Strategies for achieving healthy, sustainable, and equitable dietary transitions

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Abstract

The industrialization of global food systems has led to dietary changes that harm both health and the environment. If global food systems are to meet the needs of a growing population for healthy, environmentally sustainable, and affordable diets, substantial changes will be required. In this Review, we synthesize growing empirical evidence on the complexity of factors influencing consumer dietary and farmer production choices, especially the roles of public and private entities that shape food environments. We outline promising interventions to help facilitate beneficial global dietary transitions, including research and development for product innovation, regulation of food environments, and food assistance and food-as-medicine programs. Understanding and aligning the motives and incentives of various food systems actors is essential to achieve improved health, environment and equity outcomes.

Rising incomes, urbanization, the industrialization of agriculture and the manufacturing of thousands of flavorful processed foods are driving global dietary transitions with major health and environmental consequences (*1*–*3*). Current diets are characterized by insufficient consumption of vegetables, fruits, legumes, nuts and whole grains, and excessive intake of animal-sourced foods, and foods with added sugars, refined starches, sodium, saturated and trans fats, and artificial colors and preservatives (*2*). This dietary transition is happening in rich and poor countries alike, contributing to adverse health outcomes, such as increased incidences of type 2 diabetes, coronary heart disease, some cancers, and other non-communicable diseases (*4*). These dietary changes also contribute meaningfully to multiple global environmental issues, including climate change, water pollution, land clearing and associated species extinction, and novel infectious diseases (*5*, *6*). Livestock production, in particular, results in water and air pollution from manure management and feed cultivation, methane emissions from ruminant enteric fermentation, CO_2 emissions and biodiversity loss from lands cleared to create pastures and croplands, and accelerated zoonotic disease transmission and antimicrobial resistance (*7*). These converging health and environmental concerns have led researchers — over decades and with a growing body of compelling evidence — to identify and advocate for dietary patterns that benefit both people and the planet (*1*, *2*, *8*–*11*). Despite these findings and repeated efforts to shift agricultural production systems, food manufacturing and marketing practices, and consumer behavior, wide-scale shifts toward healthier and more environmentally sustainable diets have not occurred.

To qualify as "sustainable", dietary transitions must decrease the environmental harms of agriculture, including irreversible impacts such as species extinction. "Healthy" diets should include sufficient amounts of vegetables, fruits and nuts, and provide a balance of macronutrients, micronutrients, and bioactive components (e.g., fibers, nutraceuticals, antioxidants, and probiotics) that promote human wellbeing rather than increasing the risk of chronic diseases, while minimizing additives, anti-nutrients and contaminants (*12*, *13*). Because 3.1 billion people have incomes insufficient to afford a healthy diet (*14*) and 3.8 billion live in households with a food system worker (*15*), dietary transitions should also be just or "equitable" (*16*) so that everyone can reliably access sustainable, healthy and culturally appropriate diets. Sustainability, health and equity goals in food systems do not always align perfectly, but growing evidence shows they are largely compatible (*1*, *2*, *7*, *17*) and can reinforce one another when pursued together (*18*). This will require prioritizing the affordability of healthy and sustainable foods, many of which can be more expensive than less healthy options, especially in low- or middle-income countries (LMICs).

No country currently enjoys truly sustainable, healthy and equitable diets. Challenges vary in relative importance across societies, however. In high-income countries (HICs), greenhouse gas emissions, air and water pollution, and soil degradation are the primary agricultural sustainability challenges (*19*), while clinical obesity and non-communicable diseases like diabetes are the dominant diet-related health problems (*20*). In contrast, LMICs face all forms of malnutrition (*21*), including mineral and vitamin deficiencies (*22*) and undernourishment (i.e., insufficient calories), especially in conflict-affected regions (*23*), as well as rising rates of obesity (*24*). Meanwhile, LMICs struggle with rapid deforestation and biodiversity loss, owing partly to agricultural exports to HICs (*25*). Globally, people with low incomes, limited educational attainment, and poor social networks disproportionately suffer from food insecurity and diet-related disease, in both HICs and LMICs (*26*). The nature of the dietary transitions required, and the tools to facilitate such changes, thus vary considerably across communities and countries.

Because consumer demand drives producer behavior, and producer actions likewise influence consumer food choices, fundamental changes to the global food system and its health and environmental impacts require that both consumer and producer behaviors change in coordinated manners. Food systems' environmental outcomes arise mainly from crop production (*27*), livestock and feed production (*7*, *28*, *29*), and the associated land, water, agrochemical, and effluent management choices made by the world's 600–700 million farmers and fisherfolk (*30*). Health outcomes arise mainly from >8 billion consumers' daily dietary choices that are shaped by a complex web of influences (Fig. 1) and broader societal structures, including knowledge, taste, price, availability, incomes, convenience, social norms and culture (*31*–*34*). Equity outcomes follow from how policies and market systems reward workers and business owners throughout the economy, and from the costs of healthy diets relative to incomes and available food assistance. In upper middle- and high-income countries, workers in the midstream food industries far outnumber those in primary agricultural production (*35*) (*31*).

In this Review, we synthesize a wide body of evidence to provide a comprehensive understanding of the drivers of dietary choices and to identify promising areas of intervention for improved health, sustainability, and equity outcomes. Our evidence base encompasses a broad spectrum of potential levers, from direct influences on consumer choice like price, availability, and taxes to subtler, often-overlooked factors, such as research and development (R&D) investments, supply chain innovations, institutional procurement, and industry strategies that shape product formulation, taste and presentation (*36*–*40*). This systems perspective highlights how value chain actors that are intermediate between consumers and primary producers — e.g., manufacturers, processors, wholesalers, retailers, restaurants, food banks and pantries — offer underexplored but potentially powerful levers to accelerate progress towards transformative dietary shifts. Although these midstream actors are far fewer in number than either farmers or consumers (Fig. 1), they wield disproportionate power over both groups and shape their decisions in ways that often go unnoticed and result in adverse sustainability, health and equity outcomes (*41*). Finding ways to leverage and redirect that power is essential to achieving sustainable, healthy and equitable dietary transitions (*42*).

WHO AND WHAT INFLUENCES DIETARY DECISIONS

Rather than making fully autonomous decisions, farmers and shoppers are constrained by complex interactions among sensory preferences, price signals, cultural norms, and private and government standards and practices, cumulatively, the 'food environment'. In particular, profit-seeking companies today optimize commodity procurement and food production for consumer sensory and sociocultural appeal, affordability and shelf stability, and often at the expense of health, equity, and sustainability goals (*43*). As a result, interventions must target not just individual consumers' dietary choices or farmers' production practices but especially the systemic structures that shape dietary and production choices at scale, many of which originate in the midstream of food value chains. This demands a diverse portfolio of policy and technological innovations, tailored to specific contexts and able to confront pressing issues (*44*).

Consumers' dietary choices are strongly impacted by food industry reformulation, product innovation, and marketing (*36*, *45*). Studies from multiple countries and cultural contexts consistently highlight the central role of taste and sensory appeal in individual food choices (*46*–*48*). Most people prefer sugary, salty, fatty, and umami-tasting foods, tastes that midstream actors enhance and make more affordable through processing. These processed foods displace healthier options, such as fresh and minimally processed plant-based foods, which tend to lack the umami taste that comes from the breakdown of adenosine triphosphate in cooked animal muscular tissues. This may help explain why people also tend to consume more umami-rich cooked meats as their incomes rise — even though meats are expensive relative to other foods (*19*, *49*) — but nutritionally insufficient quantities of fresh vegetables, fruits, whole grains and legumes. A change toward a plant-rich diet requires better-tasting, smelling and looking alternatives. Indeed, highlighting taste and flavor on food packaging leads to healthier choices more successfully than does only showing nutritional content (*50*).

Affordability is another cornerstone of consumer food choice. A recent meta-analysis found that a 20% reduction of fruit and vegetable prices can lead to a 16.6% increase in purchases (*51*). Nutrient-dense foods, such as fruits, vegetables, nuts, and animal-sourced foods, cost relatively more to produce per calorie or per gram of protein than energy-dense starchy or fatty foods, and foods or drinks with added sugars and flavorings (*52*). Consumption of nutrient-poor foods is strongly associated with poor health outcomes, including child stunting and adult obesity. Addressing food prices is therefore not merely an economic issue but a public health imperative.

Convenience matters enormously to dietary choices. As incomes rise, populations urbanize and more women enter the workforce. These phenomena raise the opportunity cost of time, and consumers increasingly seek third-party food preparation, which saves time but costs money (*53*). Consumption of food away from home (FAFH) — from restaurants, schools, vending machines, and the like — rises steadily as a share of total food expenditures as incomes grow (*20*, *35*, *54*). In the US, for example, FAFH captured nearly 60% of the $2.63 trillion spent on food in 2024 (*55*). In LMICs, the fastest growing food enterprises are fast-food restaurant chains (*53*). Increased FAFH consumption, however, is associated with reduced consumer knowledge of the ingredients and culinary techniques used in the foods they eat, more impulsive consumer behavior, and perhaps relatedly, lower diet quality and increased caloric intake (*56*, *57*).

In addition to sensory appeal, affordability, and convenience, consumers also consider foods' healthfulness (*58*). But healthy diets require emphasizing nutritional quality beyond macronutrient composition. While ingesting enough protein is often cited as a dietary concern, for many populations the limiting nutrients provided by animal-based foods are not proteins but rather iron, vitamin B-12, vitamin D, omega-3 fatty acids, or other micronutrients (*59*, *60*).

Consumers make food choices within broader food environments that reflect social norms and cultural expectations (*61*–*63*). The rise of Western-style diets in many LMICs, for example, reflects not only the convenience and sensory appeal of processed foods, as well as increased incomes and urbanization, but also a cultural association of Western food with status and success (*64*). Food marketing and retail design reinforce these cultural cues. For instance, strategic placement of unhealthy foods in stores and restaurants, price promotions, product displays, packaging and advertising all contribute to the overconsumption of less healthy, less sustainable products (*37*, *65*, *66*). As such, retail and restaurant food environments are both a driver and a reflection of consumer preferences. Changing them requires regulatory tools, incentive structures, and consumer education to adjust food environments and shift the default dietary options toward healthier and more sustainable choices (*34*). Changing school food environments through, e.g., nutrition standards, fruit and vegetable provisions, and improved presentation has been shown to improve children's selection and consumption of healthier foods (*67*, *68*). The introduction of School Food Standards in the UK and the Smarter Lunchrooms movement in the US are successful examples (*69*, *70*).

On the primary production side of the food value chain, farmers' decisions follow mainly from profitability concerns that determine their income. Even in LMICs with many small farmers, the overwhelming majority of the food that farmers consume comes from market purchases rather than from their own production (*71*), hence farmers' focus on profitability. Which producer practices prove profitable depends upon input and land costs, yields, what midstream actors will pay for farm outputs, the non-price terms of procurement contracts (e.g., production practices), and government policies (e.g., price supports). As rising incomes and urbanization drive increased demand for meat and convenience, midstream actors pass those market signals upstream to producers. That induces land use changes in farming, as farmers seek bigger, more remunerative markets for their output. In Brazil, intensive crop area, particularly soybean, nearly doubled from 2000–2014, driven by market liberalization, favorable international prices, and advances in production methods (*72*). In the US, ~90% of agricultural land is tied to livestock, including both grazing areas and cropland devoted to producing feed crops like corn, soy, and hay (*73*). Through a variety of means like green premiums, carbon credits, direct partnerships, technical assistance, and contracting provisions requiring specific practices, midstream intermediaries can induce farmers to adopt more sustainable or equitable production practices when it is profitable (*74*, *75*).

These complex paths of causality behind consumer and producer behaviors help explain why nudges targeting individual consumer or producer behavior often have limited impacts (*39*, *40*). They are often overshadowed by multiple systemic influences of the broader food environment within which individual consumers make food acquisition and consumption decisions and producers make choices about land, water, and agrochemicals use (*42*). Government policies, along with civil society pressure from upstream producers and downstream consumers, can influence midstream actors' choices that in turn influence the upstream and downstream ends of the value chain where most food systems sustainability and health impacts originate. Some of these problems could be addressed if government and civil society entities became more intentional in redirecting midstream actors by making 'doing good' more consistent with 'doing well financially', using contextually-appropriate bundles of interventions of the sort to which we now turn.

PROMISING AREAS OF INTERVENTION

Research on drivers of consumer and producer choice points to several key areas of intervention that can support the transition to healthier, more sustainable and equitable diets. These interventions target different nodes within food systems and seek to realign incentives, reshape consumer, farmer and industry behavior, and promote equitable access to nutritious foods produced sustainably. Food systems transformation typically requires contextualized combinations of multiple interventions so as to suit local agroecosystem, sociocultural, and political economy conditions (*44*).

R&D for product and process innovation

Public and philanthropic R&D that promotes product and process innovation has historically been the engine of food systems transformation, reducing real food prices, improving diets among the poor, and sparing conversion of natural lands to agriculture (*38*, *44*, *76*–*78*). Yet public spending on agricultural R&D has fallen sharply in HICs since the 1990s, and by one-third since 2002 in the US, while returns on this R&D have never been higher (*79*, *80*). Private food R&D now far surpasses public and philanthropic investment (*81*, *82*) but naturally focuses much more on profits for investors, than sustainability, health, or equity benefits. Restoring, indeed boosting, public and philanthropic R&D is important to again bring down real food prices, spare conversion of natural lands, and reduce overuse of scarce freshwater and toxic chemicals. The best available causal evidence finds that agricultural R&D that boosts agricultural productivity tends to reduce land use in farming, consistent with the 'Borlaug hypothesis' (*77*, *83*, *84*).

Agrifood R&D, however, needs reorientation from increasing staple yields to improving the sustainability of agricultural production given its massive global environmental impacts (*11*). It also needs reorientation to more nutrient-dense specialty crops (*85*) because today, undernourishment — insufficient energy intake — is far less widespread than micronutrient deficiencies. To address micronutrient deficiencies, R&D investments should focus more on improving the production, affordability, and sensory appeal (taste, texture, aroma) of healthy foods, such as vegetables, fruits, nuts and healthy-oil foods. Increased productivity of these so-called specialty crops can also improve sustainability, especially through reduced land use in agriculture (*86*). Given the dietary benefits of fish and seafoods and risks to marine ecosystems from overfishing, R&D investments in aquaculture, including on- and off-shore production, should be increased to reduce the prices of many blue foods, especially those such as seaweeds and farmed bivalves and salmon that both are nutritious and have far lower environmental impacts than many livestock meats or wild capture fisheries (*87*).

Post-harvest processes account for >70% of the value addition in consumer food purchases globally (*88*). Thus, R&D to reduce the cost and energy-intensity and to improve the healthfulness and shelf-life of processed nutrient-rich foods likewise merits prioritization. Healthy foods like fruits and vegetables are highly perishable and suffer high loss rates, up to 40–50% between production farmer and final consumer in LMICs (*89*). This can be partly addressed by targeted incentives and public–private partnerships that drive industry investment in enhancing nutrient-rich foods' shelf-life and reducing their spoilage over distribution (*90*). It is likewise feasible to induce biocircular practices that capture and repurpose waste streams for use as energy, fertilizers, or livestock feed (*91*). Reducing these supply-chain losses is a complementary path to R&D for improving productivity. All of these investments in innovation are especially important in LMICs, which have far higher incidences of undernutrition, enjoy higher rates of return on agricultural R&D than HICs (*80*), and will account for most of the growth in future food demand (*44*).

Another important area of food R&D is alternative proteins. The large environmental impacts of livestock production have spurred worldwide interest in more sustainable alternative proteins (*92*), such as next-generation plant-based products designed to resemble meats, seafoods, eggs, and dairy products; cultured meat grown in bioreactors; mycoproteins grown in fermentation tanks; and farmed insects. Broad adoption of these alternative protein sources will require advances in their affordability, accessibility, desirability, convenience, and nutrient composition (*93*). They must not only replicate the sensory appeal of meats to entice people to eat them, but also provide all of the essential micronutrients found in animal-based protein sources so as to generate similar nutrition and health benefits (*94*). Achieving nutritional adequacy through these alternatives requires advances in formulation and fortification, informed by ongoing scientific research (*95*), as well as consumer nutrition education throughout the life course. These foods are complex materials that contain a wide range of additives that contribute to these attributes, including colors, flavors, thickeners, gelling agents, binders, micronutrients, and preservatives. Thus, understanding the relationship between their composition, structure, properties, and nutritional value is extremely complicated, which makes intelligent food design challenging. Alternative proteins may also be less digestible or bioavailable, and contain fewer essential amino acids than animal proteins, which may require food reformulation to achieve appropriate nutritional profiles (*96*). Many natural foods, for example fish, may offer health advantages because of one or more essential nutrients they supply, such as omega-3 fatty acids.

Affordability and access to healthy foods

Affordability depends on both food prices and the funds available for food procurement. Given that 3.1 billion people worldwide cannot afford healthy diets (*97*), expanding and strengthening food assistance programs could provide a more effective safety net and support dietary improvements among low-income populations. Food assistance programs, which supported an estimated 1.5 billion people worldwide in 2016 (*98*), are effective at improving nutrition (*99*, *100*). In LMICs, supplementary and therapeutic food assistance offer a cost-effective in-home treatment for children suffering moderate or severe acute malnutrition, significantly improving child health, nutrition, even survival (*101*, *102*). In the U.S., the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) has improved infant and child health, with high benefits per dollar spent, by providing low-income participants with resources to buy selected, nutritious foods while maintaining individual purchasing autonomy (*103*, *104*). Similarly, the Supplemental Nutrition Assistance Program (SNAP) improves food security and health among low-income American households (*105*). The importance of addressing affordability directly through means such as food assistance programs is also supported by studies on food deserts, areas with limited access to affordable, healthy foods. For example, equalizing product availability and prices between low- and high-income households would close only ~10% of the nutritional gap, with the remaining 90% driven by demand-side factors associated with income differences (*106*). Simply making healthy food available does not ensure uptake, underscoring the need for more direct interventions like food assistance programs.

Most food assistance programs provide participants with resources to spend in commercial food retail outlets. Hence the need to incentivize retailers to stock healthy, sustainable products and beneficiaries to make healthy food choices, as in the WIC design. These interventions can also generate spillover benefits, such as product reformulation and shifts in social norms, extending their influence beyond direct beneficiaries (*107*). If, by contrast, such programs fail to make healthy foods more convenient and affordable, they risk inadvertently reinforcing the consumption of inexpensive, unhealthy options. Continuous program monitoring and adjustment are essential to prevent these unintended effects. Global food assistance systems could draw lessons from WIC's targeted, nutrition-focused approach. In LMICs, expanding school meal programs, food-for-work schemes, and maternal-child nutrition initiatives can simultaneously improve health outcomes and support local food systems (*108*, *109*). For example, school feeding programs in Burkina Faso that sourced legumes and fortified vegetable oil locally not only improved child nutrition but also boosted smallholder farmer profitability and food safety (*110*).

Because even the poor depend overwhelmingly on private food marketing systems unsupported by food assistance, reducing the price gap between healthy, nutrient-rich foods and calorie-dense, nutrient-poor foods is crucial. Policies can support this goal not only by investing in R&D to boost the productivity and sustainability of horticulture and aquaculture, but also through targeted input subsidies for (especially small-scale) producers of such products, and rural infrastructure improvements to reduce post-harvest losses. Public-private partnerships could fund refrigerated crop logistics and reduce transaction costs that make nutritious foods more expensive. Another option is drying — especially solar drying — which offers a sustainable way to extend the shelf life, nutrition and year-round availability of fruits and vegetables (*111*).

Taxes and subsidies can be used to change relative prices and induce consumers to substitute cheaper, subsidized healthy foods for taxed, and thus more expensive unhealthy foods. Sugar-sweetened beverages provide the most prominent example. Evidence from middle- and high-income countries shows that taxes on sugar-sweetened beverages have consistently reduced their purchase and intake (*112*, *113*). In some high-income countries where meat intake exceeds health and environmental recommendations, similar fiscal strategies are now being considered to curb excessive meat consumption. While there is growing policy interest in meat taxes, especially within the EU (*114*), these measures face considerable political resistance, including concerns about disproportionate impacts on lower-income groups that may have insufficient meat consumption due to unaffordability. The negative distributional effects of food taxes can be minimized, however, through revenue recycling schemes that reinvest tax revenues into food assistance programs (*115*). An alternative, and perhaps less politically sensitive approach, is to adjust value-added taxes on food producers, which can yield similar health and environmental benefits (*116*).

Food as medicine

About 90% of the $4.3 trillion annual US healthcare cost is due to chronic diseases for which diet is a prominent risk factor (*117*). Integrating dietary interventions into healthcare systems is a promising strategy. This food-as-medicine movement encompasses multiple models, some of which involve nutrition incentives. Simulations suggest that a US Medicare and Medicaid 30% subsidy on fruit and vegetable purchases could prevent 1.93 million cardiovascular disease events and save $39.7 billion in formal healthcare costs (*118*). Even greater savings and disease prevention occur if whole grains, nuts/seeds, seafood, and plant oils were also subsidized (*118*). Other programs that provide healthy food interventions via medically-tailored meals or groceries have demonstrated similar benefits (*117*). A medically-tailored meal delivery program, for example, was associated with a reduction of patient health cost by 16% (*119*).

To date, however, most food-as-medicine initiatives remain at an early stage, and in need of more rigorous experiments (*120*) and thorough impact evaluation, especially of their long-term effects on health (*121*). Where low-cost methods prove effective, they should be expanded and integrated with broader public health initiatives and ongoing cost-effectiveness assessments. Health insurers and medical practitioners could prescribe dietary changes, with reimbursement models aligned accordingly. Community health workers can also play a role in delivering dietary guidance and distributing nutrient-rich foods.

Regulation of food environments

Because food production and distribution are private sector activities subject to considerable environmental and health spillovers and imperfect information about production practices and product composition (*122*), structural changes to food environments require appropriate government regulation. The main challenge is political: to ensure regulation that resists interest group capture so that state interventions meant to advance sustainability, health and equity objectives are not instead turned into instruments that reinforce the power of regulated, commercial firms (*123*).

Regulation is essential to contain the rise of corporate concentration within food value chains, market power that drives up consumer prices, thereby reducing food affordability, and drives down remuneration for farmers and workers, harming equity goals (*41*, *124*). Increased public R&D can partly combat rising market concentration in food systems by reducing the role of private intellectual property that locks in market power and discourages competition, and by steering innovation towards people and planet over profits (*44*).

Regulation can enforce a level playing field that adds value not only for consumers and primary producers, but also for midstream actors that must incur costs to improve practices, by resolving inter-firm coordination problems (*125*). Otherwise, individual firms willing to incur some cost to advance sustainability, health or equity goals get undercut by competitors unwilling to follow suit. In the absence of regulation that compels all actors to adopt more socially desirable, but privately costly, behaviors, responsible firms lose competitiveness, as was grocery chain Tesco's experience when introducing carbon footprint food labels in the UK (*126*).

Regulation can address problems that arise from consumers' imperfect understanding of the foods that businesses try to sell them (*127*, *128*). Labels (both mandatory – e.g., Nutrition Facts Panel – and voluntary – e.g., locally grown), as well as certifications can also provide valuable information to consumers. Systematic reviews find that food labeling does, in many cases, nudge consumers to purchase and consume more desirable choices (*129*). But food standards and labels have exhibited mixed effectiveness in changing consumer preferences at scale (*130*). More assertive interventions might include restricting promotional activities and advertising of less healthy and less sustainable foods, and preventing their prominent positioning in stores (*131*). In addition, such foods could be subject to mandated healthful fortification or reformulation, as occurs with salt iodization or folic acid fortification of various processed foods (*53*). Regulation of food environments is more difficult in informal markets; but the rapid spread of modern retail, even into poor rural communities, steadily expands the feasible reach of regulatory standards (*53*).

Particular attention should be given to emerging food environments, such as online delivery platforms, which have expanded rapidly over the past decade. With an estimated 3 billion users globally, these digital food environments are reshaping how people access food and must be integrated into evolving regulatory and public health frameworks (*132*). They might also offer a promising avenue to influence a large number of consumers at relatively low cost — potentially addressing the scalability challenge that limits traditional nudging interventions (*133*). While a growing body of research has explored nudges to promote healthier and more sustainable diets — with mixed but often encouraging results (*134*) — implementing specific nudges consistently across millions of independent restaurants, supermarkets, or cafeterias is complex, fragmented, and costly. Digital food platforms offer centralized, customizable interfaces through which nudges can be deployed, tested, and refined at scale, allowing for rapid experimentation, real-time feedback, and broad dissemination. For example, a recent study in China demonstrated that a simple green nudge embedded in a major delivery app substantially reduced the use of single-use plastic cutlery (*135*). Nudges to caution purchasers about unhealthy food and suggest healthier alternatives likewise show promise (*136*). Such findings highlight the potential of online food platforms to enhance the reach, consistency, and efficiency of behavioral interventions.

Public procurement policies

Governments spend huge sums buying food. For example, the US government spends nearly $150 billion on nutritional assistance, with billions more spent by the military, prison systems, schools, and individual states. India spends about $15 billion annually on its public distribution system for the poor. Public procurement policies can set standards for nutritional quality, sustainability, and social equity. Currently, environmental, health and social externalities are rarely accounted for in the price of food nor automatically built into public food procurement policies, although current prices are estimated to only account for one-third of the true societal costs of food (*122*). The remainder are hidden costs to the environment (greenhouse gases, land-use change, water footprints, fertilizers, and pesticides) and to health (PM2.5 air pollution; increased health risks and mortality due to non-communicable diseases), totaling an estimated $20 trillion annually, double the value of the food consumed ($9 trillion) (*122*). By incorporating true cost accounting into procurement decisions, governments can internalize externalities related to health, environmental degradation, and social justice (*137*). True cost-based procurement rules could be leveraged to introduce healthier and more sustainable meals in schools, hospitals, military bases, and correctional facilities, thereby normalizing sustainable, healthy eating in institutional settings. Most powerfully, if midstream firms must offer sustainable, healthy, and equitable practices and products to secure high-value government contracts, the economies of scale of those contracts generate could change defaults. This in turn can induce a race-to-the-top among competing vendors, while stimulating private market demand for healthier, more sustainable products, and providing stable markets for small and mid-sized producers.

Metrics and data systems for accountability

Sound policymaking requires reliable, standardized, public reporting of data by firms. Standardized metrics – set by government regulation or private industry standards – can support labeling schemes, procurement decisions, and consumer education. Mandatory reporting by producers of foods' health- and environment-related characteristics, coupled with public investment in monitoring and evaluation systems, allows benchmarking across companies and/or over time, which can improve transparency for civil society, investors and policymakers (*138*–*140*). Data systems should also capture equity impacts, tracking whether food systems changes exacerbate or decrease existing disparities. Strengthening publicly available data to allow independent validation of measures reported by industry is important for data quality assurance, given concerns that self-reported adherence may be overestimated (*141*). Developing real-time data sharing, interoperability standards, and open-access platforms could promote collaboration and foster innovation across the food system.

Education and social norm change

Both formal and informal food education (*142*) can help individuals better judge what constitutes a healthy, nutritious, and sustainable diet. Exposure to healthy, sustainable foods and general food literacy, especially in early childhood, is especially important because food preferences and habits form early in life (*143*). Education on foods' environmental impacts can enhance popular understanding of science more broadly, as well as of food cultures, laying a foundation of popular support for innovation and policy changes of the sorts advanced in this paper. School and community gardens, for example, have been shown to promote awareness of plant-based foods and taste (*144*), and increase vegetable consumption among children (*145*). However, growing evidence suggests that school-based programs are most effective when they combine individual-level education like a technology-driven curriculum with system-level changes like cafeteria modifications, gardening, and family engagement (*146*, *147*).

Even when individuals understand what they should eat, unfamiliarity with how to prepare plant-based foods in tasty ways can be a barrier to adoption. While additional R&D to enhance the sensory appeal of healthy foods will be helpful in the long term, there are already many simple techniques in various traditional food cultures that enhance the umami and sweetness of plant-derived foods, making them more palatable (*148*). Controlling chemical (e.g., Maillard reaction, caramelization) and biochemical (e.g., fermentation) processes during food preparation can break down proteins, carbohydrates, and nucleic acids into flavorful compounds. Alternatively, sauces, marinades, and condiments — such as soy sauce, miso, fish sauce, aged cheese, eggs, seaweed, and dried fungi — can contribute umami and sweetness. Even small amounts of caramelized meat can boost umami in plant-forward dishes, as reflected in stir fry dishes with a mix of meat and vegetables. These traditional techniques not only improve flavor but can also enhance sweetness and saltiness, reduce bitterness, and support appetite regulation, satiety, and saliva production. As such, they should be broadly promoted.

Besides consumers, education and training programs for food scientists, chefs, culinary professionals, and product developers should be broadened to include training on designing products for both nutrition and sustainability (*149*). This includes incorporating sustainable sourcing, low-waste production, and climate-friendly menu design into formal curricula and continuing education.

More broadly, mass media campaigns, social marketing, and peer-based education can complement formal programs to help reshape perceptions of what is normal, desirable, and socially appropriate to eat. Descriptive norm messaging — such as “more people are choosing delicious plant-based meals” — can encourage behavior change by highlighting growing trends (*150*). These cues are especially effective when they reference relatable individuals or communities. Engaging community leaders and cultural influencers can further promote healthy eating practices and extend their reach across diverse populations (*151*). When norms shift across multiple levels — individual, social, and environmental — they can create a reinforcing loop of healthier and more sustainable food practices.

SUMMARY AND OUTLOOK

The transformation of modern food systems to promote healthier, more sustainable, and more equitable diets will require a coordinated, “all-hands-on-deck” strategy. The areas of intervention discussed above offer a comprehensive policy agenda that could align consumer and primary producer incentives with systemic reforms and actively engage actors across the entire food value chain, particularly the often-overlooked midstream players. These food businesses, including food processors, retailers, restaurants, delivery platforms, if properly engaged and incentivized, could help bring about sustainable, healthy, and equitable dietary transformations (*42*).

Change will often be opposed by vested interests, can be politically costly, and is often slowed by biases that champion individual decision-making or that underestimate the impact of food environments on behavior (*152*, *153*). Bundles of government legislative and regulatory policies, combined with induced technological change and civil society pressure can align primary producers’ and food and beverage firms’ commercial incentives with health, equity, and environmental objectives (*44*, *153*). Above all, change requires an actor-centric approach to addressing the challenges food systems pose, paying close attention to the agency of highly diverse food consumers and producers, as well as myriad organizations that intermediate between them, the food and beverage companies that exercise disproportionate power within food systems, and the government agencies that influence those private actors.

Looking ahead, rigorous evaluation of existing and emerging interventions is critical. Areas such as food-as-medicine and school-based nutrition programs show promise but require further, rigorous trials to understand long-term impacts. As importantly, attention should be paid to emerging disruptors from outside food systems, such as weight-loss drugs that have potentially large impacts on consumer dietary behavior (*154*). Their full implications for food systems sustainability and equity warrant close attention. Future research should explore how medical and technological innovations intersect with food environments and policy, and how such interactions can be leveraged to accelerate sustainable, healthy, and equitable dietary transitions.

Fig. 1. Food system actors and sustainability, health, and equity impacts. Sustainability impacts arise primarily from agricultural production in farms, ranches, etc. (orange), while health impacts result primarily from consumers' dietary choices (red), but are also affected by agricultural production and food processing methods. Equity impacts (blue) occur throughout the food value chain. The midstream actors in the food value chain, represented by dark blue icons, exert great influence on decisions of the world's primary producers (fisheries and farms) and consumers despite being 1–2 orders of magnitude smaller in number.

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