



# Higher-diet quality is associated with higher diet costs when eating at home and away from home: National Health and Nutrition Examination Survey, 2005–2016

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Submitted 15 November 2020: Final revision received 16 June 2021: Accepted 24 June 2021

## Abstract

**Objectives:** To evaluate the association between diet quality and cost for foods purchased for consumption at home and away from home.

**Design:** Cross-sectional analysis. Multivariable linear regression models evaluated the association between diet quality and cost for all food, food at home (FAH) and food away from home (FAFH).

**Setting:** Daily food intake data from the National Health and Nutrition Examination Survey (2005–2016). Food prices were derived using data from multiple, publicly available databases. Diet quality was assessed using the Healthy Eating Index-2015 and the Alternative Healthy Eating Index-2010.

**Participants:** 30 564 individuals  $\geq 20$  years with complete and reliable dietary data.

**Results:** Mean per capita daily diet cost was \$14.19 (95 % CI (13.91, 14.48)), including \$6.92 (95 % CI (6.73, 7.10)) for FAH and \$7.28 (95 % CI (7.05, 7.50)) for FAFH. Diet quality was higher for FAH compared to FAFH ( $P < 0.001$ ). Higher diet quality was associated with higher food costs overall, FAH and FAFH ( $P < 0.001$  for all comparisons).

**Conclusions:** These findings demonstrate that higher diet quality is associated with higher costs for all food, FAH and FAFH. This research provides policymakers, public health professionals and clinicians with information needed to support healthy eating habits. These findings are particularly relevant to contemporary health and economic concerns that have worsened because of the COVID-19 pandemic.

## Keywords

Diet cost  
Diet quality  
HEI  
AHEI  
NHANES

The diet quality of many Americans remains far from optimal, despite modest improvements over the last decade<sup>(1,2)</sup>. The typical US diet is characterised by high intake of refined carbohydrates, added sugar and sodium, as well as suboptimal intake of fruits, vegetables and whole grains<sup>(1,2)</sup>. Poor diet quality is now the leading risk factor for mortality, accounting for 0.5 million deaths annually (18 % of deaths nationwide), and is among the leading causes of morbidity<sup>(3,4)</sup>.

Approximately 70–90 % of respondents in US national surveys report that food price is a somewhat or very important driver of food choice<sup>(5,6)</sup>. Others have demonstrated that lower cost food options tend to have lower nutritional value<sup>(7)</sup>, which presents a barrier to healthy eating that is more salient for individuals with lower income<sup>(8)</sup>. Consistent

evidence from cross-sectional<sup>(9–13)</sup> and longitudinal<sup>(14,15)</sup> studies, as well as reviews and meta-analyses<sup>(8,13)</sup>, demonstrate that higher diet quality is associated with higher cost, which partly explains the suboptimal eating patterns observed in the USA and elsewhere<sup>(3,4)</sup>.

However, previous studies that demonstrated a positive association between diet quality and cost did not account for the substantial price difference between foods purchased for consumption at home (e.g. grocery stores) and away from home (e.g. restaurants)<sup>(9–12,14,15)</sup>. Furthermore, not all studies have explicitly accounted for the cost of food waste and inedible portions, which represent over 40 % of the cost of purchased food<sup>(16)</sup>. Consequently, prior studies may have underestimated the true cost of food. Fortunately, new methods for

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estimating these costs have been developed<sup>(16)</sup>, and additional research on the association between diet quality and cost is critical. The present study fills this research gap by quantifying the association between multiple measures of diet quality and cost for foods purchased for consumption at home and away from home among a nationally representative sample of Americans.

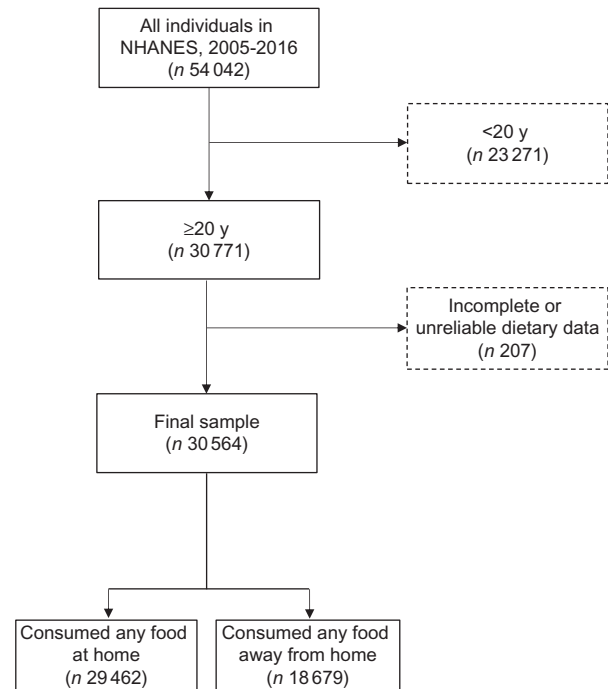
## Methods

### Food consumption data

Individual-level data on food and nutrient intake from individuals  $\geq 20$  years were acquired from the National Health and Nutrition Examination Survey (NHANES) 2005–2016<sup>(17)</sup>. NHANES is a continuous, cross-sectional survey that uses a multi-stage sampling design and is maintained by the National Center for Health Statistics (NCHS). Trained interviewers collect dietary data from approximately 5000 individuals per year using a 24-h recall facilitated by the US Department of Agriculture's (USDA) Automated Multiple Pass Method<sup>(18)</sup>. Study participants provide information on whether foods were consumed at home (FAH) or away from home (FAFH). Data were acquired for 54 042 individuals, and those  $< 20$  years of age ( $n = 23\,271$ ) and with incomplete or unreliable dietary data ( $n = 207$ ) were excluded. The analytic sample included 30 564 individuals, including 29 462 individuals (96 %) who reported consuming any FAH on the day of dietary recall and 18 679 individuals (62 %) who reported consuming any FAFH (Fig. 1).

### Data on food waste and inedible portions

Each food (i.e. mixed dish) reported as consumed by NHANES participants was disaggregated into its constituent ingredients using the Food Commodity Intake Database (FCID, 2005–2010)<sup>(19)</sup>. Each ingredient was then linked with a discrete food commodity (i.e. ingredient) in the USDA Loss-adjusted Food Availability data series (LAFA)<sup>(20)</sup> to identify the amount of waste and inedible portions attributable to each ingredient (the details of this linkage procedure, including sources of uncertainty and embedded assumptions, are described elsewhere<sup>(21,22)</sup> and in Additional File 1). However, LAFA data on inedible portions are expressed relative to the purchased amount of each ingredient, and the data on wasted portions are expressed relative to the edible amount of each ingredient; in both cases, these data need to be expressed relative to the consumed amount of each ingredient so that they can be linked with NHANES data, which are expressed in consumption amounts. Therefore, several computational steps were performed so that inedible and waste data from LAFA were expressed relative to the consumed amount of each ingredient as a coefficient that could be



**Fig. 1** Participant flowchart. NHANES, National Health and Nutrition Examination Survey

applied to NHANES data. The amount of each LAFA ingredient wasted was estimated by solving:

$$Wasted_{ail} = [Purchased_{ail} - (Purchased_{ail} \times Inedible_{pil})] \times Wasted_{pil}$$

where *Wasted* is the wasted amount (*a*) of a given ingredient (*i*) in LAFA (*I*), *Purchased* is the purchased portion, *Inedible* is the inedible portion and *p* is the proportion. The coefficient for inedible portions was estimated by solving:

$$Inedible_{cil} = Purchased_{ail} \times Inedible_{pil} / Consumed_{ail}$$

where *c* is the coefficient and *Consumed* is the consumption amount (*a*) of a given ingredient (*i*) in LAFA (*I*). The coefficient for wasted portions was estimated by solving:

$$Wasted_{cil} = (Purchased_{ail} - Inedible_{ail}) \times Wasted_{pil} / Consumed_{ail}$$

where *c* is the coefficient. The inedible amount of each NHANES ingredient was estimated by multiplying the inedible coefficient for each LAFA ingredient by the consumption amount of each NHANES ingredient and then summing the inedible amounts of all ingredients within each NHANES food. The same procedure was executed to estimate the wasted amount of each NHANES food. This can be expressed as:



$$\begin{aligned} \text{Inedible}_{afn} &= \sum (\text{Consumed}_{ain} \times \text{Inedible}_{cil}), \text{ and} \\ \text{Wasted}_{afn} &= \sum (\text{Consumed}_{ain} \times \text{Wasted}_{cil}) \end{aligned}$$

where  $f$  is a given food from NHANES ( $n$ ). Finally, the purchased amount of each NHANES food can be solved by:

$$\text{Purchased}_{afn} = \text{Inedible}_{afn} + \text{Wasted}_{afn} + \text{Consumed}_{afn}$$

Since NHANES participants report whether they consumed each FAH or FAFH, the above formula can be differentiated as:

$$\begin{aligned} \text{Purchased}_{arn} &= \text{Inedible}_{arn} + \text{Wasted}_{arn} + \text{Consumed}_{arn}, \text{ and} \\ \text{Purchased}_{asn} &= \text{Inedible}_{asn} + \text{Wasted}_{asn} + \text{Consumed}_{asn} \end{aligned}$$

to represent the purchased amount of each FAH ( $r$ ) and FAFH ( $s$ ).

### Diet quality assessment

Diet quality is a multidimensional construct used to characterise the healthfulness of dietary patterns. Diet quality can be expressed numerically by quantifying consumption of foods, food groups and nutrients, and applying scoring algorithms to produce a summary score. There is no single universally accepted method<sup>(23)</sup>, and reliance on any single method may provide an incomplete characterisation of dietary quality. The value of utilising multiple measures to provide a robust evaluation of diet quality has been described by others<sup>(24)</sup> and has been demonstrated elsewhere<sup>(25–27)</sup>. Therefore, we used two different validated methods to comprehensively measure diet quality, which were developed based on different criteria: the Healthy Eating Index (HEI-2015)<sup>(28,29)</sup> evaluates compliance with the 2015–2020 Dietary Guidelines for Americans<sup>(30)</sup>, and the Alternative Healthy Eating Index (AHEI-2010) measures the intake of food groups and nutrients associated with chronic disease risk<sup>(25)</sup>.

HEI-2015 includes nine components to encourage (total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and the ratio of unsaturated to saturated fats) and four components to limit (refined grains, sodium, added sugars and saturated fats). The consumption amounts for each component are standardised to a 4184 kJ basis using the density method<sup>(31)</sup>. Each component is scored from 0 to 5 or 0 to 10, and components to limit are reverse-scored so that higher scores are favourable for each component. Component scores are summed to compute an overall score for each respondent, with a maximum of 100. Mean scores are appropriately computed using the population ratio method<sup>(32)</sup>.

The AHEI-2010 measures the intake of food groups and nutrients associated with chronic disease risk<sup>(25)</sup>. AHEI-2010 includes six components to encourage (vegetables, fruit, whole grains, nuts and legumes, long-chain n-3 fats,

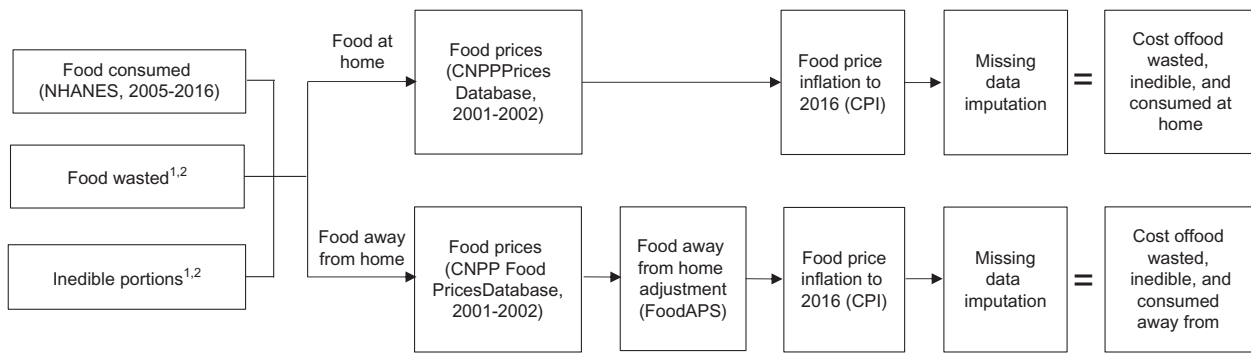
total polyunsaturated fats) and four components to limit (sugar-sweetened beverages and fruit juice, red and processed meat, sodium and alcohol). *Trans* fats, which were included in the original index, were not included in this study because NHANES does not provide complete data on *trans* fat content of foods, and population-level intake has decreased dramatically since 1999<sup>(33)</sup>. Intake of each component was standardised to the median energy intake of the source population (7916 kJ/d)<sup>(10)</sup> using the residual method<sup>(31)</sup>. Each component is scored on a scale of 0 to 10, and components to limit are reverse-scored so that higher scores are favourable for each component. Greater scores are awarded for moderate consumption of alcohol. Component scores are summed for each individual to compute an overall score with a maximum of 100.

All respondents were categorised into quintiles of HEI-2015 and AHEI-2010 score, where quintile 1 represents the lowest diet quality and quintile 5 represents the highest diet quality.

### Food-at-home price data

Price data for FAH and FAFH are based on the USDA Center for Nutrition Policy and Promotion (CNPP) Food Prices Database (2001–2002). This section describes the CNPP Food Prices Database, and subsequent sections describe the procedures used to adjust these prices for FAFH, inflation and undercoverage (i.e. missingness). These procedures are further specified in Fig. 2, Additional File 1, and elsewhere<sup>(16)</sup>.

The USDA CNPP Food Prices Database (2001–2002) provides national average prices (cost per 100 g) for each NHANES food<sup>(34)</sup>. (This unit price was divided by 100 to represent the unit price per gram and is represented in the formulas below as *Price*.) Staff at the USDA Center for Nutrition Policy and Promotion (CNPP) derived these prices from the 2001–2002 National Consumer Panel, which collects data on FAH prices and other attributes from a national panel of participating households<sup>(35)</sup>. Data on food retail prices were collected throughout the year in 2001 and 2002 from each household using self-operated handheld scanner devices or cellular phone applications, and households were given reference materials to search and record Universal Product Codes for products that do not typically have barcodes, such as bulk goods, bakery products and produce<sup>(35)</sup>. Approximately 8500 households were selected from the National Consumer Panel based on demographic attributes such as household income, family composition, educational attainment and geographic location to approximate the demographic composition of the US population<sup>(35)</sup>. Households recorded food purchases from all types of retail outlets including small grocery stores, supermarkets, supercentres and warehouse clubs. The data collected from each household were assigned a survey weight to more closely represent the national demographic composition<sup>(35)</sup>. CNPP Staff then matched these



**Fig. 2** Methodology for estimating the cost of food wasted, inedible and consumed at home and away from home. Adapted with permission from: Conrad (2020). Daily cost of consumer food wasted, inedible and consumed in the USA, 2001–2016. *Nutr J* **19**, 35. <sup>1</sup>Conrad et al., (2018). Relationship between diet quality, food waste and environmental sustainability. *PLoS One* **13**, e0195405. <sup>2</sup>Conrad (2019). Daily cost of consumer food wasted, inedible and consumed in the USA, 2001–2016. *Nutr J* **19**, 35. NHANES, National Health and Nutrition Examination Survey; CNPP, Center for Nutrition Policy and Promotion, US Department of Agriculture; CPI, Consumer Price Index; FoodAPS, National Household Food Acquisition and Purchase Survey

food prices with ingredients in the Food and Nutrient Database for Dietary Studies (FNDDS) which provides recipes for each NHANES food (most NHANES foods are mixed dishes with multiple ingredients). Approximately 90 % of FNDDS ingredients had at least 75 price observations and the remaining 10 % were consumed infrequently and in small amounts but were still included in final price estimations. In total, approximately 700 000 distinct food products were used to estimate national average prices for FNDDS foods. CNPP Staff converted each ingredient from their purchased forms to their as-consumed forms by subtracting inedible portions and adjusting for moisture and fat loss and gains from cooking, using adjustment factors from the USDA Standard Reference Legacy Release<sup>(36)</sup>, internal USDA handbooks and proxy matches. Finally, the multiple prices for each FNDDS ingredient were averaged to obtain a single price (cost/g) for each ingredient, and FNDDS recipes were used to construct the final price of each NHANES food<sup>(35)</sup>. Therefore, regardless of whether NHANES participants reported consuming FAH or FAFH, all of these foods were assigned FAH prices by CNPP Staff.

### Food-away-from-home price data

NHANES participants indicated which foods they consumed at home and away from home, but all of these were assigned FAH prices in CNPP Food Prices Database. Therefore, we used the National Household Food Acquisition and Purchase Survey (FoodAPS)<sup>(37)</sup> to compute a coefficient that converted FAH prices (from CNPP Food Prices Database) to FAFH prices for each of the foods consumed away from home by NHANES participants (see online Supplemental Table 1). FoodAPS is a cross-sectional survey of US households that used a multi-stage sampling design to collect data on the price of foods from scanned barcodes and food receipts from April 2012 to January 2013<sup>(37)</sup>. FoodAPS is the only data source that includes nationally representative household-level expenditures for FAH and FAFH. Using these data, we derived a

coefficient that represents the ratio of FAFH-to-FAH prices for each major food group (see online Supplemental Table 1), and this coefficient was multiplied by the price of each FAFH in the CNPP Food Prices Database to derive its adjusted FAFH price. For example, if the price of a given fruit was \$0.79 (from CNPP Food Prices Database), and if the mean price of FAFH fruit was 1.53 times greater than the mean price of FAH fruit (from FoodAPS), the adjusted price of that given fruit would be \$1.21 (\$0.79 × 1.53). This coefficient is represented in the formulas below as *FAFH*.

### Food price inflation

The Consumer Price Index (CPI)<sup>(38)</sup> was used to inflate food prices from CNPP Food Prices Database (2001–2002) to 2016 to report estimates in real dollars that align with the most recent year of NHANES data used in this study, which has precedent in previous studies<sup>(12,16)</sup>. CPI is maintained by the US Bureau of Labor Statistics (BLS) and represents a monthly measure of the average change in price of approximately 75 foods that are most commonly purchased by US consumers, and these data are aggregated into approximately 15 food groups (see online Supplemental Table 2)<sup>(39)</sup>. BLS staff acquire these data from a random sample of retail outlets through a monthly survey and these data are verified with store managers. We used CPI to adjust for inflation by computing a coefficient that represented the percent change in price for each major food group from 2001 to 2016. These coefficients are provided in Supplemental Table 1 and are represented in the formulas below as *Inflation*.

### Final food price estimation

The aforementioned steps provide all of the components needed to estimate final FAH and FAFH prices (Fig. 2). FAH prices can be estimated by solving:

$$\text{Purchased}_{\text{tr}} = \text{Purchased}_{\text{am}} \times \text{Price}_{\text{rw}} \times \text{Inflation}_{\text{cgo}}$$



where *Purchased* is the purchased price (*t*) of a given FAH (*r*), *a* is the amount of a given FAH (*r*) in grams from NHANES (*n*), *Price* is the unit price per gram of a given FAH (*r*) from CNPP Food Prices Database (*w*) and *Inflation* is the inflation coefficient for a given food group (*g*) from CPI (*o*). FAFH prices can be estimated by solving:

$$Purchased_{ts} = Purchased_{asn} \times Price_{sw} \times FAFH_{cgb} \times Inflation_{cgo},$$

where *Purchased* is the purchased price (*t*) of a given FAFH (*s*), *a* is the amount of a given FAFH (*s*) in grams from NHANES (*n*), *Price* is the unit price per gram of a given FAFH (*s*) from CNPP Food Prices Database (*w*), *FAFH* is the FAFH coefficient (*c*) for a given food group (*g*) from FoodAPS (*b*) and *Inflation* is the inflation coefficient (*c*) for a given food group (*g*) from CPI (*o*).

### Missing food prices

CNPP Food Prices Database (2001–2002) does not provide prices for all foods in NHANES 2005–2016 because a portion of NHANES food codes are modified over time to reflect new products added to the market and reformulations of existing products. The final sample of participants in this study reported consuming a total 443 441 food products (not including water) of which 57 845 (13 %) had missing price data. All foods were categorised into one of 41 distinct food categories. Missing prices for individual foods were assigned the average price for their food category, where the average price of each food category was weighted by the consumption amount of each food within that category. For example, if the unit price of Food A was \$0.50 and it represented 30 % of the total consumption amount of its food group, and the unit price of Food B was \$0.15 and it represented 70 % of the total consumption amount of its food group, then the weighted average would be \$0.26 = (\$0.50 × 0.3) + (\$0.15 × 0.7).

### Statistical analyses

Daily diet quality was computed overall as well as by FAH and FAFH for each observation. *Overall diet quality* and *overall diet cost* refers to the per capita daily diet quality or cost of FAH + FAFH (*n* 30 564), *FAH diet quality* and *FAH cost* refers to the per capita daily diet quality or cost of only FAH (*n* 29 462), and *FAFH diet quality* and *FAFH cost* refers to the per capita daily diet quality or cost of only FAFH (*n* 18 679). Differences in demographic characteristics by diet quality quintile were tested using Pearson's chi-squared statistic. The difference in diet quality between FAH and FAFH was examined using paired Wald tests. Trends in daily per capita costs across diet quality quintiles were tested using unadjusted linear regression models, and additional tests were adjusted for age (continuous), sex (male/female), education (less than high school, high school or equivalent, some college and

college graduate), race-ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic and other/multi-racial), income-to-poverty ratio (continuous) and NHANES survey cycle (continuous). Statistical significance was set at  $P < 0.05$ , and all tests were two-tailed. All analyses were adjusted for the multi-stage sampling design of NHANES and FoodAPS using standardised procedures and variables<sup>(40,41)</sup>. SAS 9.4 (SAS Institute) was used to estimate population ratio HEI-2015 scores using the modified code and macros provided by the National Cancer Institute<sup>(42,43)</sup>. Stata 16.1 (StataCorp.) was used for data management and for all statistical analyses.

### Sensitivity analyses

Stratified analyses investigated differences in the association between diet cost and quality between purchased, inedible, wasted and consumed food. Additional analyses were performed without imputing the missing prices to evaluate whether the imputation method introduced bias.

## Results

Respondents with higher overall diet quality (HEI-2015 and AHEI-2010) were more likely to be older and female with higher levels of educational attainment; less likely to be non-Hispanic Black and more likely to be of a race-ethnicity other than non-Hispanic White, non-Hispanic Black and Hispanic; and were more likely to have a higher income-to-poverty ratio ( $P < 0.001$  for all comparisons; Table 1 and see online Supplemental Table 3).

Overall diet quality scores were 59.3 (95 % CI (58.7, 59.9)) using HEI-2015 and 40.3 (95 % CI (40.0, 40.7)) using AHEI-2010 (Table 2). FAH diet quality scored higher than FAFH diet quality using each index ( $P < 0.001$  for all comparisons). Overall diet cost was \$14.19 (95 % CI (13.91, 14.48)), and FAH cost was \$0.36 lower than FAFH cost ( $P = 0.017$ ). Higher overall diet quality (HEI-2015 and AHEI-2010) was associated with higher overall diet costs ( $P_{\text{for trend}} < 0.001$  for all comparisons), ranging from \$11.95–13.45 in quintile 1 to \$14.58–14.95 in quintile 5, and these associations persisted after adjustment for age, sex, education, race-ethnicity, income-to-poverty ratio and survey wave ( $P < 0.001$  for all adjusted comparisons; Fig. 3).

FAH cost was \$6.92 (95 % CI (6.73, 7.10); Table 1). Higher FAH diet quality (HEI-2015 and AHEI-2010) was associated with higher FAH costs ( $P < 0.001$  for all comparisons), ranging from \$4.83–6.96 in quintile 1 to \$7.87–8.86 in quintile 5, and these associations persisted after adjustment for age, sex, education, race-ethnicity, income-to-poverty ratio and survey wave ( $P < 0.001$  for all adjusted comparisons; Fig. 4(a)). FAFH cost was \$7.28 (95 % CI (7.05, 7.50); Table 1). Higher FAFH diet quality (HEI-2015 and AHEI-2010) was associated with higher FAFH

**Table 1** Characteristics of study population by Healthy Eating Index-2015 quintile, 2005–2016 (*n* 30 564)

Characteristic	<i>n</i> *	Quintile 1 ( <i>n</i> 6112)		Quintile 2 ( <i>n</i> 6113)		Quintile 3 ( <i>n</i> 6113)		Quintile 4 ( <i>n</i> 6113)		Quintile 5 ( <i>n</i> 6113)		<i>P</i> ‡
		Percent	95 % CI†	Percent	95 % CI†	Percent	95 % CI†	Percent	95 % CI†	Percent	95 % CI†	
Age (years)	30 564											<0.001
20–30		27.3	25.7, 28.9	21.2	20.1, 22.3	19.2	17.9, 20.5	17.4	15.9, 19.0	13.2	11.8, 14.7	
31–50		21.8	20.5, 23.0	19.1	18.0, 20.3	20.9	19.6, 22.2	18.8	17.8, 19.8	17.4	15.9, 18.9	
51–70		15.0	13.8, 16.3	14.7	13.4, 16.0	20.1	18.9, 21.3	21.4	19.9, 22.9	24.4	22.9, 26.0	
70+		12.6	11.4, 14.0	19.2	17.9, 20.5	18.5	17.1, 20.1	22.4	21.0, 23.9	31.7	29.5, 34.0	
Sex	30 564											<0.001
Men		21.4	20.4, 22.4	21.5	20.5, 22.5	20.3	19.3, 21.3	19.1	18.1, 20.0	17.8	16.8, 18.8	
Women		18.3	17.1, 19.5	19.0	18.1, 19.9	19.8	18.8, 20.8	20.3	19.4, 21.3	22.6	21.4, 23.8	
Race-ethnicity	30 564											<0.001
Non-hispanic white		19.4	18.3, 20.6	20.4	19.6, 21.2	19.6	18.8, 20.5	19.8	18.8, 20.8	20.8	19.6, 22.1	
Non-Hispanic black		23.9	22.4, 25.4	22.2	21.2, 23.4	21.0	19.9, 22.2	18.1	16.9, 19.3	14.8	13.6, 16.1	
Hispanic		20.5	19.2, 21.9	19.8	18.4, 21.3	21.2	19.8, 22.6	20.3	19.1, 21.5	18.2	16.8, 19.8	
Other		15.3	13.6, 17.1	16.0	13.9, 18.3	20.0	18.2, 22.0	20.9	19.0, 23.0	27.8	25.3, 30.4	
Education	30 537											<0.001
Less than high school		23.4	21.8, 24.9	21.7	20.3, 23.1	20.7	19.2, 22.2	18.0	16.8, 19.2	16.4	15.0, 17.8	
High school or equivalent		25.3	23.7, 27.0	21.8	20.4, 23.2	20.1	18.9, 21.4	17.7	16.4, 19.1	15.0	13.7, 16.4	
Some college		20.4	19.1, 21.8	21.5	20.4, 22.6	20.4	19.4, 21.5	19.4	18.1, 20.8	18.2	16.9, 19.6	
College graduate		12.5	11.4, 13.8	16.6	15.3, 18.0	19.1	17.9, 20.4	22.7	21.5, 23.9	29.1	27.4, 30.8	
Income-to-poverty ratio	28 142											<0.001
<0.75		26.4	24.3, 28.6	21.6	19.8, 23.6	20.5	18.8, 22.3	17.1	12.9, 16.4	14.4	12.7, 16.3	
0.75–1.30		24.5	22.7, 26.4	21.3	19.9, 22.8	19.3	17.8, 21.0	18.6	14.9, 18.0	16.2	14.8, 17.8	
1.31–1.99		21.7	20.0, 23.4	20.2	18.6, 21.9	20.7	18.9, 22.6	18.6	17.0, 21.2	18.8	16.9, 21.0	
2.00–3.99		21.5	20.1, 23.0	21.2	20.1, 22.4	19.4	18.3, 20.7	19.4	17.1, 20.1	18.4	17.0, 19.9	
4.00+		15.0	13.8, 16.4	18.5	17.2, 19.9	20.6	19.5, 21.8	21.0	23.5, 26.6	24.8	23.2, 26.4	

\*Sample sizes are unweighted.

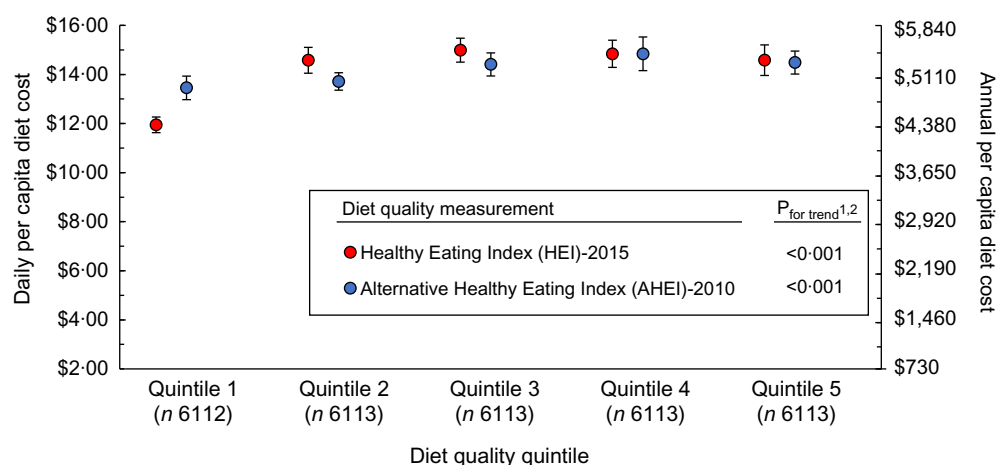
†Percentages within each column adjusted for survey weight.

‡Differences across quintiles 1–5 tested using Pearson's chi-squared statistic.

**Table 2** Daily per capita diet quality and diet cost by eating location, 2005–2016 (*n* 30 564)

Diet quality and cost	All food ( <i>n</i> 30 654)		Food at home ( <i>n</i> 29 462)		Food away from home ( <i>n</i> 18 679)		<i>P</i> *
	Score/cost	95 % CI	Score/cost	95 % CI	Score/cost	95 % CI	
Diet quality measurement							
Healthy Eating Index-2015	59.3	58.7, 59.9	61.8	61.1, 62.5	54.5	53.8, 55.1	<0.001
Alternative Healthy Eating Index-2010	40.3	40.0, 40.7	41.1	40.7, 41.5	38.8	38.5, 39.1	<0.001
Diet cost (\$)	14.19	13.91, 14.48	6.92	6.73, 7.10	7.28	7.05, 7.50	0.017

\*Difference between food at home and food away from home tested using paired Wald tests.



**Fig. 3** (colour online) Per capita diet cost by diet quality quintile, 2005–2016 (*n* 30 564). Mean overall diet cost is \$14.19 (95 % CI (13.91, 14.48)). <sup>1</sup>Test for linear trend across quintiles. <sup>2</sup>*P*-values after adjustment for age, sex, education, race-ethnicity, income-to-poverty ratio and survey wave: Healthy Eating Index (HEI)-2015 (*P* < 0.001) and Alternative Healthy Eating Index (AHEI)-2010 (*P* < 0.001)

costs (*P* < 0.001 for all comparisons), ranging from \$6.82–11.90 in quintile 1 to \$11.41–14.40 in quintile 5, and these associations persisted after adjustment for age, sex, education, race-ethnicity, income-to-poverty ratio and survey wave (*P* < 0.01 for all adjusted comparisons; Fig. 4(b)).

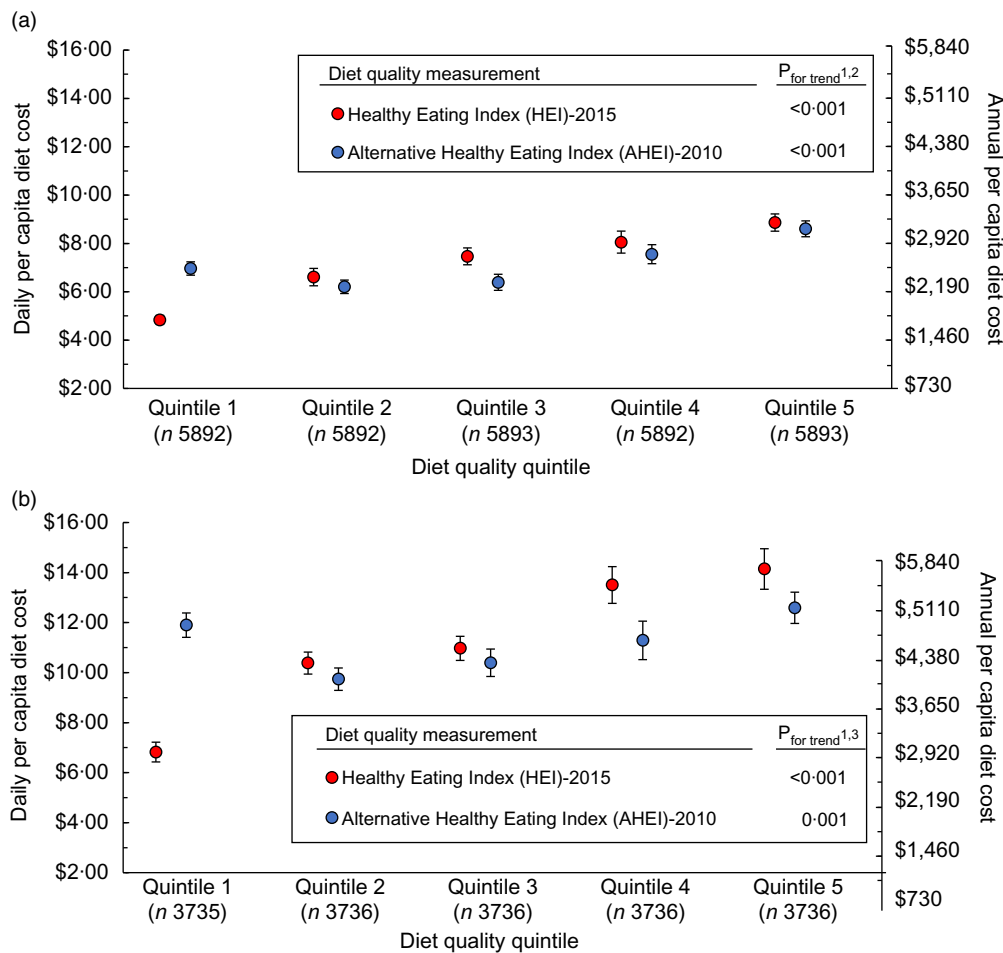
Fully adjusted models demonstrated statistically significant associations between HEI-2015 and overall diet cost for inedible (*P* < 0.001), wasted (*P* < 0.001) and consumed food (*P* = 0.020) (see online Supplemental Table 4). When using AHEI-2010, fully adjusted models demonstrated similar associations between overall diet quality and diet cost for inedible (*P* < 0.001) and wasted food (*P* < 0.001) but not consumed food (*P* = 0.921). Supplemental Table 5 displays the results of sensitivity analyses that evaluated the relationship between diet quality and overall cost, FAH cost and FAFH cost without imputation for missing price values. These results demonstrated similar associations compared to the main results (*P* < 0.00 for all comparisons).

## Discussion

This study provides a novel evaluation of the association between diet quality and cost among a nationally representative sample of the US population. By using multiple

measures of diet quality, as well as incorporating a new approach to estimate diet costs which accounts for the cost of food waste, inedible portions and foods consumed away from home, we demonstrate that higher diet quality was associated with higher diet costs for all food, FAH and FAFH. Diet quality was higher for FAH compared to FAFH, although they were similar in cost.

The observed direct association between diet quality and cost is consistent with previous cross-sectional studies<sup>(9–12)</sup>, longitudinal studies<sup>(14,15)</sup>, systematic reviews<sup>(8)</sup> and meta-analyses<sup>(13)</sup>. In the present study, this association was similar regardless of the instrument used to measure diet quality. However, these indices differed in two notable ways. First, in fully adjusted models, a statistically significant association was observed between the cost of consumed food and diet quality when using HEI-2015 but not AHEI-2010. Second, the diet cost in quintile 1 differed most when measuring FAFH. These differences are largely due to the way meat is scored in AHEI-2010, which awards greater points for lesser consumption of meat, whereas HEI-2015 does not explicitly measure meat intake. As a result, AHEI-2010 categorises individuals with higher meat intake in lower quintiles, whereas HEI-2015 disperses these individuals more evenly across the quintiles, with resultant differences in associations between diet quality and cost of



**Fig. 4** (colour online) Per capita diet cost by diet quality quintile, for food consumed (a) at home (FAH) and (b) away from home (FAFH), 2005–2016 ( $n$  30 564). Mean overall diet cost is \$6.92 (95 % CI (6.73, 7.10)) for FAH and \$7.28 (95 % CI (7.05, 7.50)) for FAFH ( $P=0.017$ ). <sup>1</sup>Test for linear trend across quintiles. <sup>2</sup> $P$ -values after adjustment for age, sex, education, race-ethnicity, income-to-poverty ratio and survey wave: Healthy Eating Index (HEI)-2015 ( $P<0.001$ ) and Alternative Healthy Eating Index (AHEI)-2010 ( $P<0.001$ ). <sup>3</sup> $P$ -values after adjustment for age, sex, education, race-ethnicity, income-to-poverty ratio and survey wave: Healthy Eating Index-2015 ( $P<0.001$ ) and Alternative Healthy Eating Index-2010 ( $P<0.001$ )

consumed food (up to 92 % of the quintile-specific cost difference between the indices was due to expenditure on meat). Additionally, FAFH meat is more expensive (per g) than most other FAFH foods<sup>(16)</sup>, which accentuates these differences. These findings highlight the importance of accounting for the cost of food waste, inedible portions and FAFH when estimating purchased food costs and show the value of using more than one index to measure diet quality<sup>(24)</sup>. Despite the observed differences between HEI-2015 and AHEI-2010, the present study demonstrates that both indices can be similarly used to evaluate the association between the cost of purchased food and diet quality.

The estimated costs for FAH and FAFH are consistent with recent estimates provided by USDA<sup>(44)</sup>. According to these data, the average daily household food expenditure in 2016 was \$33.30, including \$17.01 FAH and \$16.29 FAFH<sup>(44)</sup>, and the US Department of Commerce reported 1.95 adults per household and 2.53 people per

household<sup>(45)</sup>. Taken together, these data indicate that daily per capita consumer food expenditure in 2016 was approximately \$6.23–8.12 FAH, \$5.64–7.35 FAFH and \$11.86–15.47 total, which aligns with our estimates using self-reported food consumption data. As reported elsewhere<sup>(16)</sup>, our estimates of the per capita cost of consumed food without adjustment for food price inflation and FAFH (\$5.21 from Conrad, 2020<sup>(16)</sup>) are similar to others (\$4.81<sup>(11)</sup> and \$5.79 per 8368 kJ<sup>(12)</sup>). The present study used the most recent version of FCID (2005–2010) to disaggregate NHANES (2005–2016) foods into their constituent ingredients, which does not account for the new products and reformulations that entered the market after 2010. Sensitivity analyses from previous research demonstrated that excluding data from 2011 to 2016 resulted in moderately higher daily per capita food costs (\$0.60 difference), which suggests that our 2005–2016 estimates are conservative. In the present study, we imputed the missing food prices from 2010 to 2016, which resulted in higher



estimates of daily per capita food costs compared to ignoring these missing values (\$1.81 difference), but the association between diet cost and quality were similar ( $P < 0.001$ ).

Prior research showing positive associations between longitudinal change in food spending and diet quality<sup>(14,15)</sup> underscores the risk of decreased diet quality as a result of financial hardship. The primary vehicle for providing nutrition assistance in the USA is the Supplemental Nutrition Assistance Program (SNAP), which provides monthly benefits for food purchases based on household size and income<sup>(46)</sup>. Due to the programme's demonstrated effectiveness in preventing food insecurity and keeping households out of poverty, increases in monthly benefit levels have been recommended as a means of protecting the most vulnerable families from the health consequences of food insecurity. Consequently, this programme is especially critical during the COVID-19 pandemic, which has increased unemployment, food insecurity and poverty to levels not seen in decades<sup>(47)</sup>. Other policy opportunities include the expansion of the Gus Schumacher Nutrition Incentive Program, which enables SNAP households to purchase additional fruits and vegetables, including from local farmers<sup>(48)</sup>.

Clinicians and public health professionals can use this research to better support their clients in making healthy and affordable food choices during this critical time. We demonstrate that FAFH is less healthy than FAH and represents approximately one-half of the share of total food spending, and others have recently demonstrated that food waste accounts for nearly 30 % of food spending overall and within FAH and FAFH<sup>(16)</sup>. Taken together, these findings highlight the need for practitioners to help their clients develop effective strategies to prepare FAH and reduce waste (especially fruits and vegetables)<sup>(49)</sup> to improve diet quality and reduce spending. Our results demonstrate that decreased spending on non-alcoholic beverages like sugar-sweetened beverages may be an effective step towards improving diet quality. These strategies could be incorporated into existing educational plans, including SNAP-Ed and WIC family counselling. Practitioners will also recognise that many households experience conditions that can make dietary shifts challenging, such as limited childcare availability, insufficient social support, care for family members with illness or disability, and inconsistent employment, so practitioners should provide households with additional guidance and resources as needed.

The limitations of this study should be considered when interpreting the findings. Diet costs represent the cost of food only and do not include capital costs such as household utilities (i.e. electricity, natural gas and water), appliances and other household resources used for food preparation and storage. These findings also do not include the time cost of purchasing and preparing food. Food prices were adjusted to their 2016 value to align with the

most recent year that dietary data were collected, which may not reflect the recent destabilisation of the food supply and shifts in consumer purchasing behaviours as a result of the COVID-19 pandemic<sup>(50)</sup>. Some respondents may have purchased prepared food outside of home but consumed it at home, and some may have prepared FAH but consumed it away from home, which may have resulted in misclassification bias. Data were not available to discern price differences between different types of FAFH outlets, so FAFH prices may be overgeneralised. The food prices reported by the CNPP Food Prices Database represent national average prices and are not disaggregated by the type of store, seasonality, geographic location and other demographic and individual-level factors. As a result, subgroup analyses should be interpreted with caution. Self-reported food intake data are also subject to measurement bias, since some respondents may under-report consumption of perceived unhealthy foods and over-report consumption of perceived healthy foods. Nonetheless, self-reported dietary data remain a valuable source of detailed information on dietary patterns at the population level<sup>(51)</sup>. Although many FoodAPS foods are linked with NHANES 2012–2013 foods, not all of these have FAFH prices, and not all of them link to other NHANES data years. Additionally, NHANES is the preferred source of dietary data because it provides the most valid and reliable measures of nationally representative food intake over time, which is needed to evaluate diet quality.

This study has several notable strengths. For the first time, the association between daily per capita diet cost and quality was evaluated independently for FAH and FAFH among a nationally representative sample of the US population, while accounting for the substantial costs of food waste and inedible portions. Multiple, validated instruments were utilised to provide a robust evaluation of diet quality at the population level. These findings are particularly relevant to contemporary health concerns, as well as macro- and micro-economic conditions, that have emerged because of the COVID-19 pandemic. This information can be used immediately by policymakers, clinicians and public health professionals to help individuals make food choices that are healthy and affordable.

## Conclusions

In this nationally representative study of over 30 000 Americans, we demonstrate that higher diet quality was associated with higher costs for all food, FAH and FAFH. These findings are timely, given that the COVID-19 pandemic has compromised the health of millions of Americans while simultaneously destabilising household financial security, making it more challenging to afford healthy diets at a time when they are needed most. This research provides policymakers, public health professionals



and clinicians with information needed to support healthy eating habits.

## Acknowledgements

**Acknowledgements:** Not applicable. **Financial support:** Funding for SR's and RB's contribution to the project was provided by The Lumpkin Family Foundation, the WK Kellogg Foundation and the Union of Concerned Scientists members. The funders had no role in the design, analysis or writing of this article. **Conflict of interest:** There are no conflicts of interest. **Authorship:** Z.C. formulated the research question, designed and conducted the research, and analysed the data. Z.C. and A.M. provided essential materials. All authors wrote the paper. Z.C. had primary responsibility for final content. All authors have read and approved the final manuscript. **Ethics of human subject participation:** This study was deemed exempt from human studies review by the Institutional Review Board at William & Mary.

## Supplementary material

For supplementary material accompanying this paper visit <https://doi.org/10.1017/S1368980021002810>

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