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Research Article

Observed and Modeled Pulse Intakes are Associated with Higher Nutrient Intakes and Better Nutrient Adequacy and Diet Quality

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Abstract

Pulses are dry, edible seeds of legumes and are rich source of protein, fiber and other nutrients. We evaluated the effect of pulses on diet quality and nutrient intake/adequacy, and modeled the effects of increasing pulses in the diet. Data from adults (age 19+ years, n=17,234) participating in National Health and Nutrition Examination Survey (NHANES) 2011–2018 were used. Diet quality was estimated using Healthy Eating Index (HEI) 2020, usual intake was determined using the National Cancer Institute (NCI) method and the nutrient adequacy was determined by estimating % adults with intakes below the Estimated Average Requirement (EAR) or above the Adequate Intake (AI). Isocaloric addition of pulses to increase dietary pulses intake to 1.5 or 3.0 cups eq per week was used to model the nutritional effects of adding pulses. About 35% adults were consumers of pulses with average intake of 1.41 oz eq per day. Consumers had higher ($P<0.05$) diet quality, and intakes and fewer % of adults were below EAR or greater % of adults were above AI for fiber and several micronutrients including calcium, iron, magnesium, vitamin D, potassium and choline than non-consumers. Increasing pulses consumption to the recommended level (1.5 cup eq/week) or more in dietary modeling analysis, further improved (non-overlapping 95th percentile confidence intervals) nutrient intakes/adequacy and diet quality of consumers. These results suggest that encouraging increased pulse consumption may be an effective strategy for improving diet quality and achieving a healthier diet.

Keywords: National Health and Nutrition Examination Survey; NHANES; Healthy Eating Index; HEI; Vitamins; Minerals.

Introduction

Pulses are the dry, edible seeds of legume plants, including dry beans, dry peas, chickpeas, and lentils. They do not include oilseed legumes like soybeans and peanuts, or legumes harvested fresh like green peas and green beans [1,2]. They are rich sources of protein, fiber, several important micronutrients and bioactive phytochemicals [3-6]. They are also a key component of nutritious, healthy and environmentally sustainable food systems [6,7] and are also a more affordable source of dietary protein [8]. The Dietary Guidelines for Americans (DGA) 2020-2025 recommends consuming 1.5 cups of beans, peas and lentils per week as part of healthy dietary pattern and includes them in both the vegetable group and the protein food group as their nutritional profile is similar to foods in both food groups [9]. The recently released 2025-2030 Dietary Guidelines Advisory Committee (DGAC) report recommended to increase intake of beans, peas and lentils up to 3 cups per week based on their modeling analysis [10]. Choose MyPlate of the United States Department of Agriculture (USDA) [11] considers dry beans, peas, and lentils as a part of protein food and ¼ cup cooked counts as one-ounce equivalent protein food while ½ cup prepared beans, peas and lentils is ½ cup equivalent of vegetables. Most dietary guidelines from around the world also recommend frequent consumption of pulses, mostly as part of protein foods [12,13].

Earlier analyses of National Health and Nutrition Examination Survey (NHANES) 1999-2002 data, indicated that approximately 27% of adult Americans consumed pulses with a mean intake of about 118 g/day over a two-day period [14]. Adult consumers of pulses were found to have higher intakes of fiber, protein, folate, zinc, iron and magnesium in analysis of NHANES 1999-2002 [14], and higher intakes of potassium, zinc, iron and choline in an analysis of NHANES 2003-2014 [15] compared to non-consumers. However, these studies did not report association of pulse consumption on diet quality or prevalence of nutrient adequacy. In a dietary modeling analysis, we recently reported that addition of pulses replacing protein foods, refined grains, or combinations of protein foods and refined grains increased dietary fiber, iron, magnesium, potassium, and copper in the 2000 kcal Healthy U.S.-Style Pattern [8]. However, in that modeling analysis, we used USDA's healthy dietary patterns that identify the amounts of foods in nutrient dense forms from all five major food groups to help people plan healthier meals but did not use the actual intakes and did not measure the effect of increasing pulses on diet quality or prevalence of nutrient adequacy. Regular intake of pulses has been associated with reducing the risk of chronic diseases such as cardiovascular diseases [16-21], cancer [22,23], diabetes [24,25], and overall mortality [26] in population studies and controlled trials. Dietary intake of pulses has also been found to be associated with higher satiety, lower food intake, weight loss and a reduction in body fat in randomized controlled trials [27-29].

Given this background, we hypothesized that pulses as nutrient rich source of protein and other nutrients would be associated with higher diet quality, nutrient intake, nutrient adequacy and increasing their consumption would further improve the diet quality and nutrient intake/adequacy. Therefore, the purpose of this study was to provide an updated evaluation of the association of pulses intake on diet quality, nutrient intake, and nutrient adequacy and to model the nutritional effects of increasing pulses in the current diets of adults using NHANES 2011–2018 dietary intake data [30].

Materials and Methods

Database: Dietary recall data from adults age 19+ years participating in the NHANES 2011-2018 (n = 17,234) cross-sectional survey were used to assess current intakes and association of intake of pulses with nutrient intake, nutrient adequacy and diet quality [30]. Data considered unreliable or incomplete by NHANES staff, and the data from pregnant or lactating women and from subjects with zero calorie on either day of recall, were excluded from the analysis. Demographic information and physical activity levels were determined from the NHANES 2011-2018 questionnaire data. Body mass index (BMI) and weight status as overweight (≥25 kg/m^2) or obese (≥30 kg/m^2) were determined from body measure files. All participants provided a signed written informed consent and the NHANES survey protocol was approved by the National Center for Health Statistics Ethics Review Board. The present study was a secondary data analysis that lacked personal identifiers and therefore was exempt from additional approvals by institutional review boards. A detailed description of the NHANES study protocol including subject recruitment, survey design, and data collection procedures as well as the data used in this study are publicly available and available online [30].

Dietary intakes, diet quality, and the % below the Estimated Average Requirement (EAR)/above the Adequate Intake (AI) in consumers and non-consumers of pulses: Intakes of food groups, energy and nutrients, and the % below the EAR/above the AI in consumers and non-consumers of pulses were evaluated using NHANES 2011-2018 24-hour dietary recall data using the relevant NHANES cycle of the USDA Food Patterns Equivalents Database (FPED) for food group intakes and the USDA Nutrient Database for Standard Reference Releases in conjunction with the respective Food and Nutrient Database for Dietary Studies for energy and nutrient intakes [31,32]. A total 341 food codes containing pulses were identified as determined using the FPED variable for measuring beans, peas and lentils (i.e., v_legumes > 0). Pulse consumers were defined as those individuals consuming any amount (cup eq) of pulses on day 1 or day 2 of the dietary recalls. Diet quality scores were determined using the USDA Healthy Eating Index (HEI) 2020 using the average of two days dietary intake data [33]. HEI 2020 has 13 components (8 adequacy components and 4 moderation components) each reflects key recommendations of DGA. Usual intake of nutrients and the % below the EAR/above the AI was determined with the National Cancer Institute (NCI) method (version 2.1) [34] using two days of dietary recall. Covariates used for the usual intake estimates were day of the week of the 24-hour dietary recall (coded as weekend [Friday to Sunday] or weekday [Monday to Thursday]) and sequence of dietary recall (first or second). The percent of the population below the EAR or above the AI was estimated using the cut-point method, except for iron, where the probability method was used [35].

Dietary modeling: First, all pulse foods reported in NHANES were identified. For each pulse item, energy and nutrient contents were extracted from the Food and Nutrient Database for Dietary Studies (FNDDS). A composite pulse profile was then created by calculating the sample-weighted mean energy and nutrient content across all pulse foods consumed in the population. This composite represented the nutrient composition of one "cup-equivalent" of pulses used in all modeling scenarios. Second, for every participant, we calculated the nutrient density of their reported diet by dividing each nutrient intake by total energy intake (e.g., g/kcal, mg/kcal, etc.). These nutrient-to-energy ratios were used to ensure that any calories removed from the diet (to maintain isocaloric conditions) reflected the participant's own dietary pattern rather than removing arbitrary foods or nutrients. Third, for each modeling scenario, the amount of energy contributed by the added pulses was first calculated using the composite pulse profile. To maintain isocaloric intake, an equivalent amount of energy was removed from each participant's baseline diet. Nutrients associated with the removed calories were calculated by multiplying the participant-specific nutrient-to-energy ratios by the number of calories removed. Thus, nutrients were removed proportionally to the participant's existing diet composition. After subtracting these nutrients, the energy and nutrients from the modeled pulse intake were added to the participant's diet. The following modeling scenarios were evaluated: 1) increase consumption of pulses to the level recommended in the DGA (1.5 cup eq/week), and 2) increase consumption of pulses to twice the level recommended in the DGA (3 cup eq/week).

To estimate usual intakes and the % below the EAR/above the AI associated with isocalorically adding pulses to the diet, usual intakes of nutrients was determined with the NCI method (version 2.1) [34] using two days of modified nutrient intakes. Covariates used in the usual intake estimates were day of the week of the 24-hour dietary recall (coded as weekend [Friday to Sunday] or weekday [Monday to Thursday]) and sequence of dietary recall (first or second). The percent of the population below the EAR or above the AI was estimated using the cut-point method, except for iron, where the probability method was used [35].

Statistical analyses: Analyses were performed using SAS 9.4 and all analyses were adjusted for the complex sampling (clustered sample) design of NHANES, using appropriate survey weights (one-day or two-day dietary sampling weight depending on analyses), strata, and primary sampling units. Regression analyses were used with to assess differences in consumers and non-consumers for demographics. Regression analyses were also utilized to assess differences ($P<0.05$) in energy and nutrient intakes, selected food group intakes, and diet quality after adjustment for age, gender, ethnicity, poverty income ratio levels, current smoking status, calories and BMI. Significant differences ($P<0.05$) for % below EAR/above AI between consumers and non-consumers were assessed via z statistics. Significant differences between baseline and modeling scenarios were assessed using non-overlapping 95th percentile confidence intervals (CI) of means.

Results

Intake of pulses and consumer demographics: 34.9% adults age 19+ years were consumers of pulses with average intake of 1.41 ± 0.03 oz eq per day. Consumers of pulses were younger (-1.3 years), more likely to be male (3%), Hispanic (11%), Asian (2%), have vigorous physical activity (4%), have lower BMI (about 1 unit) and have normal weight (3% units), and were less likely to be non-Hispanic White (7%), non-Hispanic Black (5%), sedentary (3%) and obese (5%) (Table 1).

Table 1: Demographics of adult (age 19+ years, gender combined, n = 17,234) consumers and non-consumers of pulses, NHANES 2011-2018 data.

	Non-consumer	Consumer	P
Sample N	11,215	6,019	
Population N	151197168	79991889	
Age (mean)	48.2 ± 0.4	46.9 ± 0.4	0.0011
Male (%)	48.1 ± 0.7	51.0 ± 1.0	0.0288
Ethnicity			
Hispanic (%)	11.1 ± 0.9	21.8 ± 1.8	<0.0001
White (%)	67.4 ± 1.7	60.3 ± 2.1	<0.0001
Black (%)	13.3 ± 1.2	7.80 ± 0.65	<0.0001
Asian (%)	4.68 ± 0.40	6.96 ± 0.79	0.0005
Other (%)	3.54 ± 0.31	3.13 ± 0.37	0.3708
Poverty Income Ratio			
<1.35 (%)	24.1 ± 1.0	22.0 ± 1.3	0.0644
1.35 to ≤1.85 (%)	9.86 ± 0.52	10.3 ± 0.8	0.6353
>1.85 (%)	66.1 ± 1.3	67.8 ± 1.7	0.2513
Physical Activity			
Sedentary (%)	21.9 ± 0.7	18.9 ± 1.0	0.0087
Moderate (%)	36.3 ± 0.9	35.6 ± 1.1	0.6001
Vigorous (%)	41.8 ± 0.9	45.5 ± 1.4	0.017
Body Mass Index (kg/m^2)	29.5 ± 0.1	28.8 ± 0.2	<0.0001
Overweight (%)	31.2 ± 0.8	33.5 ± 1.1	0.0771
Obese (%)	40.8 ± 0.9	35.9 ± 1.3	0.0002

Consumers were those adults who consumed any amount of pulses on either of the two days of dietary recalls, and non-consumers were those who did not. Regression analyses were utilized to assess differences in consumers and non-consumers. Data are presented as mean ± standard error. NHANES: National Health and Nutrition Examination Survey.

Association of intake of pulses on intakes of energy, nutrients, food groups and diet quality: Adult consumers of pulses consumed 13% less added sugar than non-consumers (Table 2). Intakes of “total legumes”, “total fruit”, “total grain” and “total vegetables” were higher while intakes of “added sugars” and “beef, poultry & seafood” were lower among adult consumers of pulses than non-consumers (Table 2). Compared to non-consumers, adult pulse consumers consumed 10% or more of dietary fiber, copper, iron, magnesium, potassium and folate. Adult pulse consumers had 4% more protein and 5% more sodium than non-consumers. Adult consumers of pulses had 13% higher HEI 2020 total scores non-consumers (Table 3). Component scores for adequacy components: “total vegetables”, “greens and beans”, “total fruit”, whole fruit”, “whole grains”, “total protein foods”, seafood and plant protein”, “fatty acid ratio” were higher for consumers indicating higher intakes compared to non-consumers. Components scores for moderation components: “saturated fat” and “added sugar” were also higher for consumers indicating lower intakes compared to non-consumers. However, component scores for moderation components: “sodium” and “refined grains” were lower for consumers indicating higher intake than non-consumers (Table 3).

Table 2: Intake of food groups, energy and nutrients among adult (age 19+ years, gender combined, n = 15,719) consumers and non-consumers of pulses, NHANES 2011-2018 data.

	Non-consumer	Consumer	P
Food Groups			
Added sugars (tsp eq/day)	17.1 ± 0.2	14.9 ± 0.3	<0.0001
Beef, poultry, seafood (oz eq/day)	4.85 ± 0.05	4.44 ± 0.08	<0.0001
Legumes (oz eq/day)	0.02 ± 0.004	1.41 ± 0.03	<0.0001
Total dairy (cup eq/day)	1.48 ± 0.02	1.53 ± 0.03	0.0812
Total fruits (cup eq/day)	0.91 ± 0.02	1.01 ± 0.03	0.0038
Total grain (oz eq/day)	6.25 ± 0.04	6.66 ± 0.07	<0.0001
Total vegetables* (cup eq/day)	1.48 ± 0.02	1.60 ± 0.02	0.0001
Energy and Nutrients			
Energy (kcal/day)	2042 ± 7	2086 ± 8	<0.0001
Carbohydrate (g/day)	242 ± 1	252 ± 2	<0.0001
Dietary fiber (g/day)	15.0 ± 0.1	21.0 ± 0.2	<0.0001
Protein (g/day)	79.2 ± 0.4	82.6 ± 0.6	<0.0001
Total fat (g/day)	80.4 ± 0.4	80.2 ± 0.5	0.8002
Total Saturated Fatty acids (g/day)	26.2 ± 0.2	25.7 ± 0.2	0.0734
Calcium (mg/day)	916 ± 8	983 ± 9	<0.0001
Copper (mg/day)	1.15 ± 0.01	1.36 ± 0.02	<0.0001
Iron (mg/day)	14.0 ± 0.1	15.4 ± 0.1	<0.0001
Magnesium (mg/day)	281 ± 2	326 ± 3	<0.0001
Phosphorus (mg/day)	1324 ± 7	1412 ± 8	<0.0001
Potassium (mg/day)	2521 ± 18	2789 ± 18	<0.0001
Selenium (µg/day)	114 ± 1	112 ± 1	0.1766
Sodium (mg/day)	3370 ± 15	3546 ± 24	<0.0001
Zinc (mg/day)	10.7 ± 0.1	11.4 ± 0.1	<0.0001
Vitamin A, RAE (µg/day)	632 ± 9	639 ± 13	0.6387
Thiamin (mg/day)	1.55 ± 0.01	1.65 ± 0.01	<0.0001
Riboflavin (mg/day)	2.07 ± 0.02	2.13 ± 0.03	0.0786
Niacin (mg/day)	25.6 ± 0.2	25.3 ± 0.3	0.3192
Folate, DFE (µg/day)	499 ± 5	558 ± 8	<0.0001
Vitamin B_6 (mg/day)	2.08 ± 0.02	2.19 ± 0.04	0.0184
Vitamin B_{12} (µg/day)	4.91 ± 0.05	4.91 ± 0.14	0.9623
Vitamin C (mg/day)	77.1 ± 1.4	83.0 ± 1.8	0.0083
Vitamin D (µg/day)	4.57 ± 0.06	4.59 ± 0.10	0.8921
Vitamin E, ATE (mg/day)	8.59 ± 0.10	9.29 ± 0.13	0.0001
Choline (mg/day)	324 ± 2	334 ± 3	0.0014

24-hour dietary intake data. Consumers were those adults who consumed any amount of pulses on either of the two days of dietary recalls, and non-consumers were those who did not. Regression analyses were used to assess differences in consumers and non-consumers after adjustment for age, gender, ethnicity, poverty income ratio levels, current smoking status, kcal (kcal was excluded as a covariate when energy was a dependent variable) and BMI. Data are presented as least square mean ± standard error. *Total vegetables exclude legumes. AI: adequate intake; ATE: alpha-tocopherol equivalents; EAR: estimated average requirement; DFE: dietary folate equivalents; NHANES: National Health and Nutrition Examination Survey; RAE: retinol.

Table 3: Healthy Eating Index (HEI) 2020 scores among adult (age 19+ years, gender combined, n = 15,719) consumers and non-consumers of pulses, NHANES 2011-2018 data.

	Maximum Score	**Non-Consumer**	**Consumer**	**P**
HEI 2020 total score	100	51.5 ± 0.3	58.0 ± 0.4	<0.0001
Adequacy Components				
Component 1 (Total vegetables)	5	3.05 ± 0.02	3.68 ± 0.03	<0.0001
Component 2 (Greens and beans)	5	1.21 ± 0.04	3.65 ± 0.04	<0.0001
Component 3 (Total fruit)	5	2.27 ± 0.03	2.39 ± 0.05	0.0425
Component 4 (Whole fruit)	5	2.42 ± 0.04	2.62 ± 0.06	0.0043
Component 5 (Whole grain)	10	2.84 ± 0.06	3.04 ± 0.08	0.0429
Component 6 (Dairy)	10	5.20 ± 0.06	5.22 ± 0.07	0.7931
Component 7 (Total protein foods)	5	4.41 ± 0.02	4.69 ± 0.02	<0.0001
Component 8 (Seafood and plant protein)	5	2.28 ± 0.04	4.16 ± 0.04	<0.0001
Component 9 (Fatty acid ratio)	10	4.93 ± 0.05	5.20 ± 0.08	0.0038
Moderation Components				
Component 10 (Sodium)	10	4.13 ± 0.05	3.85 ± 0.08	0.0043
Component 11 (Refined grain)	10	6.36 ± 0.05	6.11 ± 0.08	0.011
Component 12 (Saturated fat)	10	5.71 ± 0.07	6.11 ± 0.08	0.0002
Component 13 (Added sugar)	10	6.69 ± 0.06	7.28 ± 0.08	<0.0001

HEI determined using the average of two days of 24-hour dietary recall. Higher score for adequacy component is indicative of higher consumption while a higher score for moderation component is indicative of lower consumption. Pulses were counted in component 1 (total vegetables), component 2 (greens and beans), 7 (total protein foods) and in component 8 (seafood and plant protein). Consumers were those adults who consumed any amount of pulses on either of the two days of dietary recalls, and non-consumers were those who did not. Regression analyses were used to assess differences in consumers and non-consumers after adjustment for age, gender, ethnicity, poverty income ratio levels, current smoking status kcal and BMI. Data are presented as least square mean ± standard error. NHANES: National Health and Nutrition Examination Survey.

Association of intake of pulses on the % below the EAR/above the AI: A significantly lower proportion of adult consumers of pulses were below the EAR for magnesium (-27% units), for calcium, copper, zinc folate and vitamin C (-10% units or more), and for vitamin A, thiamin, vitamin B_6 and vitamin E (-5% or more) compared to non-consumers. Lower proportion of consumers compared to non-consumers were also below the EAR for other nutrients but the difference, while statistically significant, was less than -5% units). A higher proportion of adult consumers of pulses were above the AI for dietary fiber (+14% units), potassium (+21% units) and choline (+5% units) as compared to non-consumers (Table 4).

Table 4: Nutrient adequacy among adult (age 19+ years, gender combined, n = 17,234) consumers and non-consumers of pulses, NHANES 2011-2018 data.

	Non-Consumer	**Consumer**	**P**
% below Estimated Average Requirement (EAR)			
Calcium	48.1 ± 0.9	33.3 ± 1.2	<0.0001
Copper	10.9 ± 0.6	1.4 ± 0.5	<0.0001
Iron	6.55 ± 0.37	2.93 ± 0.21	<0.0001
Magnesium	61.1 ± 1.1	34.2 ± 1.6	<0.0001
Phosphorus	<1.00	<1.00	
Selenium	<1.00	<1.00	
Zinc	21.6 ± 1.2	8.0 ± 1.1	<0.0001
Vitamin A, RAE	46.4 ± 1.3	39.6 ± 1.9	0.0024
Thiamin	8.85 ± 0.75	2.88 ± 0.60	<0.0001
Riboflavin	3.46 ± 0.33	2.17 ± 0.34	0.0062
Niacin	1.60 ± 0.27	<1.00	
Folate, DFE	16.9 ± 1.1	5.1 ± 1.0	<0.0001
Vitamin B_6	13.8 ± 0.9	5.7 ± 0.9	<0.0001
Vitamin B_{12}	5.20 ± 0.55	5.02 ± 0.90	0.8612
Vitamin C	51.3 ± 1.0	40.3 ± 2.2	<0.0001
Vitamin D	96.0 ± 0.5	94.2 ± 0.8	0.0491
Vitamin E, ATE	82.4 ± 1.1	73.1 ± 1.6	<0.0001
% above Adequate Intake (AI)			
Dietary fiber	3.57 ± 0.31	17.4 ± 1.6	<0.0001
Potassium	24.7 ± 1.0	45.5 ± 1.5	<0.0001
Sodium	≥99.0	>99.0	
Choline	6.42 ± 0.62	11.5 ± 1.0	<0.0001

Two-day 24-hour dietary recall data. Consumers were those adults who consumed any amount of pulses on either of the two days of dietary recalls, and non-consumers were those who did not. Data are presented as mean ± standard error. AI: adequate intake; ATE: alpha-tocopherol equivalents; EAR: estimated average requirement; DFE: dietary folate equivalents; NHANES: National Health and Nutrition Examination Survey; RAE: retinol activity equivalents.

Modeling the effect of isocaloric addition of pulses on diet quality: Modeling increasing pulse consumption to the DGA recommended level (1.5 cup eq/week) and twice the recommended levels (3.0 cup eq/week) resulted in an increase in HEI 2020 total score by 8 and 13%, respectively (Table 5). Subcomponent scores also increased 9% and 18% for total vegetables, 118% and 187% for greens and beans, 6% and 11% for total protein foods, and 66% and 99% for seafood and plant protein by increasing pulse consumption to 1.5 and 3.0 cup eq/week, respectively. And since our modeling was conducted on an isocaloric basis, increasing pulse consumption to 3.0 cup eq/week additionally improved subcomponent scores by 5% for refined grains and by 6% for saturated fat (Table 5).

Table 5: Modeling increasing pulses consumption to the recommended level and also twice the recommended levels (1.5 and 3.0 cup eq) in the DGA on diet quality (HEI 2020 scores) among adult (age 19+ years, gender combined, n = 17,234), NHANES 2011-2018 data.

	Maximum Score	Baseline	Isocaloric increase to 1.5 cup/ week pulses	Isocaloric increase to 3.0 cup/ week pulses
HEI 2020 Total Score	100	51.2 (50.7, 51.8)	55.5 (55.0, 56.1)*	58.1 (57.6, 58.6)*
Adequacy components				
Component 1 (Total vegetables)	5	3.07 (3.02, 3.12)	3.35 (3.31, 3.40)*	3.61 (3.57, 3.65)*
Component 2 (Greens and beans)	5	1.60 (1.53, 1.66)	3.49 (3.46, 3.53)*	4.59 (4.57, 4.61)*
Component 3 (Total fruit)	5	2.01 (1.94, 2.08)	1.99 (1.92, 2.07)	1.97 (1.90, 2.05)
Component 4 (Whole fruit)	5	2.08 (2.00, 2.17)	2.07 (1.99, 2.16)	2.06 (1.98, 2.15)
Component 5 (Whole grain)	10	2.64 (2.53, 2.76)	2.61 (2.49, 2.72)	2.57 (2.45, 2.68)
Component 6 (Dairy)	10	4.98 (4.88, 5.08)	4.91 (4.81, 5.00)	4.83 (4.73, 4.92)
Component 7 (Total protein foods)	5	4.22 (4.18, 4.25)	4.48 (4.46, 4.51)*	4.68 (4.66, 4.69)*
Component 8 (Seafood and plant protein)	5	2.39 (2.33, 2.46)	3.97 (3.94, 4.01)*	4.75 (4.74, 4.77)*
Component 9 (Fatty acid ratio)	10	5.09 (4.97, 5.20)	5.13 (5.02, 5.25)	5.18 (5.07, 5.29)
Moderation component				
Component 10 (Sodium)	10	4.33 (4.25, 4.41)	4.26 (4.18, 4.34)	4.19 (4.11, 4.27)
Component 11 (Refined grain)	10	6.25 (6.16, 6.34)	6.39 (6.31, 6.48)	6.54 (6.46, 6.63)*
Component 12 (Saturated fat)	10	5.80 (5.71, 5.90)	5.98 (5.88, 6.07)	6.16 (6.07, 6.25)*
Component 13 (Added sugar)	10	6.79 (6.68, 6.89)	6.88 (6.78, 6.99)	6.98 (6.88, 7.08)

Dietary modeling of NHANES 2011-2018 data; HEI determined using the average of two days of 24-hour dietary recall. Dietary modeling was accomplished by removing calories and nutrients from the diet commensurate with the calories added via pulses and then nutrients from a composite of pulses were isocalorically added to the NHANES 2011–2018 dietary intakes. Higher score for adequacy components is indicative of higher consumption while a higher score for moderation components is indicative of lower consumption. Pulses can be counted in components 1 (total vegetables), 2 (greens and beans), 7 (total protein foods) and in component 8 (seafood and plant protein). Data are presented as mean (95th percentile confidence intervals). *Values with non-overlapping 95th percentile confidence intervals (CI) of means from baseline. DGA: Dietary Guidelines for Americans; HEI, Healthy Eating Index; NHANES: National Health and Nutrition Examination Survey.

Modeling the effect of isocaloric addition of pulses on nutrient intakes: Intake of dietary fiber (+12%), iron (+3%) and folate (+5%) increased with isocaloric addition of pulses to 1.5 cup eq. With isocaloric addition of pulses to 3.0 cup eq, intakes of dietary fiber (+23%), copper (+7%), iron (+6%), magnesium (+6%), potassium (+5%) and folate (+9%) increased (Table 6).

Table 6: Modeling increasing pulses consumption to the recommended level and also twice the recommended levels (1.5 and 3.0 cup eq/week) in the DGA on nutrient intake among adult (age 19+ years, gender combined, n = 17,234), NHANES 2011-2018 data.

	Baseline	Isocaloric increase to 1.5 cup eq/week pulses	Isocaloric increase to 3.0 cup eq/week pulses
Dietary fiber (g)	17.3 (17.0, 17.7)	19.3 (18.9, 19.7)*	21.2 (20.9, 21.6)*
Calcium (mg)	965 (949, 982)	960 (943, 976)	954 (938, 970)
Choline (mg)	336 (331, 340)	339 (334, 343)	342 (337, 347)
Copper (mg)	1.26 (1.23, 1.30)	1.31 (1.28, 1.34)	1.35 (1.32, 1.38)*
Iron (mg)	14.6 (14.5, 14.8)	15.0 (14.9, 15.2)*	15.5 (15.3, 15.6)*
Magnesium (mg)	308 (303, 313)	317 (312, 322)	326 (321, 331)*
Niacin (mg)	26.1 (25.7, 26.5)	25.7 (25.4, 26.1)	25.4 (25.0, 25.7)
Phosphorus (mg)	1396 (1379, 1413)	1411 (1394, 1427)	1426 (1410, 1442)
Potassium (mg)	2678 (2639, 2718)	2746 (2707, 2785)	2815 (2776, 2854)*
Selenium (µg)	115 (114, 116)	114 (113, 115)	113 (112, 114)
Sodium (mg)	3535 (3497, 3573)	3546 (3509, 3584)	3557 (3520, 3595)
Zinc (mg)	11.2 (11.1, 11.4)	11.3 (11.2, 11.5)	11.4 (11.2, 11.5)
Vitamin A, RAE (µg)	649 (624, 673)	636 (612, 660)	623 (600, 647)
Thiamin (mg)	1.61 (1.59, 1.63)	1.62 (1.60, 1.65)	1.64 (1.62, 1.66)
Riboflavin (mg)	2.16 (2.13, 2.20)	2.14 (2.10, 2.17)	2.11 (2.08, 2.15)
Folate, DFE (µg)	527 (518, 537)	552 (543, 562)*	577 (568, 587)*
Vitamin B_6 (mg)	2.16 (2.12, 2.21)	2.17 (2.12, 2.21)	2.17 (2.13, 2.22)
Vitamin B_{12} (µg)	5.01 (4.85, 5.17)	4.92 (4.76, 5.07)	4.82 (4.66, 4.97)
Vitamin C (mg)	79.5 (76.8, 82.2)	78.3 (75.7, 80.9)	77.1 (74.5, 79.7)
Vitamin D (µg)	4.56 (4.40, 4.72)	4.47 (4.31, 4.63)	4.38 (4.23, 4.54)
Vitamin E (ATE) (mg)	9.27 (9.06, 9.49)	9.30 (9.09, 9.52)	9.33 (9.12, 9.54)

Dietary modeling of NHANES 2011-2018; day one 24-hour intake data. Dietary modeling was accomplished by removing calories and nutrients from the diet commensurate with the calories added via pulses and then nutrients from a composite of pulses were isocalorically added to the NHANES 2011–2018 dietary intakes. Data are presented as mean (95th percentile confidence intervals). *Values with non-overlapping 95th percentile confidence intervals (CI) of means from baseline. ATE: alpha-tocopherol equivalents; DFE: dietary folate equivalents; DGA: Dietary Guidelines for Americans; NHANES: National Health and Nutrition Examination Survey; RAE: retinol activity equivalents.

Modeling the effect of isocaloric addition of pulses on % below EAR/above AI: Proportion of the population below EAR decreased for copper (-2% units, -4% units), iron (-1% units, -1% units), magnesium (-4% units, -8% units) and folate (-4%, -7%) with increasing pulses to 1.5 and 3.0 cup eq, respectively (Table 7). Proportion of population above AI increased for fiber by 3% units and 7% units with increasing pulses to 1.5 and 3.0 cup eq, respectively. Increasing pulses to 3.0 cup eq additionally increased population above AI for potassium by 6% units (Table 7).

Table 7: Modeling of increasing pulses consumption to the recommended level and also twice the recommended levels (1.5 and 3.0 cup eq/week) in the DGA on % below the EAR/above the AI among adult (age 19+ years, gender combined, n = 17,234), NHANES 2011-2018 data.

	Baseline	Isocaloric increase to 1.5 cup eq/ week pulses	Isocaloric increase to 3.0 cup eq/ week pulses
% below Estimated Average Requirement (EAR)			
Calcium	43.0 (41.5, 44.4)	43.4 (41.9, 44.8)	44.0 (42.6, 45.4)
Copper	7.28 (6.38, 8.18)	4.89 (4.20, 5.59)*	3.28 (2.75, 3.80)*
Iron	5.18 (4.74, 5.61)	4.31 (3.94, 4.69)*	3.75 (3.41, 4.10)*
Magnesium	52.1 (50.4, 53.9)	48.5 (46.7, 50.3)*	44.2 (42.5, 45.9)*
Phosphorus	0.71 (0.53, 0.89)	0.54 (0.38, 0.71)	0.48 (0.34, 0.62)
Selenium	0.53 (0.34, 0.73)	0.58 (0.39, 0.78)	0.61 (0.40, 0.81)
Zinc	17.0 (15.4, 18.6)	16.1 (14.6, 17.6)	15.2 (13.7, 16.7)
Vitamin A	44.2 (41.9, 46.5)	45.9 (43.7, 48.1)	47.7 (45.5, 50.0)
Thiamin	6.72 (5.77, 7.67)	6.00 (5.10, 6.89)	5.31 (4.47, 6.16)
Riboflavin	3.10 (2.61, 3.60)	3.33 (2.80, 3.86)	3.52 (2.98, 4.06)
Niacin	1.30 (0.94, 1.65)	1.52 (1.15, 1.89)	1.72 (1.28, 2.15)
Folate, DFE	13.0 (11.5, 14.5)	8.91 (7.64, 10.2)*	5.85 (4.86, 6.84)*
Vitamin B_6	10.9 (9.57, 12.3)	10.4 (9.14, 11.7)	9.96 (8.71, 11.2)
Vitamin B_{12}	5.17 (4.24, 6.10)	5.74 (4.76, 6.71)	6.30 (5.26, 7.33)
Vitamin C	48.0 (45.9, 50.1)	49.1 (47.1, 51.2)	50.1 (48.0, 52.2)
Vitamin D	95.4 (94.6, 96.1)	96.1 (95.4, 96.8)	96.4 (95.7, 97.0)
Vitamin E	79.4 (77.5, 81.2)	79.2 (77.3, 81.1)	79.3 (77.5, 81.1)
% above Adequate Intake (AI)			
Dietary fiber	8.34 (7.25, 9.43)	11.1 (9.81, 12.3)*	15.0 (13.5, 16.5)*
Potassium	31.8 (30.2, 33.4)	34.6 (32.9, 36.2)	37.6 (35.9, 39.3)*
Sodium	99.3 (99.1, 99.5)	99.3 (99.2, 99.5)	99.4 (99.2, 99.6)
Choline	8.19 (6.98, 9.40)	8.45 (7.26, 9.65)	8.64 (7.45, 9.83)

Dietary modeling of NHANES 2011-2018 using two days of 24-hour intake data. Dietary modeling was accomplished by removing calories and nutrients from the diet commensurate with the calories added via pulses and then nutrients from a composite of pulses were isocalorically added to the NHANES 2011–2018 dietary intakes. Usual intakes were determined using the National Cancer Institute method. *Values with non-overlapping 95th percentile confidence intervals (CI) of means from baseline. Data are presented as mean (95th percentile confidence intervals). DGA: Dietary Guidelines for Americans; NHANES: National Health and Nutrition Examination Survey.

Discussion

Results of this cross-sectional analysis of NHANES 2011-2018 data indicate that about 35% US adults consume pulses while adult consumers of pulses have higher diet quality, nutrient intakes, and nutrient adequacies than non-consumers and increasing pulses consumption to DGA recommended level (1.5 cup eq/week) or more (3.0 cup eq/week) would further improve nutrient intakes, nutrient adequacy and diet quality of consumers. These results, therefore, confirmed our hypothesis. To the best of our knowledge, ours is the first study to compare diet quality (HEI 2020 score) and nutrient adequacy among pulse consumers and non-consumers while also modeling the effect of increasing the servings of pulses using NHANES dietary intake data.

In our analysis, adult consumers had a higher total HEI 2020 score compared to non-consumers and the HEI 2020 score for consumers was further increased by modeling increasing the pulses in the diet. HEI is a validated measure of diet quality developed to measure the alignment of diets with DGA recommendations [33]. It is commonly used in nutrition surveillance, to evaluate diets and the efficacy of dietary interventions, and to validate other nutrition research tools and indexes [36]. It has also been used to understand relationships between nutrients/foods/dietary patterns and health-related outcomes. In scientific studies, diet quality is also a key component of health outcomes, quality of life and longevity, and a higher diet quality has been consistently associated with lower risk of chronic diseases and associated mortality [37-39]. For example, in a pooled analyses of the Nurses' Health Study and the Health Professionals Follow-Up Study, there was a 19% reduction in all-cause mortality comparing the highest (79 points) to lowest (56 points) quintile of HEI-2015 scores, which is similar to HEI 2020 used in our study [40]. Additionally, it has been reported that there was a 21% reduction in all-cause mortality comparing the highest (80 points) to the lowest quintile (51 points) of HEI scores [41]. The differences between the first and second quintiles of HEI 2015 scores was 8.7 points which was associated with a 7% reduction in all-cause mortality. Based on the studies discussed above, it is likely that lower HEI scores in non-consumers (about 6.5 points) may potentially be associated with increase disease risk. HEI 2020 matrix has 13 components: 9 for dietary adequacy and 4 for dietary moderation, each reflecting a specific dietary recommendation from DGA 2020-2025 [33]. With this matrix, a higher HEI 2020 score for pulse consumers is indicative of higher diet quality and greater compliance/adherence to DGA 2020-2025 recommendations. However, irrespective of pulse consumption status or modeling scenarios, the total HEI score, in the current analysis, was between 50 and 60 points (out of a possible 100) and indicates the need for broad improvement on many dietary quality components.

The recent 2025-2030 DGAC report indicated that for many individuals the current nutrient intakes for dietary fiber, calcium, potassium, magnesium, iron, zinc, copper, phosphorus, vitamin A, thiamin, vitamin B_6, folate, vitamin B_{12}, vitamin C, vitamin D and vitamin E are below recommendations [10]. In our analysis we found that pulse consumers had higher intakes of most nutrients compared to non-consumers and modeling increasing pulses in the diet resulted in further increases in nutrient intakes indicating a positive association of pulse consumption with higher nutrient intakes. Higher intakes of fiber, iron, magnesium, zinc and potassium among pulse consumers were also reported in earlier analyses of NHANES 1999-2002 and 2013-2014 [14,15]. In our present analysis of NHANES 2011-2018, pulse consumers had higher intakes of several nutrients. Fiber, calcium, potassium and vitamin D and iron (for pregnant women) are "nutrients of concern" because their current intakes are low enough to be a public health concern, and additionally magnesium and vitamins A, C, E and choline are under consumed nutrients [9,42]. Additionally, in the present study, modeling isocaloric addition of pulses also increased the intake of dietary fiber, copper, iron, magnesium, potassium and folate. Addition of servings of canned beans to the diets of American adults also resulted in increased intake of several shortfall nutrients and improved diet quality [43]. In an earlier dietary modeling analysis, higher amounts of pulses replacing refined grains and/or protein foods increased fiber, iron, magnesium, potassium, and copper in the 2000 kcal Healthy U.S.-Style Pattern [8]. Since pulses are important source of several of the above nutrients, pulse consumption is naturally expected to lead to more nutrient dense diets and greater adequacy for nutrients.

A lower proportion of pulse consumers were below the EAR and a larger proportion were above the AI for most nutrients compared to non-consumers indicating a higher nutrient adequacy among consumers. The 2025-2030 DGAC report [10] indicated that over 5% or more below the EAR or 5% or less above AI can be considered that those nutrients are under-consumed. In the present analysis, while the inadequacies for phosphorus, selenium and niacin were below 5% mark for both consumers and non-consumers, the inadequacies for copper, iron, thiamin, folate and vitamin B_{12} were at 5+% below the EAR among non-consumers and 5% or less below EAR for consumers. Similarly, less than 5% of non-consumers were above AI while more than 5% of consumers were above AI for fiber. This is an important finding indicating that pulse consumption moved intakes of copper, iron, magnesium and fiber from being under-consumed to no longer being under-consumed.

The consumer/non-consumer differences in nutrient inadequacies ranged from 1% difference for riboflavin to 27% difference for magnesium. Since NHANES is a nationally probability sample, we can estimate the impact of these findings on a population level. The 17,234 adults in our modeling study represent 231 million adults with the 11,215 non-consumers representing 151 million adults and the 6,019 consumers representing 80 million adults. Based on these population numbers, we estimate that a 1% unit change (1% unit decrease in % below the EAR or 1% unit increase above the AI) in non-consumers would translate to about 1.51 million additional adults that would move to being nutritionally adequate.

Consumers and non-consumers had similar intakes of vitamin B_{12} with no difference in % of the population below the EAR which was somewhat unexpected. Possibly pulse consumers while consuming slightly less beef, poultry and seafood (about 4 oz eq/day) consumed more fortified cereals as suggested by slightly higher consumption of total grains (about 4 oz eq/day). Additionally, there were also higher intakes of sodium in pulse consumes as compared to non-consumers perhaps reflecting intake of processed pulses. However, over 99% of both consumers and non-consumers were above the AI of sodium.

Despite the nutritional benefits only about 35% adults consumed pulses in the present analysis of NHANES 2011-2018 data. Potential reasons of low prevalence of pulse consumption may include: lack of consumer awareness of potential health benefits of pulses and perception of pulses as an unattractive food mainly attributable to unpleasant digestive effects due to colonic fermentation of pulse fibers and to the presence of antinutrients, such as phytic acid and saponins [7,44,45]. This suggests that there is critical need for effective communication strategies to promote nutritional and health benefits of pulses and for development of food processing technologies to reduce antinutrients.

A major strength of our study is that our findings are generalizable to the US population, since we used a nationally representative population database. We used two-days of intake, rather than one-day to define consumers, which minimized misclassification errors. Additionally, we determined usual intake, indicative of longer-term intake, to compare the percentage of the population below the EAR/above the AI between consumers and non-consumers. The limitations with NHANES database include the use of self-reported dietary intake data, which rely on memory and are subject to potential reporting bias and may under- or over-estimate the actual intake, and NHANES is a cross-sectional survey, therefore causality of pulse intake with nutrient intake cannot be inferred. The association of pulses intake with higher nutrient intake and lower nutrient inadequacies may also be due, at least in some part, to other foods that are consumed with pulses or to residual confounding associated with other differences in pulse consumers and non-consumers not covered with covariate adjustment we used. As in any dietary modeling study, our results evaluated the maximum effect of dietary modeling and may not reflect actual individual dietary behavior. In addition, we chose to add pulses on an isocaloric basis thus removing calories and nutrients from participants overall diet and adding in energy and nutrients from increase in pulses and did not focus on removing any one food/food group. However, such dietary modeling offers a technique to test the potential nutritional impact of dietary guidance. Finally, it is possible that pulse consumers are more health conscious and thus consume an overall healthier diet by selecting more nutrient dense foods across many food categories compared to non-consumers.

Conclusions

The results showed that pulse consumers had higher nutrient intake, better nutrient adequacy and better diet quality compared to non-consumers. The dietary modeling also indicated that increasing pulse consumption to DGA recommended level or more (i.e., 3 cup eq per week) would further improve nutrient intakes, nutrient adequacy and diet quality of consumers. These results suggest that encouraging increased pulse consumption may be an effective strategy for potentially improving diet quality and achieving a healthier diet. However, contribution of other dietary constituents of pulse consumers to these results cannot be ruled out. Future randomized controlled feeding trials and large prospective cohort studies or longitudinal studies are needed to determine long term impact of pulse consumption.

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Ethical Guidelines: The data used for this manuscript were from the National Health and Nutrition Examination Survey (NHANES) and all participants or proxies provided written informed consent; data collection for NHANES was approved by the Research Ethics Review Board of the National Center for Health Statistics. NHANES has stringent consent protocols and procedures to ensure confidentiality and protection from identification. This study was a secondary data analysis, which lacked personal identifiers, and therefore did not require Institutional Review Board review.

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Conflict of Interest: Sanjiv Agarwal at NutriScience LLC performs consulting for various food and beverage companies and related entities. Victor L. Fulgoni, III at Nutrition Impact LLC performs consulting and database analyses for various food and beverage companies and related entities. The study and the writing of the manuscript were financially supported by the American Pulse Association (APA). APA did not have a role in study design, data collection, analysis, interpretation, report writing or in the decision to submit the article for publication.

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