The Role of Fortified and Enriched Refined Grains in the US Dietary Pattern: A NHANES 2009–2016 Modeling Analysis to Examine Nutrient Adequacy

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Background: While dietary recommendations call for greater whole-grain intake and reduced refined grain consumption, there are limited peer-reviewed studies examining the influence of fortified/enriched refined grains on nutrient adequacy.

Methods: A modeling analysis using data from National Health and Nutrition Examination Survey (NHANES) 2009–2016 estimated usual daily intake of shortfall nutrients for Dietary Guidelines for Americans (DGA) in the current dietary pattern and when specific percentages of fortified/enriched refined grain foods (bread, ready-to-eat cereals, and all-grained foods) were removed from the diet (19–50-year-old adults, N = 11,169; 51–99-year-old adults, N = 9,641).

Results: While American adults are currently falling short of nutrient recommendations, eliminating 25, 50, and 100% of all grains consumed in the US dietary pattern resulted in a greater percentage of adults not meeting recommendations for several shortfall nutrients, including dietary fiber, folate DFE, iron, and magnesium. Removal of all grains led to a reduced energy intake by ∼10% in both age groups examined. Currently, ∼3.8% of 19–50-year-old adults meet the adequate intake (AI) for dietary fiber. Removal of 25, 50, and 100% of grains from the diet resulted in 2.6 ± 0.3, 1.8 ± 0.2, and 0.7 ± 0.1% of adults exceeded the AI for dietary fiber, respectively. Similarly, 11.0 and 13.8% of younger and older adults, respectively, fall short of folate, DFE recommendations with the current diet. For iron, current dietary pattern consumption shows 8.4% and 0.8% of younger and older adults, respectively, fall short of folate, DFE recommendations with the current diet. Following the removal of 100% of grains from the diet, 43.4 ± 1.1 and 56.2 ± 1.0%, respectively, were below the estimated average requirement (EAR) for folate DFE. For iron, current dietary pattern consumption shows 8.4% and 0.8% of younger and older adults, respectively, are not meeting iron recommendations, however, removal of 100% of grains from the diet results in nearly 10 and 22% falling short of the EAR. Currently, about 51 and 54% of younger and older adults are below the EAR for magnesium; however, with the removal of 100% of grains, 68 and 73%, respectively, fall below the EAR.

Conclusion: Removal of specific refined grains led to an increased percentage of Americans not meeting recommendations for several shortfall nutrients, including dietary fiber, folate, iron, and magnesium.

Keywords: NHANES, ready-to-eat breakfast cereals, breads, grains, shortfall nutrients
INTRODUCTION

The 2020 Dietary Guidelines for Americans (2020 DGA) provide food and nutrition recommendations for all Americans of 2 years of age and older, with the promotion of dietary patterns emphasizing fruits, vegetables, whole grains, lean protein foods, and low-fat or fat-free dairy products, all of which are based on their contributing nutrient density to the American diet (1). While dietary guidance encourages increased consumption of whole grains, there are limitations placed on refined grain consumption (1). Both the 2015 DGA (2) and the 2020 DGA (1) have recommended that half of your daily total grain servings should be derived from whole grains. DGA (2015) further stated, “choosing both whole and refined grain foods in nutrient-dense forms, such as choosing plain popcorn instead of buttered, bread instead of croissants, and English muffins instead of biscuits also can help in meeting recommendations for a healthy eating pattern” (1). Accumulating observational evidence suggests that certain refined grain foods (i.e., ready-to-eat cereals, bread) may be important sources of nutrients, particularly, nutrients that have been identified as falling below recommended intakes in American populations (3–10). Shortfall nutrients have been defined as “nutrients that are under-consumed relative to requirement levels set by the Institute of Medicine (IOM) and includes dietary fiber, calcium, magnesium, potassium, vitamins A, C, D, and E, dietary folate, and iron in select female populations.” Dietary fiber, calcium, potassium, and vitamin D have been previously highlighted as “nutrients of public health concern” as chronic underconsumption of these nutrients have been associated with unfavorable health conditions (1). Recently published studies, that have assessed dietary sources of caloric energy and nutrients, suggest several grain-based foods contribute nutrient density to Americans of various age groups (3, 4, 7, 9, 10). Relative to caloric energy, certain grain-based foods delivered a substantial percentage of shortfall nutrients, including fiber, calcium, iron, magnesium, and folate. Grain-based foods, including breakfast cereals, bread, and tortillas have been shown to contribute ≥10% of fiber, iron, zinc, folate, niacin, and thiamin in the US dietary pattern (3, 4, 10). In addition, National Health and Nutrition Examination Survey (NHANES) findings have demonstrated that significant amounts of numerous essential nutrients originate from fortified and enriched foods, prompting researchers to conclude that documented nutrient shortfalls in Americans are further exacerbated without fortification and enrichment practices (11). Fortified and enriched foods have also been shown to positively contribute to the American diet. Specifically, fortification and enrichment practices in the US significantly contribute to iron, folate, thiamin, vitamin A, vitamin D, and vitamin C, and it has been suggested that without discretionary enrichment and/or fortification in the food supply, many Americans would not meet recommended nutrient intake levels (11).

Current US dietary recommendations promote greater intake of whole grains alongside the limitation of refined and/or enriched grain foods, however, many adults are not attaining recommended intakes for key nutrients, several of which originate from fortified and enriched grain foods. As grains represent a key food group in the US dietary pattern, it is hypothesized that specified grain foods (bread and ready-to-eat cereals) are associated with nutrient adequacy and can be an integral part of helping to meet dietary guidelines. The objective of the present study was to estimate usual intake for shortfall nutrients, in addition to enrichment and/or fortification nutrients, when 25–100% of specific grain-based foods are eliminated from the American diet.

METHODS

The present analysis used data from NHANES, thus providing a national, cross-sectional representation of free-living American adults of various age groups. NHANES data are compiled by the Centers for Disease Control and Prevention within the National Center for Health Statistics (NCHS). Written informed consent and prerequisite ethical protocols for all study participants are

| Grain foods | % Removal from current dietary pattern* | Mean | SE |
|-------------|----------------------------------------|------|----|
| 19–50 years-old | | | |
| Energy (kcal) Current | 0 | 2,250 | 11.2 |
| Breads | 25 | 2,215 | 11.4 |
| Breads | 50 | 2,231 | 11.6 |
| Breads | 100 | 2,215 | 11.4 |
| Breads + RTEC | 25 | 2,223 | 11.6 |
| Breads + RTEC | 50 | 2,194 | 10.1 |
| Breads + RTEC | 100 | 2,141 | 10.9 |
| All Grains | 25 | 2,185 | 11.0 |
| All Grains | 50 | 2,118 | 11.2 |
| All Grains | 100 | 1,987 | 11.4 |
| 51–99 years-old | | | |
| Energy (kcal) Current | 0 | 2013.0 | 10.0 |
| Breads | 25 | 1922.0 | 10.0 |
| Breads | 50 | 1968.0 | 10.3 |
| Breads | 100 | 1925.0 | 7.8 |
| Breads + RTEC | 25 | 1981.0 | 10.9 |
| Breads + RTEC | 50 | 1947.0 | 9.3 |
| Breads + RTEC | 100 | 1881.0 | 9.3 |
| All Grains | 25 | 1945.0 | 9.7 |
| All Grains | 50 | 1877.0 | 10.2 |
| All Grains | 100 | 1743.0 | 9.8 |

The data source is NHANES 2009–2016; N = 11,169; Usual intake determined using the National Cancer Institute method.

Abbreviations: DGA, Dietary Guidelines for Americans; WWEIA, What We Eat in America; NHANES, National Health and Nutrition Examination Survey; USDA, United States Department of Agriculture; EAR, Estimated Average Intake; AI, Adequate Intake.
directed and granted by the NCHS Research Ethics Review Board. Four datasets (NHANES 2009–2010; 2011–2012; 2013–2014; 2015–2016) were used to complete the analyses in adults. Data representing nutrient intakes within NHANES 2009–2016 are derived from the US Department of Agriculture (USDA) Food and Nutrient Database for Dietary Studies (FNDDS), which contribute to the dietary nutrient values reported in What We Eat in America (WWEIA), the dietary intake section.

### TABLE 2 | Nutrients of public health concern: mean usual nutrient intakes and percentages meeting recommendations in 19–50-year-old adults.

| Nutrients | Grain foods | % Removal from current dietary patterna | Usual intake | <EAR | >AI |
|-----------|-------------|----------------------------------------|--------------|-------|-----|
|           |             |                                        | Mean         | SE    | %   | SE  |
| Dietary fiber, g/d | Current | 0                                      | 17.2         | 0.2   | 3.8 | 0.4 |
|            | Breads     | 25                                     | 17.0         | 0.2   | 3.5 | 0.3 |
|            | Breads     | 50                                     | 16.7         | 0.2   | 3.3 | 0.3 |
|            | Breads     | 100                                    | 16.2         | 0.2   | 2.7 | 0.3 |
|            | Breads+RTEC | 25                                    | 16.8         | 0.2   | 3.1 | 0.3 |
|            | Breads+RTEC | 50                                    | 16.3         | 0.2   | 2.5 | 0.3 |
|            | Breads+RTEC | 100                                   | 15.4         | 0.2   | 1.7 | 0.2 |
|            | All Grains | 25                                     | 16.4         | 0.2   | 2.6 | 0.3 |
|            | All Grains | 50                                     | 15.5         | 0.2   | 1.8 | 0.2 |
|            | All Grains | 100                                    | 13.9         | 0.2   | 0.7 | 0.1 |
| Potassium, mg/d | Current | 0                                      | 2,684        | 19.1  | 2.4 | 0.3 |
|              | Breads     | 25                                     | 2,678        | 18.1  | 2.3 | 0.2 |
|              | Breads     | 50                                     | 2,669        | 18.0  | 2.3 | 0.2 |
|              | Breads     | 100                                    | 2,646        | 18.8  | 2.1 | 0.3 |
|              | Breads+RTEC | 25                                    | 2,667        | 18.8  | 2.3 | 0.2 |
|              | Breads+RTEC | 50                                    | 2,648        | 18.0  | 2.1 | 0.2 |
|              | Breads+RTEC | 100                                   | 2,614        | 17.4  | 1.9 | 0.2 |
|              | All Grains | 25                                     | 2,648        | 18.5  | 2.1 | 0.2 |
|              | All Grains | 50                                     | 2,609        | 17.6  | 1.9 | 0.2 |
|              | All Grains | 100                                    | 2,534        | 18.2  | 1.4 | 0.2 |
| Calcium, mg/d | Current | 0                                      | 1,022        | 7.7   | 31.4| 0.8 |
|                | Breads     | 25                                     | 1,013        | 7.6   | 32.2| 0.8 |
|                | Breads     | 50                                     | 1,006        | 7.7   | 32.9| 0.8 |
|                | Breads     | 100                                    | 990          | 7.5   | 34.6| 0.9 |
|                | Breads+RTEC | 25                                    | 1,008        | 7.8   | 32.6| 0.8 |
|                | Breads+RTEC | 50                                    | 997          | 7.6   | 33.6| 0.8 |
|                | Breads+RTEC | 100                                   | 974          | 7.6   | 36.0| 0.9 |
|                | All Grains | 25                                     | 996          | 7.5   | 33.9| 0.8 |
|                | All Grains | 50                                     | 969          | 7.5   | 36.8| 0.8 |
|                | All Grains | 100                                    | 920          | 7.4   | 42.1| 0.9 |
| Vitamin D\(^{a}\), µg/d | Current | 0                                      | 4.6          | 0.08  | 95.4| 0.4 |
|                | Breads     | 25                                     | 4.6          | 0.08  | 95.4| 0.4 |
|                | Breads     | 50                                     | 4.6          | 0.08  | 95.6| 0.4 |
|                | Breads     | 100                                    | 4.6          | 0.08  | 95.4| 0.4 |
|                | Breads+RTEC | 25                                    | 4.5          | 0.08  | 95.8| 0.4 |
|                | Breads+RTEC | 50                                    | 4.5          | 0.07  | 96.2| 0.4 |
|                | Breads+RTEC | 100                                   | 4.3          | 0.07  | 96.6| 0.3 |
|                | All Grains | 25                                     | 4.5          | 0.07  | 95.8| 0.4 |
|                | All Grains | 50                                     | 4.4          | 0.07  | 96.3| 0.4 |
|                | All Grains | 100                                    | 4.2          | 0.07  | 96.8| 0.3 |

\(^{a}\)Vitamin D\(^{2}\)+D\(^{3}\); EAR, Estimated Average Requirement; AI, Adequate Intake.

The data source is NHANES 2009–2016; \(N = 11,169\); Usual intake determined using the National Cancer Institute method.

\(^{b}\)Current dietary pattern using data collected from NHANES 2009–2016.
of NHANES (12–14). The WWEIA food categories provide an application to analyze food and beverages as consumed in the American diet. The classification scheme includes 150 unique categories and there are 15 main food groups and 46 subcategories of foods. WWEIA food categories have been previously published by USDA. Using WWEIA food categories and classifications, the present modeling analysis represented theoretical removal of bread, bread and cereals combined, and

| Nutrients of Public Health Concern | Grain foods | % Removal from current dietary pattern* | Usual intake | <EAR | >AI |
|-----------------------------------|-------------|----------------------------------------|--------------|------|------|
| Dietary fiber, g/d                | Current     | 0                                      | 17.6 0.2     | 14.1 | 0.7 |
|                                  | Breads      | 25                                     | 17.2 0.2     | 13.0 | 0.6 |
|                                  | Breads      | 50                                     | 16.9 0.2     | 11.9 | 0.7 |
|                                  | Breads      | 100                                    | 16.2 0.2     | 10.0 | 0.6 |
|                                  | Breads + RTEC | 25                                | 16.9 0.2     | 11.9 | 0.6 |
|                                  | Breads + RTEC | 50                                | 16.3 0.2     | 9.9  | 0.6 |
|                                  | Breads + RTEC | 100                               | 15.0 0.1     | 6.6  | 0.5 |
|                                  | All Grains  | 25                                     | 16.6 0.2     | 10.6 | 0.6 |
|                                  | All Grains  | 50                                     | 15.6 0.1     | 7.7  | 0.5 |
|                                  | All Grains  | 100                                    | 13.6 0.1     | 3.6  | 0.3 |
| Potassium, mg/d                  | Current     | 0                                      | 2,750 16.4   | 2.6  | 0.3 |
|                                  | Breads      | 25                                     | 2,739 16.3   | 2.5  | 0.2 |
|                                  | Breads      | 50                                     | 2,723 17.4   | 2.4  | 0.3 |
|                                  | Breads      | 100                                    | 2,697 17.0   | 2.3  | 0.3 |
|                                  | Breads + RTEC | 25                                 | 2,725 16.6   | 2.4  | 0.3 |
|                                  | Breads + RTEC | 50                                 | 2,699 17.2   | 2.2  | 0.2 |
|                                  | Breads + RTEC | 100                                | 2,653 16.2   | 2.0  | 0.2 |
|                                  | All Grains  | 25                                     | 2,710 15.7   | 2.3  | 0.2 |
|                                  | All Grains  | 50                                     | 2,661 15.7   | 2.0  | 0.2 |
|                                  | All Grains  | 100                                    | 2,573 15.2   | 1.5  | 0.2 |
| Calcium, mg/d                    | Current     | 0                                      | 931 8.4      | 56.0 | 1.0 |
|                                  | Breads      | 25                                     | 920 8.5      | 57.2 | 1.0 |
|                                  | Breads      | 50                                     | 910 8.6      | 58.2 | 1.0 |
|                                  | Breads      | 100                                    | 889 8.6      | 60.2 | 1.0 |
|                                  | Breads + RTEC | 25                                 | 915 8.4      | 57.7 | 1.0 |
|                                  | Breads + RTEC | 50                                 | 901 8.3      | 59.2 | 1.0 |
|                                  | Breads + RTEC | 100                                | 869 8.0      | 62.4 | 0.9 |
|                                  | All Grains  | 25                                     | 902 8.2      | 59.1 | 0.9 |
|                                  | All Grains  | 50                                     | 872 8.2      | 62.2 | 0.9 |
|                                  | All Grains  | 100                                    | 812 7.8      | 68.2 | 0.9 |
| Vitamin D<sup>a</sup>, µg/d      | Current     | 0                                      | 5.0 0.1      | 93.8 | 0.4 |
|                                  | Breads      | 25                                     | 5.0 0.1      | 94.0 | 0.4 |
|                                  | Breads      | 50                                     | 5.0 0.1      | 94.0 | 0.4 |
|                                  | Breads      | 100                                    | 5.0 0.1      | 93.9 | 0.4 |
|                                  | Breads + RTEC | 25                                 | 4.9 0.1      | 94.5 | 0.4 |
|                                  | Breads + RTEC | 50                                 | 4.8 0.1      | 95.0 | 0.4 |
|                                  | Breads + RTEC | 100                                | 4.6 0.1      | 95.6 | 0.4 |
|                                  | All Grains  | 25                                     | 4.9 0.1      | 94.5 | 0.4 |
|                                  | All Grains  | 50                                     | 4.8 0.1      | 95.2 | 0.4 |
|                                  | All Grains  | 100                                    | 4.5 0.1      | 95.9 | 0.4 |

<sup>a</sup>Vitamin D<sub>2</sub>+D<sub>3</sub>; EAR, Estimated Average Requirement; AI, Adequate Intake.

The data source is NHANES 2009–2016; N = 9,641; usual intake determined using the National Cancer Institute method.

<sup>*</sup>Current dietary pattern using data from NHANES 2009–2016.
TABLE 4 | Shortfall nutrients: mean usual nutrient intakes percentages meeting recommendations in 19–50-year-old adults.

| Nutrients | Grain foods | % Removal from current dietary pattern* | Usual intake | <EAR | >AI |
|-----------|-------------|----------------------------------------|--------------|------|-----|
|           |             |                                        | Mean | SE  | %   | SE  | %   | SE  |
| **Shortfall Nutrients** |             |                                        |      |     |     |     |     |     |
| Folate, µg DFE/d | Current     | 0                                      | 555 | 5.2 | 11.0 | 0.6 |
|                  | Breads      | 25                                     | 548 | 5.2 | 11.8 | 0.6 |
|                  | Breads      | 50                                     | 540 | 5.0 | 12.7 | 0.7 |
|                  | Breads      | 100                                    | 525 | 5.0 | 14.9 | 0.7 |
|                  | Breads+RTEC | 25                                     | 525 | 4.6 | 12.4 | 0.7 |
|                  | Breads+RTEC | 50                                     | 492 | 4.1 | 14.6 | 0.8 |
|                  | Breads+RTEC | 100                                    | 428 | 3.6 | 24.5 | 0.9 |
| All Grains       | 25                                     | 506 | 4.4 | 14.6 | 0.7 |
|                  | All Grains  | 50                                     | 457 | 3.9 | 20.1 | 0.8 |
|                  | All Grains  | 100                                    | 358 | 3.3 | 43.4 | 1.1 |
| Iron, mg/d       | Current     | 0                                      | 15.2 | 0.1 | 8.4  | 0.3 |
|                  | Breads      | 25                                     | 15.1 | 0.1 | 8.9  | 0.3 |
|                  | Breads      | 50                                     | 14.8 | 0.1 | 9.3  | 0.3 |
|                  | Breads      | 100                                    | 14.5 | 0.1 | 10.3 | 0.4 |
|                  | Breads+RTEC | 25                                     | 14.5 | 0.1 | 9.4  | 0.3 |
|                  | Breads+RTEC | 50                                     | 13.7 | 0.1 | 10.7 | 0.4 |
|                  | Breads+RTEC | 100                                    | 12.3 | 0.1 | 14.8 | 0.4 |
| All Grains       | 25                                     | 14.1 | 0.1 | 10.4 | 0.3 |
|                  | All Grains  | 50                                     | 12.9 | 0.1 | 12.9 | 0.4 |
|                  | All Grains  | 100                                    | 10.5 | 0.1 | 21.9 | 0.5 |
| Magnesium, mg/d  | Current     | 0                                      | 312 | 2.4 | 50.8 | 1.0 |
|                  | Breads      | 25                                     | 309 | 2.4 | 52.0 | 1.0 |
|                  | Breads      | 50                                     | 306 | 2.4 | 53.1 | 1.0 |
|                  | Breads      | 100                                    | 301 | 2.3 | 55.1 | 1.0 |
|                  | Breads+RTEC | 25                                     | 307 | 2.4 | 52.8 | 1.0 |
|                  | Breads+RTEC | 50                                     | 302 | 2.3 | 54.9 | 1.0 |
|                  | Breads+RTEC | 100                                    | 293 | 2.3 | 58.9 | 1.0 |
| All Grains       | 25                                     | 302 | 2.3 | 55.0 | 1.0 |
|                  | All Grains  | 50                                     | 292 | 2.2 | 59.2 | 1.0 |
|                  | All Grains  | 100                                    | 273 | 2.2 | 67.6 | 1.0 |
| Vitamin A, µg RAE/d | Current     | 0                                      | 614 | 8.6 | 49.2 | 1.2 |
|                  | Breads      | 25                                     | 614 | 9.2 | 49.0 | 1.2 |
|                  | Breads      | 50                                     | 613 | 8.8 | 49.2 | 1.2 |
|                  | Breads      | 100                                    | 613 | 8.7 | 49.3 | 1.2 |
|                  | Breads+RTEC | 25                                     | 601 | 8.5 | 51.0 | 1.2 |
|                  | Breads+RTEC | 50                                     | 588 | 8.4 | 52.9 | 1.2 |
|                  | Breads+RTEC | 100                                    | 563 | 8.1 | 56.8 | 1.2 |
| All Grains       | 25                                     | 596 | 8.5 | 51.6 | 1.2 |
|                  | All Grains  | 50                                     | 577 | 8.1 | 54.5 | 1.2 |
|                  | All Grains  | 100                                    | 541 | 7.8 | 60.3 | 1.2 |
| Vitamin C, mg/d  | Current     | 0                                      | 79.4 | 1.3 | 48.9 | 1.1 |
|                  | Breads      | 25                                     | 79.5 | 1.3 | 48.9 | 1.1 |
|                  | Breads      | 50                                     | 79.5 | 1.3 | 48.9 | 1.1 |
|                  | Breads      | 100                                    | 79.5 | 1.3 | 48.9 | 1.1 |
|                  | Breads+RTEC | 25                                     | 79.0 | 1.3 | 49.4 | 1.1 |
|                  | Breads+RTEC | 50                                     | 78.5 | 1.3 | 49.9 | 1.1 |
|                  | Breads+RTEC | 100                                    | 77.8 | 1.3 | 50.7 | 1.1 |

(Continued)
TABLE 4 | Continued

| Nutrients                  | Grain foods | % Removal from current dietary pattern* | Usual intake | <EAR | >AI |
|---------------------------|-------------|------------------------------------------|--------------|------|-----|
|                           |             | Mean | SE | % | SE | % | SE |
| All Grains                | 25          | 79.0 | 1.3 | 49.5 | 1.1 |
| All Grains                | 50          | 78.5 | 1.3 | 49.9 | 1.1 |
| All Grains                | 100         | 77.7 | 1.3 | 50.8 | 1.1 |
| Vitamin E<sup>a</sup>, mg/d | Current     | 9.0  | 0.1 | 81.3 | 0.8 |
| Bread                     | 25          | 8.9  | 0.1 | 81.6 | 0.8 |
| Bread+RTEC                | 25          | 8.9  | 0.1 | 82.3 | 0.8 |
| Bread                     | 50          | 8.8  | 0.1 | 82.9 | 0.7 |
| Bread+RTEC                | 100         | 8.5  | 0.1 | 84.5 | 0.7 |
| All Grains                | 25          | 8.8  | 0.1 | 82.6 | 0.8 |
| All Grains                | 50          | 8.6  | 0.1 | 83.8 | 0.8 |
| All Grains                | 100         | 8.3  | 0.1 | 86.0 | 0.7 |

<sup>a</sup>as alpha-tocopherol; EAR, Estimated Average Requirement; AI, Adequate Intake.

The data source is NHANES 2009–2016; N = 9,641; Usual intake determined using the National Cancer Institute method.

Current dietary pattern using data collected from NHANES 2009–2016.

all enriched and/or fortified grain foods at 25, 50, and 100% elimination. The modeling analysis was meant to examine the nutrient contribution of grain foods (bread and ready-to-eat cereals and all grains) and potential impacts to achieving nutrient recommendations.

The NHANES dataset sample included 11,169 adults of 19–50-year-old and 9,641 adults of 51–99-year-old, where all subjects presented complete and reliable 24 h dietary intake recalls. Trained certified survey analysts administered dietary recalls via the Automated Multiple-Pass Method, a computerized, evidence-based procedure developed by USDA that encompasses a comprehensive description of foods and beverages and amounts consumed (15–17).

Two days of 24 h dietary recalls were used to determine usual intakes by using the methodology of the National Cancer Institute. Usual intake means, percentiles and percent meeting National Academy of Medicine Dietary Reference Intake (DRI) cutoffs [i.e., estimated average requirement (EAR) and adequate intake (AI)] were estimated using version 2.1 of the methodology of National Cancer Institute and were used to evaluate the impact of grain removal. The percentage of the population below the EAR or above the AI was assessed using the cut-point method, except for iron, which was assessed using the probability method (18). The methodology of National Cancer Institute (version 2.1) was used to estimate usual intake means, percentiles and percent meeting Dietary Reference Intake (DRI) cutoffs [i.e., EAR and AI] following the removal of specified percentages of grain foods from the typical US dietary patterns. The age groups, gender, day sequence, and weekend of DRI were covariates considered in the present analysis. The elimination and removal of grain models examined included the following: (a) “as is/no modeling changes” in dietary intake to represent typical and current scenarios of nutrient intake patterns; (b) 25, 50, and 100% removal of bread [WWEIA category 4202 (yeast bread)]; (c) 25, 50, and 100% removal of yeast bread, ready-to-eat cereals (RTEC) (WWEIA category 4202 or subgroup 46); and (d) 25, 50, and 100% elimination of grain-based foods [all-grained foods included in enrichment and fortification practices (i.e., classified as WWEIA main group 4)].

SAS software (Version 9.4, SAS Institute, Cary, NC, USA) was used to implement statistical analyses and SAS PROC SURVEYMEANS was used to determine means and percentages presented in the modeling scenarios. Survey weights used to generate representative estimates for U.S. adults also included survey weights to adjust for the complex sample design of NHANES.

RESULTS

Energy Intake

Table 1 summarizes the mean usual energy intake in 19–50-year-old and 51–99-year-old adults. Removal of all bread and cereals leads to reductions of usual daily energy intake of 3–5% in younger adults and 4–6% in older adults. Removal of all grains led to a reduced energy intake by ~10% in both adult groups.

Nutrients of Public Health Concern

Tables 2, 3 summarize the mean usual nutrients of public health concern intakes and DRI percentages from 19- to 50-year-old and from 51 to 99-year-old adults, respectively.

Based on the current NHANES database, the percentage of individuals above the AI for dietary fiber is only 3.8 ± 0.4 and 14.1 ± 0.7%, in the younger and older adults, respectively. Removal of bread and the combination of removal of bread and RTEC further
TABLE 5 | Shortfall nutrients: mean usual nutrient intakes, usual intake percentiles, and DRI percentages in 51–99-year-old adults.

| Nutrients          | Grain foods | % Removal from current dietary pattern* | Usual intake | < EAR | > AI |
|--------------------|-------------|-----------------------------------------|--------------|-------|------|
|                    |             |                                         | Mean | SE  | %   | SE  | %   | SE  |
| Folate, µg DFE/d   | Current     | 0                                       | 523  | 4.4 | 13.8| 0.8 |
|                    | Breads      | 25                                      | 513  | 4.4 | 15.2| 0.9 |
|                    | Breads      | 50                                      | 503  | 4.3 | 16.6| 0.9 |
|                    | Breads      | 100                                     | 483  | 4.1 | 20.0| 0.9 |
|                    | Breads + RTEC| 25                                      | 487  | 3.8 | 16.7| 0.9 |
|                    | Breads + RTEC| 50                                      | 450  | 3.5 | 20.8| 0.9 |
|                    | Breads + RTEC| 100                                     | 378  | 3.2 | 37.0| 1.0 |
|                    | All Grains  | 25                                      | 472  | 3.8 | 19.0| 0.9 |
|                    | All Grains  | 50                                      | 420  | 3.3 | 27.0| 1.0 |
|                    | All Grains  | 100                                     | 319  | 2.8 | 56.2| 1.0 |
| Iron, mg/d         | Current     | 0                                       | 14.6 | 0.1 | 0.8 | 0.1 |
|                    | Breads      | 25                                      | 14.3 | 0.1 | 0.9 | 0.1 |
|                    | Breads      | 50                                      | 14.1 | 0.1 | 1.1 | 0.2 |
|                    | Breads      | 100                                     | 13.5 | 0.1 | 1.7 | 0.2 |
|                    | Breads + RTEC| 25                                      | 13.7 | 0.1 | 1.0 | 0.2 |
|                    | Breads + RTEC| 50                                      | 12.8 | 0.1 | 1.4 | 0.2 |
|                    | Breads + RTEC| 100                                     | 11.0 | 0.1 | 4.3 | 0.3 |
|                    | All Grains  | 25                                      | 13.3 | 0.1 | 1.4 | 0.2 |
|                    | All Grains  | 50                                      | 12.0 | 0.1 | 2.2 | 0.2 |
|                    | All Grains  | 100                                     | 9.4  | 0.1 | 9.9 | 0.5 |
| Magnesium, mg/d    | Current     | 0                                       | 304  | 2.1 | 54.2| 0.9 |
|                    | Breads      | 25                                      | 301  | 2.0 | 55.7| 0.9 |
|                    | Breads      | 50                                      | 297  | 2.1 | 57.3| 0.9 |
|                    | Breads      | 100                                     | 290  | 2.0 | 60.3| 0.8 |
|                    | Breads + RTEC| 25                                      | 298  | 2.1 | 56.9| 0.9 |
|                    | Breads + RTEC| 50                                      | 292  | 2.0 | 59.5| 0.9 |
|                    | Breads + RTEC| 100                                     | 279  | 2.1 | 65.1| 0.9 |
|                    | All Grains  | 25                                      | 293  | 2.0 | 59.0| 0.8 |
|                    | All Grains  | 50                                      | 282  | 2.0 | 63.9| 0.9 |
|                    | All Grains  | 100                                     | 260  | 1.8 | 73.0| 0.9 |
| Vitamin A, µg RAE/d| Current     | 0                                       | 682  | 8.9 | 38.6| 1.1 |
|                    | Breads      | 25                                      | 682  | 9.4 | 38.4| 1.1 |
|                    | Breads      | 50                                      | 682  | 8.7 | 38.6| 1.1 |
|                    | Breads      | 100                                     | 682  | 8.9 | 38.6| 1.1 |
|                    | Breads + RTEC| 25                                      | 667  | 8.7 | 40.3| 1.1 |
|                    | Breads + RTEC| 50                                      | 651  | 8.3 | 42.3| 1.0 |
|                    | Breads + RTEC| 100                                     | 622  | 7.6 | 46.6| 1.0 |
|                    | All Grains  | 25                                      | 659  | 8.5 | 41.2| 1.1 |
|                    | All Grains  | 50                                      | 639  | 8.4 | 44.0| 1.1 |
|                    | All Grains  | 100                                     | 594  | 7.6 | 50.8| 1.1 |
| Vitamin C, mg/d    | Current     | 0                                       | 87.0 | 1.5 | 41.9| 1.1 |
|                    | Breads      | 25                                      | 86.9 | 1.4 | 41.9| 1.0 |
|                    | Breads      | 50                                      | 87.1 | 1.6 | 41.9| 1.1 |
|                    | Breads      | 100                                     | 86.9 | 1.6 | 42.0| 1.1 |
|                    | Breads + RTEC| 25                                      | 86.4 | 1.5 | 42.5| 1.1 |
|                    | Breads + RTEC| 50                                      | 85.9 | 1.6 | 42.9| 1.1 |
|                    | Breads + RTEC| 100                                     | 84.8 | 1.6 | 44.1| 1.1 |

(Continued)
The data source is NHANES 2009–2016; N = 9,641; Usual intake determined using the National Cancer Institute method.

Current dietary pattern using data from NHANES 2009–2016.

As alpha-tocopherol; EAR, Estimated Average Requirement; AI, Adequate Intake.

Table 6, 7 summarize mean usual riboflavin, thiamin and niacin intakes, and DRI percentages from 19- to 50-year-old and from 51- to 99-year-old adults, respectively. Due to current enrichment practices, a small percentage of adults fall below the EAR for riboflavin, thiamin and niacin in both age groups examined. Grain foods are likely to play an important role in helping to achieve nutrient adequacy in the American adult population as evidenced by modeling the removal of grains from the diet. Indeed, the removal of all enriched and fortified grains from the diet in the age group from 19- to 50-year-old and from 51- to 99-year-old adults increased the percent of adults falling beneath the thiamin EAR, i.e., from 5.6 ± 0.4 to 28.2 ± 1.0% and from 7.8 ± 0.6 to 39.2 ± 0.9%, respectively. Similarly, the removal of all enriched and fortified grains from the diet in the age group of 19–50- and 51–99-year-old adults elevated the percent of adults not attaining the EAR for niacin, adults below the niacin EAR increased from 0.8 ± 0.1 to 4.3 ± 0.4% and from 2.0 ± 0.2 to 11.0 ± 0.7%, respectively.

### DISCUSSION

Based on published peer-reviewed literature and to the best of our knowledge, no studies have been completed examining the potential nutrient intake consequences resulting from the removal and/or elimination of specific grain foods from the American diet, particularly, in the presence of mandated fortification and enrichment policy guidelines in the US. Indeed, prior to conducting the present grain-based foods analysis, current dietary patterns in American adults still reveal a meaningful percentage of adults are falling below recommendations for several nutrients, including vitamin A, vitamin C, vitamin D, vitamin E, magnesium, fiber, and dietary
TABLE 6 | Discretionary enrichment nutrients: mean usual nutrient intakes and percentages meeting recommendations in 19–50-year-old adults.

| Nutrients       | Grain foods       | % Removal from current dietary pattern* | Usual intake | <EAR | >AI |
|-----------------|-------------------|----------------------------------------|--------------|------|-----|
| Discretionary Enrichment Nutrients |                  |                                        | Mean         | SE   | %   | SE  |
| Riboflavin, mg/d | Current           | 0                                      | 2.18         | 0.02 | 3.01| 0.24|
|                 | Breads            | 25                                     | 2.16         | 0.02 | 3.21| 0.25|
|                 | Breads            | 50                                     | 2.14         | 0.02 | 3.44| 0.25|
|                 | Breads+RTEC       | 100                                    | 2.11         | 0.02 | 3.93| 0.25|
|                 | Breads+RTEC       | 25                                     | 2.12         | 0.02 | 3.31| 0.28|
|                 | Breads+RTEC       | 50                                     | 2.07         | 0.02 | 3.72| 0.28|
|                 | Breads+RTEC       | 100                                    | 1.97         | 0.02 | 5.05| 0.32|
|                 | All Grains        | 25                                     | 2.09         | 0.02 | 3.69| 0.27|
|                 | All Grains        | 50                                     | 2.01         | 0.02 | 4.50| 0.31|
|                 | All Grains        | 100                                    | 1.85         | 0.02 | 7.42| 0.45|
| Thiamin, mg/d   | Current           | 0                                      | 1.68         | 0.01 | 5.58| 0.43|
|                 | Breads            | 25                                     | 1.65         | 0.01 | 6.19| 0.47|
|                 | Breads            | 50                                     | 1.62         | 0.01 | 6.88| 0.49|
|                 | Breads            | 100                                    | 1.57         | 0.01 | 8.81| 0.56|
|                 | Breads+RTEC       | 25                                     | 1.61         | 0.01 | 6.51| 0.49|
|                 | Breads+RTEC       | 50                                     | 1.55         | 0.01 | 7.85| 0.57|
|                 | Breads+RTEC       | 100                                    | 1.43         | 0.01 | 12.94| 0.74|
|                 | All Grains        | 25                                     | 1.56         | 0.01 | 7.99| 0.55|
|                 | All Grains        | 50                                     | 1.44         | 0.01 | 11.99| 0.68|
|                 | All Grains        | 100                                    | 1.21         | 0.01 | 28.16| 0.97|
| Niacin, mg/d    | Current           | 0                                      | 27.72        | 0.20 | 0.76| 0.10|
|                 | Breads            | 25                                     | 27.42        | 0.20 | 0.85| 0.11|
|                 | Breads            | 50                                     | 27.15        | 0.20 | 0.93| 0.13|
|                 | Breads            | 100                                    | 26.56        | 0.20 | 1.24| 0.16|
|                 | Breads+RTEC       | 25                                     | 26.96        | 0.19 | 0.89| 0.12|
|                 | Breads+RTEC       | 50                                     | 26.21        | 0.19 | 1.10| 0.15|
|                 | Breads+RTEC       | 100                                    | 24.69        | 0.18 | 2.13| 0.26|
|                 | All Grains        | 25                                     | 26.48        | 0.19 | 1.08| 0.14|
|                 | All Grains        | 50                                     | 25.26        | 0.19 | 1.60| 0.19|
|                 | All Grains        | 100                                    | 22.82        | 0.19 | 4.25| 0.40|

**EAR, Estimated Average Requirement; AI, Adequate Intake.**

*Current dietary pattern using data from NHANES 2009-2016.

Folate. The removal of bread and ready-to-eat cereals from the diet results in more adults falling short of recommendations for several nutrients, thus, further exacerbating nutrient inadequacy in Americans. Similarly, removing or reducing all grains (both whole and enriched grains) from the diet results in higher percentages of adults not meeting recommended intake levels for key nutrients, including several shortfall nutrients as distinguished by present and previous DGA. The current analysis substantiates the continued inclusion of whole and enriched grain foods as a part of the American adult eating pattern. The current analysis also illustrates the nutritional value of grain enrichment and fortification practices in the US, as a dietary strategy to help close nutrient recommendation gaps.

Since whole grains are typically not included in government-mandated fortification and enrichment practices in the US (19), there may be a misconception that refined and/or enriched grains are not required in the American diet. Indeed, while the 2015 DGAC recommended making half of total grain intake as whole grain, the inclusion of refined grains in the diet was supported by modeling studies that demonstrated the nutrient contribution of fortified and enriched grains (2). Furthermore, the perception that all refined grains are negative dietary components may lead to unintended nutrient intake and public health consequences. Indeed, the classification of all grains into the classification of refined grains when criteria for whole grain are not satisfied may be nutritionally flawed since many enriched grains (i.e., breakfast cereals, bread, cooked cereals, etc.) are nutrient-dense.
Table 7: Discretionary enrichment nutrients: mean usual nutrient intakes, usual intake percentiles, and DRI, and percentages meeting recommendations in 51–99-year-old adults.

| Nutrients      | Grain foods | % Removal from current dietary pattern* | Usual intake | < EAR | > AI |
|----------------|-------------|-----------------------------------------|--------------|------|------|
|                |             |                                         | Mean         | SE   | %    | SE   |
| Discretionary Enrichment Nutrients |             |                                         |              |      |      |      |
| Riboflavin, mg/d | Current     | 0                                      | 2.2          | 0.01 | 2.8  | 0.2  |
| Breads         | 25          |                                        | 2.1          | 0.01 | 3.0  | 0.2  |
| Breads         | 50          |                                        | 2.1          | 0.01 | 3.2  | 0.2  |
| Breads         | 100         |                                        | 2.1          | 0.01 | 3.8  | 0.2  |
| Breads + RTEC  | 25          |                                        | 2.1          | 0.01 | 3.1  | 0.2  |
| Breads + RTEC  | 50          |                                        | 2.0          | 0.01 | 3.6  | 0.2  |
| Breads + RTEC  | 100         |                                        | 1.9          | 0.01 | 5.2  | 0.3  |
| All Grains     | 25          |                                        | 2.1          | 0.01 | 3.5  | 0.2  |
| All Grains     | 50          |                                        | 2.0          | 0.01 | 4.4  | 0.3  |
| All Grains     | 100         |                                        | 1.8          | 0.01 | 7.8  | 0.4  |
| Thiamin, mg/d  | Current     | 0                                      | 1.6          | 0.01 | 7.8  | 0.6  |
| Breads         | 25          |                                        | 1.5          | 0.01 | 8.8  | 0.6  |
| Breads         | 50          |                                        | 1.5          | 0.01 | 10.1 | 0.7  |
| Breads         | 100         |                                        | 1.4          | 0.01 | 13.5 | 0.7  |
| Breads + RTEC  | 25          |                                        | 1.5          | 0.01 | 9.5  | 0.7  |
| Breads + RTEC  | 50          |                                        | 1.4          | 0.01 | 12.1 | 0.7  |
| Breads + RTEC  | 100         |                                        | 1.3          | 0.01 | 21.1 | 0.8  |
| All Grains     | 25          |                                        | 1.5          | 0.01 | 11.5 | 0.7  |
| All Grains     | 50          |                                        | 1.3          | 0.01 | 17.5 | 0.8  |
| All Grains     | 100         |                                        | 1.1          | 0.01 | 39.2 | 0.9  |
| Niacin, mg/d   | Current     | 0                                      | 24.4         | 0.2  | 2.0  | 0.2  |
| Breads         | 25          |                                        | 24.0         | 0.2  | 2.2  | 0.3  |
| Breads         | 50          |                                        | 23.6         | 0.2  | 2.6  | 0.3  |
| Breads         | 100         |                                        | 22.8         | 0.2  | 3.6  | 0.4  |
| Breads + RTEC  | 25          |                                        | 23.5         | 0.2  | 2.5  | 0.3  |
| Breads + RTEC  | 50          |                                        | 22.6         | 0.2  | 3.2  | 0.3  |
| Breads + RTEC  | 100         |                                        | 20.9         | 0.2  | 6.4  | 0.5  |
| All Grains     | 25          |                                        | 23.0         | 0.2  | 2.9  | 0.3  |
| All Grains     | 50          |                                        | 21.8         | 0.2  | 4.3  | 0.4  |
| All Grains     | 100         |                                        | 19.2         | 0.2  | 10.8 | 0.7  |

*Current dietary pattern using data from NHANES 2009–2016.

Previous reports suggest <5% of the US population meets the minimum recommendation for whole-grain consumption, with the average American adult eating <1 oz equivalent of whole grains daily (1, 20). Therefore, it is a reasonable assumption that refined and/or enriched grains are the principal types of grains eaten by American consumers. Indeed, studies from this group using NHANES show that certain grain foods are key contributors of under-consumed nutrients (3, 4, 10). Analyses from earlier NHANES datasets in US children and adults have also corroborated with the current findings by highlighting enriched and/or fortified foods as key contributors of iron, folate, niacin, thiamin, riboflavin, vitamins A, vitamin B6, vitamin B12, vitamin C, and vitamin D. Indeed, the percentage of the population with usual intakes less than the EAR for many nutrients was significantly greater when only naturally occurring nutrients were considered in the diet. Enriched and/or fortified foods contributed to significant amounts of nutrients, such that the percentage of the population with usual intakes below the EAR significantly decreased for iron (22–7%), folate (88–11%), vitamin A (74–45%), and thiamin (51–6%) (11). The researchers concluded that nutrient intake shortfalls in Americans would further worsen following the removal of enriched and/or fortified foods (11). While previous studies have focused on children and all adults (≥19-year-old) with no current data isolating older Americans (i.e., >50-year-old), the current study examined both younger adults (19–50-year-old) and older adults (51–99-year-old). Older Americans represent a substantial proportion of the...
US population with the CDC estimating that those ≥ 65-year-old will increase by 100% in the next 2.5 decades to nearly 72 million (21). Healthy aging is a multivariable process, with a key determinant of success involving meeting recommended nutrient intakes and routine consumption of a healthy dietary pattern, to optimize health and quality of life (22). Thus, intake of both macro- and micro-nutrients are critical factors in healthy aging. While it has been established that some grain-based food products provide added sugar, sodium, and saturated fat, several grain-based foods contribute numerous nutrients to encourage in older adults, including calcium, magnesium, dietary fiber, riboflavin, niacin, folate, and vitamin B12 (1, 10, 23, 24). Dietary fiber remains a shortfall nutrient in older Americans, with data showing about 4% of males and 13% of females consuming fiber above recommended levels (2). In addition, calcium intakes remain below recommendation with previous dietary guidance policy suggesting that 71% of males and 81% of females ≥71-year-old having daily intakes below the EAR. Magnesium and folate and are also under-consumed compared with the EAR in Americans (2). Previously published NHANES data further show that the percent of adults below the EAR gradually increases with age for several nutrients, including calcium, magnesium, folate, vitamin D, and vitamin E (25). Importantly, the current modeling data show that specific grain foods are important contributors of nutrients in the diet. Removal or elimination of grains in older adults resulted in meaningful increases in the percent of individuals not meeting recommendations for several shortfall nutrients, including dietary fiber, calcium, folate, iron, magnesium, vitamin A, thiamin, niacin, and riboflavin.

Study limitations inherent in the present study are typical of observational research and have been routine acknowledged in preceding publications (3–6, 10). Dietary recall data require trust in the memory function of study participants, and as such, recalled information may include a level of errors, inaccuracies, and/or personal bias which are often present in sizeable data sets (26); however, the critical advantage of NHANES encompasses the capacity to direct research analyses grounded in a large and nationally representative dataset of American adults with associations to food and beverage consumption and individualized nutrient intakes (14, 17). The current analysis only considered the percentage removal and/or complete elimination of specific fortified and enriched refined grain foods from the American diet. As such, future research can incorporate a modeling scenario that identifies results from replacing grain foods with other food group options to compare and contrast the nutritional contributions from grains relative to other food choices. While refined grain foods can be significant contributors of unfavorable nutrients in the diet, it is imperative to highlight that the current simulation did not include modeling for reductions in total sugars, added sugars, sodium, saturated fat, and other nutrients following the removal of grain foods from the dietary pattern. Future research by the group will consider these aspects in upcoming modeling that will also include substitutions to compliment the removal of foods in various age groups, including children and adults.

In conclusion, the current dietary pattern in American adults shows many adults are falling below recommendation levels for several nutrients, including dietary fiber, magnesium, folate, vitamin A, vitamin C, vitamin D, and vitamin E. The removal of bread and ready-to-eat cereals from the diet resulted in a higher percentage of adults falling short of recommended nutrient intakes. Similarly, removing or eliminating all grains from the diet further exacerbates those falling short of nutrient recommendations, leading to insufficient intake of several 2015–2020 DGA shortfall nutrients. The current analysis also illustrates the nutritional value of grain enrichment and fortification practices in the US, as a dietary strategy to help close nutrient recommendation gaps. In addition, while many Americans meet recommendations for several of the nutrients examined, including thiamin, riboflavin, and niacin, likely due in large part to mandated enrichment practices of grain foods in the US diet, removal and/or elimination of grains results in a greater percentage of the population falling below the respective EARs. Recommendations that call for the lowering of certain fortified and/or enriched grain foods from the American diet may be misaligned with public health initiatives aiming to improve nutrient adequacy in the American adult population. Rather, dietary recommendations should focus on balancing the consumption of nutrient-dense fortified/enriched refined and whole-grain foods.

**DATA AVAILABILITY STATEMENT**

Publicly available datasets were analyzed in this study. This data can be found here: https://www.cdc.gov/nchs/nhanes/index.htm.

**ETHICS STATEMENT**

The studies involving human participants were reviewed and approved by Centers for Disease Control and Prevention. The patients/participants provided their written informed consent to participate in this study.

**AUTHOR CONTRIBUTIONS**

YP and VF routinely partner on research study design, conception, data interpretation, publication of NHANES results, and interpretation of the research. VF completed all analyses of the final study. YP drafted the original manuscript. Both authors collaborated on drafting the final manuscript and approval of the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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