PERSPECTIVE

# Perspective: A Perspective on the Transition to Plant-Based Diets: a Diet Change May Attenuate Climate Change, but Can It Also Attenuate Obesity and Chronic Disease Risk?

**Faidon Magkos,[1] Inge Tetens,[1] Susanne Gjedsted Bügel,[1] Claus Felby,[2] Simon Rønnow Schacht,[1] James O Hill,[3] Eric Ravussin,[4] and Arne Astrup[1]**

*[1]Department of Nutrition, Exercise, and Sports (NEXS), University of Copenhagen, Copenhagen, Denmark; [2]Section for Forest, Nature, and Biomass, Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark; [3]Department of Nutrition Sciences, The University of Alabama at Birmingham, Birmingham, AL, USA; and [4]Pennington Biomedical Research Center, Baton Rouge, LA, USA*

**ABSTRACT**

Current dietary guidelines advocate more plant-based, sustainable diets on the basis of scientific evidence about diet–health relations but also to address environmental concerns. Here, we critically review the effects of plant-based diets on the prevalence of obesity and other health outcomes. Plant-based diets per se have limited efficacy for the prevention and treatment of obesity, but most have beneficial effects in terms of chronic disease risk. However, with the considerable possibilities of translating plant-based diets into various types of dietary patterns, our analysis suggests that potential adverse health effects should also be considered in relation to vulnerable groups of the population. A transition to more plant-based diets may exert beneficial effects on the environment, but is unlikely to affect obesity, and may also have adverse health effects if this change is made without careful consideration of the nutritional needs of the individual relative to the adequacy of the dietary intake. *Adv Nutr* 2020;11:1–9.

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## Introduction

Recent food-based dietary guidelines (FBDG) recommend eating a more plant food-based diet and limiting the consumption of animal foods. A review of the current European FBDG (1), as well as the EAT-Lancet initiative on Food, Planet, and Health (2), suggests that environmental sustainability is a key factor for transitioning to more plant-based diets, and will be an emerging and important parameter for incorporation in future FBDG. Until recently, however, only a few countries (Brazil, Germany, Qatar, and Sweden) had introduced environmental sustainability explicitly as a component of their official national FBDG (3). An update of an earlier systematic review of population-level dietary patterns and food sustainability conducted in connection with the US Dietary Guidelines Advisory Committee concluded that, across studies, there is consistent evidence indicating that a dietary pattern rich in plant-based foods and lower in animal foods (particularly red meat), as well as lower in total energy, is healthier and is associated with a lesser impact on the environment compared with current dietary practices (4). Even though the focus on plant-based diets is predominantly driven by the need to address environmental concerns, in a recent analysis it was concluded that, at present, the evidence base on the environmental impact of various dietary patterns is far from complete, and thus one should not be quick to assume which diets have a low environmental footprint (5). In this article, we critically

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Address correspondence to FM (e-mail: fma@nexs.ku.dk).

Abbreviations used: CVD, cardiovascular disease; DASH, Dietary Approaches to Stop Hypertension; EPIC, European Prospective Investigation into Cancer and Nutrition; FBDG, food-based dietary guidelines; GHG, greenhouse gas/gases; RCT, randomized controlled trial.

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analyze available evidence on the effects of diets emphasizing more plant-based foods (**Table 1**) (6–10) on obesity and other health outcomes. We searched PubMed for relevant articles, focusing mainly on systematic reviews and meta-analyses, but also considered results from large multicenter trials, as well as the positions of various health-focused organizations and expert panel committees (such as the American and the British Dietetic Associations, the Nordic Ministries of Health, and the EAT Platform).

## Sustainable Diets—What's in a Name?

Sustainable diets are defined as diets that contribute to the good nutritional status and long-term good health of the individual and the community, and at the same time have a low environmental impact (3). This definition thus embraces both healthy nutrition that focuses on individuals, dietary intake, and health outcomes; and an environmental sustainability perspective covering all environment, food production, economic, and social dimensions (11, 12). In addition, sustainable diets should be culturally acceptable, ideally be based on local foods and ingredients, and be accessible and affordable by most people in alignment with the term "food and nutrition security" (13). Along these lines, the concept of a SHARP diet has been proposed to operationalize sustainable diets: environmentally Sustainable (S), Healthy (H), Affordable (A; accessible for consumers yet also supporting the agriculture food sector), Reliable (R; stable in its supply and safe), and Preferable (P; consistent with cultural norms and food preferences) (11). This concept would be in line with the wider definition of sustainability by including nutritional, social, ecological, and economic dimensions (11). Although a plant-based dietary pattern is promoted in most national FBDG, the translation of such a diet into food choices and meal plans is quite variable (14); and a predominantly plant-based diet can contain animal foods in different amounts (Table 1). Well-known dietary patterns that have been extensively shown to be associated with longevity and good health (or lower mortality and risk of noncommunicable diseases) in the general population are the Dietary Approaches to Stop Hypertension (DASH), Mediterranean diet (PREDIMED, Lyon Diet Heart Study), and Nordic diets (15, 16).

The DASH diet is characterized by mostly plant-based foods incorporating some animal products with an emphasis on low-fat and nonfat dairy products. The Mediterranean and Nordic diets have the common theme of incorporating traditional dietary patterns prevailing in the Mediterranean and Nordic countries, respectively, and thus put emphasis on locally produced foods. The concept of the Mediterranean diet was developed to reflect the typical dietary habits followed during the early 1960s by inhabitants of the Mediterranean basin and characterized by the high consumption of plant-based foods and low consumption of animal-source foods, and alcohol in moderate amounts (17). The Nordic diet was developed in 2004 as an innovative approach to traditional foods combined with a strong focus on health and an ethical production philosophy (18). This diet is likewise characterized by a high consumption of plant-based foods, wholegrains, nuts, dairy, fish, shellfish, and free-range livestock and game (19). Overall, both the Mediterranean and Nordic diets are considered prototypes of a healthy regional omnivore diet that takes health, palatability, food culture, and the environment into consideration.

Vegetarian diets contain no meat but may contain dairy products and eggs as opposed to vegan diets that exclude all animal-source foods. Recently, the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems defined different energy-balanced dietary patterns, including the flexitarian, pescetarian, vegetarian, and vegan, with a progressive reduction of the amount of animal foods and a progressive increase of the amount of plant-based foods (2). All dietary patterns exhibit a wide diversity of dietary practices, but the question remains to what extent such diets will reduce obesity and several other diet-related disease outcomes. A transition to a fully or predominantly plant-based diet will inadvertently alter the amount and source of various macronutrients and micronutrients, with the risk of inadequacies of certain nutrients being present (20), and thereby, perhaps also alter the physiological effects and the overall health outcomes of these diets. All plant-based diets are not created equal; certainly, one can eat sustainably and healthily, but one can also eat sustainably and unhealthily, inasmuch as one can eat healthily but not sustainably (21).

## Plant-Based Diets and Obesity

Observational studies have generally found that vegetarian and vegan populations have lower prevalence rates of overweight and obesity (22). However, an analysis of North American Adventists and other observational studies suggested that the apparent health benefits of plant-based dietary patterns (i.e., lower cardiometabolic disease and cancer risk) are not necessarily the result of diet-induced changes in body weight, but may instead relate to weight-independent effects on physiological and metabolic function, or to other lifestyle factors (e.g., more physical activity, lower alcohol, and tobacco use) (23). A recent meta-analysis of observational studies identified no longitudinal studies with body weight changes as the end-point, and only a small number of cross-sectional case-control studies (22). In these analyses, vegetarians and vegans had lower body weights than omnivores and, accordingly, lower BMI values by ~1.5 and ~1.7 kg/m$^2$, respectively. These studies, however, are subject to both residual confounding and risk of inverse causality, so one should exercise caution and prudence when interpreting results from cross-sectional observations.

It is certainly difficult to evaluate "extreme" dietary patterns using randomized study designs with adequately long periods of follow-up. Only a few randomized controlled trials (RCTs) have evaluated the effects of diets with reduced animal-source foods on body weight, and most are of small size and short duration. Huang et al. (24) conducted a meta-analysis of 12 RCTs involving a total of 1151 subjects

**TABLE 1** Characteristics of various dietary patterns emphasizing plant-based foods[1]

| Diet | Macronutrient composition (% of total energy) | General information |
|---|---|---|
| Dietary Approaches to Stop Hypertension (DASH) diet | Carbohydrate: 55–60%<br>Protein: 15–20%<br>Fat: 20–30% | This diet emphasizes eating a lot of fresh fruits and vegetables, low-fat dairy products, whole grains, fish, poultry, beans, seeds, and nuts, while limiting the consumption of red meat, sugary drinks, and sodium. It is balanced in nutrients, high in fiber, and low in saturated fat. |
| Mediterranean diet | Carbohydrate: 35–40%<br>Protein: 12–20%<br>Fat: 35–50% | This diet emphasizes eating plant-based foods (fruits, vegetables, whole grains, legumes, and nuts) and vegetable (olive) oils. It is high in dietary fat (mainly monounsaturated), moderate in fish and poultry, and low in red meat. |
| Nordic diet | Carbohydrate: 45–60%<br>Protein: 10–20%<br>Fat: 25–40% | This diet emphasizes whole, local, seasonal foods, with lots of fruits, vegetables, fish, other lean proteins, and whole grains. It is rich in fruits, berries, vegetables, legumes, potatoes, whole grains, nuts, seeds, rye breads, fish, seafood, low-fat dairy, herbs, spices, and rapeseed (canola) oil; moderate in game meats, free-range eggs, cheese, and yogurt; and low in other red meats and animal fats, added sugars, processed meats, food additives, and refined fast foods. |
| Vegetarian diet | Carbohydrate: 51–55%<br>Protein: 12–14%<br>Fat: 30–33% | This diet consists of grains, vegetables, fruits, sugars, oils, eggs (ovo-vegetarian), and dairy (lacto-vegetarian), and generally not >1 serving per month of meat or seafood. Meat-based protein sources are replaced by a mix of plant-based proteins (legumes), fruits, and vegetables. |
| Pescetarian diet | Carbohydrate: 50–53%<br>Protein: 14%<br>Fat: 31–33% | This diet is similar to the lacto-ovo-vegetarian one, with the simple addition of fish and seafood. Meat-based protein sources are replaced by a mix of seafood, fruits, and vegetables. |
| Flexitarian diet | Carbohydrate: 52%<br>Protein: 13%<br>Fat: 35% | This diet is similar to the pescetarian one. It emphasizes eating plant-based foods (fruits, vegetables, legumes, and whole grains), while allowing meat and other animal products (poultry, fish, and dairy) in moderation. It limits added sugars, sweets, and processed foods in general. |
| Vegan diet | Carbohydrate: 55–58%<br>Protein: 12–14%<br>Fat: 28–30% | This diet replaces all animal-based protein sources with a mix of plant-based proteins (legumes), fruits, and vegetables. It excludes eggs and dairy products. |

[1] Compiled from information provided in Springmann et al. (6), Davey et al. (7), Tilman and Clark (8), Bray and Siri-Tarino (9), and the Nordic Council of Ministers (10).

who received an intervention over a median duration of 18 wk (the follow-up periods ranged from 8 wk to 2 y). The vegetarian diet groups without energy restriction lost ~2.0 kg more than the nonvegetarian diet groups, with vegan diets producing a greater weight loss (~2.5 kg) than lacto-ovo-vegetarian diets (~1.5 kg) (24). The vegetarian diet-induced weight loss was smaller for subjects with follow-up of more than 1 y than those with shorter follow-up (~1.1 compared with ~2.1 kg, respectively) (24), reinforcing the urgent need for prospective studies of longer duration in order to robustly evaluate the efficacy of these diets for body weight regulation. It is also possible that only some, but not all, plant-based dietary patterns have beneficial effects on body weight. In a reanalysis of data from 3 prospective cohort studies in the United States (Nurses' Health Study I and II in women, and Health Professionals Follow-Up Study in men), Satija et al. (25) observed that plant-based diets containing higher amounts of healthy foods such as wholegrains, fruits/vegetables, nuts/legumes, vegetable oils, tea/coffee were associated with less weight gain over >20 y of follow-up, but plant-based diets including higher amounts of less healthy plant foods, such as refined grains, potatoes/fries, sweets, and sweetened beverages, were linked to more weight gain over time. Nevertheless, the different degrees of inclusion of healthy and unhealthy plant-based foods in the diet had rather small effect sizes on body weight (90–170 g/y) (25). Still, in a prospective European cohort of 11,554 participants with a baseline BMI <25 kg/m$^2$, better conformity with a dietary pattern that emphasized consumption of healthy plant foods was associated with a significantly reduced risk of overweight and obesity (by ~18%) after a median follow-up of 10.3 y, whereas this was not the case for a dietary pattern that emphasized less healthy or unhealthy plant foods (~7% nonsignificantly increased risk) (26).

Nevertheless, the weight loss obtained by the vegetarian and vegan diets is in line with the magnitude of weight loss obtained by increasing the intake of dietary fiber and to some extent, wholegrains in omnivorous diets (27, 28). Hence, in relation to obesity, there is little supporting evidence to suggest that there is additional benefit of vegetarian and vegan diets compared to omnivorous diets with high intakes of fiber and whole grain, such as the DASH, Mediterranean, and Nordic diets. By contrast, there is ample evidence from several RCTs that a diet with slightly higher protein content, including animal protein, can assist in producing and maintaining greater weight loss (29, 30), and this seems to be particularly important for people with prediabetes and type 2 diabetes that comprise 40–45% of the adult population in the United States and European Union (31–33). Currently, there is little evidence to support that a more severe restriction of animal foods will contribute to reduced prevalence of overweight and obesity beyond what can be achieved by a modest reduction in animal foods in conjunction with an increased intake of dietary fiber from vegetables and wholegrain foods.

## Plant-Based Diets and Other Health Outcomes

Several primarily plant-based diets have been studied in relation to various health outcomes, both in observational studies with hard disease end-points and in RCTs with metabolic risk markers. It is well-documented that the DASH, Mediterranean, and Nordic diets, all with limited animal-source foods, have multiple beneficial effects on cardiometabolic function (34–36). Also, prospective studies provide important information on the long-term health effects of plant-based vegetarian dietary patterns. In their summary of the main findings from several large cross-sectional and prospective cohort studies in Western countries, including among others the 2 Adventist Health Studies and the Oxford part of the European Prospective Investigation into Cancer and Nutrition (EPIC) study, Appleby and Key (37) found that vegetarians have a lower risk of ischemic heart disease and type 2 diabetes compared with nonvegetarians from a comparable background, whereas the results for stroke are inconclusive.

A comprehensive systematic review and meta-analysis of cross-sectional and observational studies of vegetarians and vegans against omnivores found that vegetarian diets are associated with lower incidence of cancer and lower incidence and mortality from ischemic heart disease, and vegan diets are associated with a lower risk of cancer (22). In a lifecycle analysis of greenhouse gas (GHG) emissions and data from cohort studies on the health effects of different diets, including a Mediterranean-like diet, a pescetarian diet, and a vegetarian diet, Tilman and Clark (8) found reductions in the order of 10–40% in RRs of type 2 diabetes incidence, all cancer incidence, and coronary artery disease mortality, when compared with the region's conventional omnivorous diet. However, mortality from all causes was significantly reduced only by the Mediterranean-like and pescetarian diets (by 14–18% compared with the omnivorous diet) and not by the vegetarian diet (8). Given that a pescetarian diet is like a vegetarian diet that includes seafood, these observations suggest that exclusion of all animal foods from the diet may be associated with increased mortality from other causes that were not assessed in that study.

It must be emphasized that not all plant-based diets are necessarily beneficial in terms of chronic disease risk. Hemler and Hu (21) recently identified only a few studies that have considered the healthfulness of the specific plant foods included in plant-based dietary patterns. In a reanalysis of data from 3 prospective cohort studies in the United States (Nurses' Health Study I and II in women, and Health Professionals Follow-Up Study in men), Satija et al. (38, 39) reported that plant-based diets containing higher amounts of healthy foods such as wholegrains, fruits, vegetables, nuts, legumes, oils, tea, and coffee were associated with a lower risk of coronary artery disease and type 2 diabetes, but plant-based diets including higher amounts of less healthy plant foods, such as refined grains, potatoes/fries, and foods and beverages high in added sugar, were linked to increased cardiometabolic disease risk. Recognizing the limitations of observational studies with regard to potential imprecise dietary intake quantification, substitution effects, collinearity among dietary components, and residual confounding (i.e., vegetarian and vegan individuals typically exhibit several distinct health-related behaviors compared with the general population), the findings from these studies overall support the evidence on the health benefits of more plant-based diets.

## Nutritional Concerns with Plant-Based Diets

Adopting a more plant-based diet implies substitution of some or all animal foods. Apart from the generally favorable health effects in relation to noncommunicable disease risk mentioned above, concerns regarding the nutritional inadequacy of more plant-based diets have been raised and should be taken into account, particularly in relation to protein, vitamin B-12, vitamin D, calcium, iron, and zinc. Nonspecific recommendations to increase plant-based foods in place of animal foods can lead to unintended nutritional inadequacies (20). Infants and children, adolescents, and women of reproductive age are especially vulnerable to inadequate intake of these nutrients in relation to their increased requirements related to growth, and older adults are of concern because of their reduced energy intake, accompanied by changes in body composition, loss of appetite, and less physical activity. Here, we briefly review some of these issues.

Protein is present in many common foods in various amounts. Animal protein has high digestibility and a composition that readily matches human amino acid requirements; it is therefore considered of higher quality than most plant proteins. However, a balanced selection of plant-based foods together with an adequate energy intake can still fulfill the protein requirements of most individuals on vegetarian diets. Several studies (40, 41) have assessed the adequacy of protein intake in vegetarian and vegan diets, and overall found that both groups have lower intakes than omnivores; and have therefore suggested that protein recommendations should be increased from 0.8 to 1.0 g/(kg body weight · d) to account for the reduced bioavailability of plant proteins as compared to animal proteins (42). Furthermore, with the increasing body of evidence linking protein intake in older adults with functional health outcomes such as decreased muscle mass and strength (sarcopenia), the recommended dietary intakes for protein may need to increase from 0.8 to 1.1–1.3 g/(kg body weight · d) or even more, so that protein provides 15–20% of total daily calories (10, 43). Whereas protein intake and protein quality from a more plant-based dietary pattern are generally considered sufficient to maintain nitrogen balance in most individuals, it is still uncertain if plant-based diets will support the higher protein requirements of older adults or special segments of the population such as athletes (42).

Vitamin B-12 is found almost exclusively in animal-source foods and is therefore a nutrient of potential concern for those following vegetarian or vegan diets. A meta-analysis of 17 studies that evaluated plasma homocysteine and serum vitamin B-12 concentrations in vegetarians and vegans compared with omnivores found that vegans had the highest homocysteine and lowest vitamin B-12 concentrations, with vegetarians having intermediate concentrations between those of vegans and omnivores (44). It is less commonly recognized that even moderate restriction of animal-source foods will affect vitamin B-12 status, so omnivores have better vitamin B-12 status than those who avoid meat, poultry, and fish, and they in turn have better status than lacto-vegetarians, with vegans having the poorest status (45).

Calcium is present in high concentrations in dairy products. Comparison of the nutritional quality of the vegan, vegetarian, pescetarian, and omnivorous diets illustrates that calcium intake was below dietary recommendations and of particular concern among vegans (46). Inadequate calcium intake together with a generally low vitamin D status found in many parts of the world are associated with lower bone mineral density and increased risk of bone fractures. Moreover, calcium, as part of the dairy food matrix, may play an important role in the prevention of cardiovascular disease (CVD), type 2 diabetes, and sarcopenia (47).

Dietary iron consists of heme-iron that is almost exclusively found in animal tissues, and nonheme iron (including ferric iron) that is found in both animal- and plant-based foods. Absorption of heme-iron is efficient and largely unaffected by other dietary constituents, whereas nonheme iron is highly insoluble and its bioavailability is therefore lower; absorption of nonheme iron is modifiable by a number of endogenous and exogenous inhibitors and promoters (48). For example, vitamin C is a strong promoter of nonheme iron absorption, whereas phytate, a phosphate-rich compound found in wholegrain products of corn, cereal, rice, and legumes, is a well-known inhibitor of nonheme iron absorption (49). Also, the "meat-factor" is a constituent or attribute found in meat, poultry, and fish, which enhances the absorption of iron by an as yet unknown mechanism. An earlier study in young healthy women showed that a small amount of meat (50 g) in a phytate-rich meal low in vitamin C significantly increased the absorption of nonheme iron from the meal (50). Several studies, including the EPIC Oxford study that compared omnivores, fish-eaters, vegetarians, and vegans, found that the total dietary iron intake was greatest in vegans and not different among meat-eaters, fish-eaters, and vegetarians (7, 51). However, as the dietary iron intake in vegans consists solely of nonheme iron, much less is expected to be absorbed compared with diets that include animal-source foods (52). A recent systematic review and meta-analysis of 27 cross-sectional studies and 3 intervention studies concluded that vegetarians are more likely to have lower iron stores compared with nonvegetarians (51), but the physiological significance of a lower ferritin concentration in vegans is still uncertain.

Zinc is found mainly in protein-rich foods such as meat, poultry, fish, and seafood; other good sources include dairy products, legumes, nuts, and wholegrains. The bioavailability of zinc is affected by the presence of other dietary components, such as phytate that inhibits absorption, and protein that may either inhibit or promote absorption depending on the food source (53). A high protein intake, therefore, increases the dietary intake of zinc and may also promote zinc absorption (54). In fact, animal-based proteins from beef, egg, and cheese have been shown to counteract the inhibitory effect of phytate (54–56). It is therefore reasonable to assume that a shift to a more plant-based dietary pattern with no or little animal protein may decrease zinc status. A systematic review and meta-analysis of 34 studies in humans found that both dietary zinc intakes and serum zinc concentrations were significantly lower in populations that followed habitual vegetarian diets compared with nonvegetarians (57). The health effects of marginal zinc intake are poorly understood (58), but no differences between vegans and omnivores have been observed in functional immunocompetence assessed by natural killer cell cytotoxic activity (59), and no health effects related to zinc deficiency have been observed in vegans (60).

Individuals who consume predominantly plant-based foods for ethical, environmental, or cultural reasons may use different food preparation and processing methods and different taste enhancers, including various herbs and spices (e.g., onion and garlic), which may increase the bioavailability of certain nutrients and may even overcome the inhibitory effect of other dietary constituents (61). However, the opposite can also be true, for example several phenolic compounds in herbs and spices (e.g., herb tea, black tea, coffee, rosemary, and chili) can diminish iron absorption (62–64). Various food processing methods such as microwave heating and pressure cooking can also affect nutrient bioavailability and not always in the same manner (e.g., they improve the bioaccessibility of iron from cereals and pulses but reduce that of zinc) (61).

## Food Matrix Effects

Substituting animal foods in the diet for more plant-based foods may affect health outcomes beyond what can be predicted from the sole perspective of adequacy or inadequacy of isolated nutrient intakes. Most foods contain thousands of substances with potential health-related effects, which can only be observed when the whole food or even a whole meal is consumed. In many cases, the nutrient and nonnutrient components that are ultimately responsible for the observed health effects, collectively referred to as the food matrix, have not been adequately characterized or even identified. Therefore, the food matrix (i.e., the chemical-physical properties of the food) should be taken into account when assessing the health impact of different dietary patterns, rather than simply considering nutrient content. Some examples include the "meat-factor" effect in relation to iron absorption, mentioned above, as well as the "cheese/yogurt-factor" effect in relation to risk markers of cardiometabolic disease.

Even though FBDG recommend low-fat or fat-free versions of milk and dairy products to reduce saturated fat intake, both mechanistic research and observational studies report that whole-fat fermented dairy, e.g., cheese and yogurt, may actually reduce the risk of CVD and type 2 diabetes

(65, 66). Also, plasma biomarkers of dairy intake (C17:0 fatty acid) have been inversely associated with CVD risk (65, 66). A number of meta-analyses not only found no adverse association between milk and total dairy intake (regardless of fat content) and CVD, but instead found that cheese and yogurt intakes are inversely associated with CVD risk. In particular, higher cheese consumption was associated with an 8% lower risk of coronary artery disease and a 13% lower risk of stroke (67, 68). These analyses suggest that the health effects of foods cannot by extrapolated from their content of just one or a few nutrients. Indeed, cheese and yogurt consist of complex food matrices and ingredients with diverse biological effects. Major components include different fatty acids, proteins (whey and casein), minerals (calcium, magnesium, phosphate), sodium, and phospholipid components of the milk fat globule membrane (47). A recent study, for instance, found that a 4-wk dietary intervention based on cream cheese naturally enriched with polar lipids (part of the milk fat globule membrane), markedly improved an array of lipid markers of CVD risk in postmenopausal women (69). In addition, yogurt and cheese are fermented dairy products containing bacteria and microorganism-produced bioactive peptides, short chain fatty acids, and vitamins such as menaquinones.

Another example of a food matrix effect can be demonstrated in the results from 2 large US cohorts, the Nurses' Health Study in women and the Health Professionals Follow-Up Study in men, regarding the association between intake of dairy foods and risk of hip fracture (70). The main finding was that total dairy intake was associated with a significant ∼6% lower risk of hip fracture per serving in both sexes. However, this beneficial effect could not be explained by the contents of calcium, vitamin D, and protein in dairy, suggesting that other factors, or the dairy food matrix itself, may be responsible for the observed benefit. The adequacy of vegetarian and vegan diets in relation to bone fractures was addressed in a recent meta-analysis of 20 observational studies including 37,134 individuals (71). The analysis found that vegetarians and vegans have lower bone mineral density and a 32% greater risk of bone fractures compared with omnivores. Although vegans are typically advised to take dietary supplements to ensure sufficient calcium and vitamin D intakes, this advice is clearly not effective to prevent osteoporotic fractures in real life. The increasing recognition of the existence of nutrient interactions in whole foods, and between whole foods within the same meal or even within the whole diet plan, and their potential health effects should be taken into account (72)—and also considered in future studies of modeling of food–health relations.

## Conclusions

In a recent analysis of the environmental impact of various dietary patterns, based on modeling of data from 150 countries, Springmann et al. (6) suggested that energy-balanced, low-meat dietary patterns could reduce premature mortality by ∼19% (flexitarian diet) and ∼22% (vegan diet), and reduce GHG emissions by 54–87%. These estimates rest on the assumption that overweight and obesity rates are substantially reduced, or even that these conditions are eliminated. Whereas it is relatively easy to statistically normalize all individuals with excess body weight to normal body weight, it has been a major challenge to reduce overweight and obesity in real life. Simple advice such as eat fewer calories and expend more energy by physical activity has not had any positive impact on obesity rates. Weight gain leading to overweight and obesity develops due to a slightly positive but sustained energy balance, and the causal factors leading to the failure of the physiological appetite control mechanisms to reduce energy intake in order to match energy expenditure are not completely understood. There is accumulating evidence for an important role of diet composition interacting with genetic and epigenetic factors, the microbiome, mental stress, impaired sleep, and other factors to affect appetite control. It is also possible that appetite control is inherently asymmetric, being tight in conditions of negative energy balance but rather loose in conditions of positive energy balance (73), thereby favoring weight gain in modern affluent societies.

It is currently not known whether flexitarian or vegan diets without forced energy restriction will make it easier for individuals to prevent (or treat) weight gain and obesity. The EAT-Lancet initiative recommends large reductions in animal foods, and points at major positive effects on the environment and human health (2). The presumed health benefits rest mainly on observational data indicating adverse effects of processed red meat on the risk of various cancers and CVD (2). However, there is little evidence to support the premise that a more plant-based dietary pattern, such as a vegan diet, will have major effects on body weight control. The existing research is dominated by observational studies of a cross-sectional nature that compare vegetarian and vegan cohorts with omnivorous subjects; these studies are confounded by major differences in other lifestyle factors that are also likely to affect body weight. Even with these shortcomings, available data do not indicate that vegetarian and vegan dietary patterns produce better results in long-term weight control than prudent omnivorous dietary patterns (e.g., DASH, Mediterranean, and Nordic diets).

A diet with more dietary fiber and wholegrains without energy restriction is likely to assist in producing a modest weight loss of 2–3 kg over time, but it seems important to maintain a certain level of protein intake to increase efficacy (29, 30). Notably, plant proteins have a comparable satiety effect as animal proteins (74), but are suboptimal for protein synthesis in skeletal muscle and other tissues, unless care is taken to ensure intake of the optimal mixture of amino acids (75). Although it is clear that GHG emissions associated with the production of plant-based foods are lower compared with animal-based foods (76), the GHG emission burden for producing various protein-containing foods is less clear-cut when the optimal amino acid composition for human health is taken into consideration. Recent data show that GHG emissions for producing protein that satisfies the Recommended Dietary Allowance for essential amino acids is not reduced if protein from beef or milk is replaced by protein from beans, peas, wheat, rice, or cauliflowers (77). Only soybeans may show an advantage in terms of GHG emission (77). This study emphasizes that assessment of the environmental footprint associated with the production of animal-based compared with plant-based protein-containing foods needs to be re-evaluated based on the content of essential amino acids and other required nutrients in foods.

In future diet modeling, sustainability aspects should be included in the diet–health relation estimations, but the environmental impact of the various dietary patterns should be addressed very carefully and in a comprehensive manner. A transition to more plant-based dietary patterns may exert beneficial effects on the environment but will likely have little effect on obesity per se and may also have adverse health effects, particularly if this transition is made without careful consideration of the nutritional needs of the individual relative to the adequacy of the dietary intake. This requires dietary adherence and the importance of dietary substitution to be considered as well. In practice, research should be conducted focusing on more stratified interventions supporting the personal palatability and preferences in a personalized dietary intervention scheme.


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