Perspective: The Public Health Case for Modernizing the Definition of Protein Quality

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ABSTRACT

Prevailing definitions of protein quality are predicated on considerations of biochemistry and metabolism rather than the net effects on human health or the environment of specific food sources of protein. In the vernacular, higher "quality" equates to desirability. This implication is compounded by sequential, societal trends in which first dietary fat and then dietary carbohydrate were vilified during recent decades, leaving dietary protein under an implied halo. The popular concept that protein is "good" and that the more the better, coupled with a protein quality definition that favors meat, fosters the impression that eating more meat, as well as eggs and dairy, is desirable and preferable. This message, however, is directly opposed to current Dietary Guidelines for Americans, which encourage consumption of more plant foods and less meat, and at odds with the literature on the environmental impacts of foods, from carbon emissions to water utilization, which decisively favor plant protein sources. Thus, the message conveyed by the current definitions of protein quality is at odds with imperatives of public and planetary health alike. We review the relevant literature in this context and make the case that the definition of protein quality is both misleading and antiquated. We propose a modernized definition that incorporates the quality of health and environmental outcomes associated with specific food sources of protein. We demonstrate how such an approach can be adapted into a metric and applied to the food supply. *Adv Nutr* 2019;10:755–764.

Keywords: dietary protein, protein quality, dietary guidelines, nutrition policy, sustainability, diet quality

Introduction

Protein quality has been defined by nutrition scientists as the ability of a dietary protein to meet needs for regular metabolism and maintenance or growth of body tissues (1). Because the human body requires a regular supply of all essential amino acids to synthesize body proteins, protein quality metrics have been based on the content of essential amino acids in a food and their digestibility. In turn, these metrics are used by national and international regulatory agencies to determine eligibility of foods for protein content claims (2). US consumers are particularly interested in high-protein foods (3), and protein content claims on food products can influence consumer perception of the products' overall healthfulness (4). Therefore, the regulatory framework for such claims can have a real impact on consumer behavior.

The FDA currently uses the Protein Digestibility-Corrected Amino Acid Score (PDCAAS) to measure protein quality in most foods (5), whereas the Canadian government utilizes the Protein Efficiency Ratio (PER) (6). According to these metrics, animal sources of protein (i.e., meat, seafood, and dairy) tend to rank higher than plant sources of

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This project was supported by a contribution of KIND Snacks to the True Health Initiative, a federally authorized 501c3 nonprofit organization.

Author disclosures: KND's work on this project was supported by the True Health Initiative through a contribution from KIND Snacks. DLK reports serving as a remunerated expert consultant for food industry elements, including the California Walnut Commission, Quaker Oats, and KIND. KG has served as an advisor for the Sun Valley Institute and as a spokesperson for select organic food companies and commodity boards, including the Almond Board of California, Clif Bar & Company, CamelBak, and Earth's Best Organic Baby Food, and she is a shareholder in JUST, Inc. DAJ reports serving as a remunerated expert consultant for food industry elements, including Pulse Canada. A full list of affiliations is on file and available upon request. CDG, no conflicts of interest.

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Abbreviations used: AMDR, Acceptable Macronutrient Distribution Range; DGA, Dietary Guidelines for Americans; DIAAS, Digestible Indispensable Amino Acid Score; EAR, Estimated Average Requirement; GHGE, greenhouse gas emission; IHD, ischemic heart disease; PDCAAS, Protein Digestibility-Corrected Amino Acid Score; PER, Protein Efficiency Ratio; RCT, randomized controlled trial.

protein because of high digestibility and a distribution of the 9 essential amino acids that is considered perfectly aligned with human requirements, whereas the food matrix of plant proteins partially impairs digestion and the essential amino acid distribution can be proportionally low, relative to dietary requirements, in one or more. For example, grains tend to be proportionally low in lysine, whereas legumes are proportionally low in methionine (7, 8). However, when a variety of plant protein sources are consumed in sufficient quantities, as would be true of almost any dietary pattern that includes appropriate variety and quantity to meet other nutrient requirements, needs for essential amino acids can be met without any animal protein intake (9). The risk of protein inadequacy is low for most population groups in the United States (10), as are clinical manifestations of protein-energy malnutrition (11). Therefore, the rationale for defining protein quality as a function of a food's essential amino acid composition is of questionable validity, at least for the populations of developed countries.

The word "quality" implies superiority, but food sources of "high-quality" protein, as defined by existing metrics, do not reliably improve the quality of the diet or health. For example, consumption of certain animal sources of protein is associated with higher chronic disease risk (12), whereas consumption of protein-rich plant foods and adherence to plant-based dietary patterns are associated with more favorable health outcomes (12–14). The production of animal sources of protein also has a more substantial impact on the environment, although there is considerable variation within and across animal proteins (e.g., livestock, poultry, and fish) (15). In this commentary, we contend that in the United States and other developed countries, the definition of protein quality needs to be modernized to better reflect the actual impact of dietary protein sources on public health and the environment and to align with national dietary recommendations and current scientific evidence. We review the existing evidence for the effects of consumption of plant and animal protein sources, respectively, on protein adequacy, overall diet quality, health outcomes, and the longer term impacts on the ability to produce food with existing land and water resources.

Protein Quality Assessment

PER, which represents grams of body weight gained per gram of protein eaten in young, growing rats, was described in 1919 (16, 17). In its 1989 report on protein quality evaluation, the Joint FAO/WHO Expert Consultation (17) acknowledged that the PER's reliance on rat growth, rather than human growth, for measurement is a limitation and may lead to overestimation of the quality of certain animal proteins and underestimation of the quality of certain plant proteins. In the same report, the FAO/WHO Expert Consultation endorsed PDCAAS, which was subsequently adopted by the United States and regulatory authorities in many other countries for determining eligibility of foods for protein content claims. Canada, however, continues to rely on PER as the protein quality evaluation method for determining eligibility for protein content claims (6). PER is also still used in the United States to evaluate protein quality of infant formulas. PDCAAS values are determined by calculating the ratio of the concentration of the limiting amino acid in the test protein to the concentration of the same amino acid in a reference protein or requirement pattern. This ratio is then adjusted for true protein digestibility, which represents the difference between quantity of nitrogen ingested and fecal nitrogen excreted, accounting for metabolic losses (17).

In 2013, the FAO released a report recommending replacement of PDCAAS with Digestible Indispensible Amino Acid Score (DIAAS) for assessing protein quality (18). DIAAS methodology overcomes some of the limitations of PDCAAS. Specifically, DIAAS uses ileal digestibility coefficients for each amino acid instead of true fecal nitrogen digestibility, and DIAAS values are not truncated at an upper limit of 100.

US Dietary Recommendations

The overall nutritional quality of foods can be measured and has been shown to correlate importantly with health outcomes, including total chronic disease burden and all-cause mortality (19). Although there is no standard metric for overall nutritional quality of foods used routinely in the United States, the federal government does make specific recommendations for foods to emphasize and foods to limit in the diet in the Dietary Guidelines for Americans (DGA) report that is released every 5 years (20). Prevailing measures of protein quality (e.g., PER and PDCAAS) are often at odds with these guidelines. For example, the DGA for 2015–2020 includes a recommendation that Americans consume "a variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products" (20), but legumes, nuts, and seeds have lower PDCAAS values compared with animal sources of protein. The DGA also acknowledges that although healthy eating patterns may include lean meats, many healthy eating patterns are characterized by lower intakes of meat and processed meats. Although the DGA stops short of advising Americans to reduce their intake of red and processed meats—another controversial choice (21)—it does recommend a "shift" to more seafood, legumes, and nuts (20) and the reduction of saturated fat and sodium intake. The AHA is more explicit in its advice to Americans to reduce their intake of red meat (22). The Academy of Nutrition and Dietetics considers vegetarian and vegan diets to be "healthful, nutritionally adequate," and potentially beneficial for preventing some diseases (9).

Current Regulatory Frameworks for Protein Content Claims

In the United States, food manufacturers are permitted to make a protein content claim if a food contains 10–19% of the daily value for protein per reference amount customarily consumed for "good source" or $\geq$20% for "high" (23). The percentage daily value is determined based on a corrected amount of protein, which is the amount of protein per serving multiplied by the PDCAAS (5). PDCAAS values are truncated at 100% (alternatively expressed as 1.00). Animal foods generally score at or near 100, whereas plant foods score lower (**Table 1**) (24–26). Therefore, plant sources of protein need to have a higher protein content per reference amount customarily consumed to qualify for protein content claims (27). If PDCAAS is replaced by DIAAS in the United States, as proposed by the FAO, eligibility for protein content claims will change for some plant foods; some that were not eligible will become eligible and vice versa (27). Animal foods will continue to score highly.

Regardless of which method is used, measures of protein quality that consider only content and distribution of essential amino acids can be misleading because they represent the biological value of a single nutrient in isolation, not the net effects of consuming the source of that nutrient. But in reality, people generally do not consume protein independent of food sources. Furthermore, they consume mixed diets with many different sources of protein with different amino acid profiles. Thus, the amino acid composition of the overall diet will determine protein adequacy, whereas the food sources of those amino acids will determine diet quality and the likely impact of "quality" on attendant health outcomes. Nitrogen balance studies have shown that even when 90% of dietary protein is supplied by plant sources, protein needs are not significantly more than when 90% of protein is supplied by animal sources (28), suggesting that a diversity of food sources of protein can allow for adequacy at the level of the whole diet.

In light of this evidence, alternative regulatory frameworks have already been adopted by some other developed countries. Australia and New Zealand, for example, consider only grams of protein per serving when determining eligibility for protein content claims (29). European Union member countries consider protein quantity as a percentage of energy per serving (30). Codex Alimentarius (18, 31), China (32), and South Korea all use thresholds for protein content by weight or energy. There is no evidence that a policy of ignoring protein quality while prioritizing overall dietary quality has led to any adverse effects on population health status in these countries.

Public Health Issues Related to Dietary Protein Differ Throughout the World: "Developing" Compared with "Developed" World Priorities

Although protein malnutrition remains a significant public health challenge in many regions of the world (33–35), this is not the case for most developed countries (36). This is especially true in the United States, where stunting and wasting affect 2% and 0.5% of children aged <5 y, respectively (36), whereas obesity affects 6%. Protein in excess of need is converted to body fat just as are other sources of excess food energy. Average total protein intake in the United States is well in excess of DRI recommendations (10). Perhaps because of its rarity, few recent studies have investigated prevalence of protein malnutrition in the United States, outside of studies of chronically ill or hospitalized patients (33–35). However, rare cases of kwashiorkor have been

TABLE 1 Sample modernized protein rating metrics[1]

Criterion	Maximum score	Beef, most cuts[2]	Beef, extra lean[2]	Dark meat chicken, with skin[3]	Skinless chicken breast[3]	Low-fat milk[2]	Soy[2]	Chickpeas[4]	Almonds[3]	Pistachios[3]	Whole-grain wheat[2]	Brown rice[3]
Sample metric 1: stand-alone rating system												
PDCAAS (>80: 2; 50 to <80: 1; 30 to <50: 0; <30: −1)	2	2	2	2	2	2	2	1	0	1	0	1
Recommended for health (recommended: 2; no mention: 0; discouraged: −1)	2	−1	2	−1	2	2	2	2	2	2	2	2
Environmental impact (low: 2; medium: 0; high: −1)	2	−1	−1	2	2	0	2	2	2	2	2	2
Total	6	0	3	3	6	4	6	5	4	5	4	5
Sample metric 2: metric used as an adjustment factor												
PDCAAS (range: 0.0–1.0)	1	0.92	0.92	0.94	0.94	1.0	0.92	0.52	0.43	0.73	0.42	0.69
Recommended for health (recommended or no mention: 1; discouraged: 0)	1	0	1	0	1	1	1	1	1	1	1	1
Environmental impact (low: 1; medium: 0.5; high: 0)	1	0	0	1	1	0.5	1	1	1	1	1	1
Average score	1	0.31	0.64	0.65	0.98	0.83	0.97	0.84	0.81	0.91	0.81	0.90

[1]PDCAAS, Protein Digestibility-Corrected Amino Acid Score.
[2]Data from reference 24.
[3]Data from reference 25.
[4]Data from reference 26.

reported in infants and children aged <2 y in the United States, usually as a result of nutritional ignorance or perceived milk allergy or intolerance (11). Stunting prevalence among American children aged 2–19 y is also low at 3.5% overall, according to NHANES data from 2003–2010 (37). However, this rate is higher among Hispanic children (6.1%), despite this population's higher prevalence of overweight and obesity (38.2% compared with 29.8% among non-Hispanic white children) (37). The reason for this disparity is not known, but it may be related to higher prevalence of vitamin D deficiency (5.7% compared with 1.0% in non-Hispanic whites) (37) or deficiency of other micronutrients that can influence growth (38). It is unlikely that greater stunting among Hispanic American children is due to insufficient protein intake because another NHANES study showed that Hispanic children had significantly higher intakes of protein compared with non-Hispanic white children (10). However, the sources of dietary protein were not described in that study.

Dietary Patterns and Protein Adequacy

The DRIs for protein include an RDA and an Acceptable Macronutrient Distribution Range (AMDR) for most age groups (39). An Adequate Intake has been established for infants ≤6 mo of age. The RDA for protein is 0.80 g of "good quality protein" per kilogram of body weight per day for both men and women aged >19 y. The RDAs are greater for infants, children, adolescents, and pregnant women. Infants up to 6 mo of age have the highest daily protein requirement: 1.52 g/kg. The RDA decreases incrementally with age. Pregnant and lactating women require 1.1 g/kg and 1.3 g/kg each day, respectively (39). The AMDR for children aged >3 y and adults is 10–30% or 10–35% of total energy, depending on age and gender group. The AMDR minimum should approximate the RDA, whereas the upper end of the range is set to allow for adequate intake of other macronutrients (40). Therefore, protein intake at the low end of the AMDR should be considered more than adequate.

Although it has been argued that the DRIs should be increased for those consuming a vegetarian diet, to account for the reduced digestibility of plant proteins (41), they have not been increased because the findings of a meta-analysis of nitrogen balance studies showed no significant effect of dietary protein source on protein requirements (42). It is also the position of the Academy of Nutrition and Dietetics that vegetarian and vegan diets generally supply adequate protein and essential amino acids when protein is consumed from a variety of plant sources throughout each day and energy needs are met (9). It was previously believed that plant proteins with complementary amino acid profiles should be combined within each meal to ensure adequate supply of all essential amino acids, but there is no evidence that this is the case. Rather, needs can be met simply by eating a variety of protein-containing foods during the course of a day, without specifically trying to ensure that protein sources complement one another (43). Vegan diets can be adequate in protein even for growing children, as long as a variety of foods are consumed and energy needs are met (44).

Overall, protein intake is more than adequate in the United States. According to 2013–2014 data from NHANES, the percentage of Americans consuming below the Estimated Average Requirement (EAR) for protein ranged from 0% among children aged 2–8 y to 11.5% among females between the ages of 9 and 13 y (10). In this group, 23.4% had protein intakes below the RDA. In other age groups, relatively small percentages of males (0.6–5.9%) and females (1.8–6.9%) had intakes below the EAR (10). However, because protein intake may be underestimated by 10–20% when self-report measures are used, compared with 24-h urinary nitrogen excretion (45–48), actual protein intake is likely to be higher than these estimates suggest. Protein adequacy in the United States may be partly attributable to high intake of meats and dairy, which comprise approximately 62% of Americans' total protein intake (49); however, studies in the United States and other developed countries suggest that protein intake is also adequate for most vegetarians. One study found that non-meat eaters, whether or not they were self-described vegetarians, consumed ~12% of total energy from protein, still within the AMDR for all adult groups (50). Another study, using NHANES data from 1999–2003, estimated average daily protein intake of vegetarians to be 63.4 g (51), which exceeds the RDA for women (46 g/day) and men (56 g/day) based on reference body weights of 57.5 kg and 70 kg, respectively (39).

Evidence from cross-sectional studies of free-living adults in Belgium (52) and Finland (53) suggests that individuals following vegan diets consume less protein (74–82 g/day) than nonvegetarians (103–112 g/day) but nevertheless consume an adequate amount of protein. The RDA is 46 g and 56 g for adult women and men, respectively. Millward and Jackson (54) compared the protein-to-energy ratio of actual diets in the United Kingdom, India, and West Bengal to reference protein-to-energy ratios adjusted for PDCAAS, age, gender, and physical activity level to estimate the proportion of various population groups "at risk" for protein deficiency in these countries, defined as consuming less than the EAR for protein daily. In the United Kingdom, a very small percentage of the population would be at risk. The highest-risk group is sedentary, heavier, elderly women. For example, among inactive 75-y-old women weighing 70 kg, ~5% of those eating an omnivorous diet and 31% of those eating a vegetarian diet would consume less than the EAR for protein. Among younger adults and children, the percentage of each group at risk with a typical UK vegetarian diet was 0–3% for most groups, with higher rates for heavier, sedentary, elderly men (18%) and for heavier, sedentary, adolescent girls (19%) (54).

However, there is evidence that some vegetarians may consume insufficient protein. Among French adults in a 2009–2015 NutriNet-Santé cohort study, mean daily intake of total protein was 80.7 g for meat eaters, 66.6 g for vegetarians, and 62.0 g for vegans (55). Higher percentages of vegetarians (14.3%) and vegans (27.3%) had intakes of protein that were below the lower end of the acceptable distribution range as defined by French national recommendations, compared with meat eaters (4.0%) (55). This reference range is 10–20% of total energy for adults aged <70 y and 15–20% for those aged >70 y (55). Notably, whether the potentially inadequate protein intake in this population resulted in any adverse clinical outcomes was not examined. A 2016 study of participants in the European Prospective Investigation into Cancer and Nutrition (EPIC)-Oxford study cohort reported lower prevalence of potentially inadequate protein intake among vegetarians (9.8% and 6.0% for men and women, respectively) and vegans (16.5% and 8.1% for men and women, respectively) (56). In that study, inadequate intake was defined as intake below the EAR based on body weight (0.6 g/kg) (56). However, by definition, the individual requirement for protein for half of the population is less than the EAR.

Dietary Protein Sources and Overall Diet Quality

Observational studies comparing the nutrient content and/or diet quality of plant-based and omnivorous diets have shown that plant-based diets—a term we use to refer collectively to vegan, vegetarian, pesco-vegetarian, and semi-vegetarian diets—have many nutritional benefits. For example, among Belgian adults, a vegan diet is associated with the highest Healthy Eating Index 2010 score, compared with vegetarian, semi-vegetarian, pesco-vegetarian, and omnivorous diets (52). Among French adults in 2006–2007, plant protein intake was positively associated with probability of adequate nutrient intake (PANDiet) score, a global measure of likelihood of adequate intake of 24 different nutrients, whereas total and animal protein intakes were inversely associated with PANDiet score (57). However, the relation between intake of specific types of animal protein and nutrient adequacy varied. For example, intakes of processed meat, cheese, and eggs were inversely associated with nutrient adequacy, whereas intakes of fish, milk, and yogurt were positively associated. In men only, intakes of red meat and poultry were also inversely associated (57).

On the more extreme end of the plant-based diet spectrum, such diets can have drawbacks. Vegetarians and vegans in the NutriNet-Santé study were more likely than meat eaters to have low intakes of calcium, vitamin D, and vitamin B-12, as well as protein. However, the vegetarians and vegans also had higher mean intakes of omega-3 and monounsaturated fatty acids, folate, vitamin C, vitamin E, and potassium and lower intakes of sodium and saturated fatty acids (55). These findings are similar to those of the EPIC-Oxford study (56).

Several randomized controlled trials (RCTs) have shown improvements in diet quality and/or intake of specific nutrients after adoption of a vegan diet (58–60). Findings from these trials include greater reductions in saturated fat intake and greater increases in fiber, vitamin A, vitamin C, folate, magnesium, and potassium in the vegan diet groups compared with healthful omnivorous diets. However, some disadvantageous changes in dietary intake also occurred with adherence to a vegan diet, including a smaller reduction in sodium intake and decreases in intake of vitamin D, vitamin B-12, calcium, selenium, phosphorous, and zinc from foods (58).

Dietary Protein Sources and Health

Plant-based diet patterns and health outcomes

Both observational and intervention studies have identified potential health benefits of plant-based diets. Evidence from observational studies suggests that vegetarians and vegans may have lower BMIs and lower risk of ischemic heart disease, diabetes, and eye cataracts compared with similar nonvegetarians (61). In one study, risk of type 2 diabetes was approximately halved in semi-vegetarians, vegetarians, and vegans compared with nonvegetarians, controlling for differences in BMI (62). However, individuals who choose a vegetarian or vegan lifestyle differ from non-vegetarians in many important ways. Vegetarians tend to be younger, more educated, female, single without children (55), and health conscious (63). Therefore, many sociodemographic factors and health behaviors may confound the observed relation between diet and health outcomes in this population.

In addition to demonstrating improvements in diet quality, RCTs of plant-based diets have also provided evidence of improvements in cardiovascular disease risk factors. In one such trial, overweight, menopausal women assigned to a low-fat vegan diet for 14 wk lost more weight than those assigned to a National Cholesterol Education Program diet at 1 y and 2 y (64). Another trial comparing 4 different plant-based diets (vegan, vegetarian, pesco-vegetarian, and semi-vegetarian) and an omnivorous diet for 2 mo in overweight adults found that the vegan diet group lost the most weight at 6-mo follow-up (−7.5%), followed by vegetarian (−6.3%), pesco-vegetarian (−3.2%), semi-vegetarian (−3.2%), and omnivorous groups (−3.1%) (60). Meta-analyses of controlled trials suggest that vegetarian diets can improve blood lipid profiles in a range of adult populations (13) and improve glycemic control in individuals with type 2 diabetes (65).

Food sources of protein and health outcomes

Higher intake of animal protein has been associated with obesity among US men aged 40–55 y, whereas higher vegetable protein intake is associated with reduced odds of obesity (66). Among adult women in the US Nurses' Health Study cohort, consumption of red meat (including or excluding processed meat) and high-fat dairy was associated with greater risk of coronary artery disease over 26 y (67). One serving of red meat (excluding processed meat) was associated with 19% greater risk of coronary artery disease, and high-fat dairy was associated with a 3% increased risk. In comparison, 1 serving per day of nuts was associated with a 22% reduced risk, and 1 serving of fish was associated with a 19% reduced risk (67). Song and colleagues (68) investigated the association between dietary protein sources and mortality in the Nurses' Health Study cohort and the Health Professionals Follow-up Study cohort, which included men. Among individuals with at least 1 lifestyle risk factor, animal protein intake was not associated with all-cause mortality, but it was associated with greater cardiovascular mortality (HR: 1.08 per 10% energy increment; 95% CI: 1.01, 1.16; P-trend = 0.04). Plant protein intake was associated with reduced all-cause mortality (HR: 0.90 per 3% energy increment; 95% CI: 0.86, 0.95; P-trend < 0.001) and cardiovascular mortality (HR: 0.88 per 3% energy increment; 95% CI: 0.80, 0.97; P-trend = 0.007).

A meta-analysis of 9 prospective cohort studies also found that each daily serving of processed meat was associated with a 15% increased risk of both all-cause and cardiovascular mortality and an 8% increased risk of cancer mortality (12). Associations were similar for total red meat intake but not for unprocessed red meat. However, when analyses were restricted to 4 US studies, unprocessed red meat was associated with increased risk of mortality from all causes (RR: 1.23; 95% CI: 1.17, 1.30), cardiovascular disease (RR: 1.37; 95% CI: 1.18, 1.59), and cancer (RR: 1.17; 95% CI: 1.09, 1.25) (12). Associations between processed meat and mortality were similar regardless of study location.

Many plant protein-rich foods have well-documented health benefits. Nuts, in particular, have been studied extensively for their effects on cardiovascular health. A meta-analysis of observational (n = 25) and intervention (n = 2) studies found that consumption of four 28.4-g servings of nuts weekly was associated with reduced risk of fatal ischemic heart disease (IHD) (RR: 0.76; 95% CI: 0.69, 0.84), nonfatal IHD (RR: 0.78; 95% CI: 0.67, 0.92), and diabetes (RR: 0.87; 95% CI: 0.81, 0.94) (12). Consumption of four 100-g servings of legumes weekly was associated with reduced total IHD (RR: 0.86; 95% CI: 0.78, 0.94) but not with stroke or diabetes (12).

Meta-analyses of RCTs have demonstrated consistent improvements in blood lipids and vascular function with regular nut consumption (14, 69). One such study of 32 RCTs found that daily consumption of tree nuts or peanuts for at least 3 wk significantly improved endothelial function (69). Another including 61 studies that were longer in duration (3–26 wk) found that consumption of nuts improved total cholesterol, LDL, apolipoprotein B, and triglycerides in adults without cardiovascular disease. The strongest effects on total cholesterol and LDL were observed at doses of ≥60 g/d (14).

The overall quality and nutrient density of plant-based diets may account for the observed differences in cardiometabolic health between vegetarians and nonvegetarians. Plant-based diets may protect against chronic diseases by influencing the gut microbiome (70, 71). There is considerable interindividual variation in the proportion of the 2 predominant phyla in the human gut—Bacteroidetes and Firmicutes—and species present (71). Lower diversity of gut microbiota has been associated with obesity and inflammatory bowel disease, and plant-based diets are associated with greater gut microbial diversity (71). Changes in diet can rapidly alter the microbiota (72), and plant-based diets may promote more favorable changes, most likely due to the important role fiber plays in the colon for the microbiota (71).

Environmental Impacts of Dietary Protein Sources

The positive public health outcomes and associated cost savings are significant enough to stand on their own as rationale for an updated metric. Yet with the imminent challenges of climate change, population growth, and resource constraints on food security and long-term sustainability, it is becoming ever more critical to examine the impact of food production on the fundamental natural systems on which public health depends (15). The total impact of a food on the environment can be thought of as the combined effects of production on greenhouse gas emissions (GHGEs); land and water use; and use of fertilizers, pesticides, antibiotics, and other pharmaceuticals (73). There is substantial variation in each of these categories of environmental impact across and within food groups (74). However, beef and lamb have been associated with the highest GHGEs across studies (75). Beef and other meats also tend to have high "water footprints," as do nuts (76).

Although the effects of food production activities on all aspects of the environment vary considerably according to production methods, there is considerable evidence that plant-based diets, in general, conserve resources and are less damaging to the environment. Semi-vegetarian and vegetarian diets have been associated with GHGEs that are reduced by 22% and 29%, respectively, relative to a nonvegetarian diet (77). Meat and cheese contributed 40% of GHGEs resulting from diets in the Netherlands (78). Differences in meat consumption were the largest determinant of differences in GHGEs between diets. In the United Kingdom, GHGEs associated with the diets of meat eaters were approximately double those associated with diets of vegans (79). The production of livestock contributes ∼20% of total GHGEs (80). Springmann and colleagues (74) have recently argued that a shift toward more plant-based diets is essential for mitigating the impact of GHGEs on the climate. According to Gardner et al. (81), a 25% reduction in overall protein intake and a 25% shift from animal to plant sources of protein in the United States could reduce the GHGE contribution from food production by 40% while improving adherence to the DGA.

Although the 2015 US Dietary Guidelines Advisory Committee mentioned sustainability in its scientific report (82), the DGA did not include a goal of sustainability, with the rationale that it is outside the scope of the DGA (83). This omission was controversial (84). Some countries, such as Sweden, Brazil, Qatar (85–87), and the Netherlands (88), incorporate consideration of environmental impact of foods into their national dietary guidelines, so there is a precedent for governments setting nutrition policy with the environment in mind.

Need to Modernize the Definition of Protein Quality

Although protein malnutrition is still prevalent in many areas of the world, it is exceedingly rare in the United

States. Instead, the most formidable public health threats to the United States are from chronic diseases. Many of these, including cardiovascular disease, type 2 diabetes, and cancer, have been linked to unhealthful dietary patterns in general and to excess intake of red meats and processed meats in particular. In contrast, it is clear that plant sources of protein, especially nuts and legumes, promote favorable health outcomes. It is now established that long-held beliefs about the inability of plant-based diets to meet protein requirements and the need to carefully complement plant protein sources within every meal are not evidence-based, except perhaps when overall energy intake is very low.

We contend that the prevailing definition of protein quality is out of date, at least in high-income countries such as the United States. The term "quality" implies advantages from making a given choice. Preferential selection of the highest "protein quality" sources in the food supply, however, is at odds with the shifts required to improve the quality of the typical American diet and the quality of health outcomes. When the term "quality" as applied to a cause is directly in opposition to the "quality" of attendant effects, the term is being used in an overtly misleading manner.

Despite the low prevalence of protein inadequacy in the United States, Americans are very attentive to their protein intake: 50% say they have "a form of protein" at every meal, 30% say that the source of protein is important, and 19% monitor their protein intake daily (3). This attention would not necessarily be problematic if Americans were choosing health-promoting food sources of protein, but this is not generally the case. More than 60% of protein intake in the United States comes from meats (49); 58% of these are red meats and 22% are processed (89). Despite consistent messaging from the USDA and other national organizations about limiting saturated fat and sodium in their diets, the majority of Americans still exceed the recommended intake limits (20). Meats, poultry, fish, and eggs contribute to 23% of Americans' total saturated fat intake (90), and processed meats account for >15% of sodium intake (91). Americans' misperceptions of health effects of different food sources of protein may contribute to their consistently high intake of animal sources of protein. Approximately one-third of US consumers believe that those who avoid animal protein are deficient in some nutrients, and 30% believe that animal protein is associated with positive health effects (3).

Research on consumers' attitudes also suggests that Americans value foods and beverages with high-protein claims; introduction of such products is higher in the United States than in any other country (92). Claims may help consumers identify high-protein foods because most have limited knowledge about sources of protein (3). Studies have shown that the presence of a nutrient content claim can increase consumers' perceptions of a food's overall healthfulness (93, 94). At least 1 study has demonstrated this "health halo" effect (95), for protein content claims specifically (4). Therefore, it is imperative that the regulation of protein content claims actually assists consumers in choosing foods that will promote health. Under the current regulatory system, some decidedly unhealthful protein sources are eligible for protein content claims, whereas many nutrient-dense foods are ineligible simply because they do not meet a threshold for protein "quality" according to a definition that is no longer relevant in the United States. We suggest that a new definition of protein quality is needed—one that still includes consideration of concentration of protein and individual amino acids but also includes *1*) an assessment of the evidence of health outcomes associated with the food and *2*) environmental impact.

We propose the development of a simple points-based metric. Two sample metrics are presented in Table 1 for illustrative purposes. Sample metric 1 is a rating system that could be used in conjunction with protein content to determine eligibility for protein content claims (e.g., a food must both contain a minimum quantity of protein per serving and attain a minimum score on the new protein quality metric to be eligible for a claim). Sample metric 2 is an adjustment factor that could be used in a similar way as the PDCAAS is currently used to determine eligibility for protein content claims—by adjusting the protein content per serving by this value. The relative weight of each category and the range of possible values within each category may be revised in any number of ways. We defer such details to the US federal agencies overseeing nutrient recommendations and food labeling (i.e., the FDA, Institute of Medicine, and USDA). For the purposes of illustration, we have created ordinal scales to assess health and environmental impacts. In our examples, health impact is determined simply by whether the food has been recommended or discouraged in the DGA. However, other measures may be considered—for example, the effect of a serving of a food on the Healthy Eating Index score. There are also several possible ways to quantify environmental impact of foods. We have used GHGEs per gram of protein, as determined by life cycle analysis (75). Either metric could be used to identify food sources of protein to be encouraged or discouraged by the DGA and to inform discussion about protein quality more generally.

Conclusion

Adequate intake of all essential amino acids is necessary for growth, development, and maintenance of body tissues. In some areas of the world, insufficient intake of protein and/or energy is responsible for significant morbidity and mortality. It is therefore understandable that international organizations, such as WHO and FAO, periodically make recommendations for assessment of protein quality, as defined by how efficiently the consumption of a protein source can contribute to intake of essential amino acids. However, such recommendations may have unintended consequences in the United States and other economically advantaged countries in which protein intake is high and largely derived from sources that are otherwise deleterious to the health of people and planet alike. For the United States, a modernized, more comprehensive metric for protein quality is needed—one that takes into account not only the quality of a food's amino acid profile but also the quality of its impact on human health and the environment. We have provided examples of how this could be accomplished. The adoption of such a shift in protein quality assessment would allow for clearer, more consistent messaging to the public and better alignment of nutrition policy with nutrition science.

Acknowledgments

All authors: read and approved the final manuscript.

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