Preventive Medicine Reports 28 (2022) 101878

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Health and sustainability co-benefits of eating behaviors: Towards a science of dietary eco-wellness

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ARTICLE INFO

Keywords:
Climate change
Dietary intake
Environmental health
Health behavior
Nutrition
Sustainability
Wellness

ABSTRACT

Two of the greatest challenges of our times - climate change and the linked epidemics of obesity, diabetes, and cardiovascular disease - are fueled in part by the over-consumption of carbon-intensive high calorie foodstuffs. Converging evidence from hundreds of studies has confirmed that transitioning from diets high in meat and dairy to largely plant-based diets not only is necessary for climate change mitigation but will also lead to substantive reductions in morbidity and mortality. Nevertheless, there are only the faintest beginnings of a robust science of *behavioral eco-wellness*, defined here as *the study of how individual choices, behaviors, and habits impact both personal health and environmental sustainability*. This paper focusses on the sub-field of *dietary eco-wellness,* which looks at *health and sustainability impacts of food production, procurement, preparation, and consumption*. To advance this crucial agenda, investigators will need to invent, develop, and assess approaches aimed at helping people transition towards healthier and more sustainable diets. In order to accurately and reliably assess appropriate outcomes, existing assessment methods will need to be refined, new techniques will need to be advanced, and all measurement methods will need to be validated. Local conditions will influence the effectiveness of various approaches, and so it is important that scientists and communities share their stories of success and challenge for others to learn from. This paper reviews emerging evidence from relevant studies in dozens of countries, suggesting next steps, potential pathways, and a framework for interpretation.

1. Introduction

Greenhouse gas (GHG) emissions are heating the planet's surface and increasing the frequency and severity of heatwaves, droughts, wildfires, windstorms, hurricanes, floods, and inundations. The production and consumption of foodstuffs accounts for more than a quarter of total GHG emissions. At the same time, energy and macro-nutrient dense diets are fueling the global epidemics of obesity, diabetes, and dyslipidemia, promoting cardiovascular disease, the leading cause of death in many countries. (Wang et al., 2019) Unhealthy eating patterns may be the single greatest behavioral contributor towards human morbidity and mortality, estimated to cause more harm than unsafe sex, alcohol, tobacco, and other drugs combined. (Afshin et al., 2019) Fortunately, most of the dietary changes needed to reduce the global disease burden will also contribute to reductions in GHG emissions. (Cobiac and Scarborough, 2019) The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems has systematically reviewed the world's best science, yielding "an integrated framework providing quantitative scientific targets for healthy diets and sustainable food production, which together define a safe space within which food systems should operate." (Willett et al., 2019) This recommended healthy-and-sustainable diet consists of vegetables, fruits, nuts, whole grains, and unsaturated oils, with low-to-moderate amounts of fish, poultry, eggs, and low fat dairy. Red and processed meats, added sugars, and refined carbohydrates should be kept to a minimum, or avoided altogether. (Gakidou et al., 2017; Buttriss and Riley, 2013; Hallström et al., 2017).

This paper aims to 1) review the current state of science regarding dietary behaviors that bring health and sustainability co-benefits, and 2) identify a few research priorities that should be considered so that the field of behavioral nutritional science can maximize its contributions toward supporting both human health and environmental sustainability.

2. Climate change

In 1856, the American scientist Eunice Foote published results of her experiments on the heat-trapping effects of carbon dioxide and water vapor, writing that, "An atmosphere of that gas would give to our earth a high temperature." (Jackson, 2020) A few years later John Tyndall

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https://doi.org/10.1016/j.pmedr.2022.101878
Received 25 February 2022; Received in revised form 20 June 2022; Accepted 24 June 2022
Available online 27 June 2022

published results of more detailed experiments, and has since been credited with the discovery of GHGs. In 1896, Nobel prize-winning Swedish scientist Svante Arrhenius published the results of his calculations finding that a human-induced doubling in CO_2 levels would lead to global warming of 5–6 °C. (Uppenbrink, 1996) It was not until nearly a century later that accurate measurements of rapidly rising atmospheric GHG concentrations and corresponding global temperature rise were accepted by the world's scientific community. (Houghton, 1990) Since then, the Intergovernmental Panel on Climate Change (IPCC) and virtually all other scientific bodies have published increasingly dire findings and predictions regarding anthropogenic global warming and climate change. (Skea et al., 2021; Patz et al., 2014; Barrett et al., 2015).

The August 2021 IPCC report found that atmospheric CO_2 concentrations now average 410 ppm, up from 275 ppm before the industrial revolution and higher than any time in the past 2 million years. (Ipcc, 2021) Increasing CO_2; CH_4 and N_2O levels have raised average global surface temperatures 1.09 °C above preindustrial levels. Warming temperatures have led to glacial melting, polar cap ice loss, and thermal expansion of the oceans, raising sea levels 20 cm over the past 120 years. (IPCC, 2021) Increased frequency and severity of inundations, droughts, wildfires, and tropical storms have accompanied the massive increases of heat energy in the atmosphere. Observed and predicted effects on agricultural production are quite worrisome and interact with a variety of other climate-linked threats to human health. (Ramankutty et al., 2018) Taking into account projected impacts of increasing numbers of floods, fires, heat waves, and other extreme weather events, it has been estimated that one excess death will occur from every 4,434 metric tons of CO_2 emitted – equivalent to lifetime GHG emissions of 3.5 Americans. (Bressler, 2021) Climate change is now considered to be the single largest threat to public health for the foreseeable future; many potential mitigation and adaptation pathways are under active investigation. (Costello et al., 2009; McGushin et al., 2018; Patz, 2016; Hobbhahn et al., 2019; Haines, 2019).

3. Caloric overconsumption

Obesity, dyslipidemia, and type 2 diabetes contribute to cardiovascular disease, a leading cause of death and disability both in most so-called developed nations and also in many low income, resource-deprived countries. (Murray et al., 2020) Wang et al. estimated that 24% of premature deaths (11 million) in 2017 could have been avoided with best practice dietary intake. The major nutritional factors behind the global epidemics obesity, diabetes, and cardiovascular disease are 1) too many calories from refined carbohydrates such as those in sweetened beverages, and 2) too much red and processed meat, along with 3) corresponding insufficiencies in vegetables, fruits, nuts, legumes and whole grains. (Afshin et al., 2019; Gakidou et al., 2017; Murray et al., 2020) While the calories-in, calories-out model of obesity may be too simplistic, (Ludwig and Ebbeling, 2018; Mozaffarian, 2017) there is little doubt that high caloric intake is a major driver of the obesity and diabetes epidemics. It is also undeniable that animal-based foods such as meat and cheese are calorie-dense, often contain unhealthy fats, and require far more land, water, energy, and agrochemical input than plant-based foodstuffs.

4. Health benefits of sustainable diets

Research examining the expected health benefits from transitioning from animal-based to plant-based foods is authoritative and convincing, with increasingly precise and reliable estimates of morbidity reduction benefits. (Sabate and Soret, 2014; Qian et al., 2019; Willett et al., 2021; Gibbs et al., 2021) For example, in a study published in *Proceedings of the National Academy of Sciences*, Springmann and colleagues modelled the impacts of dietary intake on disease, death, and economic outcomes and found that transitioning towards plant-based diets "could reduce global mortality by 6–10% and food-related greenhouse gas emissions by 29–70% compared with a reference scenario in 2050." (Springmann et al., 2016) A North American study of 73,308 people found that vegetarian or semi-vegetarian diets were associated with 22% and 29% reductions in GHGs, and with 14% and 9% reductions in mortality. (Soret et al., 2014) A prospective study of 96,775 Swedish adults found that eating a healthy and sustainable diet was associated with lower mortality for women, but not for men. (Strid et al., 2021) The EAT–Lancet commission has summarized dozens of other studies supporting the finding that a diet composed of plant-based foods leads to better health outcomes as well as lower environmental impact. (Willett et al., 2019) These conclusions are supported by decades of research on the Mediterranean Diet, which has been shown in multiple randomized trial to reduce cardiovascular disease burden. (Estruch et al., 2013; Ruiz-Canela et al., 2014; Martínez-González et al., 2019) Because this dietary pattern is largely plant-based, it also leads to reduced environmental impacts, including lower GHG emissions. (Pairotti et al., 2015; Aboussaleh et al., 2017; Berry, 2019; Truzzi et al., 2020).

The Global Burden of Disease project has synthesized tens of thousands of studies including data from 195 countries. (Afshin et al., 2019; Gakidou et al., 2017; Murray et al., 2020) Results suggest that between 20% and 25% of humanity's morbidity and mortality burden could be avoided if people switched to high quality diets. While some of this burden comes from low levels of protein, calories, and specific nutrients, a large and increasing portion is due to the global transition towards animal-based foodstuffs. Supporting this conclusion are studies finding that risks are dose-dependent. For example, a British study of some 475,000 people found that eating meat three or more times per week is linked with increased diabetes, cardiovascular disease, and all-cause mortality. (Papier et al., 2020) A synthesis of two U.S.-based prospective cohort studies with more than 80,000 subjects and 1.2 million years of follow-up found that an increase of only half a serving of red meat each day was associated with a 10% increase in all-cause mortality. (Zheng et al., 2019) One meta-analysis of 12 prospective studies including 177,655 deaths found that each additional 100 g of red meat consumed daily was associated with a 10% increase in all-cause mortality in a "linear dose–response" manner. (Schwingshackl et al., 2017) Mortality risks associated with processed meat consumption are even higher. (Micha et al., 2010).

Systematic reviews of this emerging field are rapidly populating the literature. For example, meta-analyses have found that vegetarian diets are associated with decreased risk of diabetes (Qian et al., 2019; Lee and Park, 2017; Pollakova et al., 2021), and that diabetics who adopt vegetarian diets have reduced blood sugar levels (Yokoyama et al., 2014; Papamichou et al., 2019) as well as more favorable cardiovascular risk factors such as body mass index and LDL cholesterol. (Viguiliouk et al., 2019) Meta-analyses similarly have found that vegetarian diets were associated with reduced blood pressure (Gibbs et al., 2021; Lee et al., 2020) and reduced coronary heart disease incidence and mortality. (Glenn et al., 2019) Systemic reviews of both observational studies and clinical trials have reported that vegetarian diets are associated with lower obesity rates and reduced body weight. (Nour et al., 2018; Barnard et al., 2015; Remde et al., 2021) Finally, meta-analyses have found that vegetarian diets are associated with lower incidence and mortality from both ischemic heart disease and cancer. (Dinu et al., 2017) While the dozens of studies contributing to these meta-analyses are largely cross-sectional with limited experimental or randomized trial data, the breadth and consistency of published reports leave little doubt that the preponderance of evidence supports substantive health benefits from vegetarian diets.

5. Environmental benefits of healthy eating

Transitioning towards plant-based diets will bring a host of environmental benefits including reduced strain on land and water resources, less pollution, and fewer nitrogen- and carbon-based GHG emissions. Best estimates suggest that between 26% (Poore and

Nemecek, 2018) and 35% (Xu et al., 2021) of GHGs come from food production, with the bulk of those attributable to animal-based foods. A recent comprehensive life cycle analysis found that the production of meat leads to twice the GHG emissions as that of all plant foods combined, despite the fact that meats make up a small proportion of the human diet. (Xu et al., 2021) These findings are consistent with other systematic reviews reporting that meat and dairy contribute disproportionally to environmental harm, (Chai et al., 2019) and that population-level dietary change among some affluent societies could reduce total GHG emissions and land use demand by as much as 50%. (Hallström et al., 2015).

Regional studies based on primary data support these comprehensive global analyses. For example, a study from Ontario, Canada, based on 24-hour recall dietary intake data (n = 10,723) found that people eating meats along with other foodstuffs (omnivores) had more than twice the carbon footprint of vegetarians and vegans. (Veeramani et al., 2017) An empirical cohort study from Italy (n = 1806) found that "the adoption of healthy dietary patterns involves less use of natural resources and GHG emissions." (Grosso et al., 2020) Studies of young adults in Albania and among the Roma people in Hungary have shown that adherence to recommended healthy and sustainable dietary patterns are suboptimal, and influenced more by cultural patterns and available food sources than by cost or health recommendations. (Llanaj and Hanley-Cook, 2021; Llanaj et al., 2021) Several regional studies have demonstrated carbon footprint gradients across a range of meat consumption. For instance, a 4-country European study (n = 7806) found that an relative increase of "5 energy percent (50 g/2000 kcal) higher meat intake was associated with a 10% and a 14% higher GHGE and LU [land use] density, with ruminant meat being the main contributor to environmental footprints." (Mertens et al., 2019).

Agricultural and animal husbandry practices are a primary driver of water scarcity, with irrigation responsible for greater than 70% of fresh water use. (Bailey and Harper, 2015) One comprehensive study found that transitioning from meat towards plant-based diets would have "synergies, rather than tradeoffs" in terms of minimizing impact on land and water, with substantive GHG reductions (Gephart et al., 2016) Other studies point out that the available data relating land and water use to healthy diets is limited, and that more research is needed. (Ridoutt et al., 2017) For example, a study from Hungary supports the general positive relationship between dietary health and sustainability, but found little difference in attributable water use between more and less healthy diets. (Tompa et al., 2020).

6. Behavioral eco-wellnesss

While culture, social norms, geographic region, socioeconomic status, and family traditions all importantly influence what foods are eaten, (Monterrosa et al., 2020) it is the individual human being who actually consumes food, bite by bite. Despite a broad base of research looking at the health and sustainability impacts of dietary intake patterns, very few empirical research studies have examined individual eating behaviors through an eco-wellness lens. To develop a meaningful science of dietary eco-wellness, we will need to define the scope and boundaries of the discipline and then delineate potentially fruitful investigative pathways, including A) conceptual framework, B) potential influencers of dietary eco-wellness behaviors, C) the specific choices, behaviors and habits involved, and D) outcomes, consequences, and ramifications of dietary choices relating to both health and sustainability. To further this conversation, I will tentatively define *behavioral eco-wellness* as *the study of how individual choices, behaviors, and habits impact both personal health and environmental sustainability*, and the sub-field of *dietary eco-wellness* as the study of the *health and sustainability impacts of food production, procurement, preparation, and consumption*. See Figure.

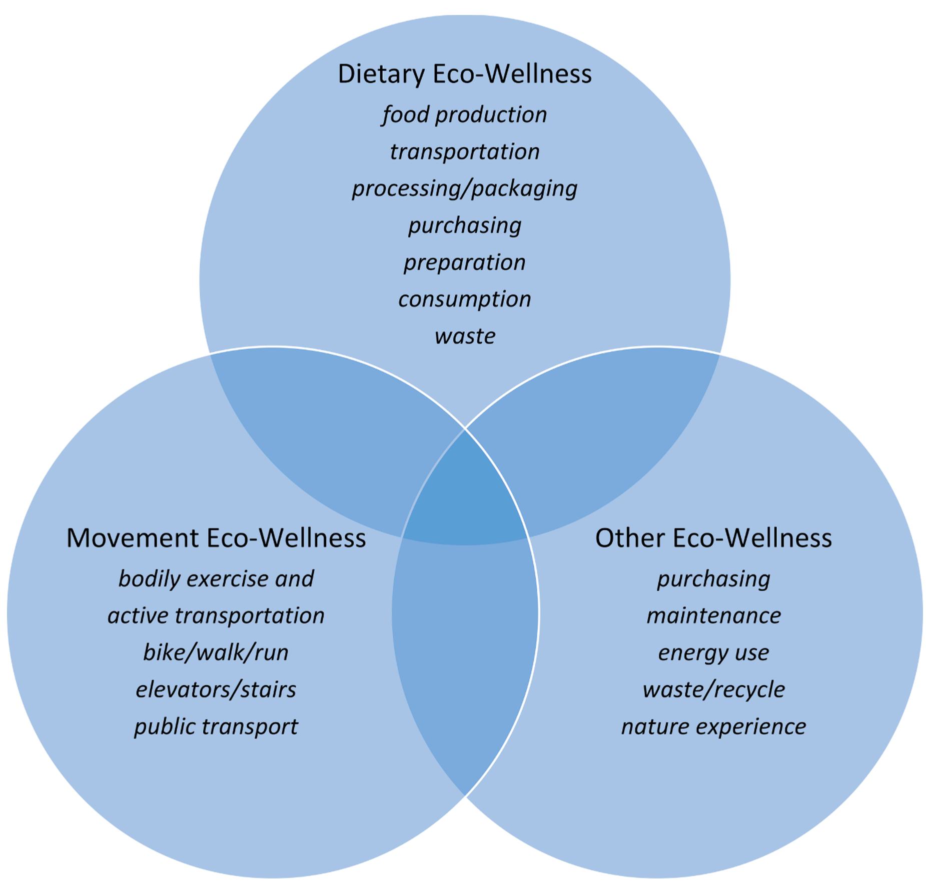

Fig. 1. Eco-Wellness Behaviors Influence both Health and Sustainability.

6.1. Assessing dietary eco-wellness behaviors and related outcomes

One important goal of dietary eco-wellness will be to identify the quantity of specific foods ingested and then to link that information to databases relating those foods to specific health and sustainability impacts. Accurately assessing individual-level dietary consumption, however, is notoriously challenging. Food frequency questionnaires, 24-hour dietary recall, and food records all are based on self-report and subject to memory error as well as to social desirability and other known biases. (Park et al., 2018; Freedman et al., 2014) Even well-developed and validated instruments such as the ASA-24 are imprecise as well as potentially biased, and require a great deal of effort on the part of research participants. (Subar et al., 2012; Subar et al., 2015) As an example, in a pilot study that I directed, the ASA-24 was used by participants adopting mindfulness practices in order to improve their eco-wellness behaviors. (Barrett et al., 2016; Grabow et al., 2018) My team member Tom Bryan developed the miDIET calculator linking identified ASA-24 food intake data to environmental impact estimates compiled by Poore and Nemecek, (Poore and Nemecek, 2018) yielding individual-level estimates of carbon footprint and several other sustainability metrics. (Bryan et al., 2019) The miDIET tool was then applied to 121,482 food records from 8505 participants in the national NHANES study, (Chen et al., 2018) yielding environmental impact estimates for 41,928 (34.5%) of the records. (Bryan et al., 2019) The finding that barely more than a third of foods are linked to ecological impacts illustrates that the state of dietary eco-wellness knowledge is limited by the breadth and depth of environmental and nutritional science as well as availability of validated assessment tools. This in turn provides impetus to improve the science of food production, environmental assessment, and dietary intake in tandem, instead of as isolated research threads.

6.2. Influencing dietary intake for health and sustainability

A well-developed science of dietary eco-wellness would aim not only for accurate assessment, but also for the ability to design, test, improve and disseminate interventions at both individual and system levels. Thankfully, the beginnings of this body of work are already emerging. For example, several groups have begun to look at how fiscal incentives might influence healthy-and-sustainable food choices. Countries reporting some success with fiscal incentives include Finland, France, Hungary, Mexico, Norway, some Pacific Islands, and a few areas in the United States. (Bailey and Harper, 2015) So far, most of these large scale "natural experiments" with incentives/disincentives have been aimed at reducing consumption of sweetened beverages. A few, however, have aimed more directly at eco-wellness, such as an Australian sustainability coaching project in 25,000 households that reported substantive changes and cost-effectiveness in a variety of sustainability-related behaviors. (Ashton-Graham et al., 2013) Looking beyond fiscal incentives, discussion of national or regional policy effectiveness has progressed rapidly. For example, several countries have implemented food labelling with carbon footprint or other sustainability metrics; a number of studies have looked at effects of labelling on consumer purchasing. (Rondoni and Grasso, 2021) A study from Australia looking at various policies failed to reach consensus on which approaches were effective, but did find that three enablers and five barriers were backed by substantive evidence. (Denniss et al., 2021) Identified barriers included "the complex nature of the food system, competing interests of stakeholders, pressure from industry, government silos and lack of political will." Enablers identified were "building relationships with key stakeholders across multiple disciplines and sectors, understanding the policy making process, and developing a clear and coherent solution." (Denniss et al., 2021).

Evidence from policy development and "natural experiments" is complemented by smaller and more methodologically rigorous experimental studies. For example, a randomized virtual supermarket experiment in the Netherlands suggested that both "nudging" and "pricing" would have positive impacts on food purchasing, with differential health and sustainability impacts among both strategies and food groups. (Stuber et al., 2021) A European randomized behavior change trial (n = 744; 12 month follow-up) found that those assigned to "food-related behavioral activation therapy" aimed at a Mediterranean style diet reported significantly increased intake of vegetables, fruits, legumes and whole grains compared to controls. (Grasso et al., 2020) However, sustainability-related outcomes in this study were similar in intervention and control groups. A study from Sweden found that intention to reduce meat consumption was motivated by fear of climate change threats, and that concerns about potential harms to family and friends was a greater motivator than harm to self. (Hunter and Röös, 2016) A study among Italian women and men ≥ 60 years of age found that the factual framing of messages related to personal wellness was effective in reducing intention to eat meat. (Bertolotti et al., 2016) Another study looking at fruits and vegetable consumption among Italian college students found that self-identity was an important factor in determining both dietary intention and actual self-reported eating behaviors. (Carfora et al., 2016) Finally, it should be remembered that many people have chosen sustainable lifestyles for ethical reasons, including concern for protecting animals and natural ecosystems. (Bain and Bongiorno, 2020; Pereira and Forster, 2015; Turaga et al., 2010).

7. Cooking and food preparation

Behaviors related to dietary eco-wellness include not only procurement and consumption, but also preparation and storage, which have their own attributable health-and-sustainability impacts. For instance, the act of cooking foods requires a heat source. Electric stoves can be powered by clean or dirty means. Combustion-based stoves are most commonly heated by propane, butane, charcoal, wood, or animal dung. Environmental and health consequences can be substantive, as described in a robust literature on indoor air pollution resulting from cook stoves. (Quinn et al., 2018; Wathore et al., 2017; Islam et al., 2021) Solar cookers are an excellent solution in terms of cost and lack of pollution, but they don't work without sunshine and can be inconvenient or culturally incongruent. (Khatri et al., 2021; Indora and Kandpal, 2018; Iessa et al., 2017) Numerous empirical studies looking at cooking technology have reported health and environmental co-benefits resulting from cleaner fuels and advanced stoves. (Anderman et al., 2015; Patange et al., 2015; Aung et al., 2018) Systematic reviews have reported that health, economic, environmental, and gender equity co-benefits can result from cleaner methods of cooking foods. (Mazorra et al., 2020; Thakur et al., 2018) One meta-analysis reported good evidence for reduction of particulate matter and carbon monoxide but inconclusive evidence on actual health outcomes. (Quansah et al., 2017).

8. Locality and seasonality

Health and sustainability impacts related to diet vary by locality and seasonality. (Vargas et al., 2021; Sandström et al., 2018) In general, consuming locally produced foods reduces impact, as food transport requires energy, usually involving fossil fuel combustion. While food transport accounts for only about 10% of total food cycle footprint globally, local variations are considerable. (Poore and Nemecek, 2018; Ritchie and Roser, 2020). The ability to efficiently produce nutritious foodstuffs is constrained by sunlight, soil, rainfall, water, and seasonal patterns. In northern climes such as Wisconsin where I live, food production is limited to about half of the year, requiring food storage and/or importing food at other times. Transporting foods by ship or rail usually has a low relative impact. Transporting food by large trucks adds a bit more in terms of environmental impact, as do refrigeration and small delivery volumes. Transporting fresh foods by air is particularly egregious in terms of sustainability impact per unit of nutrition delivered. (Wakeland et al., 2012) Consumption of locally grown vegetables during a Wisconsin summer is good for both health and sustainability. Eating the same diet during winter may be good for the body, but not so great for the environment.

9. Food waste

At least a quarter and perhaps a third of the food that is produced for humans is wasted, yielding the equivalent of 3.3 gigatons of CO_2 each year, more than any single country other than the US or China. (Kummu et al., 2012; Irfanoglu et al., 2014) Consumers in industrialized countries waste an estimated 222 million tons of food each year, almost as much as the total amount of food consumed in sub-Saharan Africa (approximately 230 million tons). (Barrera and Hertel, 2021) While some wastes occur at the production, processing, distribution, and retail levels, individual consumer behavior may constitute the largest single share. When food is wasted, the GHGs and other pollutants caused by production and distribution are not balanced or justified by nutritional benefits. Food waste properly composted may sequester carbon and enhance soil fertility, but foodstuffs rotting in landfills usually produce unusable methane and other GHGs. While scientists and policy makers have made many suggestions as to how to reduce food waste, few proposed interventions have been properly developed or tested. (Barrera and Hertel, 2021; Aschemann-Witzel et al., 2015; Nordin et al., 2020; Reisch et al., 2020) A systematic review of empirical studies looking at food behavior interventions found only18 studies looking at food waste behaviors. (Reisch et al., 2020) Another review identified six strategies aimed at reducing food waste: "separation or composting behavior, eating behavior, cooking behavior, consumer's environmental knowledge of food waste, consumer's environmental awareness and government policy…". (Nordin et al., 2020) Advancing this area of eco-wellness science will be necessary if we are to develop and implement evidence-based mitigation of the impact of the food cycle on health and sustainability.

10. Economic costs

In most settings, plant-based sustainable diets are less expensive than those with significant amounts of meat or dairy. (Lusk and Norwood, 2009) Nevertheless, fresh fruits and vegetables can be costly, and even foods such as seeds, nuts, beans, and high nutrient grains can be unaffordable for low income populations. (Fulgoni and Drewnowski, 2019) Hirvonen and colleagues estimated that the EAT-Lancet healthy-and-sustainable diet (which allows some animal-based foods) would be unaffordable to 1.58 billion people. (Hirvonen et al., 2020) In most localities, the Mediterranean diet would cost even more. In a study from Spain, adherence to the Mediterranean diet was negatively associated with income. (Rubini et al., 2021) A German study compared monetary costs of seven reasonably healthy dietary patterns and found that the low fat vegetarian diet was the most affordable, with the other dietary patterns ranging from 10% to 70% more costly. (Kabisch et al., 2021) An analysis from the U.K. found that healthy-and-sustainable diets could be affordable among all income quintiles, but that some adjustments might be needed. (Reynolds et al., 2019) Economic savings from transitioning towards a plant-based diet may go beyond the purchase costs of foods. A study from Taiwan compared medical expenditures of 2166 vegetarians to 4332 age-sex-matched omnivores, and found 15% lower medical costs among those reporting vegetarian diets. (Lin et al., 2019) In summary, while it is usually less costly to eat sustainable plant-based diets rather than those high in meat and dairy, there are some trade-offs and many complexities that influence both nutritional value and economic costs.

11. Recomendations

The way in which people manage the production and consumption of foodstuffs has tremendous impact on both human health and the sustainability of a livable world. Overwhelming evidence demonstrates that the overconsumption of animal-based foods is a core element of both environmental decay and the ongoing epidemics of obesity, diabetes, and related disease processes. The inequitable use of resources needed to produce the high calorie diets consumed (and wasted) by high income countries and individuals is a major factor contributing to not only environmental threats but to nutritional deficiency and even starvation for the poor. Nevertheless, despite the magnitude of potential benefits that could accompany major food system and dietary choice changes, a paucity of sound research is available to guide the choices and pathways facing us. To advance this agenda, I propose two research avenues to enhance the science of dietary behavioral eco-wellness: improved measurement and well-developed and validated interventions.

11.1. Improved measurement

New and better tools are needed to assess human dietary intake, and to assign nutritional and sustainability metric values to specific foods and to diets as a whole. While this area is rapidly growing, (Burgui-Burgui and Chuvieco, 2020; Harray et al., 2015; Sullivan et al., 2016; Hallström et al., 2018; van Dooren et al., 2017; Ridoutt and Huang, 2019; Vermeir et al., 2020) it still has a long way to go. The measurement of dietary intake itself seems to have plateaued with well-developed and validated self-report tools such as the ASA-24. (Park et al., 2018; Subar et al., 2012) Incremental gains may be possible in terms of psychometric validation of prospective vs retrospective reporting, convergent assessment using biomarkers or third-party reporting, or ecological momentary assessment. (Freedman et al., 2014; Amoutzopoulos et al., 2015; Schembre et al., 2018) Nevertheless, it will be difficult to get past the well-documented errors and biases in memory, cognition, and reporting that are involved with self-reporting of food consumption. One pathway towards better measurement could involve computer-assisted analysis of photos of foods. (Shoneye et al., 2019; Fang et al., 2019; Wang et al., 2018; Boushey et al., 2017) If computer-based image analysis techniques prove to accurately assess both food type and portion size, then dietary intake research will be limited more by the reliability of human subjects actually taking pictures of the foods they consume, and less by mental processes involved with remembering and reporting those foods. If the research stream summarized by Poore and Nemecheck in 2018 (Poore and Nemecek, 2018) reaches maturation, then we should be able to assign sound sustainability metrics to the vast majority of foods typically consumed, perhaps doubling the 34.5% that we found with our study. (Bryan et al., 2019).

11.2. Well-developed and validated interventions for behavior change

Several attempts to support the transitions toward improved dietary habits have been made, as summarized earlier. These have employed techniques such as nudging, pricing, and framing, while taking account of intentions, motivations, and fears. (Denniss et al., 2021; Stuber et al., 2021; Grasso et al., 2020; Hunter and Röös, 2016; Bertolotti et al., 2016; Reisch et al., 2020; Burgui-Burgui and Chuvieco, 2020; Ridoutt and Huang, 2019) Behavioral interventions such as these will require iterative development and testing, with large high quality pragmatic randomized trials as the final arbitrator of what works, what doesn't, and what the cost-effectiveness and unintended consequences might be. Trials will need to be conducted both in specific and general populations in order to investigate whether and to what extent intervention effectiveness depends on local factors.

Behavioral support mechanisms will need to take into account factors such as regional dietary cuisines and cultural preferences, as well as availability and cost of specific foodstuffs. They will also need to account for a wide variety of individual values and personal preferences involved with procuring, preparing and consuming food. The trans-theoretical (stages of change) model of behavior change should be considered;

(Prochaska and Velicer, 1997) significant segments of the population may be in the pre-contemplative (denial) stage. The receptiveness of people to consider changing their dietary habits for personal health and/or sustainability will be a factor determining which interventions are effective, and among which populations they should be deployed. (Nicholls and Drewnowski, 2021).

11.3. Optimization, implementation and dissemination

Interventions that prove effective in intensive behavior training settings will need to be adapted to methods involving less participant burden, a process that will require rigorous testing to assess potential dose–response attributes. Resource-intensive approaches such as in-person individual and group counselling will be complemented by and perhaps integrated with a variety of mHealth apps and web-based trainings. (Cavero-Redondo et al., 2020; Milne-Ives et al., 2020; Halse et al., 2019; McCarroll et al., 2017) Once proof-of-concept and efficacy-testing have been accomplished, streams of dissemination and implementation research will be needed to adapt and test dietary eco-wellness programs in larger, less controlled, and more diverse settings, using pragmatic trials and similar approaches. (Ford et al., 2016; Nielsen et al, 2018; Baumann et al., 2017) At each step, iterative development and testing will be needed to adapt interventions to specific populations and settings, and to streamline implementation processes aiming for both efficiency and impact.

Assessment and intervention should not remain isolated. As smartphone apps link through high speed networks to sophisticated programs and databases, photos of foods and meals will be translated into nutrient profiles in minutes or seconds, allowing for real-time behavioral training feedback at the point of consumption. (Shoneye et al., 2019) Lessons learned from advertising and marketing should be taken into account, both as sources of information on effective behavioral change techniques, and as cautionary tales of how such techniques can push foods with dramatically unfavorable nutrient profiles into widespread use. (O'Dowd, 2017; Harris and Graff, 2012; Dixon et al., 2007) Development, testing, and implementation of dietary eco-wellness interventions should be accompanied by explicit explanations of moral and rational underpinnings. (Bain and Bongiorno, 2020; Pereira and Forster, 2015; Turaga et al., 2010; Testa et al., 2021) Hopefully, respect for truth and desire for health and sustainability will be sufficient to counteract the massive expenditures that push junk food on vulnerable populations, (O'Dowd, 2017) and the inevitable pushback from financially conflicted sectors, and from those unwilling or unable to grasp the necessity of dietary change.

12. Conclusion

If humanity is to have a healthy and sustainable future, we must profoundly reduce greenhouse gas emissions. For most of the developed world, this will require radical transformation of how food is produced and consumed. For populations suffering from the linked epidemics of obesity, diabetes, and cardiovascular disease, many of the necessary changes will bring substantive health co-benefits. Nevertheless, despite the magnitude of both the threats and the potential benefits, very little work has been done to develop and test the methods and tools that will be needed. With these goals in mind, this paper reviews the state-of-the-science, introduces the terms "behavioral eco-wellness" and "dietary eco-wellness," and points towards a few potentially fruitful pathways towards a better future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper was made possible by the inspired and diligent efforts of thousands of scientists from across this planet, including those cited here. My gratitude also to the Department of Family Medicine and Community Health in the School of Medicine and Public Health at the University of Wisconsin, Madison, for providing me a meaningful and rewarding career. Cathy Middlecamp helped direct our Mindful Climate Action project (MCA; https://www.fammed.wisc.edu/mca/) and provided editorial assistance, as did MCA team member Elisa Torres. Maggie Grabow, Margaret Mooney, and Tom Bryan also contributed substantively to MCA. Nathaniel Javid helped with formatting and submission.

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