Version 1.0.[Online]. Beltsville MD: USDA, ARS, Community Nutrition Research Group; 2006. www.ars.usda.gov/ba/bhnrc/fsrg.
29. Fung TT, Willett WC, Stampfer MJ, Manson JE, Hu FB. Dietary Patterns and the Risk of Coronary Heart Disease in Women. Arch Intern Med. 2001; 161(15):1857–1862. [PubMed: 11493127]
30. Halton TL, Willett WC, Liu S, Manson JE, Stampfer MJ, Hu FB. Potato and french fry consumption and risk of type 2 diabetes in women. Am J Clin Nutr. 2006; 83(2):284–290. [PubMed: 16469985]
31. U.S.Centers for Disease Control and Prevention. National report on biochemical indicators of diet and nutrition in the U.S. population 1999–2002. Atlanta, GA: National Center for Environmental Health; 2008.
32. U.S.Department of Agriculture and U.S.Department of Health and Human Services. Dietary Guidelines for Americans, 2010. 7th Edition. Washington, DC: U.S. Government Printing Office; 2010.
33. George SM, Park Y, Leitzmann MF, Freedman ND, Dowling EC, Reedy J, Schatzkin A, Hollenbeck A, Subar AF. Fruit and vegetable intake and risk of cancer: a prospective cohort study. Am J Clin Nutr. 2009; 89(1):347–353. [PubMed: 19056579]
34. de KL, Chiuve SE, Fung TT, Willett WC, Rimm EB, Hu FB. Diet-quality scores and the risk of type 2 diabetes in men. Diabetes Care. 2011; 34(5):1150–1156. [PubMed: 21464460]
35. Ross AB, Bruce SJ, Blondel-Lubrano A, Oguey-Araymon S, Beaumont M, Bourgeois A, Nielsen-Moennoz C, Vigo M, Fay LB, Kochhar S, Bibiloni R, Pittet AC, Emady-Azar S, Grathwohl D, Rezzi S. A whole-grain cereal-rich diet increases plasma betaine, and tends to decrease total and LDL-cholesterol compared with a refined-grain diet in healthy subjects. Br J Nutr. 2011; 105(10): 1492–1502. [PubMed: 21272402]
36. Sahyoun NR, Jacques PF, Zhang XL, Juan W, McKeown NM. Whole-grain intake is inversely associated with the metabolic syndrome and mortality in older adults. Am J Clin Nutr. 2006; 83(1):124–131. [PubMed: 16400060]
37. McKeown NM, Meigs JB, Liu S, Wilson PW, Jacques PF. Whole-grain intake is favorably associated with metabolic risk factors for type 2 diabetes and cardiovascular disease in the Framingham Offspring Study. Am J Clin Nutr. 2002; 76(2):390–398. [PubMed: 12145012]

NIH-PA Author Manuscript
NIH-PA Author Manuscript

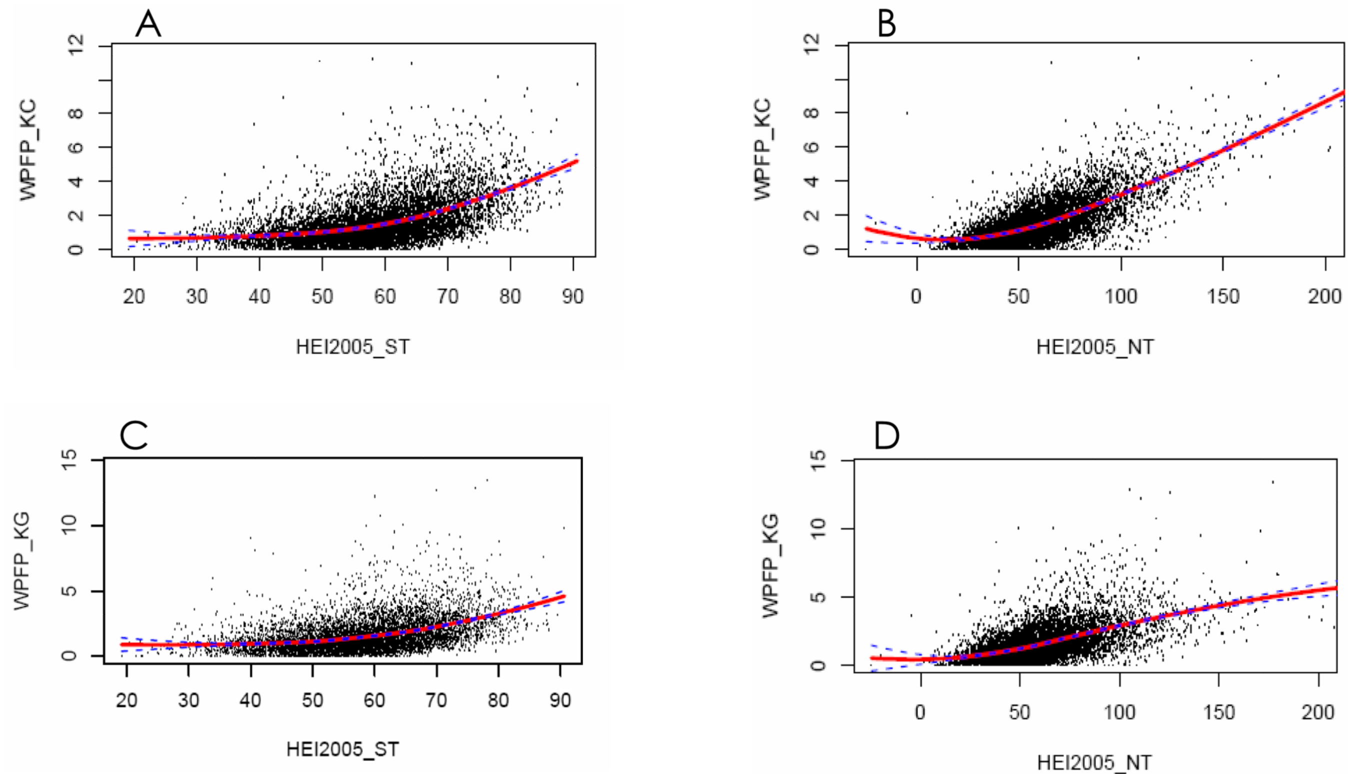

Figure 1.

Scatter plots and lowess smoothed curves for relations between select WPF and HEI measures using 24-hour dietary recall data from participants age>6y from the 1999–2002 National Health and Nutrition Examination Survey (NHANES). WPFP_KC- cup/oz equivalents of whole plant foods including potatoes per 1000 kcal, WPFNP_KC-cup/oz equivalents of whole plant foods excluding potatoes per 1000 kcal, WPFP_KG- cup/oz equivalents of whole plant foods including potatoes per kg, WPFNP_KG- cup/oz equivalents of whole plant foods excluding potatoes per kg, HEI2005_ST- standard truncated Healthy Eating Index-2005, HEI2005_NT- non-truncated Health Eating Index-2005.

Table 1

Diet quality measures

	Name	Calculation
Healthy Eating Index-2005	HEI2005_ST	Standard calculation for HEI-2005 total score
	HEI2005_NT	Non-truncated version of HEI-2005
Whole Plant Foods (WPF)		
Total intake	WPFP_TOT	Sum of cup or ounce equivalents of whole fruit, vegetables, whole grains, legumes, nuts and seeds per 1000 kcal consumed (total intake)
	WPFP_TOT	Same as WPF, excluding white potatoes (total intake)
Proportional intake	WPFP_kc	Sum of cup or ounce equivalents of whole fruit, vegetables, whole grains, legumes, nuts and seeds per 1000 kcal consumed (energy-adjusted)
	WPFNP_kc	Same as wpf/kcal, excluding white potatoes in the numerator (energy-adjusted)
	WPFP_kg	Sum of cup or ounce equivalents of whole fruit, vegetables, whole grains, legumes, nuts and seeds per kg consumed (food mass-adjusted)
	WPFNP_kg	Same as wpf_kg, excluding white potatoes in the numerator (food mass-adjusted)

Table 2

Characteristics of subjects

	No (%) or Means± SD
Sociodemographic	
Sex	
Male	4380 (51)
Female	4270 (49)
Race/ethnicity	
Non-Hispanic White	3665 (42)
Non-Hispanic Black	2188 (25)
Mexican American	2162 (25)
Other Race (including multi-racial)	247 (3)
Other Hispanic	388 (5)
Age[a]	39.0 (6/85)
Diet quality measures	
HEI2005_ST	58.8± 0.19
HEI2005_NT	61.5± 0.43
WPFP_TOT	3.6± 0.05
WPFNP_TOT	2.7±0.05
WPFP_KC	1.7± 0.02
WPFNP_KC	1.3± 0.02
WPFP_KG	1.7± 0.03
WPFNP_KG	1.3± 0.03
Biomarkers	
Carotenoids (ug/dL)	46.6± 0.56
HDL cholesterol (HDL-C, mg/dL)	50.8± 0.25
Total cholesterol (TC, mg/dL)	194.5± 0.78
Fasting sample (n = 3501)	
LDL colesterol (LDL-C, mg/dL)	115.4±0.81
Glycohemoglobin (A1C, %)	5.5± 0.01
Fasting glucose (mg/dL)	100.9± 0.64
Fasting insulin (uU/mL)	12.1± 0.22
C-peptide (nmol/L)	0.8± 0.01
C-reactive protein (CRP, mg/dL)	0.4± 0.01

HEI2005_ST-Standard Healthy Eating Index-2005, HEI2005_NT- Non-truncated Healthy Eating Index-2005, WPFP_TOT - total cup/oz equivalents of whole plant foods (WPF) including potatoes, WPFNP_TOT- total cup/oz equivalents of WPF excluding potatoes, WPFP_KC- cup/oz equivalents of WPF including potatoes per 1000 kcal, WPFNP_KC- cup/oz equivalents of WPF excluding potatoes per 1000 kcal, WPFP_kg - cup/oz equivalents of WPF including potatoes per kg, WPFNP_KG- cup/oz equivalents of WPF excluding potatoes per kg.

[a]Age presented as mean (min/max)

Table 3

Coefficients of determination (R^2) for relations between WPF and HEI variables[a,b]

	HEI variable	
WPF variable	**standard**	**non-truncated**
WPFP_TOT	0.18	0.24
WPFNP_TOT	0.21	0.27
WPFP_KC	0.24	0.50
WPFNP_KC	0.25	0.48
WPFP_KG	0.15	0.29
WPFNP_KG	0.17	0.30

HEI2005_ST- standard Healthy Eating Index-2005, HEI2005_NT- non-truncated Healthy Eating Index-2005, WPFP_TOT - total cup/oz equivalents of whole plant foods(WPF) including potatoes, WPFNP_TOT- total cup/oz equivalents of WPF excluding potatoes, WPFP_KC- cup/oz equivalents of WPF including potatoes per 1000 kcal, WPFNP_KC- cup/oz equivalents of WPF excluding potatoes per 1000 kcal, WPFP_kg - cup/oz equivalents of WPF including potatoes per kg, WPFNP_KG- cup/oz equivalents of WPF excluding potatoes per kg.

[a]Unadjusted linear regression models

[b]All relations $p < 0.001$

Table 4

Relations of diet quality measures with diet and health biomarkers[a,b,c]

Diet quality measure		Carotenoids (ug/dL) N = 7 189		HDL-C (mg/dL) N = 7 183		LDL-C (mg/dL) N = 3 208		TC (mg/dL) N = 7 183		TG (mg/dL) N = 3 501	
		βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2
WPF	WPFP_TOT	3.89(0.35)***	0.13	0.44(0.11)**	0.02	0.25(0.39)	<0.01	1.02(0.45)*	<0.01	1.08(0.76)	<0.01
	WPFNP_TOT	4.03(0.35)***	0.14	0.47(0.11)***	0.02	0.17(0.38)	<0.01	0.85(0.51)	<0.01	1.41(0.98)	<0.01
	WPFP_KC	8.18(0.87)***	0.13	1.04(0.25)***	0.02	0.56(0.63)	<0.01	2.37(0.74)**	<0.01	1.77(1.41)	<0.01
	WPFNP_KC	8.53(0.90)***	0.14	1.1(0.23)***	0.02	0.46(0.60)	<0.01	2.16(0.85)*	<0.01	2.32(1.70)	<0.01
	WPFP_KG	5.98(0.72)***	0.08	0.71(0.24)*	0.02	−1.07(0.62)	<0.01	0.06(0.89)	<0.01	2.75(3.80)	<0.01
	WPFNP_KG	6.52(0.83)***	0.09	0.77(0.23)**	0.02	−0.91(0.61)	<0.01	0.28(1.06)	<0.01	3.32(4.02)	<0.01
HEI	HEI-2005_ST	0.82(0.05)***	0.08	0.14(0.02)***	0.02	−0.07(0.08)	<0.01	0.01(0.06)	<0.01	−0.06(0.36)	<0.01
	HEI-2005_NT	0.46(0.04)***	0.13	0.05(0.02)**	0.02	−0.005(0.03)	<0.01	0.05(0.03)	<0.01	0.04(0.13)	<0.01

Relations of diet quality measures with diet and health biomarkers[a,b]

Diet quality measure		A1c (%) N = 6 330		Glucose (mg/dL) N = 3 091		Insulin (uU/mL) N = 3 089		C-peptide (nmol/L) N = 3 089		CRP (mg/dL) N = 7 258	
		βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2
WPF	WPFP_TOT	0.02(0.008)*	<0.01	0.41(0.17)*	<0.01	−0.31(0.09)**	0.01	−0.01(0.002)**	<0.01	−0.01(0.003)***	<0.01
	WPFNP_TOT	0.02(0.009)	<0.01	0.27(0.19)	<0.01	−0.35(0.08)***	0.01	−0.01(0.002)**	<0.01	−0.01(0.003)***	<0.01
	WPFP_KC	0.06(0.02)**	0.01	1.18(0.46)*	<0.01	−0.71(0.17)***	0.01	−0.02(0.005)**	<0.01	−0.02(0.007)*	<0.01
	WPFNP_KC	0.06(0.02)*	0.01	0.93(0.51)	<0.01	−0.76(0.14)***	0.01	−0.02(0.005)***	<0.01	−0.02(0.007)*	<0.01
	WPFP_KG	0.04(0.02)	<0.01	0.54(0.44)	<0.01	−0.51(0.16)**	<0.01	−0.01(0.004)**	<0.01	−0.02(0.006)**	<0.01
	WPFNP_KG	0.04(0.02)	<0.01	0.42(0.51)	<0.01	−0.61(0.16)**	<0.01	−0.02(0.004)***	<0.01	−0.02(0.005)**	<0.01

Relations of diet quality measures with diet and health biomarkers[a,b]

		Biomarkers									
		A1c (%) N = 6 330		Glucose (mg/dL) N = 3 091		Insulin (uU/mL) N = 3 089		C-peptide (nmol/L) N = 3 089		CRP (mg/dL) N = 7 258	
Diet quality measure		βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2
HEI	HEI-2005_ST	−0.001(0.002)	<0.01	0.006(0.05)	<0.01	−0.07(0.02) *	<0.01	<0.01(0.0009) **	<0.01	< 0.01(0.001) ***	0.01
	HEI-2005_NT	0.02(0.001) *	0.01	0.04(0.02)	<0.01	−0.02(−0.009)	<0.01	<0.01(0.0003)	<0.01	< 0.01(0.0003) **	0.01

HEI2005_ST- Standard, truncated Healthy Eating Index-2005, HEI2005_NT- Non-truncated Healthy Eating Index-2005, WPFP_TOT - total cup/oz equivalents of whole plant foods(WPF) including potatoes, WPFNP_TOT- total cup/oz equivalents of WPF excluding potatoes, WPFP_KC- cup/oz equivalents of WPF including potatoes per 1000 kcal, WPFNP_KC- cup/oz equivalents of WPF excluding potatoes per 1000 kcal, WPFP_kg - cup/oz equivalents of WPF including potatoes per kg, WPFNP_KG- cup/oz equivalents of WPF excluding potatoes per kg.

[a] Linear regression models predicting biomarkers adjusted for total energy intake

[b] *p < 0.05, **p < 0.01, ***p < 0.001

[c] R^2=0.01 for regressions of outcomes on total energy intake only for HDL-C and CRP; those for other health indicators were < 0.01.

A1C- glycated hemoglobin, CRP- c-reactive protein, HEI2005_ST- Standard, truncated Healthy Eating Index-2005, HEI2005_NT-Non-truncated Healthy Eating Index-2005, WPFP_TOT - total cup/oz equivalents of whole plant foods(WPF) including potatoes, WPFNP_TOT- total cup/oz equivalents of WPF excluding potatoes, WPFP_KC- cup/oz equivalents of WPF including potatoes per 1000 kcal, WPFNP_KC- cup/oz equivalents of WPF excluding potatoes per 1000 kcal, WPFP_kg - cup/oz equivalents of WPF including potatoes per kg, WPFNP_KG- cup/oz equivalents of WPF excluding potatoes per kg.

[a] Linear regression models predicting biomarkers adjusted for total energy intake

[b] *p <0.05, **p < 0.01, ***p < 0.001

Table 5

Adjusted relations of diet quality measures with diet and health biomarkers[a,b,c]

Diet quality measure		Carotenoids (ug/dL) N = 7 189		HDL-C (mg/dL) N = 7 183		LDL-C (mg/dL) N = 3 208		TC (mg/dL) N = 7 183		TG (mg/dL) N = 3 501	
		βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2
WPF	WPFP_TOT	3.09(0.32)***	0.20	0.23(0.10)*	0.15	−0.54(0.33)	0.10	−0.23(0.41)	0.15	−0.52(0.76)	0.04
	WPFNP_TOT	3.23(0.33)***	0.21	0.23(0.09)*	0.15	−0.60(0.29)	0.10	−0.35(0.42)	0.15	−0.03(0.93)	0.04
	WPFP_KC	6.52(0.79)***	0.20	0.55(0.22)*	0.15	−1.36(0.49)*	0.10	−0.64(0.75)	0.15	−2.21(1.43)	0.04
	WPFNP_KC	6.86(0.82)***	0.21	0.54(0.19)*	0.15	−1.41(0.45)**	0.10	−0.74(0.74)	0.15	−1.28(1.49)	0.04
	WPFP_KG	4.61(0.66)***	0.17	0.39(0.22)	0.15	−1.54(0.48)**	0.10	−1.13(0.76)	0.15	2.88(3.57)	0.04
	WPFNP_KG	5.06(0.74)***	0.18	0.36(0.20)	0.15	−1.55(0.38)***	0.10	−1.13(0.78)	0.15	3.19(3.62)	0.04
HEI	HEI-2005_ST	0.59(0.05)***	0.17	0.07(0.02)**	0.15	−0.21(0.07)*	0.10	−0.21(0.06)**	0.15	−0.31(0.43)	0.04
	HEI-2005_NT	0.37(0.04)***	0.20	0.03(0.01)*	0.15	−0.10(0.03)**	0.10	−0.08(0.03)*	0.15	−0.18(0.15)	0.04

Adjusted relations of diet quality measures with diet and health biomarkers[a,b]

Diet quality measure		A1c (%) N = 6 330		Glucose (mg/dL) N = 3 091		Insulin (uU/mL) N = 3 089		C-peptide (nmol/L) N = 3 089		CRP (mg/dL) N = 7 258	
		βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2
WPF	WPFP_TOT	0.002(0.01)	0.11	0.04(0.15)	0.09	−0.36(0.09)**	0.04	−0.01(0.003)***	0.08	−0.02(0.003)***	0.06
	WPFNP_TOT	0.003(0.01)	0.11	−0.09(0.14)	0.09	−0.40(0.09)***	0.04	−0.02(0.003)***	0.09	−0.02(0.003)***	0.06
	WPFP_KC	0.02(0.02)	0.11	0.35(0.41)	0.09	−0.82(0.20)***	0.04	−0.03(0.01)***	0.09	−0.04(0.01)***	0.06
	WPFNP_KC	0.02(0.02)	0.11	0.11(0.38)	0.09	−0.87(0.16)***	0.04	−0.04(0.01)***	0.09	−0.04(0.01)***	0.06
	WPFP_KG	0.02(0.02)	0.11	0.40(0.33)	0.09	−0.59(0.19)**	0.04	−0.02(0.01)**	0.08	−0.03(0.01)***	0.06
	WPFNP_KG	0.02(0.02)	0.11	0.22(0.36)	0.09	−0.69(0.20)**	0.04	−0.03(0.01)**	0.08	−0.03(0.01)***	0.06

Adjusted relations of diet quality measures with diet and health biomarkers[a,b]

		Biomarkers									
		A1c (%) N = 6 330		Glucose (mg/dL) N = 3 091		Insulin (uU/mL) N = 3 089		C-peptide (nmol/L) N = 3 089		CRP (mg/dL) N = 7 258	
Diet quality measure		βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2	βest(SE)	R^2
HEI	HEI-2005_ST	−0.004(0.002)*	0.11	−0.06(0.06)	0.09	−0.07(0.03)*	0.04	−0.004(0.001)**	0.08	−0.01(0.001)***	0.07
	HEI-2005_NT	0.001(0.001)	0.11	−0.010.02	0.09	−0.03(0.01)*	0.04	−0.001(0.0003)**	0.08	−0.002(0.0003)***	0.06

HEI2005_ST- Standard Healthy Eating Index-2005, HEI2005_NT- Non-truncated Healthy Eating Index-2005, WPFP_TOT - total cup/oz equivalents of whole plant foods(WPF) including potatoes, WPFNP_TOT- total cup/oz equivalents of WPF excluding potatoes, WPFP_KC- cup/oz equivalents of WPF including potatoes per 1000 kcal, WPFNP_KC- cup/oz equivalents of WPF excluding potatoes per 1000 kcal, WPFP_kg - cup/oz equivalents of WPF including potatoes per kg, WPFNP_KG- cup/oz equivalents of WPF excluding potatoes per kg.

[a]Multiple linear regression models predicting biomarkers adjusted for total energy intake, age, sex, race/ethnicity

[b]*p < 0.05, **p < 0.01, *** p < 0.001

[c]R^2 values of regressions adjusted for total energy intake, age, sex, race/ethnicity, physical activity, smoking, alcohol use, and supplement intake are 0.13, 0.15, 0.10, 0.15, 0.04, 0.11, 0.09, 0.03, 0.07, and 0.06 for Carotenoids, HDL-C, LDL-C, TC, TG, A1c, Glucose, Insulin, C-peptide, and CRP, respectively.

A1C- glycated hemoglobin, CRP- c-reactive protein, HEI2005_ST- Standard, truncated Healthy Eating Index-2005, HEI2005_NT- Non-truncated Healthy Eating Index-2005, WPFP_TOT - total cup/oz equivalents of whole plant foods(WPF) including potatoes, WPFNP_TOT- total cup/oz equivalents of WPF excluding potatoes, WPFP_KC- cup/oz equivalents of WPF including potatoes per 1000 kcal, WPFNP_KC- cup/oz equivalents of WPF excluding potatoes per 1000 kcal, WPFP_kg - cup/oz equivalents of WPF including potatoes per kg, WPFNP_KG- cup/oz equivalents of WPF excluding potatoes per kg.

[a]Multiple linear regression models predicting biomarkers adjusted for total energy intake, age, sex, race/ethnicity

[b]*p < 0.05, **p < 0.01, ***p < 0.001

[c]R^2 values of regression results adjusted for total energy intake, age, sex, race/ethnicity, physical activity, smoking, alcohol use, and supplement intake are 0.13, 0.15, 0.10, 0.15, 0.04, 0.11, 0.09, 0.03, 0.07, and 0.06 for Carotenoids, HDL-C, LDL-C, TC, TG, A1c, Glucose, Insulin, C-peptide, and CRP, respectively.