HISTORY AND PUBLIC HEALTH BENEFITS OF ENRICHMENT AND FORTIFICATION OF REFINED GRAINS

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INTRODUCTION

The relationship between nutrition and health or chronic disease is well-documented. As a modifiable risk factor, diet can either contribute to or reduce the likelihood of developing chronic conditions such as obesity, metabolic syndrome, cardiovascular disease, type 2 diabetes, and hypertension.[1] Prevalence of these chronic conditions remains extremely high in the United States (US), with 60% of adults having one or more diet-related disease.[2] The most recent National Health and Nutrition Examination Survey (NHANES; August 2021 – August 2023) found that obesity prevalence in US adults was 40.3%.[3] Over the same period, total diabetes prevalence was 15.8%, which is an increase from 9.7% in 1999-2000.[4] Nearly half (47.7%) of adults have high blood pressure, with prevalence increasing with age.[5] Additionally, heart disease remains the leading cause of death in the US,[6] with estimated costs of $252.2 billion over 2019-2020 from health care services, medications, and lost productivity due to death.[7]

Simultaneously, diet quality remains poor in the US, with Americans' most recent Healthy Eating Index-2020 (HEI-2020) score being 56 out of 100.[8] HEI values have remained relatively stagnant over the past two decades, with scores ranging from 56 to 60 for Americans 2 years and older.[2] Fiber has been identified as a specific nutrient of public health concern for the entirety of the population, with folate and iron of concern for specific age/population subgroups (folate: people who are pregnant; iron: people who are pregnant and infants aged 6-11 months fed primarily human milk). Based on consistent associations for reduced risk of several chronic diseases, the 2020-2025 Dietary Guidelines for Americans (DGA) defined the core elements of a healthy dietary pattern as vegetables, fruits, grains (at least half of which are whole), low-fat or non-fat dairy, and lean protein with limited intake of added sugars, saturated fat, and sodium.

REFINED GRAINS IN THE CONTEXT OF DIETARY GUIDELINES AND PUBLIC HEALTH

Within discussions about healthy dietary patterns and strategies to improve the health of the general population, refined grains are often highlighted as a specific Grains subgroup that is over-consumed, with recommendations to limit or reduce intake. For instance, the 2010 Dietary Guidelines Advisory Committee (DGAC) Report stated "Americans eat too many calories and too much [...] refined grains".[9] As part of their main findings to be used in developing the 2010 DGA, the Committee recommended that "at least half" of all refined grains should be replaced with whole grains to help reduce excessive calorie intake and the prevalence of overweight and obesity.

Similarly, the 2015 DGAC Report recommended that "to improve dietary quality, the US population should replace most refined grains with whole grains".[10] In line with previous DGACs, the 2020 DGAC Report reiterated previous statements that "a shift toward a higher proportion of total Grains as whole grains and a reduction in refined grains is needed" and that "detrimental health outcomes were associated with dietary patterns characterized by higher intake of red and processed meats, sugar-sweetened foods and beverages, and refined grains".[11]

In their discussion of food pattern modeling results and diet quality, the Committee stated that when "nutrient-poor but energy-rich foods, such as refined grains" contribute a larger proportion of energy intake, this increases the risk of overweight/obesity and associated chronic diseases. Concerns about refined grain intake were again raised repeatedly in 2025 DGAC meetings, with members going so far as to suggest that enriching/fortifying whole grains should be considered by future DGACs as a strategy to reduce refined grain intake without creating nutrient deficiencies. Ultimately, the 2025 DGAC Report recommends that when consuming grains, "encourage mostly whole grains and lower refined grains".[8]

Contrary to these concerns, enriched and fortified grain products are a key source of micronutrients in the US diet, such as folic acid, B vitamins, and iron, as well as fiber. Additionally, the refined grains category spans a wide variety of products, from "staple" grain foods that are enriched and fortified, with limited to no saturated fat or added sugar (e.g., bread, cereal, pasta), to "indulgent" grain foods that tend to have higher fat and sugar content (e.g., cakes and other bakery products).[12] Observational studies typically do not distinguish between these types of grain foods, nor do the DGA. However, most refined grains consumed by Americans are "staple" grain foods, with less than one-quarter as "indulgent" (flour-based desserts – 9.6% of the subgroup; stuffing/breading – 5.0%; quick bread – 3.9%; biscuit – 2.0%; pie/pastry crusts – 1.9%; and croissant – 0.6%).[8] Furthermore, refined grains are often misclassified and/or grouped with other foods (such as red and processed meat, sugar-sweetened foods and beverages, fried foods, and high-fat dairy products) as part of an "unhealthy" or "Western" dietary pattern in epidemiological studies reporting adverse associations between refined grain intake and health outcomes.[12]

When analyzed individually, refined grain intake was not associated with increased risk of all-cause mortality, type 2 diabetes, cardiovascular disease, coronary heart disease, stroke, hypertension, or cancer.

The history of the enrichment and fortification of refined grains demonstrates their essential role in responding to public health concerns and filling vital nutrient gaps. In addition to reducing the prevalence of micronutrient deficiency diseases and micronutrient related health risks, enriched and fortified grain products have proven to be an affordable and effective means of increasing the intake of underconsumed nutrients and improving diet quality. Reducing the consumption of enriched and fortified refined grains could have negative consequences for both micronutrient intake and associated public health outcomes.

ENRICHMENT OF REFINED FLOUR IN RESPONSE TO B-VITAMIN DEFICIENCIES EFFECTIVELY ELIMINATED PELLAGRA, BERIBERI, AND RIBOFLAVIN DEFICIENCY IN THE GENERAL US POPULATION

Enrichment is defined as replenishing nutrients naturally found in the food that were lost or reduced during processing – often in amounts greater than that originally found in the food. The enrichment of refined grains with B vitamins and iron was proposed due to relatively high rates of B vitamin deficiency diseases in the early 1900s, including pellagra (niacin deficiency), beriberi (thiamin deficiency), and riboflavin deficiency disease. Pellagra was prevalent throughout the US in the early 1900s, but most severe in southern states. Mortality statistics suggest pellagra was potentially the most severe nutrient deficiency disease in US history.

Most refined grains consumed by Americans are "staple" grain foods, with only 16% considered as "indulgent".[8]

Deaths from pellagra far outnumbered those due to any other nutritional deficiency, and at its height in 1928 and 1929, pellagra was the 8th or 9th cause of death (excluding accidents) in many southern states.[13] Additionally, concerns had been raised about low thiamin intake among the civilian population and unfavorable implications for the strength of the country's recruits in case of war. Given these factors, the American Medical Association's Council of Foods and Nutrition issued a statement in 1939 encouraging the "restorative" addition of vitamins or minerals to foods if doing so would benefit public health.[14]

Initially, bakers began voluntarily adding high-vitamin yeasts or synthetic vitamins to their breads in the late 1930s.[18] By the end of 1940, the term "enriched" had been officially adopted by the Food and Drug Administration (FDA). Many bakers and millers were interested in improving the nutritional quality of their products and the American Bakers Association undertook campaigns to educate bakers about enrichment technology. Marketing efforts appealing to patriotism and promotional campaigns by both government and industry were also helpful in increasing consumer demand. In 1941, the Food and Nutrition Board officially adopted a resolution encouraging enrichment of flour and bread, adding further support for the initiative.

Despite these efforts, the percentage of the nation's flour that was enriched had only risen to ~40% by the beginning of 1942.[19] Limitations of scale made it unfeasible for smaller producers without large mills to produce enriched flour in the absence of greater consumer demand. In response to appeals from nutritionists and growing awareness that the health of their recruits depended on that of the civilian population, the US Army decided they would purchase only enriched flour, which helped to create additional demand. However, nutritionists continued to worry that low-income populations already at greatest risk of deficiency and in most need of enriched products would continue to buy less expensive, unfortified products. Several states passed legislation mandating exclusive production of enriched flour and bread in the 1940s, but inconsistencies persisted with the lack of federal guidance.

Eventually, in 1943, the War Foods Administration issued a War Foods Order requiring the enrichment of all bread and flour, effectively making enrichment mandatory across the country. After World War II, rather than mandate enrichment, the FDA created two different standards of identity for "flour" and "enriched flour".

Box 1. Identifying an Appropriate Food for Enrichment and/or Fortification[15, 16, 17]

Several factors are taken into consideration when identifying an appropriate food for enrichment and/or fortification:

1. **Consumption** - The food must be regularly consumed, throughout the year, by a large proportion of the population at risk for deficiency.
2. **Stability and Sensory Properties** - Stability of the nutrient to degradation from heat, moisture, light, etc. and potential changes in the organoleptic properties of the food (e.g., taste, smell, texture, appearance, etc.).
3. **Production** - The role of the food sector is key as buy-in from industry groups and large-scale centralized facilities are vital to efficient production and distribution.
4. **Cost** - Implementation costs for equipment and trained operators, purchase of vitamin mixes, establishment of quality control and monitoring programs, marketing/promotional campaigns, etc.

Refined grain products presented an ideal candidate food for enrichment as they were widely consumed throughout the country, their sensory qualities were not altered by the addition of nutrients, and the food industry was a highly involved and cooperative partner throughout the process.

According to the standard of identity, enriched flour contains 2.9 mg of thiamin, 1.8 mg of riboflavin, 24 mg of niacin, and 20 mg of iron per pound.[20] While unenriched flour is not prohibited given these standards, refined grain products sold today are almost exclusively enriched, ranging from pasta to bread to ready-to-eat cereal.

From a public health perspective, the enrichment of refined grains with B vitamins served to effectively eliminate pellagra, beriberi, and riboflavin deficiency disease among the general US population. Pellagra-attributed mortality declined significantly in the 1940s and 1950s compared to peak levels in the late 1920s, with it being virtually eradicated in the US by 1960. Analyses of pellagra-attributed morbidity and mortality trends have concluded that cereal grain enrichment played a significant role in its eradication.[13]

Pellagra is now only occasionally seen in the US, usually in association with alcohol misuse, where dietary intake and absorption are severely limited. Similarly, beriberi is now considered extremely rare in the US;[21] however, it can still occur in individuals with compromised nutritional status, including: alcohol misuse, individuals with genetic conditions that limit nutrient absorption, individuals with severe eating disorders, post-bariatric surgery (due to reduced nutrient absorption), individuals with diabetes (potentially due to increased clearance by the kidneys), and during pregnancy with hyperemesis.[22]

Riboflavin deficiency disease is also now extremely rare in the US,[23] though specific populations remain at risk due to limited absorption and/or intake, including individuals with alcohol misuse, women taking birth control pills, vegans, pregnant and lactating individuals, and individuals with rare genetic conditions (i.e., riboflavin transporter deficiency).[24] Overall, clinically diagnosed vitamin deficiencies and disorders are now rare in representative samples of the US population.[25]

FOLIC ACID FORTIFICATION OF REFINED GRAIN PRODUCTS SIGNIFICANTLY DECREASED THE RATE OF NEURAL TUBE DEFECTS IN THE UNITED STATES

Whereas enrichment involves replenishing nutrients lost during processing, fortification is the addition of nutrients not naturally found in a food in order to meet a specific health need.[26] The fortification of refined grains with folic acid arose in response to a growing understanding of the etiology and prevalence of neural tube defects (NTDs) – severe and debilitating birth defects of the brain and spine that include both spina bifida and anencephaly – in the 1980s and 1990s.[27]

Although a relationship between folate and NTDs had been suggested as early as 1965,[28] randomized controlled trials (RCTs) conducted in the early 1990s established the role of folic acid in preventing both the initial occurrence and recurrence of NTDs in at-risk women. A study by the British Medical Research Council first demonstrated that 4,000 micrograms (µg) of folic acid per day reduced NTD recurrence by 72% in women with a previously affected pregnancy, whereas the mixture of other vitamins tested (vitamins A, D, B1, B2, B6, C, and nicotinamide) had no protective effect.[29] A subsequent RCT demonstrated that prenatal supplementation with 800 µg/d of folic acid entirely prevented the occurrence of NTDs in the study population.[30]

Based on these and similar findings, the Centers for Disease Control and Prevention recommended that women with a history of NTD-affected pregnancies should consume 4,000 µg/d of folic acid when planning a pregnancy. In 1992, the U.S. Public Health Service recommended that all women of childbearing age consume 400 µg/d of folic acid through fortification, supplementation, and diet to prevent NTDs. The Institute of Medicine issued a similar recommendation in 1998 for all women capable of becoming pregnant.[27]

However, encouraging folate intake via a folic acid supplement has limited utility and effectiveness. A large percentage of pregnancies (~42% in 2019)[31] are unplanned and neural tube closure occurs relatively early in fetal development (~28 days after conception).[32] Therefore, the critical period for folic acid supplementation starts at least 1 month prior to conception and continues through the first 2 to 3 months of pregnancy due to increased folate needs.[33] Unfortunately, educational campaigns and recommendations for folic acid supplementation have not been shown to increase folic acid supplement use or improve NTD trends.[27]

Given the challenges associated with folic acid supplementation, fortification of enriched grain products – a popular, commonly consumed food – was identified as a solution to increase folic acid intake. In 1996, the FDA amended the standard of identity for enriched grain products to include folic acid, with mandatory folic acid fortification of enriched cereal grain products fully implemented in 1998. Industry manufacturers now fortify cereal grain products labeled as "enriched" with 140 µg of folic acid per 100 grams of flour. This amount of fortification was estimated to provide an additional ~100 µg of folic acid per day.[34] Analysis of NHANES dietary records following fortification (2001-2002) found an average increase of 128 µg/d of folic acid intake from fortified foods among women of reproductive age,[35] confirming the effectiveness of the fortification program for the general population.

Box 2. Dietary Folate Equivalents and Folate Bioavailability[36]

Dietary folate equivalents (DFE) were developed by the Food and Nutrition Board to account for the higher bioavailability of folic acid compared to folate naturally occurring in foods. For folic acid, at least 85% is estimated to be bioavailable when consumed with food, while only ~50% of folate naturally found in food is bioavailable. Based on this, DFEs are defined as:

- 1 µg DFE = 1 µg food folate
- 1 µg DFE = 0.6 µg folic acid from fortified foods or dietary supplements consumed with foods
- 1 µg DFE = 0.5 µg folic acid from dietary supplements taken on an empty stomach

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The introduction of mandatory folic acid fortification of refined grain products produced clear public health benefit with a reduction in the incidence of NTDs in the general population. Various studies have reported decreases of 19–32% in NTD prevalence since the fortification program was implemented in 1998,[27, 37] with the largest declines occurring shortly after implementation. For instance, the prevalence of spina bifida was found to decrease by 31% from the pre-fortification period (1995-1996) to the mandatory fortification period (1998-1999) and the prevalence of anencephaly decreased 16% over the same time period.[38] The prevalence of anencephaly continued to significantly decrease over time (20% reduction from 1999-2000 to 2003-2004) while the decline in spina bifida remained stable.[39]

More recent analyses indicate the decline in NTD birth prevalence during the initial post-fortification period has remained relatively stable, with an overall 28% reduction in prevalence. Annually, this is approximately 1,326 births that would otherwise have been affected by NTDs.[40] This translates to annual savings in total direct costs of approximately $508 million from the NTD-affected births that were prevented. In addition to the reduction in NTD prevalence, the effectiveness of folic acid fortification can be measured by blood folate concentrations, which serve as a marker for NTD risk. Since mandatory fortification, the prevalence of low serum and red blood cell (RBC) folate (<10 nmol/L and <340 nmol/L, respectively) decreased from 24% and 3.5% respectively to ≤1% in the post-fortification period measured (1999-2010).[41]

Remaining challenges and opportunities for further public health improvement

Although blood folate concentrations have increased in the general population, folate remains a nutrient of public health concern for women of childbearing age due to greater needs during pregnancy and lactation, and many women of childbearing age still do not consume the recommended 400 µg/d.[42] The most recent analyses of usual intake from *What We Eat in America* (NHANES 2017-March 2020 Prepandemic) indicate that among the entire population (1+ years), approximately 16% remain below the estimated average requirement (EAR) for folate. This percentage is even greater among at-risk populations (including females 14 – 50 years old), where 24-34% have inadequate intakes. This is also true among females 51 years and older, with 30% below the EAR.[43] Analyses of the blood folate status of women of child-bearing age (n = 3,861) have also shown that nearly a quarter (22.8%) had “suboptimal” RBC folate concentrations associated with higher NTD prevalence.

Differences were also found according to race/ethnicity, with significantly lower RBC folate concentrations in both Hispanic women and non-Hispanic Black women compared to non-Hispanic white women.[44] While lower blood folate and lower daily folic acid intake has consistently been reported in non-Hispanic Black women,[45] this does not appear to translate to a higher risk of NTD-affected pregnancies.[40] This contradiction has potentially been attributed to a lack of genetic susceptibility[46] and/or lower folate requirements due to high vitamin B12 concentrations that allow for more efficient folate use.[44]

Conversely, while NTDs have declined in all race/ethnicity groups in the period post-fortification, Hispanic women continue to have a higher prevalence of NTDs, along with lower folic acid intake and lower blood folate concentrations,[40] compared to other race/ethnicity groups.

With regard to folic acid intake, Mexican Americans consistently report lower total folic acid intake compared to individuals who are white.[42] Additionally, fewer Hispanic women (17%) report consuming the recommended 400 µg of folic acid/d from both diet and supplements compared to non-Hispanic white women (30%).[45] This is particularly true for Mexican American women with lower acculturation factors (e.g., women who report speaking primarily Spanish).[47] In terms of NTD prevalence, the rate of NTDs in the Hispanic population is approximately 7 NTDs per 10,000 live births compared to 4 and 5 per 10,000 live births for non-Hispanic Black and non-Hispanic white women, respectively.[40]

Differences in average daily folic acid intake may have a variety of explanations. For instance, lower folic acid supplement use by Mexican American women (21%) compared to non-Hispanic white women (37%)[48] may explain a portion of the differences in intake. Additionally, a genetic polymorphism (methylenetetrahydrofolate reductase [MTHFR] 677CàT) that reduces enzyme activity and is associated with lower blood folate concentrations[49] is more common in the Hispanic population and may increase susceptibility for folate deficiency.[50] Cultural differences in the intake of enriched and fortified white flour products in the Hispanic population are also likely responsible.

Folic acid fortification of corn masa flour (up to 140 µg per 100 g) was identified as a targeted strategy to increase folic acid intake and blood folate concentrations in the Hispanic population as this is a frequently consumed ingredient in Latin American foodways. As a result of a public-private partnership between manufacturers, scientists, and members of the affected population, voluntary fortification of corn masa flour was approved by the FDA in 2016.[51] In modeling analyses, fortification of corn masa flour was predicted to increase the usual daily folic acid intakes of Mexican Americans by 19.9%, bringing them much closer to that reported by non-Hispanic white women.[48]

From a public health perspective, it was estimated that corn masa flour fortification could prevent 30 Hispanic infants from having spina bifida and 10 infants from having anencephaly annually.[52] This would represent a decrease in prevalence of 6% and 4%, respectively. However, since the voluntary fortification program was implemented in 2017, no significant effect on folate status has been identified.[53] Earlier analyses indicated an increase in RBC folate concentrations in lesser acculturated groups who rely primarily on fortified foods for folic acid (i.e., non-supplement users), though there was no increase in RBC folate in Hispanic women of reproductive age as a whole.[54] Updated analyses have confirmed these initial findings. Comparing pre-fortification (2011–2016) to post-fortification (2017–March 2020), there was no difference in modeled usual intakes of folic acid nor a change in the proportion of Hispanic women of reproductive age with usual intakes below 400 µg/d (86.1% vs 87.8%).[53] The proportion with RBC folate below optimal concentrations (<748 nmol/L) also did not change over this timeframe (16% vs 18.1%). This may be due in part to the voluntary nature of the fortification program and limited availability of fortified corn masa flour products,[55, 56] which has limited the program's potential impact.

Lack of awareness in the Hispanic population about fortification, the role of folic acid in preventing NTDs, and the importance of choosing fortified products is also likely a contributing factor.[57] For instance, although awareness of folic acid increased from 2000 to 2005, Hispanic respondents consistently reported lower awareness of folic acid compared to non-Hispanic individuals.[58] This indicates the need for additional, targeted consumer education initiatives to improve public health outcomes for this population as well as consideration of a mandatory fortification program for corn masa flour.

THE ESSENTIAL ROLE OF ENRICHED AND FORTIFIED GRAIN PRODUCTS IN IMPROVING MICRONUTRIENT INTAKES AND DIET QUALITY IN THE US

In addition to their public health benefits, enriched and fortified refined grain products also play a key role in improving diet quality and micronutrient status of the US population. Using dietary intake data from NHANES 2003-2006 (n = 16,110), Fulgoni et al. evaluated the relative contribution of micronutrients naturally occurring in foods and micronutrients from enriched and/or fortified products.[59] In this analysis, the percentage of the population below the EAR for thiamin, riboflavin, niacin, iron, and folate (as well as many other nutrients) decreased substantially when accounting for nutrients from enriched/fortified foods compared to naturally occurring sources only (thiamin: % <EAR decreased from 51% to 6%; riboflavin: % <EAR decreased from 9% to 2%; niacin: % <EAR decreased from 11% to 2%; iron: % <EAR decreased from 22% to 7%; and folate: % <EAR decreased from 88% to 11%).

Enriched/fortified foods also provided a substantial amount of the daily intake for each of these micronutrients (thiamin: 45%; riboflavin: 25%; niacin: 28%; iron: 38%; and folate: 50%). These findings effectively demonstrated the essential role of enriched/fortified products in meeting recommendations for thiamin, riboflavin, niacin, iron, and folate in individuals 2 years and older and was supported by an updated analysis of dietary intake from NHANES 2009-2012 (n = 16,975).[60] This analysis similarly found that the contribution of enriched/fortified foods substantially reduced the percentage of the general population (2 years and older) with usual intakes below the EAR compared to naturally occurring sources of micronutrients only (thiamin: % <EAR decreased from 41% to 5%; riboflavin: % <EAR decreased from 13% to 3%; niacin: % <EAR decreased from 9% to 1%; iron: % <EAR decreased from 14% to 2%; and folate: % <EAR decreased from 81% to 8%).

Enriched/fortified foods are also major contributors to micronutrient intake in children and adolescents.[61] In a population of over 7,000 US children and adolescents (2-18 years of age), a high percentage had inadequate intakes of multiple micronutrients when considering only intrinsic (i.e., naturally occurring) food sources of these nutrients, particularly older girls. For instance, among all age/sex groups, when considering only intrinsic sources, the percentage below the EAR for folate ranged from 58% (children 2-8 years) to 99.7% (females 14-18 years). Among females 14-18 years, when considering only intrinsic sources, approximately 86% had inadequate intake (<EAR) of thiamin, 23% were below the EAR for riboflavin, 35% were below the EAR for niacin, and 52% were below the EAR for iron. Particularly among this age/sex group, thiamin, riboflavin, and niacin would also be considered "shortfall nutrients" without the contribution of enriched/fortified foods. Additionally, ready-to-eat cereal and yeast breads/rolls, both of which are enriched/fortified foods, were among the top food sources for folate, thiamin, niacin, riboflavin, and iron among this entire age group (2-18 years).

In addition to these micronutrients, enriched and fortified refined grain foods are also a primary source of fiber, an underconsumed nutrient of public health concern, and other shortfall nutrients in the US diet. For instance, among adults 19 years and older (NHANES 2009-2012; n = 10,697), the grains category as a whole provided 23% of dietary fiber, 34% of folate, 30% of iron, 13% of calcium, 14% of magnesium and minimal amounts of nutrients to limit (calories, sodium, saturated fat) in the daily diet.[62]

This is also true of specific grain subcategories, such as breads, rolls, and tortillas and ready-to-eat cereals. Conversely, sweet bakery products (i.e., cakes, cookies, pies, etc.) provided meaningful amounts of nutrients to limit (i.e., calories, saturated fat, and total sugar) with a smaller contribution of nutrients to encourage. This difference emphasizes the importance of distinguishing between staple grain foods that are nutrient-dense and indulgent grain foods that should be consumed in moderation.

Grain foods also contribute to the nutrient density of the diet of older adults (51 years and older).[63] Among the 15 main food groups analyzed (NHANES 2011-2014; n = 4,522), grains were the highest contributor of dietary fiber (providing 23%), iron (38%), and folate (40%) while providing 14% of energy and only 5% of saturated fat, 14% of sodium, and 9% of added sugar in the daily diet. Although both studies considered total grains rather than analyzing whole and refined grains separately, the majority of total grains consumed by Americans are enriched/fortified refined grains.[8] In total, grain-based foods contributed 54.5% of all dietary fiber (NHANES 2003-2010),[64] which has consistently been identified as a nutrient of public concern in multiple iterations of the DGA. Within this, approximately 72% came from refined grains, with ~39% of total dietary fiber being provided by refined grains. Comparatively, all whole-grain-containing foods contributed only 15.3% of total dietary fiber. Thus, enriched and fortified refined grain foods are not lacking in nutrient density and provide meaningful contributions of dietary fiber and other shortfall nutrients in the US diet.

In addition to being a key contributor to shortfall nutrients of public health concern, grain food consumption is also associated with improved diet quality across all life stages.

When considering different grain food consumption patterns (based on calories consumed from different types of grain food products), children and adolescents (2-18 years) in the "pasta, cooked cereals, and rice", "yeast breads and rolls", "cereals", and "crackers and salty snacks" grain food patterns had significantly higher diet quality (as measured by the HEI-2010) compared to those with no consumption of grains (50.6 ± 1.0, 46.1 ± 0.5, 48.5 ± 1.2, and 46.0 ± 0.4, respectively compared to 42.7 ± 0.9 in the no grains group; $p < 0.05$).[65] A similar relationship between grain food consumption and diet quality was also found in adults (19 years and older).[66] Those consuming "cereals", "pasta, cooked cereals, and rice", and "mixed grains" had significantly higher HEI-2010 scores (54.7 ± 1.0, 54.4 ± 0.6, and 49.5 ± 0.3, respectively) than those consuming no grain foods (46.8 ± 0.9; $p < 0.05$).

However, it is important to consider the type of grain food consumed. For instance, children/adolescents in the "cakes, cookies, and pies" pattern consumed significantly more calories from solid fats and added sugars compared to the no grains group. Similarly, when considering the different types of grain foods, adults in the "cakes, cookies, and pies" cluster consumed a greater number of calories from solid fats and added sugars. Individuals in this cluster also had a lower HEI-2010 score (45.1 ± 0.65), although this did not reach statistical significance compared to the no grain consumption group ($p = 0.08$). This further indicates differences between staple grain foods and indulgent grain foods but also illustrates that many grain foods consumption patterns are associated with higher diet quality.

Enriched and fortified grain foods provide meaningful contributions of dietary fiber and other shortfall nutrients in the US diet.

IMPLICATIONS OF REDUCING ENRICHED AND FORTIFIED GRAIN INTAKE – MICRONUTRIENTS, DIET QUALITY, AND ACCESSIBILITY

As they are a staple, nutrient-dense food in the US diet, a reduction in enriched and fortified refined grain consumption could result in multiple negative consequences. For example, modeling analyses of dietary intake data from NHANES 2009-2016 found that removal of specific enriched/fortified refined grain foods (i.e., bread, ready-to-eat cereals, and all-grained foods) would exacerbate nutrient inadequacies and result in a larger percentage of Americans not meeting recommendations for multiple shortfall nutrients, including dietary fiber, folate, and iron.[67]

At the time of this analysis, only 3.8% of adults (19-50 years old; total population n = 11,169) were above the adequate intake (AI) for dietary fiber based on current intakes. When just 25% of all enriched and fortified grain products were removed, this fell to only 2.6% of the population, with even greater reductions when 50% and 100% of grain products were removed from modeled diets. Similarly, removal of 25% of all enriched and fortified grain products increased the percentage of the population below the EAR for both folate and iron (from 11.0% to 14.6% and from 8.4% to 10.4%, respectively). The removal of 25% of all enriched and fortified grain products from the diet had similarly negative effects on other nutrients of public health concern, including calcium, potassium, vitamin D, and other shortfall nutrients, such as magnesium. Although this was a modeling analysis based on observational data and only considered removal of refined grains from the diet (as opposed to their replacement with another food group), it illustrates the nutritional value and importance of enriched and fortified refined grain foods as part of an American diet. Other analyses of low carbohydrate diets also found a lower mean intake of folic acid among women with restricted carbohydrate intake and a slightly higher risk of NTDs (adjusted odds ratio = 1.30, 95% CI: 1.02, 1.67).[68]

This is also demonstrated by the modeling studies done by multiple DGACs. For instance, the 2025 DGAC concluded that inadequate intake of carbohydrate-containing foods leads to nutrient deficiencies (including thiamin, riboflavin, niacin, folate, and fiber),[8] which supports the inclusion of refined grains in the diet due to their nutrient contribution. Similarly, the 2025 DGAC did not recommend interchangeability for the Grains food group and Starchy Vegetables subgroup, Starchy Red and Orange Vegetables subgroup, and Beans, Peas, and Lentils subgroup or low-carbohydrate eating patterns due to concerns about nutrient shortfalls.

Healthy equity and inclusivity of cultural practices and preferences are primary themes throughout the 2025 DGAC Scientific Report, yet a reduction of enriched/fortified refined grain intake is contradictory to this message. For instance, white rice and corn or wheat tortillas are staples of modern Asian and Hispanic cultural foodways, respectively. The USDA Economic Research Service's report "The US Grain Consumption Landscape" confirmed an overall national preference for refined grains, but with variations among race and ethnicity.[69] This report, which analyzed data from the USDA's *Continuing Survey of Food Intakes by Individuals (CSFII)* conducted in 1995-96 and 1998, found that Asian American individuals averaged the lowest whole grain intake at 22% of the recommended amount, compared to 25%, 36%, and 41% for Black, white, and Hispanic individuals, respectively. Similarly, Asian American individuals consumed the highest amount of refined grains, at 7.11 ounces per day, compared to 5.66 oz/d, 5.39 oz/d, and 5.17 oz/d for white, Black, and Hispanic individuals, respectively. Data from the Multiethnic Cohort (MEC), a cross-sectional study of five different ethnic groups in Hawaii and Los Angeles, CA conducted from 1993 to 1996 (n = 186,916), also showed that refined grain foods were the highest contributor to total grain intake for all ethnic-sex groups, except African American women.[70] In particular, Japanese American men had the highest refined grain intake compared to all other ethnic-sex groups. White rice was the most commonly consumed type of refined grain food among all ethnic groups except for Latinos, who primarily consumed corn tortillas/bread.

In more recent analyses of What We Eat in America (WWEIA), the highest intakes of refined grains are reported by Hispanic and non-Hispanic Asian individuals (2 years and older; 5.81 oz-eq and 6.75 oz-eq, respectively from NHANES 2015-2016).[71] However, non-Hispanic Asian individuals also have the highest whole grain intake at 1.21 oz-eq, with the next highest being in non-Hispanic white individuals at 0.98 oz-eq. A similar pattern is shown by WWEIA data from NHANES 2017 – March 2020 Prepandemic,[72] with refined grain intake remaining highest in non-Hispanic Asian and Hispanic individuals, at 5.99 oz-eq and 6.73 oz-eq, respectively. In the 2025 DGAC's Food Pattern Modeling report,[73] refined grains are the largest contributor to the Total Grains food group in Hispanic individuals (ages 1 year and older) at 88.9% of the food group while refined grain intake makes up the smallest proportion of total Grains for non-Hispanic Asian individuals at 79.7%. However, white rice intake is highest among non-Hispanic Asian individuals (at 31.2% of the subgroup and 24.9% of total grains intake) and brown rice represents a smaller proportion of their grain intake (12.3% of whole grain intake and 2.5% of total grain intake).

Corn tortillas and wheat flour tortillas are the main food sources of refined grains for Hispanic individuals, at 18.6% and 19.9% of the subgroup. While this pattern of higher refined grain intake may in part reflect a level of acculturation, both Hispanic and non-Hispanic Asian individuals have higher HEI scores than non-Hispanic white and non-Hispanic Black individuals.

In the 2020 DGA,[2] non-Hispanic Asian individuals and Hispanic individuals scored 65.4 and 63.9 on the HEI-2015 compared to scores of 59.0 and 55.6 for non-Hispanic white and non-Hispanic Black individuals, respectively. Similarly, in the 2025 DGAC Report, non-Hispanic Asian adults have a HEI-2020 score of 64,[8] which is meaningfully higher than the total population's score of 56 and higher than all other race/ethnicity groups. Therefore, a recommendation to further reduce enriched/fortified refined grain consumption would potentially be culturally insensitive for population subgroups that currently have better diet quality than the average American, even with higher rates of refined grain intake.

Additionally, there are socio-economic considerations to recommending a reduction in refined grain intake. Food cost is a primary determinant of how and what people eat, and healthy dietary patterns tend to be more expensive. Socioeconomic status (SES) and its contributing factors (e.g., occupation, education, and income levels) have repeatedly been shown to be related to diet quality.[74] Specifically, whole grains are more likely to be consumed by groups with higher SES and the consumption of refined grains is often associated with lower SES. This is likely due to many factors, including refined grain products being the lower cost option and differences in nutritional knowledge.

This pattern of diet quality and grain consumption according to SES continues to hold true in the most recent population data, with the 2025 DGAC reporting that HEI-2020 scores ranged from 53 among adult men with a poverty to income ratio (PIR) ≤ 1.85 to 60 among adult women with a PIR ≥ 1.85.[8]

Similarly, the most recent *WWEIA* data (NHANES 2017 – March 2020 Prepandemic)[75] shows higher refined grain intake in individuals (2 years and over) with family income under 131% of poverty level (5.97 oz-eq) compared to those at both 131-350% of poverty level and over 350% of poverty level (5.73 oz-eq and 5.50 oz-eq, respectively). In addition to population level dietary intake surveys (i.e., NHANES), an analysis of household purchasing data also found that lower income households with children purchased a significantly higher proportion of products with refined grain ingredients.[76] In contrast, the highest income group purchased a significantly lower proportion of products with refined grain ingredients (28.6%) compared to the lowest income group (33.4%) and the middle-income group (32.0%) ($p < 0.0001$). Other analyses have found household income to be only indirectly related to grain consumption, via use of nutrition labels, which are more likely to be read during shopping as household income rises.[69]

In terms of shortfall nutrients, grains have been shown to be the least expensive source of iron for both children and adults,[77] further demonstrating that enrichment/fortification helps provide accessible, affordable sources of shortfall nutrients. Overall, large-scale food fortification is a safe, economical, and effective method[78] to improve diet quality and the nutritional status of populations,[79] and a reduction in the intake of enriched/fortified refined grain products has the potential to disproportionately harm at-risk populations who already have lower diet quality and higher risk for many diet-related chronic diseases.

While they are rare in the US, micronutrient deficiencies and associated diseases remain prevalent in many other countries, many of which do not have mandatory enrichment and fortification programs.

Globally, it is estimated that more than 4 billion people do not consume enough iron (65% of the global population), riboflavin (55%), or folate (54%) from food sources (excluding fortification and dietary supplements).[80] While not accounting for fortified foods and supplements may slightly overestimate inadequate intakes, fortification of foods with these nutrients is relatively uncommon[81] and/or limited in scope globally, particularly in South Asia where these nutrient inadequacies are most prevalent.[80] Modeling analyses based on biomarker data estimated similarly high global prevalence of deficiencies in core micronutrients (iron, zinc, and vitamin A for children and iron, zinc, and folate for women), equating to 372 million preschool-aged children and 1.2 billion non-pregnant women of reproductive age with at least one micronutrient deficiency.[83] In this analysis, iron and folate deficiency were highly prevalent among non-pregnant women of reproductive age in most countries and iron deficiency among preschool-aged children was 20% or higher in datasets from 13 of 22 countries (with limited data availability for folate).

Thiamin deficiency and thiamin deficiency diseases also remain common in many regions worldwide, including Southeast Asia, South Asia, and West Africa.[17] Pellagra also still occurs in many African countries, India, and parts of China.[84] Riboflavin deficiency primarily occurs in developing countries such as Africa and Asia (e.g., India and Cambodia),[85] with rates as high as 92% in rural areas of Cambodia.[86] However, subclinical riboflavin deficiencies have also been reported in Western countries, with 41% of men and 31% of women having inadequate intakes.[87]

Overall, large-scale food fortification is a safe, economical, and effective method to improve diet quality and the nutritional status of populations.

The prevalence of NTDs is also disproportionately high in developing countries and/or regions that do not have standardized folate fortification programs. While the estimated global NTD prevalence is ~20 cases per 10,000 births, which translates to approximately 214,000 – 322,000 affected pregnancies annually worldwide,[88] this is driven largely by prevalence rates in regions such as Southern Asia (31.96), East Asia (19.44), North Africa and Western Asia (17.45), and Sub-Saharan Africa (15.27), whereas rates in Europe (8.63) and Latin American and the Caribbean regions with folic acid fortification (7.78) are much lower.[89]

Systematic reviews analyzing the regional prevalence of NTDs have also found lower rates in areas with mandatory fortification programs. For instance, in a meta-analysis of studies in English and French published between 1985 and 2010 (n = 123 studies), the prevalence of spina bifida in all pregnancy outcomes (including live births, stillbirths, and terminations) was lower when there was mandatory folate fortification (3.5 cases per 10,000 births) compared to when folate fortification was voluntary or absent (5.2 cases per 10,000 births).[90] A more recent systematic review reinforced this finding, with mean NTD prevalence rates per 10,000 births of 4.19 (95% CI: 4.11 – 4.28), 7.61 (7.47 – 7.75), and 9.66 (9.52 – 9.81) in countries with mandatory, voluntary, and no folic acid fortification.[91]

CONCLUSION – THE NEED FOR NUANCE WHEN RECOMMENDING ENRICHED AND FORTIFIED STAPLE REFINED GRAINS

The enrichment and fortification of refined grain products in the US occurred in response to a clear public health need and resulted in numerous beneficial outcomes. This includes improvements in micronutrient intake (e.g., folate, B vitamins, and iron) and associated diet quality, the near elimination of B vitamin deficiency diseases in the US, and significant reductions in the prevalence of NTDs.

Moreover, enriched and fortified refined grain foods have become a primary source of underconsumed dietary fiber. A reduction in refined grain consumption could potentially pose greater harm by reducing the intake of folate, thiamin, niacin, riboflavin, and iron below the EAR for large percentages of the US population – in addition to exacerbating already low intakes of dietary fiber, worsening diet quality, and reversing public health successes, such as increasing the rate of NTDs and associated medical costs.

Additionally, a key consideration voiced by the 2025 DGAC in the development and implementation of the DGA is the theme of "meeting people where they are" – in that small, iterative changes are more likely to be implemented and improve public health than recommendations that require individuals to make drastic changes to their diet. Recommendations to further reduce the intake of enriched and fortified refined grains are contrary to this message. Refined grains are an ideal carrier for micronutrients, in part, because they are a staple food in the American diet and are foundational to the foodways of many cultural groups prevalent in the US. Even if the enrichment or fortification of whole grains was technologically feasible, the quantity and frequency of consumption by most of the US population is insufficient to have the same reach as enriched and fortified refined grains. Refined grains can also serve as a vehicle for underconsumed food groups, such as vegetables, thereby further improving diet quality.

Empowering Americans with a clearer understanding of refined grains is crucial. By distinguishing between nutrient-dense staple grain foods and indulgent options, dietary guidance can better support healthy choices. Many enriched and fortified grain foods consumed by Americans are positive contributors to the American diet. Emphasizing the benefits of regularly incorporating enriched and fortified staple grains, while enjoying indulgent grains in moderation, can support improved diet quality and overall well-being. Recognizing the different contributions of staple and indulgent grain foods in the American diet would provide greater precision in assessing diet quality, improving public health outcomes, and potentially increasing dietary guidance adherence.

While the public health benefits of enriching and fortifying refined grains are clear, there are also opportunities for improvement.

Folate remains a nutrient of public health concern for women of childbearing age, with serum folate concentrations at "suboptimal" levels in ~25% of this population. This is particularly concerning for Hispanic populations, which continue to experience disproportionate rates of NTDs, potentially due to lower intakes of enriched/fortified grain foods and the limited reach of voluntary fortification programs for corn masa flour. In addition, fiber remains a nutrient of public health concern for the general population and diet quality (i.e., HEI scores), despite small improvements since 2005, has remained relatively stagnant over the past ~20 years.[2] The opportunity exists – for both food manufacturers and policy makers – to continue to investigate how enrichment and fortification could address ongoing issues like these. Further, remembering the public health successes that enrichment in the 1940s and fortification in the 1990s brought illuminates the essential nature of refined enriched and fortified foods in the American diet.

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GRAIN FOODS
RESEARCH INSTITUTE

About the Grain Foods Research Institute

The Grain Foods Research Institute (GFRI) is a nonprofit organization committed to supporting research to better understand the nutritional role of grain foods in healthy lifestyles.

GFRI champions evidence-based research that explores the importance of grain foods in a balanced diet. By partnering with its sister organization, the Grain Foods Foundation (GFF), GFRI aims to amplify the understanding of how grain-based foods contribute to overall health and wellness to consumers, health professionals, policymakers and industry stakeholders.

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