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Climate Change, Food Supply, and Dietary Guidelines

Colin W. Binns,[1] Mi Kyung Lee,[2] Bruce Maycock,[3,4] Liv Elin Torheim,[5] Keiko Nanishi,[6] and Doan Thi Thuy Duong[7]

[1]School of Public Health, Curtin University, Perth, Western Australia 6845, Australia; email: c.binns@curtin.edu.au

[2]College of Science, Health, Engineering and Education, Murdoch University, Murdoch, Western Australia 6150, Australia; email: m.k.lee@murdoch.edu.au

[3]College of Medicine and Health, University of Exeter, Exeter EX1 2LU, United Kingdom

[4]Asia-Pacific Academic Consortium of Public Health (APACPH), APACPH KL Secretariat Office, Department of Social and Preventive Medicine, Faculty of Medicine, University of Malaya, 50603 Kuala Lumpur, Malaysia; email: bmaycock@iinet.net.au

[5]Faculty of Health Sciences, Department of Nursing and Health Promotion, Oslo Metropolitan University, NO-0130 Oslo, Norway, email: livtor@oslomet.no

[6]Office of International Academic Affairs, Graduate School of Medicine, The University of Tokyo, Bunkyo-Ku, Tokyo 113-0033, Japan; email: keikonanishi@yahoo.co.jp

[7]Faculty of Social Sciences, Behavior and Health Education, Hanoi University of Public Health, Bac Tu Liem District, Hanoi 100000, Vietnam; email: dttd@huph.edu.vn

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Abstract

Food production is affected by climate change, and, in turn, food production is responsible for 20–30% of greenhouse gases. The food system must increase output as the population increases and must meet nutrition and health needs while simultaneously assisting in achieving the Sustainable Development Goals. Good nutrition is important for combatting infection, reducing child mortality, and controlling obesity and chronic disease throughout the life course. Dietary guidelines provide advice for a healthy diet, and the main principles are now well established and compatible with sustainable development. Climate change will have a significant effect on food supply; however, with political commitment and substantial investment, projected improvements will be sufficient to provide food for the healthy diets needed to achieve the Sustainable Development Goals. Some changes will need to be made to food production, nutrient content will need monitoring, and more equitable distribution is required to meet the dietary guidelines. Increased breastfeeding rates will improve infant and adult health while helping to reduce greenhouse gases.

1. INTRODUCTION

This article is the third review on nutrition and climate change in the *Annual Review of Public Health* (*ARPH*), which reflects its importance to global health and extends the discussion of food for population health and changes brought on by climate change (63, 102). A decade ago, the *Lancet* Commission concluded that anthropogenic climate change threatened to undermine the healthy lives of billions and to undo the past 50 years of gains in public health. An effective response to climate change could be the greatest global health opportunity of the 21st century (36). Food production is affected by climate change, which in turn is responsible for 20–30% of greenhouse gases (GHGs). The food system must increase output as the population increases and must meet nutrition and health needs while simultaneously assisting in the achievement of the Sustainable Development Goals (SDGs) (15, 99, 136). The climate crisis comes from a rapid increase in human use of natural resources to satisfy rising standards of living, increased energy use, population growth, and dietary shifts toward higher consumption of animal products (45). The effects of climate change on nutrition and health have been discussed for at least six decades (49, 87). Many of the causes and outcomes identified decades ago have since worsened, with only limited international cooperation emerging to change global trajectory. Substantial increases in the production of CO_2 and other GHGs have resulted in overall global warming during the Anthropocene (1). While a proportion of the CO_2 generated is utilized by plants, excess accumulates in the atmosphere or oceans, the latter being the great CO_2 sink. The result is increasing ocean acidification, altering its ecology (35, 116). Water vapor is also a GHG, levels of which increase by rising temperatures and in turn increase rainfall in some areas, contributing to adverse weather events. If climate change continues unabated, in a generation 1–3 billion people will be attempting to live in temperatures experienced now by only small populations in the Sahara (154).

Since the publication of the previous *ARPH* articles on this subject, world events have illustrated the fragility of global initiatives against climate change; efforts to reduce the rate of change stall as major countries withdraw or do not meet commitments outlined in the Paris Accord (85). The rate of climate change is increasing: 2015–2019 was the hottest five-year period on record, resulting from ever-increasing CO_2 emissions (152). There has been increased crop damage from storms, droughts, floods, salination, landslides, and wildfires on all continents. The loss of plants and animals from these events, together with the concentration of cropping on fewer hectares, reduces biodiversity (62). These changes will increase climate-related strain on food supplies and nutrition and health, with the coronavirus disease 2019 (COVID-19) pandemic imposing additional health and economic burdens.

The aim of this review is to consider the ways in which climate change is altering food supply and how these changes will relate to dietary guidelines in the future.

1.1. Progress and Challenges in Global Health, Food, and Nutrition

Substantial improvements have been made to health and nutrition in recent decades, even though a number of the Millennium Development Goals targets were not fully met. The global under-5 child mortality rate decreased from 118/1,000 live births in 1980 to 39/1,000 in 2018. In West and Central Africa, the corresponding values were 217/1,000 down to 97/1,000. Changes in China are even more dramatic; infant mortality declined from an estimated 300/1,000 (in 1941) to 7 per 1,000 (in 2018), demonstrating concerted efforts to improve nutrition and health (139). The global prevalence of underweight due to insufficient energy intake has been reduced by nearly 50% since 1990, driven largely by increased yields of the major crops, including wheat, rice, and maize (53). The Intergovernmental Panel on Climate Change (IPCC) has estimated that, since 1961, per capita availability of food has increased by one-third (96). This increase has required greater use of nitrogen fertilizers (up by 800%) and water resources for irrigation (by at least double). Despite the improvements in the proportion of the population suffering from nutrition problems, in absolute numbers an estimated 821 million people are currently undernourished, 150 million children under five are stunted, and 613 million women aged 15–49 suffer from iron deficiency (96). The world is still faced with the tragedy of nearly 5 million child deaths annually. Micronutrient deficiencies affect an estimated 2 billion people worldwide, which could increase in the coming decades as food diversity decreases (133). Improvements in food supply resulted in a shift to the right of the distribution curve of food consumption, decreasing undernutrition. An unwanted side effect was an increase in the global prevalence of overweight and obesity.

Climate change and malnutrition in all its forms, including obesity and undernutrition, constitute two of the greatest threats to planetary and human health (44). Risks to human health include increases in infectious diseases, heat-related chronic disease, allergies, and injuries and stress from adverse weather events (30, 63, 79, 144). Pollution occurring concurrently with climate change may affect health (98). The exact impacts will vary with location and national wealth, but most impact will still fall on children and poorer populations. Children should be the focus of climate change discussion and implementation of the SDGs (34, 157). This approach is consistent with the legal obligations to which most countries have committed by their ratification of the Convention of the Rights of the Child, which includes obligations to protect children's right to a healthy food environment (140).

The Global Burden of Disease (GBD) study provides a comprehensive description of the impact of suboptimal diets on chronic disease morbidity and mortality, around 60% of the risk of disability-adjusted life years (DALYs), and demonstrates the need for improving nutrition in all regions and at all levels of development to control disease burden (2, 61, 127). Despite the decrease in world poverty levels and increase in world food production, both in absolute terms and in per capita availability, dietary inequalities persist, a condition all countries have committed to ending by 2030 in accord with the SDGs. Overall food energy supply by region, with inequities between rich and poor populations, is illustrated in **Figure 1** (54).

While food production has increased, a large amount of food is wasted, estimated at 35% (11). Food waste is often underestimated and has a double or even triple effect, as energy is required for production, by humans in agriculture labor, and in food preparation, all contributing to GHGs (143). Wastage occurs at many stages of food production, including mechanical damage and spillage during harvest, sorting, handling, storage, transportation, processing, retailing, and home use (14, 58). Wastage at final consumption varies, depending on economic level; for fruit and vegetables, it is estimated to be 2–5% in Africa, Asia, and Latin America compared with 12–17% in Europe, North America, Oceania, and industrialized parts of Asia (51, 55).

1.2. Food Security and the United Nations Sustainable Development Goals (SDGs)

The Food and Agricultural Organization (FAO) lists four dimensions of food security (50):

- Sufficient food is available.
- Everyone has access to it.

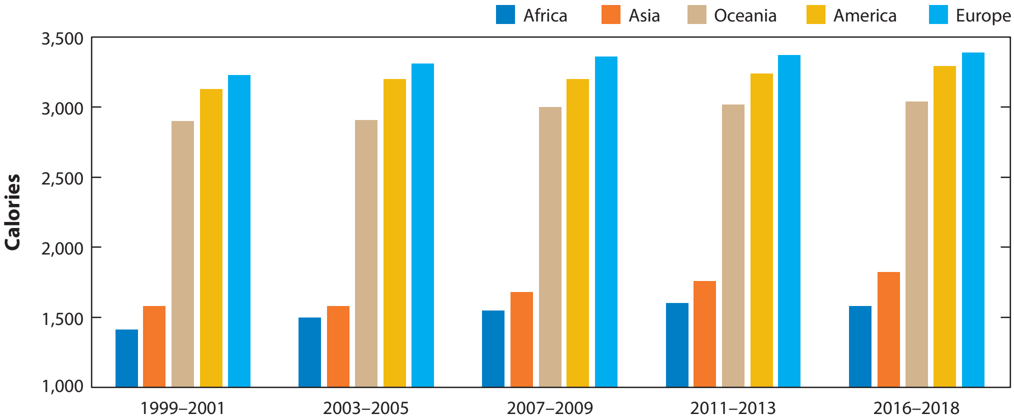

Figure 1

Average dietary energy supply by region. Figure adapted from Reference 35.

- The food supply is well utilized.
- All three of these dimensions are stable over time.

Sustainable diets are defined as being "protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources" (82, p. 641; 113). To the economist, that real prices of agricultural products have been trending downward for the past 50 years suggests that food production is sufficient, but the prevalence of undernutrition, overnutrition (obesity), and micronutrient deficiency shows that distribution is inequitable. The global food system faces an ambitious challenge in meeting nutritional needs for all, while reducing GHGs. Goal 2 of the SDGs emphasizes nutrition, "End hunger, achieve food security and improved nutrition and promote sustainable agriculture," but the majority of the SDGs affect food production and nutrition in some way (19). This is illustrated in **Figure 2**, using as its basis the UNICEF framework on nutrition, its antecedents, and outcomes.

1.3. Population Trends Affecting Food Requirements and Production

Additional changes in human ecology are occurring in parallel with climate change. The world population growth rate has slowed to 1.1%, but the population is still increasing by 83 million annually. The globe is becoming more urbanized, and vast numbers of migrants and refugees are changing population structures and water, food, employment, and housing requirements. The United National Development Program (UNDP) has summarized population trends that will affect the production of, and requirements for, food (142). The world's population has grown from 2.6 billion in 1950 to 7.7 billion in 2019 and will reach 8.5 billion in 2030 and 9.7 billion in 2050. By 2050, the world will have 9 billion people, and providing them with enough food, despite climate change and environmental pressures, will be the greatest challenge of the twenty-first century (40). The population will continue to age (>60 years) from 901 million in 2015 to 1.4 billion in 2030 and will continue to urbanize, with cities (>1 million) increasing from 23% of the world's population to 28% in 2030. The rural population will decline from 45% to 40%, decreasing the workforce for food production (137, 141). While the population of Sub-Saharan Africa will double by 2050, many higher-income countries (HICs) will continue to have declining

The Sustainable Development Goals

No.	Goal
1	Poverty
2	Zero hunger
3	Health
4	Learning, education
5	Gender equality
6	Clean sustainable water, sanitation
7	Energy
8	Economic growth, work
9	Industry
10	Reduce inequality
11	Sustainable communities
12	Responsible consumption
13	Climate action
14	Life below water
15	Life on land
16	Peace
17	Partnership

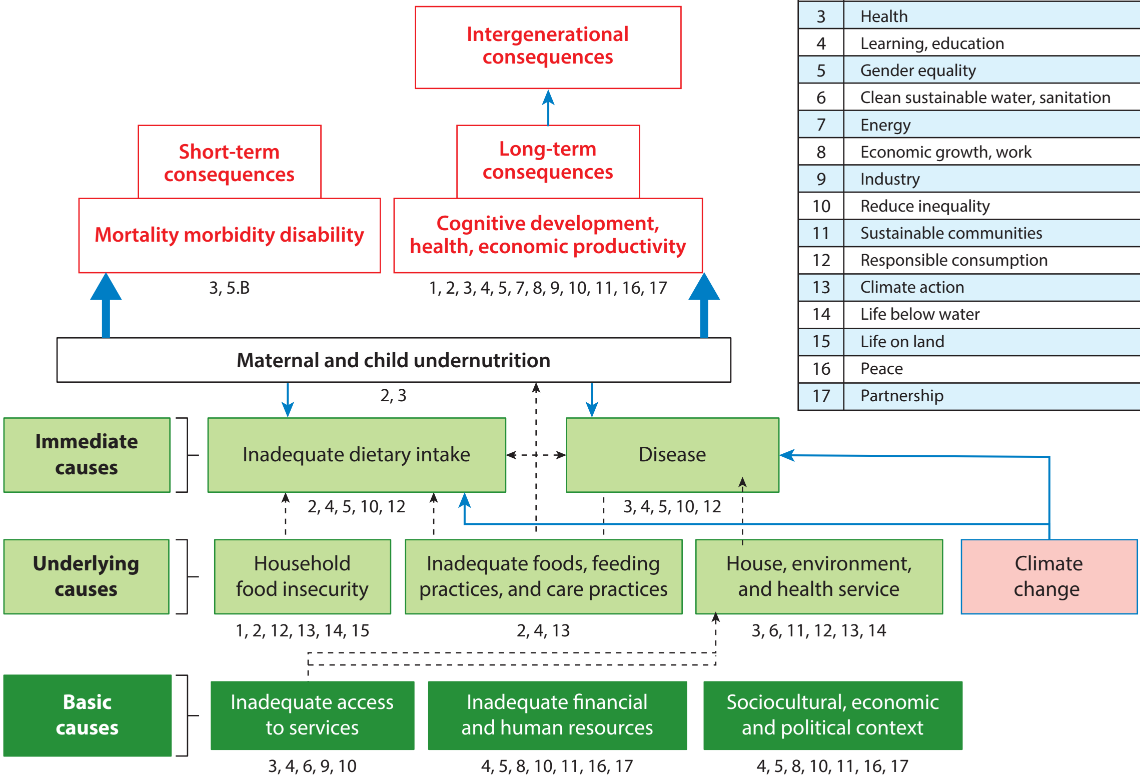

Figure 2

Relationship between UNICEF conceptual framework of undernutrition and the Sustainable Development Goals (SDGs). Numbers correspond to the relevant SDGs. Figure adapted from Reference 44.

populations. Infants, young children, pregnant women, and the elderly will be more impacted by climate change (28, 34, 131).

2. IMPACT OF CHANGES IN CLIMATE ON FOOD PRODUCTION AND SUPPLY

2.1. Changes to Global Food Supply

In a series of reports over the past 15 years, the IPCC has provided scientific evidence of the effect of climate change on global food supplies (2, 50–55, 57, 59–71).

- Hotter climates will shift production toward the poles and will also cause faster plant growth and ripening and decrease nutrient density.
- Areas of dry land will increase, while some regions will have increased rainfall (80). The amount of arable land in use is almost at a maximum. Increasing environmental degradation, desertification, soil depletion, overgrazing, rising sea levels, urban development, roads,

and industrial use may reduce land further. Saltwater encroachment will affect some particularly low-lying, but highly productive rice-growing areas of Asia. As a result, agricultural productivity will have to increase.

- Adverse weather events including storms, hurricanes, droughts, flooding, landslides, and erosion will increase in frequency and severity, which will damage crops and disrupt harvesting, transportation, and storage.
- Transport will be disrupted owing to adverse weather events, increased fuel costs, conflict, and political issues.
- Spoilage and bacterial damage, including *Listeria*, *Salmonella*, and mycotoxin contamination, increase with rising temperatures and increased numbers of extreme heat days (100). Mitigating this damage will require improved agricultural practices and better processing, packaging, and storage.
- Agricultural yields depend on crop protection measures. The main purpose of pesticide use is to increase food security by controlling pests and weeds, and these will increase with climate change. The increased number of insects, including locust plagues, will cause crop damage, decrease crop yield, and result in greater costs with increased chemical residues (43, 153). Pesticide use will increase, and higher temperatures and adverse weather may cause faster dissipation (41).
- Contaminants may enter food at several stages of agriculture, processing, packaging, transport, or storage. New toxic residues (emerging contaminants) in food are increasing as a consequence of changes in industrial processes, intensifying agricultural practices, environmental pollution, and climate change (57). Chemical contaminants have become a food safety concern, owing to pesticide residues and environmental contaminants (74).
- Climate change will have a serious negative impact on crop productivity as the level of warming progresses (80). Productivity of both commercial crops (maize, rice, and wheat) and crops such as millet and sorghum will be affected. Impacts will vary depending on CO_2 concentrations, fertility levels, and region (80). A meta-analysis shows that adoption of improved farming practices and technologies such as improved varieties, planting at optimal times, and improved water and fertilizer management has the potential to reduce the negative impact on crop yield (3). With this scenario, climate change may not add significantly to the challenge of food production for the majority of countries except for some potential hot spots around the world. However, massive investment, policy, and institutional support will be required to facilitate adoption and scaling-out of such practices and to address climatic variability (3).
- Food variety will decrease, as measured by the "food diversity index" (47). Diverse food systems are more resilient in enhancing food security in the face of climate change. They are important for nutrient cycling, carbon sequestration, control of soil erosion, reduction of GHG emissions, and control of hydrological processes (97). For human nutrition, food diversity is important, especially for children, because it increases the likelihood of meeting nutritional needs, including intakes of phytochemicals, and decreases the impact of contaminants and toxicants (83, 123).
- Potable water supplies will decline owing to decreased rainfall, salinization, pollution, increasing population, and industrial use. This decline will affect water-intensive production systems, and dairying will be the most affected (67, 73). Decreases in milk production will reduce the availability of an important source of calcium and high-quality protein. At the same time, osteoporosis will become more prevalent in aging populations, which may require additional interventions. Decreases in the dairy herd may have a public health benefit

by reducing the production and use of infant formula. More irrigation is a strategy to increase food production, but the lack of water will limit its expansion (38).

- The global food system contributes 25% of GHG emissions, with the largest source being livestock production. The food and agriculture industries project that an increase in demand for meat is likely to undermine efforts to keep global average warming below a 2°C target (114). How GHGs are accounted for may differ in the country of production compared with the country of consumption. For example, the GHG production of Hong Kong is underestimated as imports of meat are ignored. GHG emissions hidden in meat and dairy products, which are all imported into Hong Kong, demonstrate that consumption is about 59% higher than the city's total GHG emissions using conventional production-based calculations (155).
- Nuts have important benefits for nutrition, but yields will decrease with climate change (4).

2.2. Oceans, Fish, and Seafood

Fish and seafood, containing protein, a high level of omega-3 fatty acids in fatty fish, and micronutrients, are important components of a healthy diet (148). Fish provide at least 15% of the daily average intake of animal protein for 4.5 billion people, and in 2010 it provided more protein than cattle and poultry combined (13). For some populations in West Africa, island states, and coastal Asia, fish consumption is over 50% of the total animal protein consumed; small fish, eaten whole, are also an important source of many micronutrients (76). As ocean health changes, sustainable production will decrease, requiring more effort to reduce pollution (42). The world's oceans are changing because of increasing acidification (dissolved CO_2), increased fishing, minerals and petroleum extraction, and increasing use for aquaculture (35, 106). Ocean acidification has the greatest effect on calcifying organisms, including mollusks, corals, and plankton (25), which affects species higher up the food chain. Acidification can affect the growth and life span of some fish, such as sea bream, and can reduce plankton size, which decreases the growth of species such as anchovy and sardines (6, 31).

Catching and consuming fish are generally localized activities. Nine of the top 15 countries for marine capture are in the Asia-Pacific region, accounting for 87% of the global catch (52, 78). The EAT-*Lancet* Commission on healthy diets recommended 28 g per day of fatty fish for the protective effect of omega-3, but only the East Asia-Pacific region currently achieves this goal. The 2010 dietary guidelines for Americans encourage individuals to double their intake of fish (94), which would require a doubling of the current production to meet these recommendations (148). The oceans cannot supply these recommended levels of fish; the maximum sustainable catch has already been exceeded, with 30% of ocean wild fish stocks overfished and 60% fully fished (52). Wild fish stocks face compounding pressures from pollution, loss of habitat from coastal developments, and increased eutrophication. Increasing sea temperatures will result in the migration of stocks toward the poles (59). Aquaculture is the only method available to increase fish production, and currently two-thirds of production comes from Asia (excluding China). Changes to fish feeding methods and growth patterns may alter nutritional content, with reduced lipids, vitamin D, omega-3 fatty acids, and proteins (59, 81, 103, 134, 148). These changes will need monitoring and research to reduce the environmental impacts of mariculture (52).

2.3. Interactions Between Climate and Food Production

The global food production system is influenced by climate change, while the system itself in turn influences GHGs (see **Figure 3**). As production increases, land use will intensify and biodiversity will be lost, as fewer cultivars are used to increase yields. Land and sea pollution will increase, particularly in lower-income countries (LICs), where the majority of farmers have small

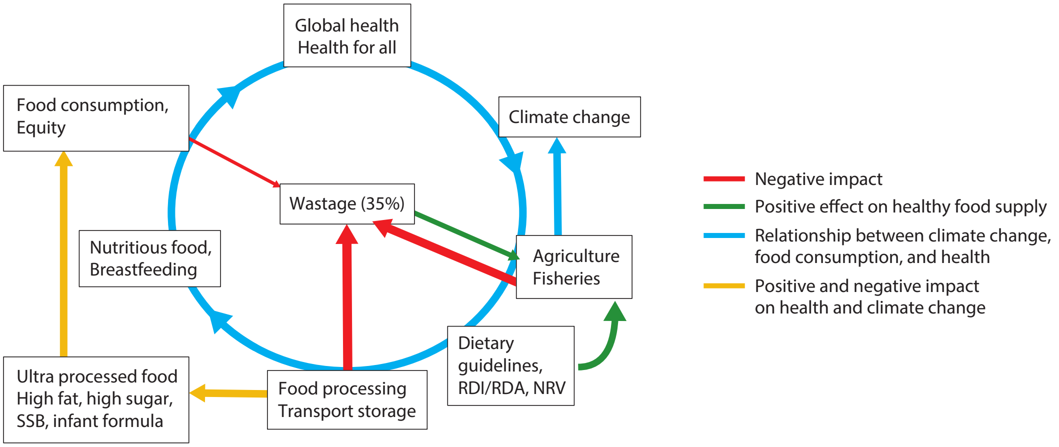

Figure 3

Food production, dietary guidelines, and healthy diet. Wastage is depicted as a negative impact (*red arrows*), but if wastage can be reduced, it will have a positive impact on food supply (*green arrows*). Abbreviations: NRV, nutrient reference value; RDA, recommended dietary allowance; RDI, recommended dietary intake; SSB, sugar-sweetened beverages.

holdings and will find it difficult to invest in technological solutions (68, 126). Some proposed climate mitigation strategies could have adverse side effects on food production; for example, using land for afforestation may reduce the land available for food production (65). The opposite effect may occur in some countries, with forests being destroyed to increase agricultural land. Another important issue for nutrition is a decrease in micronutrient density, as yield increases require improved monitoring and efforts to increase the nutrient content in food crops (90). Dietary choices affect food production, which in turn has an effect on the environment. Dietary guidelines recommend eating fewer animal products. If this guidance is followed, the decrease in production will lessen GHG emissions (115). Some of the interactions between climate change, dietary guidelines, and food production are shown in **Figure 3**.

3. BRINGING TOGETHER CLIMATE CHANGE, FOOD, AND HEALTH

3.1. A Diet That Is Good for the People and the Planet

Recommendations for healthy eating go back millennia to Hippocrates and earlier. Scientific nutrition recommendations began with the era of analytical chemistry in the nineteenth century, which led to the measurement of protein and subsequently energy, vitamins, and micronutrients. Recommendations were initially made for nutrient deficiencies in vitamin C and thiamin, followed by additional micronutrients, including iron and iodine (101, 121). Beginning in the 1950s, the infectious disease burden of undernutrition was documented, and, more recently, the burden of chronic disease, including obesity, diabetes, heart disease, and cancer, has come to the fore. Other important areas include the effect of early-life nutrition (the first 1,000 days and developmental origins of health and disease hypothesis) and the maintenance of a healthy human microbiome for good health (10, 122, 138). The promotion of sustainable, resilient food systems for healthy diets is the first principle for action during the UN Decade of Action on Nutrition (86).

3.2. Food-Based Dietary Guidelines

Most food-based dietary guidelines (FBDG) are based on the following principles: address significant public health issues, both acute and chronic; be food-based to allow for easier translation into practical dietary advice; achieve required nutrients; maintain healthy growth and body weight; and optimize whole of life health. In addition, guidelines should meet the SDGs and reduce GHGs (22). A review of food-based dietary guidelines from 34 European countries and their sustainability credentials concluded that shifting from current Western diets to more sustainable dietary patterns produces benefits. Consuming more plant-based foods (e.g., vegetables, fruit, legumes, seeds, nuts, whole grains) and fewer animal-based foods (especially red meat), snack foods, and beverages would improve health and have environmental benefits (12). Recent regional dietary guidelines recommend similar changes and usually include physical activity, healthy body weight, breastfeeding, clean water, safe food, less sugar and salt, decreases in saturated fats, and elimination of *trans* fats (22). Another example of regional recommendations is the Nordic Nutrition Guidelines, which would produce health benefits such as a reduction in cardiovascular disease and cancer and would lessen environmental stress (117). In **Table 1**, the general recommendations in dietary guidelines are shown for the major food groups, current production levels, and suggested changes to implement by 2030.

3.3. Dietary Guidelines and Changes Needed to Ensure Sustainable Food Production

In a summary of 12 major reviews of DGs and climate change, all the diets optimized for sustainability and nutrition were more plant based, with reductions in meat, particularly ruminant meats (beef and lamb). Six studies recommended increased fish intake, while the majority suggested fewer dairy products. Other foods to be reduced included sweet foods (biscuits, cakes, desserts), savory snacks, white bread, and both alcoholic beverages and sugar-sweetened beverages (SSBs). These findings are similar to those in 7 out of 8 recent review articles on the sustainability of diets (150). Examining the 14 discrete environmental areas of concern identified in the SDGs, most studies are on GHG emissions and, to a lesser extent, land and water use. In the case of GHG emissions, changes in land use and soil carbon stocks were seldom considered, which represents a disconnect between science informing strategic climate action in the agricultural sector and science informing public health nutrition. In the case of land and water use, few studies used metrics that are appropriate in a life-cycle context. The evidence available shows that recommended diets have lower environmental impacts than do typical diets (112). A consistent scientific approach to estimating the impact of climate on diet and vice versa is required (68, 71, 72).

Many national DGs already include recommendations related to changes that would improve health and would be beneficial to the environment and sustainability. For example, Argentina Australia, China, New Zealand, Sweden, Switzerland, the United Kingdom, and the United States suggest increasing consumption of whole plant foods, vegetables, fruits, legumes, and fewer animal foods (7, 29, 32, 48, 66, 95). Canada is representative of a number of countries who also recommend reducing SSBs and eliminating *trans* fats (8).

3.4. Special Population Groups

The special needs of some population groups, including infants, children, pregnant women, and the elderly, should be considered in planning responses to climate changes and healthy eating. In many countries, complementary diets given to infants after the age of six months are high volume and often low nutrient density, limiting nutrient intake (e.g., iron) (18). While nutrient density is important in infants and young children, a diet high in fiber becomes more important in adults for the prevention of chronic disease.

Children are the population segment most susceptible to the effects of climate change, bearing an estimated 88% of the increased burden of disease (108, 110, 128). Food security for infants

Table 1 Changes to food production to meet sustainable dietary guidelines

Food group	Projected changes in food production (IPCC)	DGs recommendations[a]	WHO nutrition recommendations	Nordic recommendations	HICs, current availability	LICs, current availability	Conclusion: changes needed by 2030
Nuts	Decrease	Increase	Increase	Increase	Insufficient	Insufficient	Increase needed
Meat, animal products	Decrease	Decrease red and processed	Decrease	Decrease	High (reduce)	Sufficient	Decrease red and processed
Fish	Insufficient	Increase	Increase	Increase	Insufficient	Coastal areas vary; often sufficient	Increase (aquaculture)
Grains	Increase	Increase whole grain	Increase	Increase	Insufficient	Usually sufficient	Increase
Vegetables, pulses	Increase	Increase	Increase	Increase	Insufficient	Sufficient	Increase
Fruits, berries	Decrease	Increase	Increase	Increase not enough	Insufficient	Insufficient	Increase
Dairy		Decrease; use low fat		Decrease; use low fat	Too high	Insufficient	Decrease
Fats and oils		Decrease overall, especially saturated and *trans*	Avoid animal fats; limit saturated; No *trans*		Decrease	Decrease fats	Decrease fats
		Increase unsaturated	Prefer unsaturated			Increase unsaturated from fish, plants	Increase unsaturated from fish, plants
Sugar, SSB	Decrease	Decrease	Decrease	Decrease	Too high	High	Decrease
Salt		Decrease	Decrease; use iodized		Too high	Too high	Decrease
Alcohol		Limit	Limit	Limit	Limit	Limit	Decrease
Breastfeeding		Increase	Increase	Increase	Insufficient EBF	Insufficient EBF	Increase EBF
Food processing[b]		Decrease ultra processing					Implement DGs in processing
Wastage	Decrease	Decrease			Too high 35%	Less than 20%	Reduce wastage

Abbreviations: DG, dietary guidelines; EBF, exclusive breastfeeding; HICs, high-income countries; IPCC, Intergovernmental Panel on Climate Change; LICs, low-income countries; SSB, sugar-sweetened beverages; WHO, World Health Organization.

Colors: green, increase; red, decrease or limit; yellow, insufficient or change needed.

[a]Recommendations common to most dietary guidelines.

[b]Important for reducing wastage, improving bioavailability; aim to achieve DGs.

and young children is not possible without promoting and achieving high rates of breastfeeding. Despite endorsements by all international professional organizations, the World Health Organization (WHO), and governments, breastfeeding targets have never been achieved on a global scale (118). The health benefits of breastfeeding, both during infancy and throughout life, including the preservation of a healthy microbiome, have been extensively studied and will provide some protection against the effects of climate change (16, 17, 149). Even in disaster situations, including famine, breastfeeding remains the best option for meeting infants' nutritional needs (23). The alternative to breastfeeding is infant formula, which is usually based on cow's milk. While milk production in the twenty-first century is more efficient than in the past, the total impact is greater owing to increased production (27). When compared with breastmilk, milk production uses large amounts of water, which will be in scarce supply with climate change, and has a high carbon footprint (124, 130).

Vietnam is an example of a low- to middle-income country (LMIC) that will experience water stress owing to climate change affecting the Mekong system; at the same time, Vietnam's milk production has increased by 12% per annum over the past decade (146). In LMICs, infant formula is increasingly advertised on the Internet, which is accessible almost everywhere by smartphone and is driving increased consumption and decreased breastfeeding. In recent years (2006–2011), imports of infant formula to Vietnam have increased by 150%, and the response of the local industry, with government support, is to boost the formula and dairy industries (125). Breastmilk is the ideal food for infants, with benefits that last into adulthood, which is important for achieving the SDGs; however, the global infant formula and dairy industries are formidable opponents (19, 21, 88, 124). Extensive promotion of breastfeeding would provide benefits for infant health, reduce health costs, and benefit the environment (46). The increase in adverse weather events along with rising population densities and uncontrolled distribution of infant formula heightens the risk to breastfeeding in disaster situations (i.e., the possibility of breastfeeding being discontinued) (23).

The elderly are vulnerable to increasing temperatures and require extra fluids and access to nutritious diets. They often move to urban environments away from traditional foods and extended family support. For them, food traditions are deeply engrained in culture and change is not easy. Traditional foods may no longer be available owing to agriculture shifts because of climate change, and meeting their nutrient needs is often compounded by dentition and mobility problems. Specific nutrients at risk include vitamin D, B_{12}, iron, and protein (105). In a Swedish study, the diets of the elderly were found to be more GHG intensive (129).

4. IMPLEMENTING CHANGE: WHAT WILL BE NEEDED?

Future objectives for the food and nutrition sector will be to improve the quality of the food supply for everyone (food and health for all) while navigating the changes expected in food production over the next several decades. Nutrient deficiencies may increase in LICs and recur in HICs, as food diversity decreases and changes in nutrient content occur. The changes in crops and farmed seafood (aquaculture) will require monitoring of nutrient composition and bioavailability, phytochemicals, and dietary content. The predominant guiding philosophy of public health nutrition has been to meet all nutrient needs through eating a variety of healthy foods. This approach may no longer be possible and may have to be met by fortification and supplements.

Micronutrient deficiencies, particularly iron, zinc, and vitamins, are of great importance (39). Issues around interventions are complex because it is difficult to ensure adequate amounts without a risk of toxicity (84). Biofortification with iron and vitamin A has proved challenging in delivering consistently safe doses while minimizing side effects, including infections (24). The preferred option is always to eat a varied diet of nutrient-dense foods.

With improved food production in recent decades, the distribution of food consumption has shifted to the right. Too little food, the left of the curve, results in undernutrition with a substantial burden of morbidity and mortality, whereas at the opposite end of the spectrum obesity and its sequelae cause major health problems for the two billion adults who are now overweight or obese.

India is an example of an LMIC that succeeded in shifting the food distribution curve to the right, with less undernutrition but more obesity (5, 156). Reduction of both undernutrition and overconsumption (obesity) simultaneously implies a compression of the food consumption curve by balancing increased physical activity with energy intake. This approach requires improvements in food and nutrition equity within and between countries (18, 109, 145). Swinburn et al. (132) describe an international pandemic of obesity, undernutrition, and climate change causing major health problems for humanity as a "syndemic." The obesity epidemic is also affecting infants and young children, owing at least in part to declines in breastfeeding, increased use of infant formula and SSBs, and disruption of the microbiome (60, 120) (see **Figure 3**).

Consumption of food groups such as fruits, berries, nuts, and unsaturated oils should be increased. However, these groups are projected to decrease, and research is required to increase yields. Ensuring potable water for all (for drinking, food preparation, cleaning, washing) rather than using it for increased irrigation and other projects will be difficult. The inevitable decrease in meat supplies (and other animal foods) will cause tension as decisions are made either to distribute meat more evenly around the world to meet iron and protein deficits or to supply steaks and hamburgers to wealthy countries. Additional promotion is needed for breastfeeding and for the reduction of wastage, food contamination (chemical and microbiological), and spoilage. Better packaging and storage are needed to achieve these aims.

Meeting future food needs (up to 50% more by 2050) is possible and can result in healthier diets (91). However, improved diets will not just happen from changes made to food production to moderate climate change. Health promotion will be needed to actively drive changes in eating practices (75). The strengthening of health promotion and public health programs, aimed at preventing overweight and obesity and treating chronic disease with nutrition interventions, will be an effective climate change adaptation strategy (127).

Some nutritional needs will be met with fortification or supplementation (e.g., sprinkles) rather than through an increased variety of foods (37, 111). Aquaculture and mariculture of fish with monitoring for nutrient content and improved food stocks will be needed. Nutrient content in and technological modification of cultivars will need ongoing monitoring to maintain and improve nutritional quality. Toxicants may be produced by plants in response to climate change and must be monitored. Research is needed for improving the production of fruits, nuts, berries, etc. With the loss of biodiversity, nutritional deficiencies may emerge, and it may be many decades before all nutrient functions are discovered. Potential interactions with the use of supplements and fortification should be monitored. Continuing research into the promotion of dietary guidelines and better food storage, packaging, and preservation is required. There may be a loss of cultural and culinary traditions. While change has always been a part of human society, the impact of the relatively rapidly changing climate is unknown.

Generally, the dietary guidelines that already exist are more environmentally friendly than are existing food consumption patterns, and, if applied uniformly, they will improve health and enable the SDGs to be met. A carefully selected diet that meets environmental needs can meet all nutrient requirements (9). Overcoming the barriers will depend on health promotion and motivation to change, equity in food distribution, and international collaboration to meet the threat to human life as we know it. Actions needed to improve and apply dietary guidelines in the climate change era are as follows:

1. Global commitment to international collaboration on environmental action and to carbon-neutral economies;
2. Education on nutrition and health;
3. Improved monitoring of food production and safety and nutrient content;

4. Control on the reckless promotion of unhealthy foods by industry (and by governments, e.g., the US government pressuring countries to accept infant formula);
5. Elimination of government subsidies for the production of unhealthy foods and foods that are detrimental to the environment;
6. Increases in the production of fruit, nuts, and vegetables (how do we do this when forests and orchards are disappearing?);
7. Reductions in the use of discretionary foods that are generally high in sugar, fat, or salt;
8. Taxes on sugar, salt, and saturated and *trans* fats, with incentives for nuts, etc. (107);
9. Breastfeeding promotion, control on infant formula sales, and implementation of WHO code (107, 147);
10. Improved distribution of food across countries at all levels of development along with a reduction in food wastage (104); and
11. More research on implementing change, including on determining how to get wealthy nations to reduce excessive intakes of environmentally costly foods.

We recommend that research focuses on the following three considerations. First, nudge theory may produce gradual change over time (20). Because healthy diets alone may not produce substantial reductions in GHG emissions, DGs need to emphasize recommendations for environmental sustainability. Minimizing the shift from current foods is likely to make changes more achievable (77). Second, changing populations' ambitions is a concern; when a country becomes richer, its population adopts Western diets. Why does this happen when Western diets are less healthy and have environmental and social disadvantages? Third, why are fat chubby babies perceived as healthy and desirable in Asia (33, 93)?

4.1. Threats to Progress

A range of responses to the simultaneous climate and COVID-19 crises are possible. Governments may seek rapid recovery from the COVID-induced economic crisis and use cheap fossil fuels to pursue economic growth regardless of the environmental costs. An optimistic scenario would see governments working together with low-carbon technologies to reduce GHGs while reducing poverty and inequality (135).

4.2. Food Equity

In nutrition, equity implies enough food to grow and develop optimally and to avoid deficiencies, stunting, obesity, infectious diseases, and excess chronic disease. It will never mean that everyone will eat exactly the same food prepared in the same way—a monotonous uniformity that ignores millennia of culinary traditions. It also means adequate amounts of potable water for drinking, food preparation, and washing.

4.3. Pandemics

Public health workers have been dreading another influenza pandemic. But the risk of other epidemic infectious diseases (EIDs), including newly emerging diseases, is ever present. Few recent epidemics have the global significance of COVID-19. Around 70% of EIDs, and almost all recent pandemics, have originated in animals (the majority in wildlife), and their emergence stems from complex interactions among wild and/or domestic animals and humans (45). The COVID-19 epidemic is imposing strains on the world food supply chain, including labor shortages, transport constraints, and the closure of food processing plants (151). People who live in areas of food crises have higher rates of malnutrition (acute, chronic, and micronutrient deficiencies), weakened immune systems, and increased rates of chronic disease. If they contract COVID-19, the consequences will be more severe. Increased illness and death will create further food shortages owing to labor shortages, which will exacerbate the effects of climate change on food production. Individuals with obesity and noncommunicable diseases have an increased risk of a more severe course of COVID-19 infection, which should give more impetus to governments to tackle and prevent obesity and related noncommunicable diseases (119).

4.4. Conflict

Shortages of water and/or food have historically been major sources of conflict, and these conflicts continue to this day (92). Conflict or other security issues were the main cause of food crises in 2019, but weather extremes and economic shocks became increasingly significant compared with 2018. Most of the countries with food insecurity have limited resources to deal with epidemics or severe adverse weather events. The Global Report on Food Crises documents that during 2019 135 million people were classified as acutely food-insecure (up by 12% from the previous year) (70). Food insecurity along with water shortages, poor sanitation facilities, and lack of access to quality health care have contributed to declines in child nutrition. Most instances of severe food and water shortages in Africa are often related to conflict (64, 70). A long-term association has been demonstrated between food crises and conflict (26). Rapid increases in food prices in urban areas can result in social and political unrest and, at a regional level, can be a trigger for conflict. Changes in climatic conditions, including long-term climate changes, increase the risk of violence and conflict (26).

4.5. Political Inertia and Short-Term Planning

Both climate change and the emergence of overweight and obesity are slowly evolving issues, and humans have difficulty in appreciating the need for urgent action in these situations (69). Too much time has already been lost, and this effort needs to begin now and to be integrated across all disciplines (68, 72, 132). As consumers become richer, they tend to purchase more varied, higher priced, and highly processed foods, or they eat out (72). The rich pay higher prices per nutrient and outbid poorer countries for foods that provide essential nutrients, such as iron from meat. Food prices, especially of nutritious foods, may increase as a consequence of reduced productivity, putting further strains on low-income households (56). Policies aimed at reducing poverty and income inequality, while enhancing employment and income-generating activities, are key to raising people's incomes and ensuring the affordability of healthy diets.

4.6. Multinational Businesses and Climate Change

The agriculture, transport, food processing, retail, and marketing sectors need to orient their goals toward improving health and the environment by producing and advertising foods that meet the SDGs while consuming less energy. There is an increasing need for responsible corporate policy and investment to contribute toward improving the environment (89). Can the corporate world change its ways? Can they be encouraged to produce foods that minimize climate impact, are environmentally friendly, and are health oriented?

5. CONCLUSION

Substantial progress has been made in improving global nutrition. Obesity and chronic disease now represent new global challenges, even while undernutrition persists in some populations.

Reducing and even reversing anthropogenic climate change have so far proved extremely difficult or impossible. GHGs, which are environmentally detrimental, are still increasing, driven by higher standards of living in modern consumer societies. Getting people to change individual habits and cultures and to share with other nations who are less well-off has not proved possible to date.

Many studies have shown how following dietary guidelines could improve overall health and reduce obesity and chronic disease if food production, processing, distribution, and consumption follow this advice. Research has offered consistent predictions on how food production will change in the future and how these changes could be compatible with healthy diets. As the climate changes, improved technology will be needed to maintain food supplies and ensure that all nutrition requirements are met. If food variety declines, additional research will be needed to improve micronutrient content to meet nutritional needs.

Some foods that should be made more accessible and are associated with improved health, such as whole grain cereals, fruits, vegetables, legumes, nuts, berries, and olive oil, have low environmental impacts. Red meat and dairy products have the largest negative environmental impacts and are generally associated with a higher disease risk. Increases in supplies of fish are needed, while ensuring that their nutritional quality is maintained. Increasing breastfeeding rates is important and achievable for improving health and reducing the environmental impact of alternatives. Dietary transitions toward greater consumption of healthier foods would improve environmental sustainability and health. However, considerable change in the food industry and consumer behavior will be required, as, so far, no country has successfully reversed the obesity epidemic because the systemic and institutional drivers of obesity remain largely unabated.

The evidence, to date, demonstrates that major advances in sustainable food production and availability can be achieved if all the political efforts and science can be mobilized to apply improved technologies.

SUMMARY POINTS

1. Nutrition improved in the last few decades, but undernutrition is still prevalent in some regions while obesity is increasing in others.
2. Climate change will affect health and will substantially change food production. For the medium term, it will be possible to produce enough food to maintain adequate intakes, using improved farming practices and technology and more equity in distribution.
3. Following dietary guidelines would improve health, help reduce GHGs, and meet the SDGs.
4. Monitoring of nutrients in food will be essential.
5. Increasing breastfeeding has benefits for health and the environment.
6. The combination of climate change and improvements in the quality of nutrition is the major public health challenge of this decade and, indeed, this century.

FUTURE ISSUES

1. Ongoing monitoring of and research on food supply (quantity and quality) and nutrient content are required.
2. Monitor and promote breastfeeding and the marketing of artificial substitutes.

3. Research into the environmental footprint of foods is needed.
4. Continuing efforts should focus on understanding ways of encouraging populations to follow DGs. Monitor the DGs in the light of climate and health changes.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

AUTHOR CONTRIBUTIONS

All authors have read the final manuscript and approved its contents. C.W.B. and M.K.L. undertook the initial literature search. All authors wrote sections of the manuscript. C.W.B. and M.K.L. undertook final editing and formatting before final approval by all authors.

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