Development and Evaluation of the Planetary Health Diet Index for the United States and Assessment of Dietary Constructs Associated with Sustainability

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Abstract

Dietary choices present an important avenue for promoting food system sustainability. Research suggests that plant-based dietary patterns can have positive health effects and reduce environmental impacts. The Planetary Health Diet was proposed by the EAT-*Lancet* Commission as a reference healthy and sustainable dietary pattern. A Planetary Health Diet Index (PHDI) was developed for Brazil to measure adherence to Planetary Health Diet recommendations; however, a PHDI has not been developed and evaluated for the United States (U.S.) population. Additionally, relatively few studies have assessed dietary constructs related to sustainability among U.S. adults, including the construct of meat attachment (i.e., a positive bond toward eating meat) and willingness to reduce meat intake. These gaps informed three primary research objectives. First, develop and evaluate the PHDI for the U.S. (PHDI-US). Second, use the PHDI-US to measure American adherence to the Planetary Health Diet. Third, analyze differences in meat attachment and willingness to reduce meat intake by sociodemographic and socioeconomic characteristics in a southern U.S. population. Cross-sectional data from 4,741 participants of the National Health and Nutrition Examination Survey 2017-2018 were used for analyses. Validity and reliability tests were acceptable, with total PHDI-US and Health Eating Index-2015 scores being positively associated; concurrent-criterion validity analyses identifying significantly lower scores among males, everyday smokers, and younger adults; and Cronbach's alpha equaling 0.51. The average PHDI-US score was 38.7 out of 150, indicating that American diets are far from meeting Planetary Health Diet recommendations. Using the Meat Attachment Questionnaire (MAQ), levels of meat attachment, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet were compared by gender, educational attainment, income, and age among 328 American adults. The two characteristics most associated with differences in MAQ scores were age and educational attainment, with younger adults and those with higher educational attainment having lower MAQ scores and greater willingness to follow a more plant-based diet. The results of these studies can help improve the design of interventions by providing a tool to quantitatively measure American adherence to the Planetary Health Diet and identifying that younger adults and those with higher educational attainment may be more receptive to adopting sustainable dietary patterns.

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General Audience Abstract

Dietary choices present an important avenue for promoting food system sustainability. Research suggests that plant-based dietary patterns can have positive health effects and reduce environmental impacts. The Planetary Health Diet is a recommended healthy and sustainable dietary pattern. A Planetary Health Diet Index (PHDI) was developed for Brazil to measure adherence to Planetary Health Diet recommendations; however, a PHDI has not been developed and evaluated for the United States (U.S.) population. Additionally, relatively few studies have assessed dietary constructs related to sustainability among U.S. adults, including the construct of meat attachment (i.e., a positive bond toward eating meat) and willingness to reduce meat intake. These gaps informed three research objectives. First, develop and evaluate the PHDI for the U.S. (PHDI-US). Second, use the PHDI-US to measure American adherence to the Planetary Health Diet. Third, analyze differences in meat attachment and willingness to reduce meat intake by sociodemographic and socioeconomic characteristics in a southern U.S. population. Data from 4,741 participants of the National Health and Nutrition Examination Survey 2017-2018 were used for analyses. Validity and reliability tests were acceptable, demonstrating that the PHDI-US can consistently measure dietary quality and sustainability in accordance with Planetary Health Diet recommendations. The average PHDI-US score was 38.7 out of 150, indicating that American diets are far from meeting Planetary Health Diet recommendations. Using the Meat Attachment Questionnaire (MAQ), levels of meat attachment, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet were compared by gender, education level, income, and age among 328 American adults. Younger adults and those with a higher level of education had lower MAQ scores and greater willingness to follow a more plant-based diet. The results of these studies can help improve research studies by providing a tool to measure how closely American diets are meeting Planetary Health Diet recommendations and identifying that younger adults and those with a higher level of education may be more receptive to adopting sustainable dietary patterns.

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Table of Contents

List of Tables

Chapter 3: Characterization of the sustainability and quality of American diets using the newly developed Planetary Health Diet Index for the United States

Chapter 4: Assessment of Differences in Meat Attachment and Willingness to Reduce Meat Intake by Sociodemographic and Socioeconomic Characteristics in a Southern United States Population

List of Figures

Chapter 3: Characterization of the sustainability and quality of American diets using the newly developed Planetary Health Diet Index for the United States

Attributions

Attributions Chapter 3: Characterization of the sustainability and quality of American diets using the newly developed Planetary Health Diet Index for the United States Molly Parker developed the study design with input from Valisa Hedrick, and the study design was approved by all authors (Molly Parker, Sarah Misyak, Julia Gohlke, and Valisa Hedrick). Molly Parker led the statistical analyses and drafting of the manuscript. All authors reviewed and contributed to the final version of the manuscript. This manuscript in under review in the *American Journal of Clinical Nutrition* in 2023.
Attributions Chapter 4: Assessment of Differences in Meat Attachment and Willingness to Reduce Meat Intake by Sociodemographic and Socioeconomic Characteristics in a Southern United States Population Molly Parker developed the study design with input from Valisa Hedrick and Sarah Misyak, and the study design was approved by all authors (Molly Parker, Sarah Misyak, Elena Serrano, and Valisa Hedrick). All authors were involved in disseminating the survey. Molly Parker led the statistical analyses and drafting of the manuscript. All authors reviewed and contributed to the final version of the manuscript. This manuscript is in preparation for submission to *Appetite* in 2023.

Chapter 1: Introduction

Climate change is the result of increases in concentrations of greenhouse gases (GHG) in the atmosphere that lead to higher global surface temperatures.[1] Humans have greatly contributed to these changes, causing an estimated 1.07°C increase in global surface temperature between 1850-1900 and 2010-2019. Warming is occurring at an unprecedented rate, and it is being driven by the emissions generated through human activity.[1]

Temperature increases are already leading to observable changes throughout the world. Artic sea ice is the smallest it has been since 1850, and nearly all glaciers are retreating.[1] Sea levels are rising while surface open ocean pH is decreasing. Extreme heat and heat waves have increased in frequency and intensity, whereas, cold extremes have declined. Heavy precipitation events have also increased in frequency and intensity, while simultaneously, there have been increased droughts in some regions. Unfortunately, past GHG emissions have already led to ocean warming, glacier melting, and sea level rising that will be irreversible for centuries to millennia. If warming continues, it is expected that these conditions will worsen and the intensity and frequency of hot extremes, heavy precipitation, and droughts will increase.[1]

Climate change has also been labeled as a pandemic due to the widespread effects it is having on human health and the planet.[2] In addition to climate change, the world is experiencing pandemics of obesity and undernutrition. This combination has been referred to as The Global Syndemic because all three pandemics are co-occurring, interact with one another, and share similar drivers.[2]

Malnutrition in all its forms (i.e., undernutrition, micronutrient deficiency, and overweight/obesity) is the leading contributor to disease burden globally.[2] Close to half of the deaths among children less than five years old are related to undernutrition, and as of 2014, 462 million adults were underweight globally.[3] However, overweight and obesity is more prevalent among adults and associated with more deaths worldwide than underweight.[4] Obesity rates have steadily increased over the past forty years, with 13% of the global adult population experiencing obesity and 39% experiencing overweight in 2016.[4] The prevalence of obesity among adults in the United States (U.S.) was 42.4% in 2017-2018.[5]

Climate change is expected to exacerbate undernutrition and food insecurity through the negative effects it will have on the food system, such as atmospheric warming leading to reduced crop yields and subsequently increasing food prices[2] and increased sea temperatures harming fish populations.[6] In addition, climate change disproportionately impacts low-income countries that are experiencing higher rates of food insecurity and undernutrition.[7] The present food system is also contributing to climate change.[8] It is estimated that all of the processes within the food system generate 19-29% of the global anthropogenic GHG emissions, with the production of food being the primary contributor to these emissions.[8] Food production is also contributing to an estimated 32% of global terrestrial acidification and 78% of eutrophication.[9] Feeding a growing population that will likely reach 9.7 billion people by 2050[10] will require additional resources, especially with a large portion of the population engaging in overconsumption.[2]

Two of the primary drivers of obesity and climate change include the high use of cheap energy sources in the form of food and fossil fuels and transportation systems that encourage the use of cars.[2] Governmental mechanisms, such as regulations, taxes, and subsidies, play a prominent role in the conditions present among the food, transport, land use, and urban design systems that are contributing to The Global Syndemic. In addition, large concentrated corporations, which are prevalent in the food and agricultural sector,[11] exert influence on policy inertia and the power of governments to enact regulations, like limiting advertising of unhealthy foods to children or implementing a tax on sugar-sweetened beverages. Furthermore, sociocultural influences on these systems also exist, including people's attitudes, beliefs, and behaviors. Due to the nature of supply and demand, consumers' demands for unhealthy products are generally met with greater supply, and demand can often be inflated through industry manipulation of the food environment.[2]

Dietary guidelines present an opportunity for governmental institutions to encourage healthy and sustainable diets that could help mitigate The Global Syndemic. Few countries have incorporated guidance on consuming more sustainably into their dietary guidelines.[12] In the U.S., the Dietary Guidelines for Americans (DGA) inform nutrition programs and policies, nutrition education materials, and health professionals' practice.[13] Therefore, inclusion of information on sustainability could be widely influential. In 2015, the DGA Advisory Committee determined that there was enough evidence indicating that reducing consumption of animal-based foods would be both beneficial for sustainability and health, and they recommended that this be addressed in the 2015-2020 DGA.[14] However, this suggestion was met with backlash from congresspeople, largely due to influence from lobbyists, and public comments, and consequently, no sustainability information was included.[14] Similarly, the newest 2020-2025 DGA[15] also do not have any explicit recommendations related to sustainability.

The Food and Agriculture Organization describes sustainable diets as needing to be protective of the environment while also contributing to health and food security.[16] The multiple dimensions of sustainable diets mirror the three components of The Global Syndemic – climate change, obesity, and undernutrition.[2] Thus, sustainable diets are an important component of addressing The Global Syndemic. Food systems in high-income countries like the U.S. have been recognized as generating more negative environmental impacts while having better food affordability, availability, and safety;[17] therefore, focusing on promoting sustainable dietary patterns among this population may be more feasible and meaningful. Additionally, recommended sustainable dietary shifts vary by country and region.[17,18]

One proposed sustainable diet is the Planetary Health Diet, which was established by a commission of experts to limit environmental impacts and promote human health.[19] The dietary pattern is based on whole grains, fruits, vegetables, and plant proteins, while limiting meat, saturated fats, and added sugars.[19] To measure adherence to this diet, The Planetary Health Diet Index (PHDI) was developed and validated for a Brazilian population.[20] However, a PHDI has not been developed and validated in the U.S. population, which limits the ability to measure American adherence to this diet and identify differences in adherence between sociodemographic and socioeconomic groups. Additionally, relatively few studies have assessed dietary constructs related to sustainability among U.S. consumers, including the construct of meat attachment (i.e., a positive bond toward eating meat)[21] and willingness to reduce meat intake, and how they differ by sociodemographic and socioeconomic characteristics.[22,23] Therefore, three primary research objectives were determined. First, develop and validate the PHDI for the U.S. (PHDI-US). Second, use the PHDI-US to measure current levels of American adherence to the Planetary Health Diet and assess differences in adherence by sociodemographic and socioeconomic groups. Third, analyze differences in meat attachment and willingness to reduce meat intake by sociodemographic and socioeconomic characteristics in a U.S. population to help determine which methods and strategies may be effective in encouraging the adoption of more sustainable diets.

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Chapter 2: Review of the Literature

THE FOOD SYSTEM: DEFINITIONS AND IMPACTS

A food system is made up of various activities and resources that interact to create a complex mechanism for producing, distributing, and consuming food.[1] Various systems drive, influence, and constrain the food system, including biological, political, social, and economic systems. The food system as a whole is also made up of a network of subsystems from the local to global scale. The primary inputs driving the food system are natural and human resources, with outputs of the food system including waste products, health, environmental quality, equity, and food security.[1]

The U.S. food system is currently responsible for serving a population of over 330 million people, and it has a fundamental role in the U.S. economy. In 2021, agriculture, food, and related industries accounted for over 1.2 trillion dollars or 5.4% of the U.S. gross domestic product.[2] These industries also account for a large portion of U.S. jobs, making up 10.5% of total employment. Food is one of the top expenditures for Americans, accounting for 12.4% of household expenditures.[2] In addition, the U.S. Department of Agriculture (USDA) uses its largest share of outlays on food and nutrition assistance programs.[3]

All food systems rely on the food supply chain, which involves the different stages and actions necessary to transform raw materials into food that is ready to be prepared and/or consumed.[4] The main actors within the food supply chain include: food producers, traders, food processors, distributors, wholesalers, retailers, and consumers.[4] Production is the first stage of the food supply chain. After production, food products are processed in preparation for distribution and acquisition by retailers or suppliers and then consumers.[4]

Production

The first phase in the food supply chain involves all of the agricultural inputs and operations needed to generate products for the next stage of processing.[4] Multiple agents and resources are necessary during production. Inputs such as seeds, fertilizers, animal feed, land, and equipment are the foundation of agricultural production, and input suppliers are needed to provide producers with adequate materials.[4] Development of inputs is sometimes classified as preproduction activities in the food supply chain.[5]

Agricultural production of crops and animals uses a significant amount of land, accounting for more than 50% of the U.S. land base.[2] The average farm size in the U.S. has increased, while simultaneously, there has been an overall decline in the number of farms.[6] In 2017, only 4% of farms in the U.S. were considered large farms, which are at least 2,000 acres in size, and these farms controlled 58% of farmland. The largest portion of farms were 10 to 49 acres in size, making up 29% of total farms. The predominant share of farmland and farms were used for cattle and dairy production at 44% and 34%, respectively. The second largest portion of farmland was used for oilseed and grain production, making up 30% of farmland.[6] Although there are now fewer farms, agricultural output and productivity has dramatically increased in the past 50 years.[2] Global production of cereals and meat has especially increased over this time.[7] Meat production increased from 70.57 million tons in 1961 to 337.18 million tons in 2020, with the top types of meat being poultry, beef, buffalo, and pig.[8] Cereal production increased from about 875 million tons in 1961 to over 2.5 billion tons in 2018.[7] Furthermore, approximately 41% of the cereals produced globally in 2013 were used for animal feed, with about 48% used directly for human food and 11% used for industrial purposes.[9]

This increase in productivity and output is largely the result of agricultural technological advancements, including innovative plant and animal breeds, equipment, and chemicals.[10] Agriculture has also become increasingly industrialized and globalized over the past 150 years, with new technologies, mechanization, and transportation.[11] This has led to a transition from smaller, local, diversified farms to larger, concentrated, resource-intensive farm operations that are specialized to produce one or two commodities. These systems are production-driven and can result in oversupply of select products, contributing to an abundance of affordable, energy-dense foods made from or fed with some of the top U.S. agricultural commodities of wheat, soybeans, and corn. Additionally, these methods of production can be more environmentally damaging.[11]

After production, traders can be used to facilitate the movement and sale of products from producers to processors.[4] Producers may also utilize direct markets to sell products to consumers. In order to efficiently move inputs, resources, and products, logistics companies and transporters also play a pivotal role in the production phase of the food supply chain.[4]

Processing

During the next stage in the food supply chain, raw food materials from agricultural producers are converted into products that can be marketed and sold to consumers.[4] Processing food can serve multiple purposes, including: lengthening the life of the food item, converting raw food materials into new forms, combining food products with additional ingredients, and increasing access to food items that cannot be consumed fresh.[4] The term food manufacturing is also used to describe processing that transforms a set of food ingredients into a new product, such as bread and cookies.[12] The target market and customer base will determine the type of processing that some raw food materials undergo, and changes in consumer demands can influence how foods are processed.[4] These influences, in addition to an expanding food retail sector, have driven changes in food processing. Companies that process food have shifted toward more automated operations that lower labor and energy costs, implemented more quality management systems, and increased marketing and advertising to generate product demand.[4]

The NOVA classification system was developed to categorize foods into four groups based on how, why, and to what extent they are processed.[13] Group one foods are unprocessed or minimally processed (e.g., edible parts of fruits, eggs, animal muscle), group two foods are processed culinary ingredients (e.g., oil, butter, sugar), group three foods are processed foods (e.g., cheese, canned fish, fruits in syrup), and group four foods are ultra-processed (e.g., soft drinks, frozen meals). Ultra-processed foods contain industrial food additives intended to enhance sensory quality and palatability and are typically heavily marketed.[13] Ultra-processed foods have become a prominent part of dietary intake and the food system,[13-15] making up more than half of the calories consumed in the U.S.[16] Intake of ultra-processed foods has also been associated with worse dietary quality and adverse health outcomes.[13,15,17]

Over 36,400 food and beverage processing facilities exist in the U.S.[18] These establishments employ 1.7 million people, with the largest sector of employment in meat processing. In 2019, meat processing accounted for the biggest percentage of food and beverage manufacturing at 24% of the value of shipments. Dairy, beverages, and grains and oilseeds processing are also among the top food and beverage manufacturing industries at 14%, 12%, and 9% of shipments, respectively.[18] In 2018, the top 25 U.S. packaged food and beverage manufacturers made up 42.8% of retail sales with only 28,808 products.[19] For fourteen of these manufacturers, over 90% of their products were considered ultra-processed, with only one manufacturer having less than 50% of their products being ultra-processed. These rates indicate that a large portion of U.S. food and beverage supply has become dominated by packaged and ultra-processed foods.[19]

Distribution

After a food product is processed, it needs to be distributed to retailers, foodservice organizations, or wholesalers.[4] Food brokers are commonly used to facilitate the sale of food products between processors and retailers or wholesalers.[1] Distributors are generally responsible for purchasing the food products from processors and selling and transporting them to their final destination.[4] The main modes of food transportation are truck, rail, water, and air.[20] The majority of food products are transported by trucks via roadways.[4] For example, cereal grains and other prepared foodstuffs (e.g., dairy products, processed produce, coffee and tea, edible fats and oils, soups) were two of the top ten commodities by weight transported in the U.S. in 2018, and trucks were responsible for carrying almost 74% of cereal grains and 90% of other prepared foodstuffs.[20] One of the main goals of distribution is to transport the food products in an efficient manner that reduces the chances of contamination or damage.[4]

Retail

Food retailers are responsible for providing consumers access to food products that can be purchased and prepared or consumed off site.[4] Consumers can also access foods from producers through direct markets and from foodservice outlets.[1] Food-at-home (i.e., foods purchased for home preparation) retailers generally include grocery stores, warehouse clubs, supercenters, and mail order.[21] Whereas, the foodservice or food-away-from-home market (i.e., foods prepared away from home) is typically made up of restaurants, cafeterias, food trucks, and vending machines.[21]

In 2019, sales in the foodservice sector far outweighed the food retail industry in the U.S., supplying $1.06 trillion worth of food out of a total of $1.89 trillion among foodservice and food retail combined.[22] However, in 2020, the COVID-19 pandemic and subsequent impacts ushered in a 13.0% decline in sales for foodservice establishments.[22] These type of disruptive economic events are known to influence consumers' spending on food-away-from-home by tightening consumers' budgets and loosening time constraints.[21] At this time, food-away-from-home expenditures reached a low of 50.9%. Full-service restaurants (i.e., restaurants with servers and other dining amenities) and fast food restaurants are the top two sellers among the commercial foodservice sector. In 2020, full-service establishments experienced a large decline in sales at 24.5%, whereas, fast food restaurants only saw a small decline of 3.3%. [22] In 2021, spending on food-away-from-home returned to pre-COVID-19 levels, with food-away-from-home expenditures at 55% and food-at-home expenditures at 45%.[22]

Consumption

The types of foods Americans purchase and consume has changed drastically over the past few decades.[15,23-25] Four overarching themes emerge from these shifts in dietary intake – increased accessibility of vegetable oils; increased use of caloric sweeteners; increased intake of animal-based foods; and lowered intake of legumes, coarse grains, and vegetables.[23] Compared to many parts of the world, the U.S. and other higher-income countries have high per-capita meat consumption, with the primary determinant of meat consumption being wealth.[26] As such, developing countries have demonstrated increased production of animal-based foods, including beef, pork, dairy products, eggs, and poultry.[23] In addition, large global investments in agriculture have contributed to relatively lower prices for animal-based foods, edible oils, and sugar. An increase in supermarkets has ushered in many improvements related to food safety standards and access to a variety of food products, but other suggested impacts from this change in the food retail environment are increased access to ultra-processed foods and declines in fruit, vegetable, legume, and coarse grain intake.[23] The amount of time that American adults spend making food has also declined, while food-away-from-home expenditures have generally increased, and about one third of the average American's daily calories are derived from food-away-from-home.[21] With the exception of school meals, food-away-from-home tends to be higher in saturated fat, calories, and sodium and lower in calcium, iron, and fiber compared to food-at-home.[21]

Food System Environmental Impacts

The planetary boundaries framework demonstrates the nine processes that are necessary for Earth's functioning and the operating limits of each, in order for humans to prosper.[27,28] Greatly exceeding the safe operating space of the boundaries may lead to changes in the Earth's systems that could be unfavorable to human health and development.[27] Climate change and biosphere integrity are two of the core planetary boundaries, due to their primary importance on the functioning of Earth's systems.[28] Climate change, biosphere integrity, biogeochemical flows, and land-system change currently exceed the recommended levels outlined in the planetary boundaries framework.[28] Agriculture and food production have a considerable impact on the environment, and therefore, play a role in breaching or staying within the safe operating space.

The majority of food products have the largest impact on the environment during agricultural production rather than during the latter stages in the food supply chain,[29] with the farming stage accounting for an estimated 61% of the GHG emitted during food production, 79% of terrestrial acidification, and 95% of eutrophication.[30] Data also indicate that production of animal-based foods and livestock, particularly beef, are responsible for a large proportion of these impacts.[31-33]

Climate Change and Greenhouse Gas Emissions

There is consensus that present rates of climate change are the result of human activity.[34-36] Climate change occurs through increases in concentrations of GHG in the atmosphere. Carbon dioxide, methane, and nitrous oxide are the main GHG of concern.[34] It is estimated that humans have led to global warming, defined as increases in multi-decade global mean surface temperatures, of about 1.0°C over pre-industrial levels.[37] If current rates continue, it is expected that warming of 1.5°C will occur between the years 2030 to 2052. Some regions are already experiencing climates that are at least 1.5°C over pre-industrial levels. Increased temperatures have led to more droughts and floods, sea level rise, and decreases in biodiversity.[37] In addition, global warming has resulted in increased frequency, intensity, and/or quantity of heavy precipitation globally.[36]

The biophysical conditions present over the past 11,700 years in the Holocene epoch period of geologic time have been quite stable, and these conditions are the only ones known to be capable of supporting human life.[28] However, over the past 20 years, global atmospheric carbon dioxide concentrations have increased by approximately 20 parts per million per decade.[37] This rate of increase is up to 10 times faster than the rises in carbon dioxide concentrations over the past 800,000 years. With these changes in the Earth's systems and the influence from humans, scientists propose that the Earth has entered a new geological epoch called the Anthropocene. The Pliocene epoch was 5.333 to 2.58 million years before present and is the most recent geological epoch with comparable levels of atmospheric carbon dioxide, causing concern regarding the viability of human wellbeing among the present trajectory of conditions.[37] Research has demonstrated the large impact that food and agricultural products have on the environment through GHG emissions.[5,31,38]

In 2019, the U.S. agricultural sector, including livestock and crop production, accounted for an estimated 10% of national GHG emissions.[39] GHG can be emitted through agricultural practices like applying fertilizers and irrigating, which increase the availability of nitrous oxide from soil; raising livestock that generate methane through enteric fermentation during digestion; managing manure in ways that release methane and nitrous oxide; cultivating rice, which produces methane; burning crops, which creates methane and nitrous oxide; and liming and applying urea, which release carbon dioxide. Soil management generates about 50% of GHG emissions within the agricultural sector, and enteric fermentation from livestock accounts for more than 25% of GHG emissions within the agricultural sector. GHG emissions from agriculture have increased 12% from 1990, reaching 669.5 million metric tons of carbon dioxide equivalent (CO_2-eq) in 2019. This increase was largely driven by an increase in the combined methane and nitrous oxide produced from management of livestock manure.[39] Globally, the agricultural, forestry, and other land use sector was the second largest single source of GHG emissions in 2010.[40] This sector was responsible for 24% of global GHG emissions, with agriculture being the largest contributor in this category. However, plants, soils, and dead organic matter can also sequester carbon dioxide, which may reduce this sector's emissions by about 20%.[40]

There is wide variation in the GHG emissions created during the production of different agricultural products. Clune et al. conducted a systematic review and meta-analysis of 369 studies that utilized life cycle assessment of foods in order to determine their global warming potential (GWP) and compare production methods.[31] Most of the reviewed studies were based in Europe. The functional units reported in the life cycle assessment studies were converted to kg CO_2-eq/kg bone free meat or produce for purpose of comparison. Additionally, the system boundary for the life cycle assessment studies was set at the regional distribution center, and conversions were performed for studies that had different system boundaries. This means that the final GWP values do not account for retail, consumer transportation and cooking, or consumer waste and disposal. The GWP values do represent the inputs of fertilizers, herbicides, machinery, fuel, water, energy, and raw materials and the emissions from plants, animals, machinery, processing, and waste. The results showed that field-grown vegetables had the lowest median GWP value at 0.37 kg CO_2-eq/kg, followed closely by field-grown fruit at 0.42 kg CO_2-eq/kg, cereals other than rice at 0.50 kg CO_2-eq/kg, and legumes and pulses at 0.51 kg CO_2-eq/kg. The foods with the highest median GWP values included buffalo, lobster, beef, lamb, and sole at 60.43, 27.80, 26.61, 20.86 kg CO_2-eq/kg, respectively. Foods that ranked more moderately within the scale of GWP values included pork, cream, chicken, all species of fish, and eggs at 5.77, 5.64, 3.65, 3.49, 3.46 kg CO_2-eq/kg, respectively. Fruits and vegetables that are grown in greenhouses also differ from their field grown counterparts, with those grown in passive greenhouses resulting in a median GWP value of 1.10 kg CO_2-eq/kg and those grown in heated greenhouses having a median GWP value of 2.13 kg CO_2-eq/kg. When examining the differences in the GWP values between types of fish, pilchards, pollock, carp, herring, and mackerel had lower GWP values that were similar to the higher-impact plant-based food categories, tree nuts and rice. Fish that are obtained through trawling (i.e., pulling a net across the seabed) and long line fishing produced higher GWP values because these practices utilize more fuel as compared to coastal fishing methods. For pork, GWP values fluctuated based on the location that it was produced. European pork had the lowest median GWP value at 5.50 kg CO_2-eq/kg, whereas, Australia had the highest value at 7.65 kg CO_2-eq/kg. The United Kingdom and North America were in the middle, with median GWP values of 6.00 kg CO_2-eq/kg and 6.11 kg CO_2-eq/kg, respectively. The ruminant animals included in the study demonstrated very high GWP values. This is largely due to ruminant animals producing methane during digestion. The authors suggest that the database of GWP values for 168 fresh food products provides a means for researchers to easily assess the GWP of various diets.[31]

Clark and Tilman completed a meta-analysis of 164 life cycle assessment studies that covered the environmental impacts of 90 food products from 742 food production systems.[41] The system boundaries used for the study were described as including pre-farm and on-farm activities, such as fertilizer production, fertilizer application, feed production, and manure management, and excluding any post-farm activities. Most of the analyzed food systems represent the industrialized, high-input farming practices of Europe and North America. They also compared various farming methods to determine if there were differences in their environmental impacts. When comparing organic and conventional farming methods, organic was not significantly different but resulted in 4% less GHG emissions per unit of food. The comparison of grass-fed beef and grain-fed beef revealed that grass-fed beef generated 19% more GHG emissions per unit of food but was not significantly different than grain-fed beef.

Trawling, non-trawling (including midwater trawl, short- and long-line fishing, and seine nets), and aquaculture fishing practices were also compared. Consistent with the results from Clune et al.,[31] trawling fisheries produced significantly more GHG emissions compared to non-trawling fisheries, due to trawling fisheries using large amounts of fuel to drag nets through the seabed. Non-trawling fisheries and non-recirculating aquaculture operations generated comparable amounts of GHG emissions per unit of food, but recirculating aquaculture operations had higher GHG emissions similar to the levels of trawling fisheries. When comparing greenhouse grown crops to open-field grown crops, greenhouses generated nearly three times more GHG emissions. Additionally, their results demonstrated that plant-based foods had the least environmental impacts across all indicators, and meat from ruminant animals generated impacts up to 100 times higher than plant-based foods.[41]

Poore and Nemecek published a meta-analysis where they developed a database of the environmental impacts of 40 food products using data from 570 studies.[30] The data encompassed 119 countries, and the selected foods accounted for about 90% of the protein and calories consumed globally. The researchers set the system boundary as beginning with the inputs used by producers, such as fertilizer, irrigation, and soil, and ending at retail. The environmental impacts are represented by the main nutritional benefit for each food item. They found that there was a considerable amount of variation in the environmental impacts based on the type of food product and how food products were produced. Cane sugar had median GHG emissions of 3.2 kg CO_2-eq/kg, whereas, beet sugar had lower median emissions at 1.8 kg CO_2-eq. Among the five oils included in the study, sunflower and rapeseed oil tied for the lowest median emissions at 3.5 kg CO_2-eq/L, and palm oil had the highest at 7.2 kg CO_2-eq/L. Per 100 grams of protein, nuts had negative median GHG emissions at -0.8 CO_2-eq because they are able to sequester carbon, and beef had the highest at 30 kg CO_2-eq. Other plant-based protein sources, including peas, other pulses, groundnuts, and tofu, all ranked among the lowest on the scale at medians of 0.4, 0.6, 1.3, and 1.6 CO_2-eq per 100 grams of protein, respectively. Farmed fish, eggs, and poultry ranked lowest among the animal-based protein sources at medians of 3.5, 3.8, and 4.3 kg CO_2-eq per 100 grams of protein, respectively. Cows' milk and soymilk were included in the analysis, and cows' milk had GHG emissions three times higher than soymilk, with cows' milk resulting in a median of 2.7 kg CO_2-eq/L and soymilk emitting a median of 0.9 kg CO_2-eq/L. The researchers describe five predominant reasons for the contrast between emissions from animal-based products and plant-based products: 1) the production of animal feed results in greater emissions than vegetable protein farming; 2) the majority of deforestation is driven by the need for producing animal feed like soy, maize, and pastureland; 3) certain animals generate extra emissions through enteric fermentation, manure, and aquacultures; 4) the processing of animal-based foods generally results in greater emissions; 5) animal-based products are more likely to spoil, which leads to greater waste.[30]

Land Use

As of 2012, 52% of U.S. land area was used for agricultural purposes, with 655 million acres used for grassland pasture and range, 392 million acres used for cropland, 130 million acres used for grazed forestland, and 8 million acres used for farmsteads and farm roads.[42] Globally, agriculture utilizes 38% of the Earth's land surface[43] and approximately 50% of habitable land.[44] Cropland makes up about one third of global agricultural land, with the rest used for grazing livestock.[43] Over the years 1961 to 2016, the amount of cropland per capita decreased by over half.[43]

The meta-analysis conducted by Clark and Tilman found that organic farming systems used more land than conventional systems, ranging from 25% to 110% more land per unit of food.[41] Producing grass-fed beef also used more land than grain-fed beef. Greenhouse grown produce required 75% less land on average than open-field produce, but there was not a statistically significant difference between the two. Meat from ruminants required the greatest amount of land per calorie, with maize, wheat, rice, and fresh produce requiring the least per calorie.[41] Similar results were found by Poore and Nemecek.[30]

Water Quantity and Quality

It is estimated that on average, agriculture is responsible for 70% of the world's freshwater withdrawals.[45] Further, some areas that are the most prominent cereal producers are also among the regions currently experiencing water scarcity. Climate change is expected to affect the water cycle with alterations in rainfall, recharge rates of groundwater, and sea levels.[45] Irrigation of agricultural and horticultural operations (e.g., farms, golf courses, nurseries) accounted for 37% of total water withdrawals in the U.S. at an estimated 118,000 million gallons of water per day in 2015.[46] Agricultural irrigation makes up the largest portion of U.S. consumptive water use, and agriculture as a whole accounts for about 80% of U.S. consumptive water use.[47] Between the years 2013 and 2018, the amount of irrigated farm land increased, but the overall amount of water used for irrigation decreased by 5.8%.[48] In 2018, 50% of irrigated U.S. acres were located in California, Nebraska, Arkansas, Texas, and Idaho. The most common source of irrigation is groundwater from wells.[48] Additionally, irrigated agricultural operations contribute to the production of livestock and poultry through growing forage and feed crops.[47]

Freshwater withdrawals used for livestock and dairy production in 2015 were estimated at 2,000 million gallons per day, which is 16% less than the peak amount used in 2000.[46]

Agriculture also plays a major role in water pollution, largely resulting from use of fertilizers, insecticides, herbicides, fungicides, and bactericides.[45] The amount of nutrients (i.e., phosphorous and nitrogen species) that enter U.S. waterways has dramatically increased over the past few decades due to humans.[49] Eutrophication is the process of nutrient levels increasing in bodies of water. This leads to the growth of excessive aquatic vegetation, which can generate hypoxic water conditions and create dead zones where many aquatic species cannot survive. Algal blooms can also occur because of eutrophication, and these can produce toxic compounds that are harmful for humans and fish. Streams that are near an abundance of row-crop agricultural operations have been found to have high concentrations of nitrogen and phosphorous.[49] Livestock excreta is also one of the most prominent sources of nitrogen pollution, leading to nitrates and nitrites entering surface and groundwaters.[50] Polluted waters can negatively impact fisheries, reduce the amount of water available for agriculture, and increase costs related to water treatment.[45] In addition, the majority of global fish stocks are fully fished and more than 30% are overfished.[51]

Aquaculture operations can also harm their local ecosystems.[51] These operations farm aquatic organisms such as fish, mollusks, crustaceans, and sport fish through means including seeding, stocking, feeding, and protecting the organisms from predators.[52] In 2018, fish raised for food and their eggs made up 47% of aquaculture sales in the U.S., with catfish being the top product. At that time, aquaculture operations encompassed 228,599 freshwater acres and 230,251 saltwater acres, and they used four types of water sources – groundwater, on-farm surface water, off-farm surface water, and saltwater.[52] A meta-analysis of 52 studies found a high amount of variability regarding the studies' estimated ecological effects on water quality from aquaculture operations, but the studies indicated that loadings from aquaculture operations can result in significant changes from the natural patterns in the surrounding water column.[53] Ammonium was most impacted by aquaculture loadings, followed by nitrites, nitrates, and phosphorous, with silicates not significantly affected. The type of organism being produced and the ecosystem in which the organisms are produced were the two main variables leading to differences among most of the studies' results. Fish and shrimp aquaculture had higher size effects on dissolved nutrients than bivalves, and operations located in smaller, more enclosed bodies of water were correlated with higher size effects.[53]

Air Pollution

The food supply chain generates air pollution, primarily GHG, ammonia, and particulate matters, throughout all of its stages.[54] The World Health Organization considers fine particulate matter to be the most directly harmful to human health, being associated with various illnesses, including lung cancer and cardiopulmonary disease. The majority of particulate matter is generated through the combustion of fuel.[55] Soil and land cultivation, machinery, and agrochemical use all contribute to air pollution during the production phase of the food system.[54] Rising temperatures due to climate change can also increase the volatilization of nitrogen fertilizers and pesticides, increasing the amount that can reach the air. The processing and transporting of food products is also a key driver of air pollution, with road traffic generating GHG, carbon monoxide, nitrogen and sulfur oxides, hydrocarbons, particulate matter and airborne trace minerals.[54]

Biodiversity

The range of plants, animals, micro-organisms, and genetics that make up the Earth's ecosystems is of vital importance for the food system.[56] A greater amount of diversity among these organisms allows for a more resilient food system, in the case of disruptions, especially those posed by climate change. Namely as a result of pollution, habitat degradation, and overuse, many species that aid agricultural production, such as pollinators, predators to pests, and soil organisms, are declining.[56] Food production as a whole is considered the main reason for biodiversity loss globally, with the conversion of natural lands into agricultural lands being the primary driver of habitat destruction.[44] Animal farming is largely responsible for the expansion of agricultural lands.[44] In 2007, the creation of cattle ranches made up an estimated 70% of the deforestation that occurred in Brazil, and most of the global land that is converted to agricultural land is used for producing livestock and their feed.[57]

The introduction of resilient alien species into ecosystems can influence how the ecosystem functions and has a detrimental impact on biodiversity.[58] An increase in biological invasions is expected to have negative impacts on surface water runoff, groundwater recharge, and livestock production.[58] It is proposed that climate change will influence invasive species by: impacting the ways that they are transported and introduced, leading to the establishment of new invasive species that may have been previously constrained, changing the distribution of current invasive species, altering the impacts of current invasive species, and impacting the effectiveness of management methods.[59]

FOOD SYSTEM SUSTAINABILITY

With a growing global population that is expected to reach 9.7 billion by 2050,[60] providing adequate food that is both healthy and culturally appropriate for everyone poses an immense challenge to the food system.[61] As incomes rise and more people begin living in urban areas, the demand for foods that are refined, high in saturated fats, and high in added sugars is expected to increase.[57] The consumption of animal protein is also expected to rise substantially, possibly being four times higher by 2050.[57] There is increasing consensus that rapid changes to the ecosystem are threatening human health and that actions need to be taken to mitigate these negative impacts.[27,34-36] Implementing changes to current food systems, in order to make them more sustainable, is necessary to help reduce environmental degradation and feed a growing population.

The Food and Agriculture Organization of the United Nations (FAO) defines a sustainable food system as, “a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised.”[62] These three dimension – economic, social, and environmental – demonstrate the dynamic nature and considerable scale of the food system and the complex actions that are required at local, national, regional, and global levels to develop a sustainable food system.[62] The complexity of the food system necessitates a coordinated effort among stakeholders, balancing of tradeoffs, and implementing actions that help to reach multiple goals.[62] High-income countries like the U.S. tend to have better food system sustainability for some indicators, including nutrient adequacy, food affordability and availability, food safety, and sociocultural wellbeing when compared to lower-income countries, but they have worse ecosystem stability and waste and losses. In addition, countries that have better food nutrient adequacy tend to have lower ecosystem stability.[63]

Status of U.S. Food System Sustainability

Dietary Recommendations

As the Dietary Guidelines for Americans (DGA) inform policy, programming, and practice, they should include language about sustainability in order to help achieve food system sustainability. However, the recently released 2020-2025 DGA[64] include no mention of the word "sustainable" or "sustainability." An analysis published by the FAO in 2016 found that only 4 countries – Brazil, Sweden, Qatar, and Germany – out of 83 countries with food-based dietary guidelines had incorporated messaging about sustainability.[65] There are differences among the messages included or emphasized within these four dietary guidelines, but they generally promote eating predominately plant-based foods and reducing meat consumption. However, little specific information is provided, and when maximum consumption levels of meat are recommended, they are based on health-related guidelines. Germany provides information about cooking efficiently and reducing food packaging. Brazil includes messaging about avoiding ultra-processed foods and being weary of advertisements and marketing.[65] Similar messages and information could be included in the DGA.

Despite no specific mention of sustainable consumption, one of the recommended dietary patterns within the DGA may promote greater food system sustainability. A study was conducted to examine the environmental impacts of recommended dietary patterns in the 2015-2020 DGA.[66] The three patterns included the Healthy U.S.-Style Pattern, the Healthy Mediterranean-Style Pattern, and the Healthy Vegetarian Pattern. These patterns are designed to help Americans follow the DGA, and they include daily quantities of foods to consume among the major food groups for different calorie levels.[67] The 2,000-kcal level diet recommendations were assessed.[66] The researchers focused on the following environmental indicators: GWP, marine eutrophication potential, freshwater eutrophication potential, land use, water depletion, and particulate matter or respiratory organics. Compared to the Healthy Mediterranean-Style Pattern, the Healthy U.S.-Style Pattern had a 31% lower freshwater eutrophication potential, mainly due to lower seafood recommendations than the Healthy Mediterranean-Style Pattern, but overall, they had similar environmental impacts. Except for water depletion, which was similar for all of the patterns, the vegetarian eating pattern had 42-84% lower environmental impacts than the other two patterns. Unlike the Healthy Mediterranean-Style Pattern and the Healthy U.S.-Style Pattern, the protein food group in the Healthy Vegetarian Pattern was only a small contributor to the pattern's environmental impacts, with the exception of land use.[66] The results clearly demonstrate that the vegetarian pattern has environmental benefits as compared to the other patterns.

Dietary Patterns

National Health and Nutrition Examination Survey (NHANES) data from 1999 to 2016 reveal the recent dietary patterns of U.S. adults and how they have changed over time.[68] Calorie intake from carbohydrates significantly decreased from 52.5% to 50.5%, while calories from total protein and fat increased from 15.5% and 32.0% to 16.4% and 33.2%, respectively. Calories coming from low-quality carbohydrates, primarily from added sugars, also declined, and calories from high-quality carbohydrates, mostly from whole grains, increased. Intake of calories from animal protein increased from 10.2% to 10.6% during this time period, which was primarily associated with increased intake of poultry and eggs. Calories derived from plant proteins also increased from 5.38% to 5.76%, which was associated with increased intake of whole grains, nuts, and soy. The percentage of calories consumed from non-starchy vegetables increased from 1.67% to 1.81% and whole fruits increased from 2.87% to 3.21%. Healthy Eating Index (HEI)-2015 scores, measuring overall dietary quality on a 100-point scale based on the 2015-2020 DGA, increased by about two points to reach a mean score of 57.7 out of 100.[68] HEI-2015 scores of 81 and above have been associated with lower risk of all-cause mortality and cardiovascular disease mortality.[69]

Another study using NHANES 2005-2016 data demonstrated that HEI-2015 scores have increased over time and tend to increase as incomes rise, with the lowest and highest income deciles separated by nine points.[70] Within each HEI-2015 component, the highest income decile had a higher score than the lowest income decile, except for the dairy and sodium components. Greater intakes of fruits, oils and fats, dairy and livestock products, seafood, plant-based proteins, and foods like sugar-sweetened beverages, snacks and sweets, and condiments were associated with higher incomes. Based on the dietary intake from NHANES, the per capita environmental impacts were estimated at an average of 3.4 kg CO_2-eq, 15.6 m^2 of land use, 972 L blue water, and 28.9 megajoules of energy consumption per day. When extrapolated to represent impacts at a national scale, these estimates equate to 385 megatons CO_2-eq, 1.77 million km^2 land, 110 billion m^3 water, and 3.27 million terajoules of energy for one year. Within the U.S., these values account for 7.2% of the consumption-based GHG emissions generated in 2009, 29.7% of consumption-based land used in 2007, 13.4% of consumption-based water footprints between 1996 and 2005, and 3.4% of the consumption-based energy used in 2012. All of these indicators also generally increased with income for 2015-2016, demonstrating that those with higher incomes have diets with greater environmental impacts. These differences are largely driven by greater intake of dairy and livestock products, seafood, legumes, nuts and seeds, and fruits.[68]

Food Security

Sustainable food systems are described as needing to support health and food security while also limiting negative environmental impacts; thus, achieving widespread food security is an essential component of a sustainable food system.[62] In 2019, about 89.5% of households in the U.S. were considered food secure.[71] The term food secure indicates that the household members perceived having access at all times to enough food for an active, healthy life.[71] Whereas, 10.5% of households in the U.S. were food insecure, meaning they were, at some point in the year, unable to obtain enough food for one or more members of the household because of inadequate money or resources.[71] Of these households experiencing food insecurity, 4.1% were considered to have very low food security. This level of food insecurity is more serious and indicates that at least one person in the household had disrupted eating patterns, due to insufficient money and resources to acquire food.[71] Children and adults experienced food insecurity in 6.5% of U.S. households with children during 2019. Among households that had children and incomes close to or under the federal poverty level, rates of food insecurity were higher than the national average. Households that were headed by Black or Hispanic individuals also experienced higher than average rates of food insecurity. Additionally, prevalence of food insecurity is higher in the southern region of the U.S.[71]

Approximately 58% of households experiencing food insecurity reported participating in at least one of the following Federal programs: National School Lunch Program (NSLP); Special Supplemental Nutrition Program for Women, Infants, and Children (WIC); and Supplemental

Nutrition Assistance Program (SNAP).). SNAP is overall quite effective at improving household food security.[72,73] However, food insecurity is still present among households participating in the NSLP, WIC, and SNAP with rates of food insecurity at 36.9%, 34.1%, and 49.7%, respectively, in 2019.[71]

National School Lunch Program

Oostindjer et al. discussed how school meals and programs could contribute to food system sustainability.[74] The NSLP has been linked to reduced rates of food insecurity,[75] helping to achieve food system sustainability.[62] Despite these benefits, food waste is an issue within the NSLP.[76] It is estimated that 12% of the food served is thrown away, with vegetables and salads making up most of this waste.[76] However, a recent study using life cycle assessment, environmental life cycle costing, and food waste audits for a school canteen found that after preparation, serving, and student consumption, 54% of purchased food was wasted.[77] Plate waste from students made up the largest percentage of this waste at 37%. Food waste also accounted for 40-57% of the meals' total GWP, but the food procurement stage as a whole represented 80% of the GWP of meals, indicating that this stage has an important role in increasing the sustainability of meals.[77] Increasing the flexibility in meals by utilizing an offer versus serve method and allowing students to select certain food items may help to reduce the amount of food that goes uneaten.[76] The NSLP does utilize foods that were produced at a surplus, in order to prevent waste.[74] This can have a positive impact, but there is also concern about the longevity of this method and how overproduction can impact long-term sustainability.[74]

Farm-to-school programs are an emerging method to join schools with local farmers, by which both parties benefit and the supply chain is shortened.[78] Many of these programs also incorporate field trips to the farms and lessons regarding nutrition, agriculture, science, and environmental topics. School gardens where students can help grow and taste different fruits and vegetables are also a common theme for farm-to-school programs. It has been proposed that wider adoption of these programs could help preserve farmland by supporting farmers.[78] Some also feel that schools are the natural location for a widespread, cultural shift, which is necessary to achieve the scoping changes required for food system sustainability, as schools present an opportunity to educate young people about sustainable behaviors.[79] Further, a number of school garden programs have been associated with more positive social and environmental behaviors from students.[80] However, implementation of farm-to-school programs is not without obstacles. Some of the major issues include farms having difficulty competing with the USDA commodity prices, lack of storage capacity for fresh fruits and vegetables at schools, consistency in products, and overall logistics.[78]

Special Supplemental Nutrition Program for Women, Infants, and Children

WIC is a federal nutrition assistance program that provides benefits for supplemental food, health care referrals, and nutrition education for women with low incomes that are pregnant, breastfeeding, or non-breastfeeding postpartum and infants and children who are five years or younger and at nutritional risk.[81] The WIC program prioritizes foods that help to meet the nutritional needs of these individuals, such as fruits, vegetables, foods with whole grains, eggs, milk, cheese, beans, and baby foods.[82] In 1992, Congress established the WIC Farmers' Market Nutrition Program (FMNP) where eligible WIC participants are provided coupons to purchase fruits and vegetables from authorized farmers, farmers' markets, and roadside stands.[83] FMNP programs have been linked to increased fruit and vegetable intake.[84,85] In addition, participation in FMNP and previous redemption of FMNP vouchers have been associated with higher rates of farmers' market use.[86] Unfortunately, redemption rates of vouchers are relatively low.[87] One study conducted a survey with WIC participants and WIC non-participants at a new WIC-based farmers' market to better understand the sociodemographic characteristics, behaviors, and motivators related to attending the market.[87] They found that most visitors were non-Hispanic white and female, and the majority of WIC participants at the market were younger than WIC non-participants. Among WIC participants, some of the top motivators for attending the market were low prices and the ease of redeeming FMNP vouchers, with only 35% citing supporting local farmers as a motivator. Overall, the study concluded that having the market at the WIC clinic helped WIC FMNP participants to redeem their vouchers and increase their purchase of a variety of fruits and vegetables. This study provides support for holding farmers' markets in convenient locations for WIC participants, in order to increase access and utilization.[87] Increased voucher redemption and farmers' market use could help support local farmers and economies and improve food system sustainability.

Supplemental Nutrition Assistance Program

SNAP is a federal program that provides benefits to families with low incomes to supplement their food budget.[88] The Agricultural Act of 2014 (i.e., the Farm Bill) established the Food Insecurity Nutrition Incentive Grant Program (FINI), which is now the Gus Schumacher Nutrition Incentive Program (GusNIP), to fund programs that would help to increase the fruit and vegetable purchases of SNAP participants through point-of-purchase incentives.[89] Incentives were operationalized in a variety of ways, but they generally provide matching discounts or incentive dollars in the form of loyalty cards, tokens, paper coupons, or gift cards when purchasing fruits and vegetables. Incentives are also offered at a range of locations, such as farmers' markets, grocery stores, farm stands, community-supported agriculture, and food cooperatives, depending on the program. The 2018 Farm Bill maintained most of the established programs and regulations of its predecessor, but it improved FINI by labeling it as an entitlement program.[89] Evaluations of FINI programs demonstrated that the point-of-purchase incentives have helped increase the fruit and vegetable purchases of SNAP participants, decrease food insecurity, and support local farmers.[90-93] In addition, grocery stores offering incentives reported being able to source more local produce because of increased sales.[89] All of these are outcomes that help to improve food system sustainability.

The dietary quality of SNAP participants is also an important aspect of assessing current food system sustainability. Research has indicated that ultra-processed foods make up a large portion of Americans' diets and are popular among SNAP participants.[94] A study used focus groups to investigate motivations for SNAP participants' purchase of ultra-processed foods.[94] Both SNAP participants and SNAP nonparticipants reported frequently buying foods that are ready-to-eat and ready-to-heat, with common ready-to-eat foods including soda, chips, granola bars, and cereal and common ready-to-heat foods including macaroni and cheese, frozen waffles, chicken nuggets, and frozen entrees. A wide range of factors contributed to individuals' decisions to buy certain foods, such as child food preferences, the location of foods in the store, and cost. Some participants, mostly SNAP nonparticipants, mentioned ethical or environmental concerns influencing their decision to buy products. Few people cited local, organic, or non-genetically modified organism foods as being important. Another key factor in SNAP participants' decision-making was risk aversion and not wanting to waste money on foods that their family might not like. Additionally, ultra-processed foods were often kept on hand in case of resource shortfalls, as may be experienced at the end of the monthly SNAP benefit cycle.[94]

Reports have also indicated that SNAP participants were significantly less likely to meet the recommendations outlined in the DGA.[95] A more recent systematic review on the dietary behaviors and outcomes of SNAP participants found that when compared to adults that do not participate but are income-eligible to receive SNAP (income-eligible nonparticipants), participants had similar intakes of meat, milk and milk products, fats and oils, and sweets and desserts.[96] Fiber was the only nutrient where average intake was different from income-eligible nonparticipants. SNAP participants did have significantly lower spending on food-away-from-home and lower intakes of zinc. There was less consensus in the findings for energy intake; grain, fruit, vegetable, and sugar-sweetened beverage intakes; and diet scores. Most studies found small differences in the energy intakes between groups, except for among men and women. Female SNAP participants aged 19-30 years ate more calories than nonparticipants, whereas, older female participants aged 31-50 years ate fewer calories than nonparticipants. For average age-adjusted food energy intake, male SNAP participants consumed significantly more as compared to male income-eligible nonparticipants. Four out of ten studies found significantly higher sugar-sweetened beverage intake among SNAP participants compared to income-eligible nonparticipants. The majority of studies showed little difference among the groups for intake of fruits and vegetables. Consumption of whole grains was found to be lower among SNAP participants compared to income-eligible nonparticipants. The review concluded that the studies showed SNAP participants had similarly low or significantly lower diet quality when compared to nonparticipants, but their energy intakes were generally consistent.[96]

A study using dietary data from NHANES computed diet scores based on the American Heart Association 2020 Strategic Impact Goals,[97] which includes eight dietary components: fruits and vegetables; fish and shellfish; whole grains; sugar-sweetened beverages; sodium; nuts, seeds, and legumes; processed meat; and saturated fat.[98] Higher scores indicate greater adherence to recommendations. The main goal of the study was to investigate health and dietary disparities between SNAP participants, income-eligible nonparticipants, and higher-income individuals. The results showed that SNAP participants were more likely to be younger and female and less likely to identify as non-Hispanic white. Over the years 2003-2014, diet scores did not significantly change for SNAP participants, but scores significantly increased for income-eligible nonparticipants and higher-income individuals. All groups had a small proportion of people meeting the ideal diet score, but SNAP participants had a significantly higher proportion of individuals with a poor diet score. Between 1999 and 2014, disparities grew between SNAP participants and the other groups, with SNAP participants having lower scores for processed meat, nuts and seeds, fish and shellfish, and added sugars.[98]

Another study using NHANES data sought to evaluate how sociodemographic, household, and health-related characteristics influence disparities in diet quality between SNAP participants, income-eligible nonparticipants, and income-ineligible nonparticipants.[99] Diet quality was measured by computing HEI-2015 scores. The study utilized an Oaxaca-Blinder decomposition analysis[100] to determine how much the selected characteristics can help explain the disparities in diet quality observed between SNAP participants and nonparticipants. Some of the chosen characteristics included: educational attainment, household size, food security status, poverty income ratio, and frequency of prepared meal acquisition. These were selected to represent personal and household characteristics, available resources, and time constraints.[99]

Previous research has demonstrated that these factors impact SNAP participants' ability to obtain adequate food.[101] The results of the study demonstrated a significant difference in all sociodemographic, household, and health-related characteristics for SNAP participants.[99] On average, SNAP participants were younger, had more members in their households, had higher body mass index scores, and purchased less prepared meals compared to the other groups. Additionally, a bigger percentage of SNAP participants identified as non-Hispanic black, Hispanic, food insecure, uninsured, and a current smoker. HEI-2015 scores were not very high for all subjects, with average scores of 47.1, 49.9, and 53.2 for SNAP participants, income-eligible nonparticipants, and income-ineligible nonparticipants, respectively. However, on average, SNAP participants received a significantly lower score than the other groups. The Oaxaca-Blinder assessment concluded that 35.51% of the gap in HEI-2015 scores between SNAP participants and income-eligible nonparticipants could be explained by the selected sociodemographic characteristics. Further, it showed that the combination of all the selected characteristics explained 56.86% of the gap in scores between these two groups. The percentage was even greater between SNAP participants and income-ineligible nonparticipants, with sociodemographic characteristics explaining 72.40% of the gap and all of the characteristics explaining 86.31% of the gap.[99]

The results of these studies demonstrate the disparities and sociodemographic and socioeconomic differences present among SNAP participants, income-eligible nonparticipants, and higher income individuals. Fairly consistently, research has demonstrated that SNAP participants have lower diet quality than nonparticipants (both income-eligible and income-ineligible).[96,98,99,102,103] Evidence shows that certain factors, including being a women, younger, non-Hispanic black or Hispanic, separated/divorced, less educated, and on a health plan from the government, increase the likelihood of someone participating in SNAP.[104] Alarmingly, some of these factors have been shown to, at least partially, help explain the gap in diet quality.[99]

Food Environment

The food environment of high-income countries has largely become dominated by ultra-processed foods that are generally affordable, energy-dense, palatable, and sugary or salty.[105] Those with lower levels of education, household income, nutrition knowledge, self-efficacy, and social support may have more difficulty navigating these environments in order to make healthy dietary choices.[106-108] Additionally, there is evidence that fast food restaurants are more prevalent in low-income areas and in areas with a larger proportion of ethnic minorities.[109]

A systematic review investigated the link between food environments and dietary behaviors among adults and adolescents.[110] The reviewed studies evaluated associations between dietary behaviors and various aspects of the food environment, such as food prices, access, and perceived availability, with stratification based on socioeconomic position. Indicators of socioeconomic position included household income, education level, household poverty/deprivation, employment status, public vs. private schools, area level of deprivation, and receiving benefits. The majority of studies that focused on economic factors of the food environment found that foods with higher prices were consumed less, with individuals of lower socioeconomic position being more sensitive to food prices. Many of the studies that examined measures of access, proximity, and quality of the food environment did not find significant relationships with dietary behavior. Overall, studies that focused on economic characteristics of the food environment and school food environments found more consistent results with stronger associations between dietary behaviors and food environments for populations with low socioeconomic positions; however, most of the reviewed studies showed inconsistent results.[110] Another study found that proximity to a supermarket was not associated with intake of fruits and vegetables among individuals with low incomes, but the perceived access to a supermarket within walking distance was strongly related to increased fruit and vegetable consumption.[111]

SUSTAINABLE DIETS

The Sustainable Development Goals (SDG) outlined by the United Nations in the 2030 Agenda for Sustainable Development[112] have a clear emphasis on improving the multiple dimensions that coalesce to create a sustainable system. Many of the SDG are dependent upon making changes to the current global food system, particularly the following:

- Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
- Goal 3. Ensure healthy lives and promote well-being for all at all ages.
- Goal 6. Ensure availability and sustainable management of water and sanitation for all.
- Goal 12. Ensure sustainable consumption and production patterns.
- Goal 12, Target 7. Promote public procurement practices that are sustainable, in accordance with national policies and priorities.
- Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

Sustainable diets are an important aspect of accomplishing broader food system sustainability and the SDG. The FAO states, "Sustainable diets are those with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are 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."[113] There is already substantial evidence that dietary patterns with high intakes of ultra-processed foods and added sugars are contributing to non-communicable disease and obesity.[114-117] Therefore, the shift toward high consumption of ultra-processed and animal-based foods[23,57,105] has raised concerns about the sustainability of current and future dietary patterns on the basis of their health and environmental impacts.

Diets that both promote health and safeguard natural resources, in other words, sustainable diets, have been referred to as "win-win" diets, whereas, diets that are unhealthy and environmentally unsustainable are considered "lose-lose" diets.[118] Conventional Western-type diets have been labeled as lose-lose due to their high environmental impact and overall negative health effects. Based on many findings, a healthier and more sustainable diet would consist of more dietary diversity, balanced energy intake and output, lower intake of animal products, lower intake of fish, higher intake of fruits and vegetables, higher intake of whole grains, minimal intake of processed foods, reduced food waste, and use of efficient cooking methods.[118]

A study looked at the differences in dietary composition between diets with low environmental impact and high environmental impact among a group of Spanish university graduates.[119] The researchers determined the participants' baseline habitual diets over the previous year through a food frequency questionnaire. GHG emissions in kg CO_2-eq and use of land, water, and energy resources were estimated for each participant's diet. Most participants reported being healthy, active, and of normal body mass index, and the average intake level was 2,300 kcals/day. The average daily dietary GHG emissions was 3.54 kg CO_2-eq, water use was 3,753 L, land use was 7.17 m^2, and energy use was 17.59 megajoules. Those with diets in the lowest quartile of GHG emissions had higher prevalence of hypertension and hypercholesteremia, had lower caloric intake, and were more active. After controlling for differences in energy intake, the lower GHG emitting diets contained significantly less animal-based foods and meat, and they were higher in fruits, nuts, legumes, cereals, and fats and oils. However, diets that had higher water use contained more fresh fruits, vegetables, nuts, and fats and oils. In general, the diets with lower environmental impact were lower in proteins and fats, especially saturated fat, and higher in carbohydrates and polyunsaturated fats. More specifically, the diets with lower GHG emissions had higher intakes of carbohydrates, polyunsaturated fats (excluding omega-3 fatty acids), dietary fiber, and added sugars. Although, dietary fiber was associated with higher water use. All of the analyzed minerals were less prevalent in diets with low GHG emissions, and these diets also contained less vitamin B12 and D. However, they contained higher amounts of vitamins A, C, E, and folic acid. Overall, the diets with lower environmental impacts had health promoting qualities, namely lower intake of saturated fat and sodium and higher intake of certain vitamins and dietary fiber, but they also lacked important nutrients such as vitamin D and B12 and had higher amounts of added sugars.[119] As this study demonstrated, water use was an indicator that diverged from the other trends seen between dietary intake and environmental impacts.

Another study sought to specifically focus on the water footprints of different dietary patterns.[120] The study estimated the current dietary patterns of Hungary as a baseline scenario, and then they developed multiple alternative diet scenarios, i.e., reduced meat, vegetarian, vegan, Planetary Health Diet,[51] cardioprotective, and low-carbohydrate/high-fat. They looked at green water (from precipitation and most relevant for agriculture) and blue water (from surfaces or groundwater) footprints. The water footprints of foods were obtained from the Water

Footprint Network database. They also calculated dietary scores based on meeting dietary reference values. For females, when looking at the combination of water footprint and dietary quality, the vegan diet followed by the Planetary Health Diet provided the most overall advantage by reducing water footprint and increasing dietary scores from baseline. The results are explained by these diets either eliminating animal-based foods or containing only moderate amounts of animal-based foods and increasing fruit, vegetable, and grain content. For males, the Planetary Health Diet ranked higher than the vegan diet in dietary quality. This was due to the male dietary scenario being denser in calories and nutrients. For both sexes, the cardioprotective diet was first in dietary quality, but it had a high water footprint, especially for blue water. The low-carbohydrate/high-fat diet was low in dietary quality and had a high water footprint, mainly due to it containing a large amount of fat, oil, and meat and low amount of fruits and grains. Despite the less consistent findings regarding certain dietary factors and water footprint, these results still demonstrated a clear association between lower water footprint and lower quantity of animal-based foods.[120] Similar results were found from a review of the synergies between a cardioprotective diet and environmental wellbeing.[121] The researchers reported that some foods considered to be heart healthy have higher environmental impacts. Fish, in particular, can have a large ecological impact, and based on the variety, nuts and fruits have a relatively high water footprint. With these conflicts in mind, the researchers suggest that a potential resolution could be to consume specific items within these food categories that have a lower environmental impact.[121]

Another study looked at how an extra serving per day within fifteen food categories would impact five health outcomes and five environmental indicators.[122] They found foods that were significantly linked to a reduction in disease risk for one of the health outcomes also generally had a similar relationship with other health outcomes. Nuts, minimally processed whole grains, fruits, vegetables, legumes, olive oil, and fish were all significantly associated with reduced mortality risk and/or reduced risk for one or more other diseases. By eating an additional serving of these foods per day, there was a significant reduction in risk for twenty of the thirty-four health outcome endpoints. Whole grains, fruits, vegetables, nuts, and olive oil were found to have a low average relative environmental impact across the five environmental indicators – acidification potential, eutrophication potential, GHG emissions, land use, and scarcity weighted water use. Fish had a higher average relative environmental impact, but its impact was much lower than unprocessed and processed red meats, which had the highest impact and were associated with a significant increase in mortality. Sugar-sweetened beverages had the lowest average relative environmental impact, but they were associated with increased disease risk. Overall, their results demonstrate that there are relatively few tradeoffs between healthy and sustainable dietary patterns.[122]

Planetary Health Diet

With the goal of developing evidence-based targets for a healthy diet and sustainable food production, the EAT-*Lancet* Commission on Healthy Diets from Sustainable Food Systems was established.[51] The Commission was made up of thirty-seven scientists from different fields and countries, and they utilized the scientific literature to determine a safe operating space for food systems, where the risk for negative impacts on human health and the environment are lower. The safe operating space is defined by the targets identified for the quantity of food that can be consumed within certain food groups, in order to promote human health and sustainable food production. Through these targets, the “Planetary Health Diet”, which is intended to be healthy for people and keep the food system within the safe operating space, was defined. The Planetary Health Diet is made up of predominately plant-based foods, including unsaturated fats, whole grains, fruits, vegetables, nuts, and legumes; small amounts of animal-based foods; and limited refined grains, saturated fats, ultra-processed foods, and added sugars. The targets identified for each food group are represented as ranges of intakes for a 2,500 kcal/day diet. Globally, a shift toward the Planetary Health Diet would require greatly increasing the consumption of fruits, vegetables, legumes, and nuts and decreasing the consumption of foods like red meat and sugar. Analysis of the Planetary Health Diet found that transitioning from current dietary patterns to the Planetary Health Diet would provide health benefits globally, preventing an estimated 11.1 million diet-related deaths among adults every year. The Commission also recognized that some populations would need to approach transitioning to a Planetary Health Diet differently, due to economic factors and food insecurity. Some regions would also have different priorities related to the Planetary Health Diet because of current consumption patterns. For example, 2016 data indicated that the typical diets of people living in North America exceed the recommended ranges of intake for starchy vegetables, eggs, poultry, red meat, and dairy, whereas, those in South Asia only exceed the recommended range of intake for starchy vegetables. To reach a sustainable food system, the Commission also highlighted the necessity to reduce food waste and losses by half and improve agricultural production practices.[51]

When compared to the eating patterns recommended in the DGA, there are some notable differences between the Planetary Health Diet and the Healthy U.S.-Style, Healthy Vegetarian, and Healthy Mediterranean-Style Patterns from the 2015-2020 DGA.[123,124] The Planetary Health Diet recommends more total grains than all of the DGA patterns and 2.3 times more whole grains as compared to the Healthy U.S.-Style and Healthy Mediterranean-Style Patterns. The Planetary Health Diet also recommends more red, orange, and dark green vegetables than all of the DGA patterns. The DGA patterns recommend more fruit, starchy vegetables, solid fats, and added sugars than the Planetary Health Diet. Interestingly, the Planetary Health Diet includes more protein foods than the DGA patterns, but the amount recommended within protein categories is vastly different. Beans and peas made up nearly half of the protein foods within the Planetary Health Diet, and the recommended amount of red meat was much lower than in the healthy Mediterranean-style and healthy U.S.-style patterns. The DGA patterns did align with the Planetary Health Diet in regards to total vegetables, poultry, eggs, seafood, soy, beans and peas, dairy, and unsaturated oils falling within the recommended ranges.[123] It is less clear if the Planetary Health Diet is more advantageous environmentally than the Healthy Vegetarian-Style Pattern outlined in the DGA,[123] as this pattern has also demonstrated its potential for reducing negative environmental impacts.[66]

Planetary Health Diet Index

Cacau et al. developed an index based on the EAT-*Lancet* Planetary Health Diet called the Planetary Health Diet Index (PHDI), which measures adherence to the Planetary Health Diet with sixteen index components and a total possible score of 150.[125] The PHDI is one of the most recent indexes that have been developed based on the Planetary Health Diet. Unlike the PHDI, the EAT-*Lancet* score[126] and the World Index for Sustainability and Health (WISH)[127] assess adherence using the total grams of food consumed within categories, which prevents analyzing adherence among varying energy intakes.[125] Other limitations of the EAT-*Lancet* score is its use of a binary scoring system and minimum intake values of 0 g/day for some categories, which has been found to result in high scores for not consuming certain nutrient-dense foods and associated with lower probability of micronutrient adequacy among nutrition-insecure women in low- and middle-income countries.[128] The PHDI also aligns with the recommendations of the Planetary Health Diet more closely than the other two indexes by including more of the identified food categories and using a scoring system that accounts for more of the recommended dietary possibilities.[125]

The sixteen components within the PHDI were divided into four scoring categories – adequacy, optimum, ratio, and moderation.[125] The components were categorized based on how the intake values corresponded to adherence to the recommendations and conceptual framework of the Planetary Health Diet. For example, components under the moderation category are foods that if consumed at recommended levels or lower would increase dietary quality and reduce environmental impact. Whereas, components under the adequacy category are foods that if not consumed would lower dietary quality and if consumed in higher amounts would be unlikely to have negative health and environmental impacts. The intake values used in the PHDI were converted from grams of food to proportion of calories that each food contributes to the 2,500 kcal Planetary Health Diet, in order to accommodate variations in caloric intakes.[125]

To validate the PHDI, cross-sectional, baseline data from 14,779 participants of the ELSA-Brasil cohort study were used to calculate PHDI scores.[125] In addition, linear regression models between PHDI scores and selected nutrients were used to assess whether these variables were correlated in the anticipated direction. Pearson's correlations between PHDI component and total scores and total energy intake were analyzed to examine if generated scores were independent of energy intake, and principal component analysis was used to examine how many factors explained the variability in the data. Student's t-test was used to compare the PHDI scores between groups with established differences in dietary quality as a measure of concurrent-criterion validity. Reliability was assessed using Cronbach's alpha to analyze if the PHDI components measure the same construct of interest and using item-item correlations. PHDI scores were also compared to scores of the Brazilian Healthy Eating Index-Revised, which measures dietary quality according to the Food Guide for the Brazilian Population,[129] and to estimated GHG emissions from the foods consumed by each ELSA-Brasil participant, in order to examine their relationship and whether higher PHDI scores were associated with better dietary quality and lower GHG emissions.[125]

The mean PHDI score for the sample was 60.4 out of 150.[125] There was wide variation in the mean scores received for the sixteen index components, with the red meat component resulting in the lowest mean score at 0.6 out of 10 and the vegetable component resulting in the highest mean score at 9.9 out of 10. The selected nutrients were significantly associated with the total score in the anticipated directions, with nutrients such as carbohydrates, vegetable proteins, fiber, iron, and potassium positively associated with the total PHDI score and nutrients such as animal proteins, saturated fat, cholesterol, and vitamin B12 negatively associated with the total PHDI score. The correlations between the index components and total energy intake were low, indicating that the PHDI can measure adherence to the Planetary Health Diet independent of the total caloric intake of the diet. The scree plot from principal component analysis demonstrated six factors. PHDI scores also aligned with the groups that would be expected to have differences in dietary quality. Non-smokers, elderly, and those with higher levels of physical activity had higher mean PHDI scores than smokers, adults, and those with lower rates of physical activity, respectively. In addition, PHDI scores were positively associated with dietary quality measured by the Brazilian Healthy Eating Index-Revised and negatively associated with GHG emissions.

Overall, the results support the validity and reliability of the PHDI in the Brazilian population. The study did have some limitations, including the use of a food frequency questionnaire, which has a limited number of foods, to determine dietary intake.[125] A subsequent analysis found that the PHDI had acceptable predictive validity, with PHDI scores being inversely associated with obesity indicators, such as body mass index and waist circumference.[130]

Affordability

Diets and foods that are considered healthier tend to cost more.[131] One systematic review and meta-analysis found per 2,000 calories, healthier dietary patterns cost an average of $1.54 more than less healthy dietary patterns.[131] In addition, foods that are less energy-dense, and thus help to maintain a healthy body weight, have been found to be more expensive than energy-dense foods.[132] The higher cost of healthy foods may be one of the drivers of obesity rates among food-insecure women.[133] Cost was the second most important influence on food choice among a national sample of American adults,[134] and food price is especially important for many with low incomes.[134-136] In the U.S., consumers spent on average, 8.6% of their disposable personal income on food in 2020.[137] As incomes decline, the total amount of money spent on food decreases but the share of income spent on food increases.[137] U.S. households with the lowest 20% of incomes spent on average, 36% of their disposable incomes on food in 2019.[137] Therefore, in order for a sustainable diet to be widely adopted, it must be achievable with a range of incomes.

There is some conflicting data regarding the potential affordability of more sustainable diets. An optimization study using data from the Brazilian population found a healthy, culturally acceptable diet that reduced GHG emissions did result in a 15% to 22% cost increase from the baseline, observed diets.[138] However, further constraining the healthy models to meet up to around a 60% reduction in GHG emissions generally led to a decline in the cost of the diet, namely due to incremental reductions in meats and foods that were labeled as high fat, sugar, salt (i.e., sugar-sweetened beverages, snacks, pizza, salt pastries, and sweets).[138] Another study used optimization and data from NHANES 2005-2016 to identify how transitioning to a healthy diet that was most similar to observed intake patterns would influence environmental impacts and affordability.[70] Their analysis found that the healthier dietary patterns would lead to lower GHG emissions, land use, and energy consumption, and 94.5% of the participants would be able to meet a nutritionally adequate diet when considering their budgetary constraints. Although, the majority of the participants within the lowest income quintile that would be able to afford healthier diets would be spending a considerable percentage of their income on food at over 20%.[70]

In another study, researchers developed biweekly diet baskets based on the Planetary Health Diet, the Mexican Dietary Guidelines, and the current dietary intake among people living in Mexico.[139] The diet baskets were assessed to determine cost differences. They found that the healthier diet baskets based on the Planetary Health Diet and the Mexican Dietary Guidelines were less expensive on average than the diet baskets based on current intakes. The Planetary Health Diet baskets cost the least on average, resulting in a 21% lower cost than the Mexican Dietary Guidelines baskets and a 40% lower cost than the non-isocaloric current intake baskets. The Planetary Health Diet baskets led to increased spending on fruits, vegetables, grains, starchy vegetables, and legumes and nuts, but this was offset by decreased spending on animal proteins, sugar-sweetened beverages, and foods that were considered discretionary (i.e., cookies, bakery items, sugary breakfast cereals, desserts, sweets, chocolate, sugar, honey, salty snacks, and processed meats).[139]

One study assessed the affordability of the EAT-*Lancet* Planetary Health Diet globally.[140] The researchers used the 2011 prices of food items throughout the world to determine the lowest-cost items that would meet the criteria of the Planetary Health Diet. They also investigated how many people would be able to afford the total estimated cost based on income and compared the local Planetary Health Diet costs to different lowest-cost diets that would meet requirements for twenty nutrients. The median daily cost of the Planetary Health Diet was $2.84 to meet the needs of a 2,500-kcal diet. The median daily cost of the diet varied by geographical region and countries' income status, with the median cost being greatest in Latin American and Caribbean regions and in upper-middle income countries. Fruits and vegetables were the primary contributor to total cost globally at 31.2%, followed by legumes and nuts at 18.7%. The proportion of mean daily household income per capita for which the lowest-cost Planetary Health Diet accounted ranged widely based on countries' income status. In high-income countries, the diet accounted for 6% of mean daily household income per capita, dropping to a median of 4.42% for North America, which is close to half the mean percentage of disposable personal income spent on food in the U.S. in 2020.[137] Whereas, in low-income countries, the estimated proportion of mean daily household income per capita was a staggering 89.1%.[140] Moreover, it was estimated that 1.58 billion had incomes that would not allow them to afford the lowest-cost Planetary Health Diet, and the majority of these people reside in middle-income countries. The Planetary Health Diet was on average, 60% more expensive than other nutritionally adequate diets, largely due to the Planetary Health Diet including more animal-based foods, fruits, and vegetables than necessary for meeting the twenty nutrients.[140] The results of this study demonstrate that depending on the country and local dietary practices, different recommendations may be warranted to meet sustainable dietary patterns.

The Thrifty Food Plan is the lowest-cost USDA Food Plan and is intended to meet the nutritional needs of a family of four (i.e., one woman and one man aged 20-50 years, one child aged 6-8 years, and one child aged 9-11 years) on a limited budget for one month.[141] The plan is used to set the maximum benefit allotment provided through SNAP and prioritizes foods that are nutrient-dense, low cost, and similar to American consumption patterns while meeting the DGA. The Thrifty Food Plan was reevaluated for 2021 and took into consideration up-to-date food prices and composition, consumption patterns, and DGA recommendations. The reevaluation resulted in a 21.0% cost increase, as compared to the previous Thrifty Food Plan, totaling $835.57 per month.[141] If the median daily price of the lowest-cost Planetary Health Diet in high-income countries of $2.66[140] was extrapolated to represent the family size and time conditions of the Thrifty Food Plan, the lowest-cost Planetary Health Diet would cost approximately $322.72 for a family of four for one month. This is a little over one-third of the cost of the 2021 Thrifty Food Plan. While the study used food prices from 2011 and designed the lowest-cost version of the Planetary Health Diet,[140] it is plausible that in current conditions with some higher-cost food items incorporated, the Planetary Health Diet could cost less than or equal to the 2021 Thrifty Food Plan.

CONSUMER SUSTAINABILITY PERCEPTIONS AND BEHAVIORS

Technological advancements in agriculture alone are unlikely to solve the unsustainability of the current food system, thus, consumers also have an important role in improving food system sustainability through dietary choices.[142] By understanding their knowledge and behaviors surrounding environmentally sustainable foods, better interventions and strategies can be utilized to encourage dietary shifts toward foods that are both sustainable and health promoting. A systematic review investigated what consumers' beliefs, attitudes, and behaviors were regarding the environmental impacts of meat consumption and the consumption of alternatives.[143] The majority of the 38 reviewed studies were conducted in Europe. Most of the studies that assessed consumers' knowledge of the unsustainability of meat production and consumption found that only a small percentage of participants were aware of the negative impacts. Three studies analyzed multiple behaviors that are important for the environment, and they found that participants prioritized behaviors like recycling and buying locally grown foods and discounted the impact of meat consumption. There was wide variation in the results among studies that assessed participants' willingness to lower meat consumption because of its negative environmental impacts. The proportion of participants that would be willing to lower their consumption ranged from 19% to 56%, with studies that provided information to participants regarding the environmental effects of meat production and consumption resulting in higher percentages. Women were more willing to lower their meat consumption as compared to men, and two studies found that women were more aware of the negative impacts of meat. Few studies examined other sociodemographic differences in the willingness to reduce meat consumption. Lower willingness to reduce meat consumption was associated with eating meat more often and having positive attitudes regarding meat. Higher willingness was associated with greater knowledge of sustainable foods. Among the studies that explored participants' acceptance of meat substitutes, a very small percentage of participants stated that they frequently consume them. Participants that did not buy meat substitutes were less favorable toward the idea of having at least one meal without meat during the week as compared to participants that did buy meat substitutes. The authors suggest that future studies should examine consumers' perceptions of the environmental impacts related to the production of different animals and protein sources and whether these perceptions are accurate according to life cycle assessment studies. In addition, whether consumers intend to replace meat in their diets with meat substitutes and whether there are certain meats that they are more willing to replace should be explored further.[143] A more recently published systematic review drew similar conclusions, finding that the studies indicated most consumers were unaware of the harmful environmental effects of meat production and consumption, underestimated the environmental benefits of reducing meat consumption, and preferred other behaviors over reducing meat consumption to improve climate change.[144] The researchers recommend that future studies investigate consumers' willingness to reduce meat consumption in relation to consumers' cooking skills, social network, and hedonic motivations.[144]

A study among U.S. adults found cultural worldviews categorized as heuristic individualists (the average participant in this category was politically Independent although leaned Republican and conservative) and egalitarian communitarians (the average participant in this category was politically Independent although leaned Democrat and liberal) were a significant predictor of reduced climate change risk perception independent of scientific literacy and numeracy.[145] In addition, increased scientific literacy and numeracy was negatively correlated with climate change risk perception. These findings may imply that individuals do not necessarily perceive climate change risk according to scientific facts or consensus but rather according to their personal philosophies and to the perceptions of those with which they affiliate.[145]

Conservative political views have also been associated with higher meat consumption.[146,147] In addition to political orientation, gender, age, education level, and the "Big Five" personality traits (i.e., openness, conscientiousness, extraversion, agreeableness, and neuroticism) have been associated with levels of meat intake. Those who are male,[146,148-153] younger,[146,148-152] have less education,[146,148,152-154] and are less agreeable and open[146] tend to be more likely to have higher meat intake. However, younger individuals also tend to be more likely to identify as a vegetarian[155,156] and be accepting of plant-based meat alternatives.[157,158]

The Theory of Planned Behavior[159] has also been used to better understand consumers' behaviors related to meat consumption. The Theory of Planned Behavior asserts that a person's intentions are determined by motivational factors and precede the performance of behaviors.[159] These independent motivational factors include attitudes toward the behavior (i.e., the evaluation of the degree to which the behavior is favorable or unfavorable), subjective norms (i.e., the perception of the social pressure to perform or not perform the behavior), and perceived behavioral control (i.e., the perception of whether performing the behavior is within one's control and of the ease or difficulty associated with performing the behavior). Stronger intention to perform a behavior is expected to increase the probability that a behavior will actually be performed.[159] Intention to reduce meat intake has been found to predict actual reduction in meat intake.[160] The three motivational factors of the Theory of Planned Behavior have significantly predicted the intention to eat meat, with subjective norms being the least predictive,[161,162] and individuals' attitudes have demonstrated the strongest predictive ability regarding intention to reduce meat consumption.[163-165] Wang and Scrimgeour assessed factors related to willingness to reduce meat intake and utilized personal norms and perceived consumer effectiveness[166] as extensions of the Theory of Planned Behavior[166] based on their effective use to specifically explore pro-environmental and sustainability behaviors.[164,167,168] They found that personal norms, attitudes, and perceived behavioral control significantly positively impacted willingness to adopt a more plant-based diet, with personal norms being the strongest predictor.[166]

Moreover, a study used models of behavior to determine which factors would be most influential in leading people to change their dietary behavior to be more sustainable.[169] The models used feedback mechanisms based on the Theory of Planned Behavior[159] and Protection Motivation Theory[170] to provide a psychological framework of how shifts in dietary behavior may take place. The simulations found that in all of the dietary composition scenarios, the median percentage of the total population that would become vegetarian by 2100 was around 20%. Social norms among those 15-44 years old and self-efficacy among females were the most influential elements leading to dietary behavior change. Changes in dietary behavior were less sensitive to health risk attitudes and climate change risk perceptions.[169] A systematic review and meta-analysis has also identified the consistent influence of informational eating norms (i.e., information on other people's eating habits) on individual's dietary choices.[171]

Researchers developed a Meat Attachment Questionnaire (MAQ) in an effort to further explore consumers' positive bond towards eating meat (i.e., meat attachment) and consumers' willingness to reduce meat intake.[161] The MAQ contains four factors – hedonism, affinity, entitlement, and dependence – and a second-order global dimension of meat attachment. Each factor includes a number of statements that individuals rank according to how strongly they agree or disagree with them. Higher scores within the hedonism factor indicate feelings of pleasure towards eating meat. Higher scores within the affinity factor indicate greater affinity towards eating meat. Higher scores within the entitlement factor indicate feeling entitled to eat meat. Higher scores within the dependence factor indicate feelings that eating meat is important personally. During the assessment of the MAQ, scores within all factors were significantly positively correlated with the participants' attitudes towards meat, subjective norms related to meat intake, habits related to eating meat, and beliefs about human supremacy. MAQ scores were also significantly positively correlated to identifying as a meat eater and omnivore and negatively correlated to identifying as a vegetarian and vegan. In addition, men scored significantly higher in all factors and in the global dimension, indicating greater meat attachment, than women. Hierarchical regressions revealed that the concept of meat attachment measured through the MAQ significantly predicted willingness to reduce meat consumption and willingness to eat a plant-based diet.[161]

Using the MAQ[161] and components of the Theory of Planned Behavior,[159] a cross-sectional study among adults in New Zealand found meat attachment and attitudes to be strong predictors of willingness and intention to reduce meat intake.[172] The study also found that participants ranked eating less meat significantly lower than six other sustainable behaviors related to food, with buying foods with less packaging ranked as having the greatest positive impact. In addition, they found that the strength of motivations to reduce meat intake varied depending on current meat-eating practices. Those that were standard consumers and those that were trying to reduce their meat intake were more motivated to reduce meat intake based on cost and health concerns. Whereas, those that abstained from eating meat were more motivated by ethical concerns, primarily animal welfare.[172]

A study among U.S. consumers found cost and health to be the most common reasons selected for reducing meat intake, with cost being especially important for participants with low incomes.[173] However, focus groups investigating influences on food choices and grocery shopping behavior among women with low incomes in Minnesota, U.S.[174] revealed that most of the participants felt meat was the most important food they purchased and spent the largest portion of their food dollars on meat.[174] The category of meat, poultry, fish and eggs was selected by most of the participants as their favorite food group and where they would spend more money if given increased benefits through SNAP.[174]

CONCLUSIONS

The food system is a complex and multidimensional network of producers, suppliers, distributors, processors, consumers, and regulators that interact to generate food and other outcomes like health, environmental impacts, and food security.[1] The production of food requires a considerable amount of natural resources[4] and can lead to negative environmental impacts, including GHG emissions, terrestrial acidification, and eutrophication.[30] However, not all food products contribute equally to these impacts. Meat from ruminant animals and animal-based products tend to be the most harmful.[30,31,41] The level of impacts generated can also vary between countries and individuals. Higher-income countries generally have greater environmental impacts while also having greater nutrient adequacy.[63] This same pattern is seen on the individual level, with higher-income individuals in the U.S. having better dietary quality based on HEI-2015 scores but generating more dietary environmental impacts.[70] Many studies have also found that individuals with low incomes receiving SNAP have lower dietary quality than nonparticipants.[96,98,99,102,103] However, Americans in general have low dietary quality, as demonstrated by the average HEI-2015 score of 57.7 out of 100.[68]

The expected increase in demand for unhealthy foods and animal proteins[57] conflicts with the goal of developing a more sustainable food system with sustainable diets, which are characterized by having low environmental impacts while promoting health and allowing for food and nutrition security.[113] Consumers have a critical role in promoting food system sustainability through their dietary choices.[30,142] The EAT-*Lancet* Planetary Health Diet may help guide consumers to adopting a healthy, sustainable diet made up of an abundance of plant-based foods and a moderate amount of animal-based foods.[51] With food security being a pivotal component of sustainable diets,[113] they also must be affordable. While the Planetary Health Diet may be too expensive for some in low- and middle-income countries, it would likely be achievable for a large portion of the population, especially those in high-income countries.[140] Primarily focusing on a dietary shift among higher-income populations may be more effective and feasible, given the fact that high-income countries are also generating more negative environmental impacts.[63] In addition, adoption of the Planetary Health Diet among people in low- and middle-income countries may not actually reduce their GHG emissions.[175]

A widespread shift toward a diet with less meat and animal-based products and more plant-based foods will pose a challenge. Based on systematic reviews on peoples' beliefs, attitudes, and behaviors regarding the environmental impacts of meat, many consumers were unaware of the negative effects of meat production and consumption and think other pro-environmental behaviors are more important.[143,144] Individuals with a high meat attachment may also be more unlikely to reduce their meat intake.[161,166,172]

To guide strategies for increasing food system sustainability and consumption of sustainable diets in the U.S., further research is needed to determine how well U.S. diets align to the proposed Planetary Health Diet[51] and whether certain groups are adhering better to this dietary pattern. This research will help establish a representative baseline of current dietary patterns and identify where shifts are needed, as recommended by the FAO for the actions necessary to implement sustainable healthy diets.[176] Understanding U.S. consumers' level of adherence to these recommendations and potential differences among consumer groups is also fundamental to determining where efforts and resources should be utilized to improve intakes. Additionally, the results will identify disparities among groups and allow for more targeted nutrition education and messaging. Because adoption of the Planetary Health Diet will require reductions in meat intake,[51] more information is needed on U.S. consumers' level of meat attachment and willingness to reduce meat intake. Many sociodemographic and socioeconomic factors have been associated to meat intake,[146-154] but only gender differences have been evaluated among the construct of meat attachment.[161,172] Consumers with lower meat attachment may be more receptive to interventions focused on reducing meat intake;[177,178] therefore, identifying differences in meat attachment among multiple sociodemographic and socioeconomic characteristics, including educational attainment, income, gender, and age, is essential to informing nutrition interventions. These insights will aid various stakeholders in the development of interventions, programs, campaigns, and marketing that aim to promote the adoption of sustainable and healthy dietary patterns.

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Chapter 3: Characterization of the sustainability and quality of American diets using the newly developed Planetary Health Diet Index for the United States

ABSTRACT

Dietary choices are an important avenue for improving food system sustainability. The Planetary Health Diet was proposed by the EAT-*Lancet* Commission as a reference healthy and sustainable dietary pattern. To assess American adherence to the Planetary Health Diet, this study developed and evaluated the Planetary Health Diet Index for the United States (PHDI-US), based on the original PHDI validated in the Brazilian population. The PHDI-US has sixteen components with scores ranging between 0-150, and higher scores indicate better adherence to the Planetary Health Diet. Cross-sectional dietary data from 4,741 participants of the National Health and Nutrition Examination Survey (NHANES) 2017-2018 were used to assess the validity and reliability the PHDI-US and analyze PHDI-US scores among adults. Validity and reliability tests were acceptable, with principal component analysis identifying seven factors; total PHDI-US and Health Eating Index-2015 scores being positively associated; concurrent-criterion validity analyses identifying significantly lower scores among males, everyday smokers, and younger adults; and a Cronbach's alpha value of 0.51. The average PHDI-US score was 38.7 out of 150, indicating that American diets are far from meeting Planetary Health Diet recommendations. Americans could improve diet quality and sustainability by increasing intake of plant-based foods and reducing intake of red and processed meats. Results indicate that the PHDI-US is a new tool that can assess American adherence to the Planetary Health Diet, and our results have identified key aspects of Americans' diets that could be altered to help improve human and planetary health.

INTRODUCTION

The global food system is one of the top contributors to climate change, generating an estimated 26% of anthropogenic greenhouse gas emissions, 32% of global terrestrial acidification, and 78% of eutrophication.[1] The majority of the environmental impacts from the food system are produced during the farm stage in the supply chain,[1] with the production of animal-based foods, and particularly meat from ruminant animals, contributing more greenhouse gas emissions and requiring more land and water than most plant-based foods.[1-3] Without any improvements, feeding a growing population that will likely reach 9.7 billion people by 2050[4] will exacerbate these impacts.[5]

While producers have an important role in reducing the environmental impacts from food, consumers can also contribute to improving the food system through dietary choices.[1] Sustainable diets, according to the Food and Agriculture Organization, are diets that are protective of the environment while also being healthy and promoting food security.[6] The EAT-*Lancet* Commission on Healthy Diets from Sustainable Food Systems developed a "Planetary Health Diet" that can be used as a reference for a diet that is health promoting while simultaneously limiting negative environmental impacts.[5] This is accomplished by basing the diet on healthy plant-based foods; including moderate amounts of animal-based foods; and limiting saturated fats, added sugars, and refined grains.[5] The EAT-*Lancet* commission projected that by the year 2050, adoption of the Planetary Health Diet could reduce greenhouse gas emissions by about 50% and reduce the use of nitrogen and phosphorous fertilizers by about 10%.[5] Diets made up of predominately plant-based foods have also been shown to improve major risk factors for the world's leading non-communicable diseases[7] through weight loss, reduced blood lipid levels, lower blood pressure, and better glycemic control.[8-11] Based on EAT-

Lancet commission estimates, shifts from current dietary patterns to the Planetary Health Diet could prevent about 11 million adult deaths from diet-related diseases per year.[5]

Assessing how closely populations are following healthy, sustainable dietary patterns is key to understanding what dietary changes are needed to improve food system sustainability. To measure adherence to the recommendations outlined in the Planetary Health Diet among the Brazilian population, Cacau et al., developed the Planetary Health Diet Index (PHDI).[12] Unlike other proposed indexes,[13,14] the PHDI allows for the measurement of adherence among variable caloric intakes. The PHDI has demonstrated acceptable validity and reliability when assessing the diets of Brazilians.[12] However, this index has not been adapted and validated for use in the United States (U.S.) population. Modification of this tool could provide a novel method to understand and measure how well U.S. diets currently adhere to the Planetary Health Diet.

Additionally, the index could provide insight on how well the diets of various populations align with the Planetary Health Diet. There is evidence of differences in dietary quality and environmental impacts by income status, age, race/ethnicity, and gender.[15] Studies have also found lower dietary quality among those that participate in the Supplemental Nutrition Assistance Program (SNAP),[16-20] a federal program that provided benefits to supplement the food budget of an average of 41,563,000 individuals with low incomes in 2021.[21,22] However, the diets of individuals with low incomes have been identified as having lower environmental impacts.[15] Therefore, exploring scores of SNAP participants and SNAP nonparticipants will help to gauge the differences in how closely these groups follow a healthy and environmentally sustainable diet as defined by the Planetary Health Diet. Exploring index scores by SNAP participation and income level is especially important due to concerns raised about the affordability of the Planetary Health Diet[23] and the goal of sustainable diets promoting food security.[6]

The primary aims of this study were (1) to develop a PHDI for the U.S (hereafter referred to as PHDI-US) and identify the level of adherence to the Planetary Health Diet among the U.S. population and (2) to assess the validity and reliability of the PHDI-US using National Health and Nutrition Examination Survey (NHANES) 2017-2018 data.

METHODS

Statistical Analysis

SAS statistical software (Cary, NC, U.S.) was used for statistical analyses. Analyses were weighted according to the NHANES weighting procedure.[24] P-values of ≤ 0.05 were considered significant. Specific statistical tests used for each aim are described in the respective method sections below.

Aim 1: Develop the PHDI-US and Assess U.S. Adherence to the Planetary Health Diet

Study Population. NHANES 2017-2018 participants that were 20 years of age or older at the time of screening were included for analysis. Children (0-9 years of age) and adolescents (10-19 years of age)[25] and participants that did not have a reliable dietary recall or report intake of any foods. Demographic information for NHANES participants was collected during the field interview.[26] NHANES uses a multistage, probability sampling procedure to collect data that is nationally representative of the civilian, non-institutionalized U.S. population. Certain subgroups are oversampled to improve the reliability and precision of the health measures for these populations.[26] Oversampled populations for NHANES 2017-2018 include: Hispanic persons;

Non-Hispanic Black persons; Non-Hispanic, non-Black Asian persons; Non-Hispanic white persons and persons of other races and ethnicities at or below 185% of the Federal poverty level; and Non-Hispanic white persons and persons of other races and ethnicities 0–11 years old or 80 years and older.[24] Further detail about the NHANES procedures and methodology can be found through the Centers for Disease Control and Prevention.[27] The National Center for Health Statistics Research Ethics Review Board approved the NHANES 2017-2018 protocol,[28] and all participants underwent the informed consent process.[26]

Dietary Intake. NHANES participants provided dietary intake information during a computer-assisted, in-person interview in a mobile examination center.[26] The 24-hour dietary recall conducted during the day one dietary interview was utilized. One 24-hour dietary recall has been considered acceptable for estimating population means.[29] The NHANES 2017-2018 dietary data was used to determine the total grams of food and quantities of nutrients consumed by each participant. The Food Patterns Equivalent Database 2017-2018 for NHANES 2017-2018 was used to determine the quantity of U.S. Department of Agriculture food pattern equivalents[30] (FPE) consumed by each participant. FPE represent individual foods and beverages that are categorized into 37 food pattern components and are also used for scoring the Healthy Eating Index (HEI).[30]

PHDI-US Components and Scoring Criteria. Consistent with the original PHDI,[12] the PHDI-US is comprised of sixteen components with a total possible score of 150. Higher PHDI-US scores indicate greater adherence to the Planetary Health Diet.[5] The components are separated into four categories – adequacy, optimum, ratio, and moderation.[12] Each component in the adequacy, optimum, and moderation categories has a possible score up to 10, and the two components within the ratio category have a possible score up to 5.[12] The final version of the PHDI-US and differences between the original PHDI and the PHDI-US can be found in **Table 1.**

To translate NHANES dietary data into the PHDI-US components, the FPE from the Food Patterns Equivalent Database 2017-2018 were mapped to the food groups in the Planetary Health Diet[5] and the components of the original PHDI.[12] Then conversion factors determined by Blackstone and Conrad[31] were used to convert the quantity of FPE consumed by each NHANES 2017-2018 participant into the grams of food consumed within each PHDI-US component (**Table 2**). Using the FPE resulted in slight alterations to the specific foods included within each PHDI-US component compared to the original PHDI, with the PHDI-US now aligning more closely with the Planetary Health Diet recommendations (e.g., Unsaturated Oils component within the PHDI-US excludes palm oils as is consistent with the Planetary Health Diet)[5] (**Table 1**).

Table 1. The Planetary Health Diet Index for the United States (PHDI-US) and a comparison of the components and scoring criteria with the original PHDI

PHDI-US	PHDI	PHDI-US					PHDI				
Components		**Scores (Points)[a]**					**Scores (Points)[b]**				
		0	5	10	5	0	0	5	10	5	0
Adequacy components											
Nuts and Peanuts[c]		0.0	⟷	≥2.5			0.0	⟷	≥11.6		
Legumes[d]		0.0	⟷	≥8.5			0.0	⟷	≥11.3		
Fruits		0.0	⟷	≥10.1			0.0	⟷	≥5.0		
Non-starchy Vegetables[e]	Vegetables	0.0	⟷	≥15.2			0.0	⟷	≥3.1		
Whole Grains		0.0	⟷	≥25.0			0.0	⟷	≥32.4		
Optimum components											
Eggs		0.0	⟷	0.7	⟷	≥1.3	0.0	⟷	0.8	⟷	≥1.5
Fish and Seafood		0.0	⟷	1.4	⟷	≥5.1	0.0	⟷	1.6	⟷	≥5.7
Tubers and Starchy Vegetables[e]	Tubers and potatoes	0.0	⟷	2.5	⟷	≥5.1	0.0	⟷	1.6	⟷	≥3.1
Dairy[f]		0.0	⟷	12.6	⟷	≥25.3	0.0	⟷	6.1	⟷	≥12.2
Unsaturated Oils[e,g]	Vegetable Oils[h]	0.0	⟷	2.0	⟷	≥4.0	0.0	⟷	16.5	⟷	≥30.7
Ratio components											
DGV/total ratio[i]		0.0 ⟷	33.3		33.3 ⟷	100	0.0 ⟷	29.5		29.5 ⟷	100
ReV/total ratio[j]		0.0 ⟷	33.3		33.3 ⟷	100	0.0 ⟷	38.5		38.5 ⟷	100
Moderation components											
Red and Processed Meat[k]	Red meat[l]	≥1.4	⟷	0.0			≥2.4	⟷	0.0		
Poultry[e,m]	Chicken and substitutes	≥2.9	⟷	0.0			≥5.0	⟷	0.0		
Saturated Fats[e,n]	Animal fats[o]	≥0.6	⟷	0.0			≥1.4	⟷	0.0		
Added Sugars		≥1.6	⟷	0.0			≥4.8	⟷	0.0		

[a]Component criteria are represented as percentage of total grams of food consumed.
[b]Component criteria are represented as caloric densities.
[c]Nuts and Peanuts component for original PHDI includes coconut pulp and milk. PHDI-US excludes coconut.
[d]Legumes component includes beans and soy. Original PHDI includes soymilk within soy products and PHDI-US includes specifically unfortified soymilk within soy products.
[e]Names of these components for PHDI-US were changed to help clarify what is included in each component.
[f]Dairy component for original PHDI excludes dairy fats. PHDI-US includes milk, yogurt, cheese, whey, and fortified soymilk and excludes butter.
[g]Unsaturated Oils component for PHDI-US includes oils naturally found in nuts, seeds, olives, and avocadoes and unsaturated fats and excludes palm oil.
[h]Vegetable oils component for original PHDI includes palm oil.
[i]DGV/total ratio component for original PHDI is the ratio between the energy intake of dark green vegetables (DGV) and the Vegetables component multiplied by 10. DGV/total ratio component for PHDI-US is the ratio between the grams of dark green vegetables (DGV) consumed and the grams consumed within the Non-starchy Vegetables component multiplied by 10.
[j]ReV/total ratio component for original PHDI is the ratio between the energy intake of red and orange vegetables (ReV) and the Vegetables component multiplied by 10. ReV/total ratio component for PHDI-US is the ratio between the grams of red and orange vegetables (ReV) consumed and the grams consumed within the Non-starchy Vegetables component multiplied by 10.
[k]Red and Processed Meat component for PHDI-US includes beef, lamb, pork, game, veal and processed/cured meats made from poultry and red meat.
[l]Red meat component for original PHDI includes beef, lamb, and pork.
[m]Poultry component for PHDI-US includes chicken, turkey, Cornish hen, and game birds and excludes organ meats and processed/cured meats made from poultry. This component does not include substitutions for eggs and/or seafood.
[n]Saturated Fats component for PHDI-US includes fats naturally occurring in red meat, poultry, and eggs when in excess of 2.63 g per oz and fats naturally occurring in dairy products when in excess of 1.5 g per cup. This component also includes tallow, cocoa butter, palm oil, and vegetable and animal shortening.
[o]Animal fats component for original PHDI includes lard, tallow, and dairy fats.

Table 2. Planetary Health Diet Index for the United States (PHDI-US) components with corresponding USDA[1] food pattern equivalents (FPE) and the conversion factors used to convert FPE into grams of food

PHDI-US Components	Corresponding USDA Food Pattern Equivalent(s) (FPE)[30]	Conversion Factor[31]
Nuts and Peanuts	Nuts and seeds	15
Legumes	Beans and peas computed as protein foods	44
	Soybean products	24
Fruits	Total fruit	182
Non-starchy Vegetables	Dark green vegetables	118
	Total red and orange vegetables	144
	Other vegetables	140
Whole Grains	Whole grains	51
Eggs	Eggs	50
Fish and Seafood	Seafood high in n-3 fatty acids	29
	Seafood low in n-3 fatty acids	29
Tubers and Starchy Vegetables	Total starchy vegetables	134
Dairy	Total dairy	149
Unsaturated Oils	Oils	Not applicable[a]
Red and Processed Meat	Meat	31
	Cured meat	31[b]
Poultry	Poultry	29
Saturated Fats	Solid fats	Not applicable[a]
Added Sugars	Added sugars	4.2[c]

[1]USDA: United States Department of Agriculture
[a]No conversion factor required for Oils and Solid fats because these FPE are reported in grams in Food Patterns Equivalents Database 2017-2018.[30]
[b]Determined during the development of the PHDI-US using the average ounce-equivalents per 100 grams of foods where the primary component was categorized as Cured meat in Food Patterns Equivalents Database 2017-2018.[30]
[c]4.2 grams are a teaspoon-equivalent of added sugars in Food Patterns Equivalents Database 2017-2018.[30]

The rationale used for the intake ranges and cutoff points for scoring the PHDI-US are consistent with the original PHDI,[12] however, the PHDI-US utilizes percentage of grams of foods consumed for the scoring criteria rather than the caloric densities utilized in the original PHDI.[12] This change allows the PHDI-US to be used with FPE while maintaining consistency with the units used in Planetary Health Diet recommendations[5] and maintaining the ability to assess diets with variable amounts of intake. To determine the ranges of percentages for scoring each PHDI-US component, the grams of food recommended among the different food groups in the 2,500-kcal Planetary Health Diet were divided by the total grams of food recommended.[5] Additional detail regarding PHDI-US components and adaptations from the original PHDI are discussed in detail below.

The criteria for the two PHDI-US ratio components represent the Planetary Health Diet recommendations to have diversified vegetable intake, with the 2,500-kcal pattern demonstrating one-third of vegetables as dark green, one-third of vegetables as red and orange, and one-third as other vegetables.[5]

The Poultry component was changed from the original PHDI[12] to not include substitutions for eggs and/or seafood, as the Poultry component is not within the same optimum category as the Eggs and Fish and Seafood components, and accommodating excess intake of these foods within the Poultry component would doubly negatively impact individuals' scores by taking away points for overconsuming eggs and/or seafood and for having higher intake within the Poultry component.

The Saturated Fats component includes palm oil, which is a discrete category in the Planetary Health Diet.[5] The recommended upper limit of 6.8 grams for palm oil was combined with the intake recommendations for dairy fats, lard, and tallow to reach a maximum intake of 11.8 grams for the 2,500-kcal Planetary Health Diet.[5] This value was used to determine the Saturated Fats scoring criteria.

The most prominent change was to the Red Meat component of the original PHDI,[12] which was altered for the PHDI-US to include red meat and processed meat made from both red meat and poultry. This change was made in order to capture the similar negative health impacts associated with red and processed meats[32-40] and the Planetary Health Diet recommendations that red meat and especially processed meat should be limited to low intakes.[5]

Beans, lentils, and peas and whole grains were converted from dry gram weights as recommended in the Planetary Health Diet[5] to as-consumed gram weights using conversion factors of 2.86 and 2.13, respectively.[31]

American Adherence. The means±standard error for each of the PHDI-US component scores and total PHDI-US score were determined for the NHANES 2017-2018 participants and were used to assess level of adherence to the Planetary Health Diet[5] for the U.S. population. Descriptive statistics were performed to determine the frequencies of sociodemographic variables, including age, gender, race/ethnicity, smoking status, and ratio of family income to poverty guidelines[41] (PIR). Participants' reported PIR were categorized into four groups: <1.31; 1.31 to 2.50; >2.50 to 3.50; and >3.50. Independent t-tests were used to assess significant differences in PHDI-US scores between sociodemographic groups.

SNAP participation status is recorded during the NHANES household interview.[42] Each household member's receipt of SNAP benefits is captured through a questionnaire completed by one adult in the household and then summarized at the household level.[42] Study participants were classified as SNAP participants if they had an affirmative response to the prompt, "In the last 12 months, did [you/you or any member of your household] receive SNAP or Food Stamp benefits?" Participants were classified as SNAP nonparticipants if they had a negative response to this prompt. Income eligibility to receive SNAP benefits was determined through the PIR reported in the NHANES 2017-2018 dataset. A ratio of ≤1.3 was used to indicate that someone was income-eligible to receive SNAP benefits based on SNAP eligibility guidelines.[43] Using independent t-tests, PHDI-US scores were compared between income-eligible SNAP participants, income-eligible SNAP nonparticipants, and those who were income-ineligible to participate in SNAP. In addition to assessing total PHDI-US scores, scores within the Fruits, Non-starchy Vegetables, and Red and Processed Meat components were compared among these groups because SNAP participants have been found to consume fewer fruits and vegetables[17,44,45] and purchase more red and processed meats[46-48] than nonparticipants (including income-eligible and income-ineligible).

Aim 2: Assess the validity and reliability of the PHDI-US

Validity. To establish validity and reliability, methods similar to those used for the assessment of the original PHDI[12] and the HEI[49-51] were employed. To validate the PHDI-US, construct validity (i.e., the extent to which a tool measures the construct it intends to measure)[52] was assessed four ways. Correlations between the mean total PHDI-US score and intake of selected nutrients (i.e., cholesterol, vitamin B12, saturated fats, vitamin C, fiber, and polyunsaturated fats) were examined using linear regression to determine if nutrients more prevalent in animal-based foods were negatively associated with PHDI-US scores and if nutrients more prevalent in plant-based foods were positively associated with PHDI-US scores. Pearson's correlations were calculated to assess if there was a low correlation between the total PHDI-US score and energy intake, which would indicate that the PHDI-US can measure adherence to the Planetary Health Diet[5] independent of energy intake.[12] Principal component analysis of the sixteen index components was used to determine how many factors are responsible for the variability of the data. Eigenvalues over one were considered to significantly explain the variance. Lastly, HEI-2015 scores, which measure dietary quality in accordance with the 2015-2020 Dietary

Guidelines for Americans,[53] were calculated, and linear regression was used to compare the relationship between HEI-2015 and PHDI-US total scores. Higher HEI-2015 scores were expected to be positively correlated to PHDI-US scores, as both indexes are intended to measure constructs of dietary quality.[12]

Concurrent-criterion validity (i.e., the extent to which the attributes of a tool are correlated with related variables or criterion that are measured concurrently with the construct),[54] was assessed using independent t-tests to compare the PHDI-US scores among groups with established differences in dietary quality, as was completed with the HEI.[49-51] Non-smokers, women, and older adults have been found to have better dietary quality than smokers, men, and younger and middle-aged adults.[55-57] It was expected that groups who have been found to have better dietary quality will also have higher PHDI-US scores. Smoking status was determined by responses to the question, "Do you now smoke cigarettes?" on the NHANES 2017-2018 Smoking – Cigarette Use Questionnaire.[58] Responses of "Every day," "Some days," and "Not at all" were used to classify participants into three smoking status groups. Participants were categorized into four age groups: 20-39, 40-49, 50-59, and ≥ 60 years of age. Independent t-tests were used to compare scores based on smoking status, gender, and age.

Reliability. Internal consistency (i.e., the extent to which the items of a tool are conceptually related)[52] was assessed through Cronbach's alpha to determine the degree to which each of the sixteen PHDI-US components relate in the measurement of dietary sustainability and quality in accordance with the Planetary Health Diet.[5] Pearson's correlations were used to examine item-item and item-total correlations and the relationships among the sixteen index components and total score.

RESULTS

American Adherence to the Planetary Health Diet

The final NHANES 2017-2018 sample size was 4,741 after excluding 3,685 children (0-9 years of age) and adolescents (10-19 years of age),[25] 827 individuals for having unreliable or incomplete dietary recalls, and 1 individual for reporting no intake of any foods.

The mean±standard error total PHDI-US score for the full sample was very low at 38.7±0.64 out of 150. The 1st and 99th percentiles for total PHDI-US scores ranged from 13.2 to 73.7. The three components with the lowest scores proportional to the maximum were Whole Grains, Legumes, and Fish and Seafood, while the three components with the highest scores were Poultry, Unsaturated Oils, and Dairy. **Table 3** includes the mean scores received in each PHDI-US component.

Table 3. Planetary Health Diet Index for the United States (PHDI-US) scores for adults from National Health and Nutrition Examination Survey (NHANES) 2017-2018 data[1]

PHDI-US Component (maximum possible score)	**PHDI-US Component Scores Mean±standard error**
Nuts and Peanuts (10)	1.3±0.09
Legumes (10)	0.8±0.08
Fruits (10)	3.5±0.13
Non-starchy Vegetables (10)	3.0±0.12
Whole Grains (10)	0.5±0.03
Eggs (10)	1.5±0.05
Fish and Seafood (10)	0.8±0.06
Tubers and Starchy Vegetables (10)	2.1±0.10
Dairy (10)	4.0±0.07
Unsaturated Oils (10)	4.2±0.09
DGV/total ratio[2] (5)	0.7±0.04
ReV/total ratio[3] (5)	2.2±0.05
Red and Processed Meat (10)	3.7±0.14
Poultry (10)	6.8±0.12
Saturated Fats (10)	1.3±0.06
Added Sugars (10)	2.5±0.11
Total PHDI-US score (150)	38.7±0.64

[1]Included adults ≥ 20 years of age, n = 4,741
[2]DGV/total ratio is the ratio between the grams of dark green vegetables (DGV) consumed and the grams consumed within the Non-starchy Vegetables component multiplied by 10.
[3]ReV/total ratio is the ratio between the grams of red and orange vegetables (ReV) consumed and the grams consumed within the Non-starchy Vegetables component multiplied by 10.

Analysis of total PHDI-US scores by race/ethnicity revealed significant differences between multiple groups. Non-Hispanic Asian individuals had the highest mean total PHDI-US score at 46.5±1.02, and the mean score among non-Hispanic Black individuals was significantly lower than the mean scores across all other race/ethnicity groups at 35.0±0.64 (**Figure 1**).

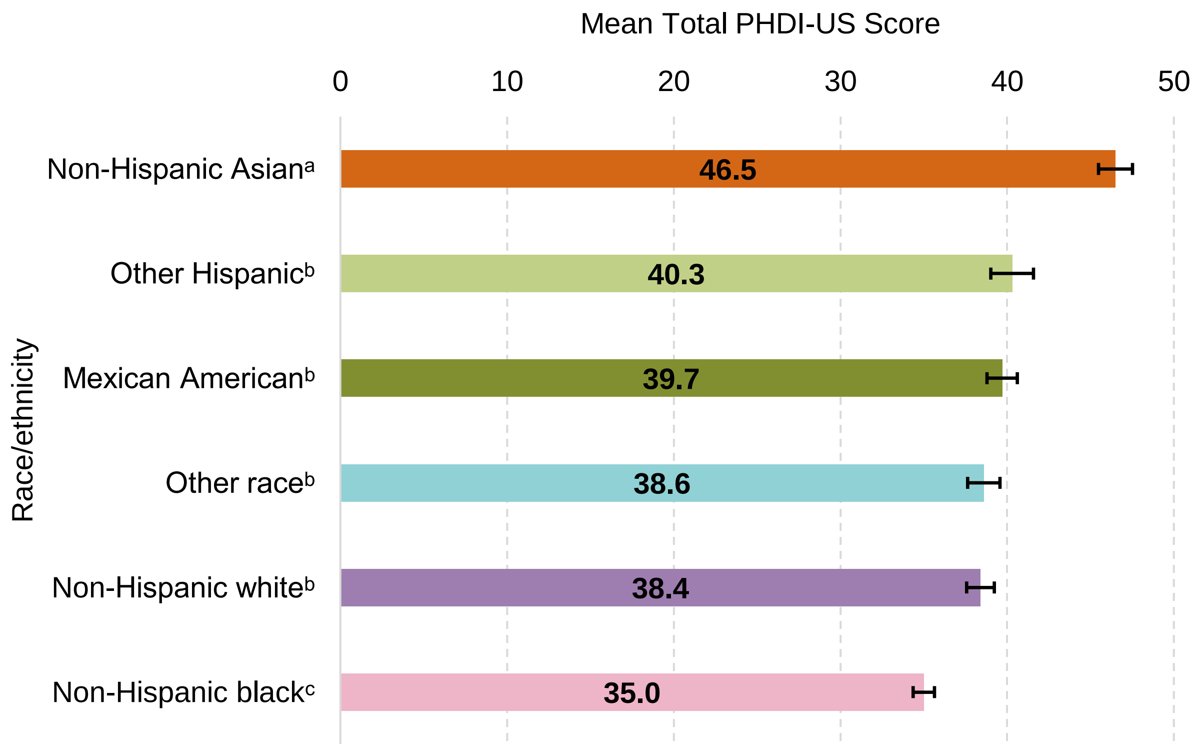

Figure 1. Total Planetary Health Diet Index for the United States (PHDI-US) scores for adults from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 stratified by race/ethnicity. Mean total PHDI-US scores are displayed for each race/ethnicity group. Groups without a common superscript significantly differ via independent t-test ($p \leq 0.05$). The PHDI-US score scale was truncated to 50 from a maximum possible score of 150 for the purpose of this figure. Bars indicate standard error. The "Other race" group includes non-Hispanic individuals that do not identify as black, Asian, or white and non-Hispanic multi-racial individuals. Analyses included adults ≥ 20 years of age. Sample sizes were as follows: Non-Hispanic Asian, n = 626; Other Hispanic, n = 435; Mexican American, n = 622; Other race, n = 236; Non-Hispanic white, n = 1694; Non-Hispanic black, n = 1128.

Examination of total PHDI-US scores by PIR also resulted in significant differences. Of four PIR groups, those with the highest PIR had a significantly higher total PHDI-US score than lower income groups, with the exception of those in the >2.50 to 3.50 group (**Figure 2**).

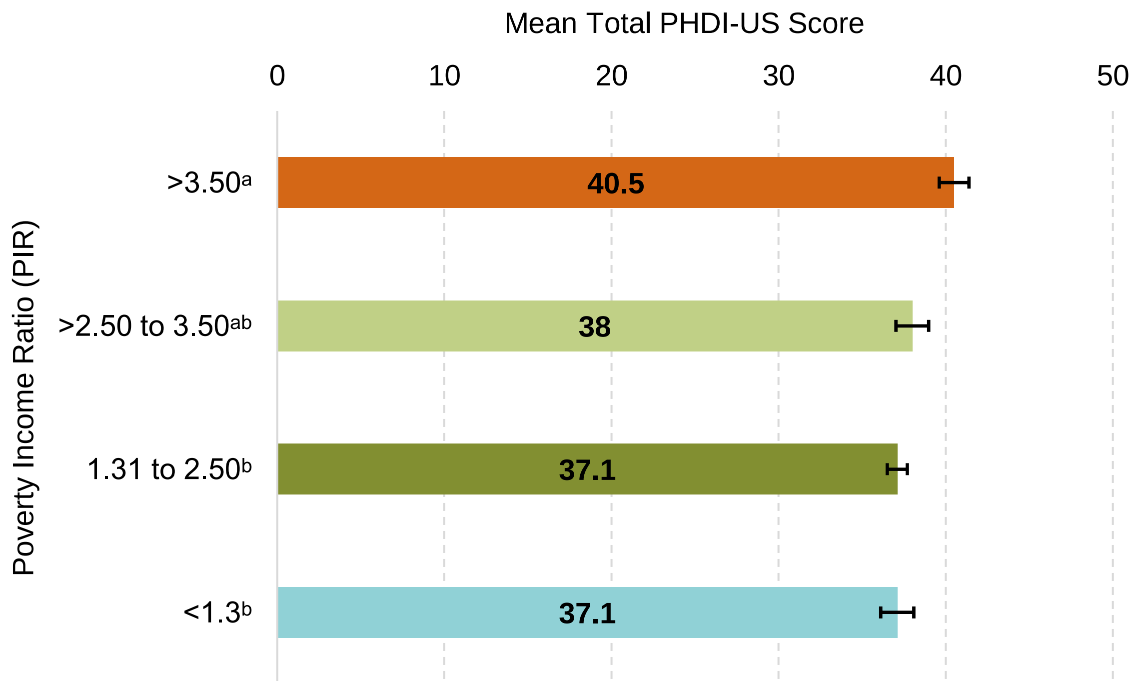

Figure 2. Total Planetary Health Diet Index for the United States (PHDI-US) scores for adults from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 stratified by poverty income ratio (PIR). The figure shows the mean total PHDI-US scores for each PIR group. Groups without a common superscript significantly differ via independent t-test ($p \leq 0.05$). The PHDI-US score scale was truncated to 50 from a maximum possible score of 150 for the purpose of this figure. Bars indicate standard error. PIR was reported in NHANES 2017-2018 as the ratio of family income to federal poverty guidelines. Analyses included adults ≥ 20 years of age. Sample sizes were as follows: PIR >3.50, n = 1282; PIR >2.50 to 3.50, n = 554; PIR 1.31-2.50, n = 1168; PIR <1.31, n = 1179.

Those who were income-ineligible to participate in SNAP had significantly higher scores for the Fruits and Non-starchy Vegetables components and the total PHDI-US score compared to those who were income-eligible to participate in SNAP (**Table 4**). Of those who were income-eligible to participate in SNAP, those who participated had a significantly higher total PHDI-US score and a higher score for the Non-starchy Vegetables component, but scores for the Fruits component were not significantly different. Among all three groups, there were no significant differences in scores for the Red and Processed Meat component.

Table 4. Planetary Health Diet Index for the U.S. (PHDI-US) scores for adults from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 stratified by Supplemental Nutrition Assistance Program (SNAP) eligibility and participation[1,2]

PHDI-US Component (maximum score)	Income-eligible nonparticipant (n = 248)	Income-eligible participant (n = 1084)	Income-ineligible nonparticipant (n = 2637)
	Mean±standard error PHDI-US Score[3]		
Fruits (10)	2.5±0.35[a]	3.0±0.19[a]	3.6±0.14[c]
Non-starchy Vegetables (10)	2.3±0.12[a]	2.5±0.10[b]	3.1±0.14[c]
Red and Processed Meat (10)	3.7±0.26[a]	3.8±0.26[a]	3.8±0.14[a]
Total PHDI-US score (150)	33.3±0.89[a]	35.9±0.52[b]	39.4±0.70[c]

[1]Included adults ≥20 years of age

[2]Income eligibility was based on ratio of family income to poverty via NHANES 2017-2018. A ratio of ≤1.3 indicates income eligibility based on federal SNAP eligibility guidelines. Participation in SNAP was based on responses to the question, "In the last 12 months, did [you/you or any member of your household] receive SNAP or Food Stamp benefits?" on NHANES 2017-2018 Food Security Questionnaire.

[3]Means without a common letter differ significantly via independent t-test ($p \leq 0.05$).

Construct Validity

Linear regression analyses identified nutrients that had generally low but significant correlations with total PHDI-US scores. Nutrients more prevalent in animal-based foods, cholesterol, vitamin B12, and saturated fat, were negatively correlated with total PHDI-US scores (ß = -0.01, p = 0.0006; ß = -0.16, p = 0.0116; and ß = -0.07, p = 0.0025, respectively) and nutrients more prevalent in plant-based foods, vitamin C, fiber, and polyunsaturated fat, were positively correlated with total PHDI-US scores (ß = 0.04, p <0.0001; ß = 0.53, p <0.0001; and ß = 0.13, p <0.0001, respectively). As expected, the correlation between the mean total PHDI-US score and energy intake was low at r = -0.03, p = 0.0337.

Principal component analysis demonstrated that more than one combination of index components was responsible for the variability of the data, with seven factors having eigenvalues over one (**Figure 3**). The average total HEI-2015 score for the sample was 49.9±0.71 out of 100

(**Table 5**). Linear regression analysis showed that total HEI-2015 and PHDI-US scores were significantly positively associated with one another (ß = 0.57, $p < 0.0001$; $R^2 = 0.39$).

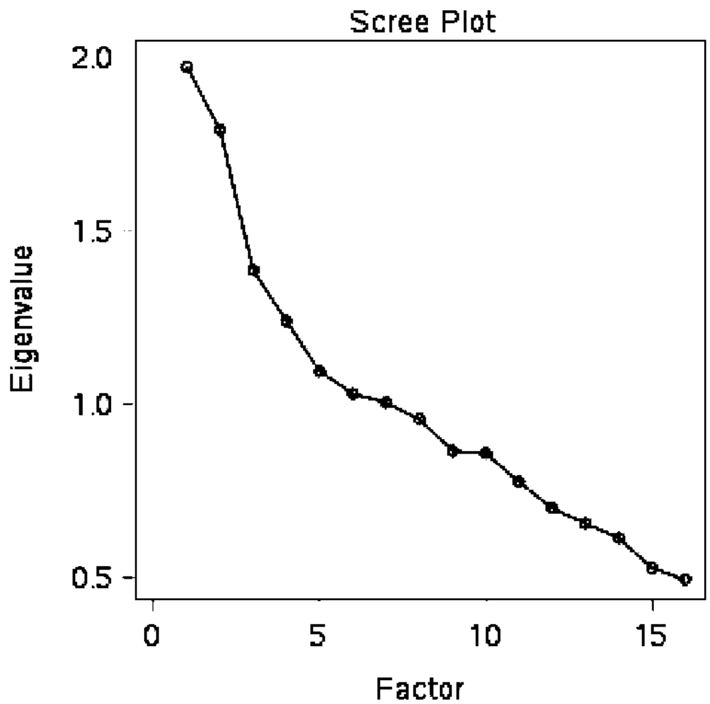

Figure 3. Scree plot from Principal Component Analysis of Planetary Health Diet Index for the United States (PHDI-US). The scree plot was generated from a principal component analysis of the PHDI-US using National Health and Nutrition Examination Survey (NHANES) 2017-2018 data. Seven PHDI-US factors had eigenvalues over one. Analysis included adults ≥ 20 years of age, n = 4,741.

Table 5. Healthy Eating Index-2015 (HEI-2015) scores for adults from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 data[1]

HEI-2015 Component (maximum score)	HEI-2015 Component Score Mean±standard error
Greens and beans (5)	1.6±0.07
Total fruits (5)	1.9±0.07
Whole fruits (5)	2.0±0.09
Total vegetables (5)	3.0±0.06
Whole grains (10)	2.3±0.11
Total protein foods (5)	4.2±0.04
Seafood and plant proteins (5)	2.4±0.06
Dairy (10)	4.7±0.08
Fatty acids (10)	4.9±0.15
Refined grains (10)	6.1±0.08
Sodium (10)	4.5±0.09
Saturated fats (10)	5.4±0.12
Added sugars (10)	6.9±0.13
Total HEI-2015 score (100)	49.9±0.71

[1]Included adults ≥ 20 years of age, n = 4,741

Concurrent-Criterion Validity

Individuals that did not smoke had a significantly higher mean total PHDI-US score compared to everyday smokers (p <0.0001); however, it was not significantly different from those who smoke on some days (p = 0.1721) (**Figure 4**). Females had a total PHDI-US score of 39.9±0.59, which was significantly higher than the mean total PHDI-US score for men at 37.5±0.69 (p <0.0001). Participants that were age 60 and older had a mean total PHDI-US score that was significantly higher than younger age groups, except for those 50-59 years of age (p = 0.9379).

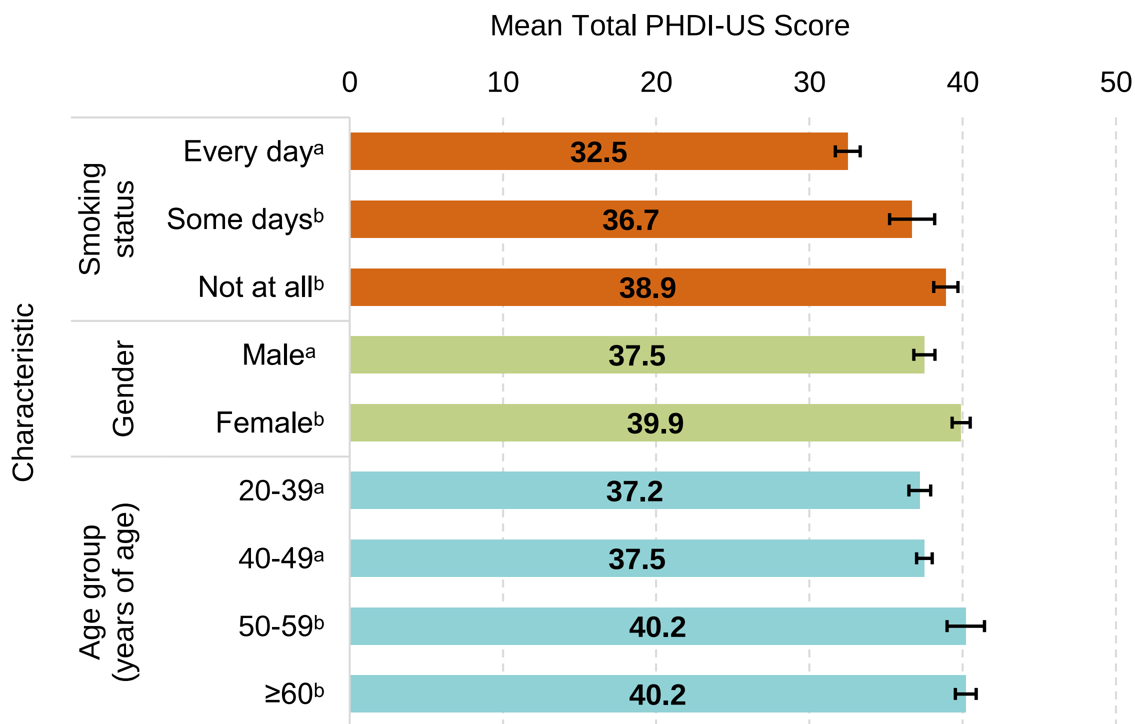

Figure 4. Total Planetary Health Diet Index for the United States (PHDI-US) scores for adults from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 stratified by smoking status, gender, and age. This figure shows the mean total PHDI-US scores received among the groups selected for assessment of concurrent-criterion validity. Within each group, characteristics without a common superscript significantly differ via independent t-test ($p \leq 0.05$). The PHDI-US score scale was truncated to 50 from a maximum possible score of 150 for the purpose of this figure. Bars indicate standard error. Analyses included adults ≥ 20 years of age. Sample sizes were as follows: Smoke every day, n = 683; Smoke some days, n = 183; Smoke not at all, n = 1161; Male, n = 2307; Female, n = 2434; Age range 20-39, n = 1429; Age range 40-49, n = 707; Age range 50-59, n = 794; Age ≥ 60, n = 1811.

Internal Consistency

The standardized Cronbach's alpha was 0.51 for the sixteen PHDI-US components. Correlations between PHDI-US components were generally significant and low, with r ranging between 0.000 and 0.360 (**Table 6**). The largest absolute significant correlation was between ReV/total ratio and Non-starchy Vegetables at r = 0.360, and the lowest absolute significant correlation was r = 0.029 between Legumes and Unsaturated Oils and between Fish and Seafood and Poultry. Item-total correlations between the sixteen components and total PHDI-US scores were significant and generally moderate, with r ranging from 0.174 to 0.460.

Table 6. Pearson's correlations between Planetary Health Diet Index for the United States (PHDI-US) component and total scores for adults from National Health and Nutrition Examination Survey (NHANES) 2017-2018[1]

	Nuts and Peanuts	Legumes	Fruits	Non-starchy vegetables	Whole Grains	Eggs	Fish and Seafood	Tubers and Starchy Vegetables	Dairy	Un-saturated oils	DGV/total ratio	ReV/total ratio	Red and Processed Meat	Poultry	Saturated Fat	Added Sugars
Legumes	0.001	1.000														
Fruits	0.138**	0.019	1.000													
Non-starchy Vegetables	0.075*	0.085**	0.106	1.000												
Whole Grains	0.110**	0.023	0.134**	0.058**	1.000											
Eggs	-0.002	-0.077**	0.015	0.035*	-0.032*	1.000										
Fish and Seafood	-0.003	-0.013	0.037*	0.068**	-0.021	0.099**	1.000									
Tubers and Starchy Vegetables	0.026	0.037*	0.033*	-0.030*	-0.014	0.051**	0.028	1.000								
Dairy	-0.008	0.033*	0.019	0.088**	0.064**	0.030*	-0.020	-0.039**	1.000							
Unsaturated Oils	-0.338**	0.029*	-0.002	0.237**	0.105**	0.116**	0.026	0.067**	0.113**	1.000						
DGV/total ratio	0.068**	-0.013	0.141**	0.344**	0.033*	0.024	0.043**	0.006	0.008	0.056**	1.000					
ReV/total ratio	0.005	0.098**	0.041**	0.360**	-0.014	0.063**	0.056**	0.070**	0.087**	0.107**	0.239**	1.000				
Red and Processed Meat	0.086**	0.020	0.075**	-0.007	0.047**	-0.024	0.056**	-0.031*	-0.074**	-0.000	0.094**	-0.093**	1.000			
Poultry	-0.010	0.057**	-0.018	-0.088**	0.011	-0.052**	0.029*	-0.048**	0.041**	-0.185**	-0.068**	-0.065**	-0.220**	1.000		
Saturated Fat	-0.005	0.000	0.046**	-0.028	-0.022	-0.082**	0.032*	-0.010	-0.357**	-0.202**	0.068**	-0.072*	0.251**	0.020	1.000	
Added Sugars	-0.051**	0.030*	0.046**	0.083**	0.023	-0.124**	0.012	-0.043**	-0.159	-0.212**	0.156**	0.051*	0.095**	0.048**	0.313**	1.000
Total PHDI-US score	0.361**	0.210**	0.460**	0.432**	0.201**	0.194**	0.274**	0.239**	0.174**	0.275**	0.366**	0.299**	0.376**	0.188**	0.236**	0.311**

[1]Included adults ≥ 20 years of age, n = 4,741

* P-value ≤ 0.05

** P-value ≤ 0.01

DISCUSSION

The results demonstrated support for the validity and reliability of the PHDI-US and revealed that the overall U.S. population is not adhering to Planetary Health Diet recommendations.[5] The average score on the PHDI-US was very low at 38.7 out of 150, and even at the 99th percentile, the mean total PHDI-US score only reached to about half of the maximum score. Based on the scores within each PHDI-US component, some of the primary changes that Americans would need to make include consuming less added sugars, saturated fats, and red and processed meat and consuming much greater quantities of whole grains, legumes, and nuts and peanuts. Additionally, Americans would need to consume more fruits and vegetables, with an emphasis on diversifying the types of vegetables consumed, as can be seen by the low scores within the ratio components and especially the DGV/total ratio component. These results are consistent with previous findings on the typical foods consumed by American adults.[59]

Disparities in PHDI-US scores were identified by race/ethnicity, income, smoking status, gender, and age. Racial/ethnic minorities, except for non-Hispanic Black individuals, tended to receive higher PHDI-US scores as compared to non-Hispanic white individuals, with non-Hispanic Asian individuals receiving a significantly higher score than all other groups. These results are similar to findings that non-Hispanic white individuals had greater environmental impacts from their diets and lower dietary quality than individuals from other races/ethnicities except for non-Hispanic Black individuals who had lower dietary quality.[15] The PHDI-US scores by race/ethnicity also followed a pattern consistent with what has been found for HEI-2015 scores, with average HEI-2015 scores highest among non-Hispanic Asian individuals and lowest among non-Hispanic Black individuals.[60,61]

Although individuals with lower incomes have been identified as having diets with lower environmental impacts,[15] those with a lower PIR did not receive the highest mean total PHDI-US score. Higher income has been associated with better dietary quality,[15,57,62] which may partly explain the increasing PHDI-US scores with income. While the total PHDI-US score among the PIR groups could point to issues with the affordability of the Planetary Health Diet,[23] studies have demonstrated that following the Planetary Health Diet can be less expensive than typical dietary patterns in certain countries, including the U.S,[63-65] and the average scores received by the highest and lowest income groups only differed by 3.4 points.

Results based on SNAP participation and eligibility demonstrated that both income-eligible and income-ineligible individuals had very low scores. Contrary to what the results of some other studies would suggest,[16-20,44,45] participation in SNAP did result in a significantly higher total PHDI-US score and a higher score for the Non-Starchy Vegetables component among those who were income-eligible to receive SNAP benefits. Those who were income-ineligible to receive SNAP had significantly higher scores than both income-eligible groups; however, no significant differences were found for the Red and Processed Meat component among all three groups. These results are inconsistent with findings that SNAP participants purchase more red and processed meats,[46-48] but other studies have indicated that overall meat intake is similar regardless of income.[17,66-68] Individuals with low incomes have also been found to view meat as the most important meal component and spend the greatest portion of their food budget on meat.[69-71] Given the high cost of meat relative to other food groups[72] and the prioritization of meat among individuals with low incomes, meat may be displacing fruits and vegetables in the diet and leading to lower scores in these PHDI-US components. This is supported with findings that the percentages of total sales from SNAP purchases and non-SNAP purchases at a large supermarket chain were similar among various types of foods, with the only major differences being that SNAP purchases had a 6% higher proportion of total sales on meat and a 7% smaller proportion of total sales on fruits and vegetables.[47]

Consistent with validity evaluations of the original PHDI[12] and the HEI,[49-51] mean total PHDI-US scores were significantly higher for non-smokers, women, and older adults as compared to everyday smokers, men, and younger adults, respectively. These results are also consistent with findings that men and younger adults have diets with greater environmental impacts and lower nutritional quality than females and older adults, respectively.[15] Future studies should investigate potential drivers of the differences in PHDI-US scores observed by race/ethnicity, income, smoking status, age, and gender, such as cultural food practices, food security, meat attachment (i.e., positive bond towards eating meat),[73] and knowledge of sustainable foods.

Comparison of HEI-2015 scores and PHDI-US scores for construct validity identified that the total HEI-2015 score was proportionally higher than the total PHDI-US score, with the HEI-2015 resulting in a score that was 49.9% of the maximum versus the PHDI-US resulting in a score that was only 25.8% of the maximum. This is the result of differences between the recommendations of the Planetary Health Diet[5] and the Dietary Guidelines for Americans.[74] The Planetary Health Diet explicitly focuses on limiting but still integrating animal-based products to improve food system sustainability and accommodate more traditional dietary patterns,[5] whereas, the Dietary Guidelines for Americans do not recommend limiting animal-based products.[74] This is highlighted through the comparison of index components among the HEI-2015 and PHDI-US. Both the HEI-2015 and PHDI-US can capture a range of plant-based dietary patterns within their scoring, including vegan patterns, but the indexes evaluate the consumption of animal-based foods differently. The HEI-2015 components for protein foods and dairy are based on adequacy with no upper limit to receive a perfect score, and only seafood and plant proteins have a distinct component where no intake results in a score of zero.[51] Whereas, the PHDI-US has distinct components for all major protein foods, with all animal-based proteins and dairy having an upper limit and a decreasing score for consuming more than recommended. These differences are what make the Planetary Health Diet[5] more promotive of environmental sustainability than typical dietary recommendations, allowing the PHDI-US to measure dimensions of dietary sustainability. Additionally, scores on the HEI-2015 and the PHDI-US were positively correlated to each other, demonstrating that the PHDI-US is also capable of measuring dietary quality in alignment with the HEI-2015.

Internal consistency measured by Cronbach's alpha resulted in a standardized value of 0.51, which is comparable to those computed for the assessments of the original PHDI[12] and HEI[49-51] at 0.51 and 0.43-0.68, respectively. While values of ≥ 0.70 are generally used to indicate acceptable internal consistency, lower values of Cronbach's alpha are often found with indexes that assess dietary quality because this construct is complex and multidimensional.[49-51] In addition, the U.S. population is heterogeneous, and individuals may meet certain dietary recommendations while failing to meet others, all of which can impact internal consistency.[51]

Future work should assess the ability of the PHDI-US to predict health outcomes, similar to the original PHDI, which has demonstrated predictive validity through PHDI scores being inversely associated to obesity indicators.[75] The development of the PHDI-US benefitted from the use of 24-hour dietary recalls that were collected using the automated multiple-pass method, which limits reporting bias,[76] rather than a food frequency questionnaire, as was used with the original PHDI.[12] However, one 24-hour dietary recall was used for analyses, so the results are only representative of dietary intake on a given day.

Results from the validity and reliability tests were acceptable overall and provide strong support for the ability of the PHDI-US to assess U.S. adherence to the Planetary Health Diet.[5] The PHDI-US provides a new metric that can be used for research and epidemiology to measure the quality and environmental sustainability of American diets in accordance with the Planetary Health Diet[5] and can be easily used with NHANES and related datasets. This study has established a reference point for the level of adherence to the Planetary Health Diet[5] among U.S. adults that will help to measure changes over time. Differences in the level of adherence among sociodemographic and socioeconomic groups have also been identified, allowing for more targeted interventions and research. The scores received within all index components have helped to identify where the U.S. population needs to make modifications to their dietary patterns in order to improve dietary quality and planetary health.

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Chapter 4: Assessment of Differences in Meat Attachment and Willingness to Reduce Meat Intake by Sociodemographic and Socioeconomic Characteristics in a Southern United States Population

ABSTRACT

Reducing meat consumption among Americans is essential for improving food system sustainability. However, lowering meat intake may be especially challenging due to some individuals experiencing a positive affective connection or bond toward eating. This proposed psychological construct has been termed meat attachment. Higher meat attachment has been associated with lower willingness to reduce meat intake. Previously, the only sociodemographic characteristic studied in relation to level of meat attachment was gender. Using the Meat Attachment Questionnaire (MAQ), this study aimed to evaluate meat attachment, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet by multiple characteristics, including gender, educational attainment, household income, and age. After confirming the structure of the MAQ through factor analysis, independent t-tests were used to compare mean differences for the variables of interest among a sample of 328 individuals living in the southern United States. The average level of meat attachment was 4.7 out of 7. Younger adults and those with higher educational attainment had significantly lower scores for several MAQ subscales and greater willingness to follow a more plant-based diet as compared to older adults and those with less educational attainment, respectively. Average meat attachment was significantly lower at 4.0 for those who reported eating meat less than once per day compared to those eating meat at least once per day at 5.1. Lower scores are indicative of a weaker attachment or positive bond toward eating meat. These results suggest that younger adults and those with higher educational attainment may be more receptive to interventions focused on reducing meat intake and that reducing meat attachment may also be important for lowering meat intake.

INTRODUCTION

Consumers can have considerable influence on improving the sustainability of the food system through shifts to dietary patterns made up of predominately plant foods (i.e., plant-based diets).[1-4] Additionally, plant-based diets have been found to confer health benefits, including weight loss, improved glycemic control, lower blood pressure, and reduced blood lipid levels.[5-8] Intake of red and processed meats are of particular concern, due to their high environmental impacts[2,9,10] and association with negative health effects,[11] including increased risk of stroke, type 2 diabetes mellitus, cardiovascular disease, and colorectal cancer.[12-20] One recommended dietary pattern that is both sustainable and healthy is the Planetary Health Diet developed by the EAT-*Lancet* Commission on Healthy Diets from Sustainable Food Systems.[3] The Planetary Health Diet Index for the United States (PHDI-US) was used to assess American adults' adherence to the Planetary Health Diet (under review). Application of the index identified that in order to align more closely with recommendations, Americans would need to make drastic changes to their diets, including increased consumption of fruits, vegetables, whole grains, legumes, and nuts and peanuts and reduced intake of red and processed meats. However, it is still unclear what motivates Americans to adopt healthier dietary patterns and reduce their meat consumption, as the majority of studies exploring consumers' attitudes regarding meat consumption and willingness to reduce meat intake have been conducted in Europe.[21,22]

The PHDI-US was also used to identify disparities in adherence to the Planetary Health Diet between sociodemographic and socioeconomic groups, with the lowest scores associated with men, younger adults, non-Hispanic black individuals, and individuals with low incomes. Some of these characteristics have also been associated with meat consumption. Those who are male,[23-29] younger,[23-28] and have less education[23,24,28-30] tend to be more likely to have higher meat intake. Education level has also been found to be a strong predictor of specifically red and processed meat intake in the U.S., with higher consumption of red and processed meats associated with lower educational attainment.[31]

Meat intake is similar regardless of income level;[25,27,32,33] however, individuals with low incomes tend to opt for lower-priced[34] and red and processed meats[35-38] and consume more fatty meat.[39] Modeling data has also demonstrated that for households with incomes less than 130% of the federal poverty line, a 10% increase in income is only associated with an increase in expenditures on beef and frozen food and not on fruits and vegetables, with focus group data suggesting that meat might be prioritized for taste, convenience, and conveying status and success.[40]

Other personal factors that have been studied in relation to meat intake include concern for the environment, health, and animal welfare; food habits and routines; the "Big Five" personality traits (i.e., openness, conscientiousness, extraversion, agreeableness, and neuroticism); perceived behavior control; and meat attachment (i.e., a positive bond toward eating meat).[24,41,42] Meat attachment has been proposed as an independent psychological construct that may influence consumers' meat intake, with higher meat attachment associated with lower willingness to reduce meat intake and follow a plant-based diet.[42] Studies have identified differences in meat attachment by gender,[42,43] but research exploring differences in meat attachment by other sociodemographic and socioeconomic characteristics are lacking. Given the many personal factors that have been linked to differences in meat consumption, it is important to evaluate whether meat attachment could be an underlying construct related to these differences. This study aimed to compare level of meat attachment, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet by gender, educational attainment, income, and age. To verify the conceptual construct of meat attachment, level of meat attachment was also assessed by meat intake frequency to determine if those with lower meat intake frequency have lower levels of meat attachment.

METHODS

Study Design

This was a cross-sectional study using an online survey developed with QuestionPro software (Austin, TX, U.S.). The survey was distributed via university and Cooperative Extension listservs targeting adults with a wide range of incomes. The study was presented as exploring "individuals' views and experiences regarding eating meat" during recruitment. The survey was available online in English for two months between December 13, 2022 and February 13, 2023. The study protocol was approved by the Virginia Tech Institutional Review Board (**Appendix A**), and each respondent was provided necessary study-related information before voluntarily consenting to participate.

Study Population

Convenience sampling was used to recruit participants. Those who were at least 18 years of age and living in a southern U.S. state (i.e., Delaware, Maryland, District of Columbia, Virginia, West Virginia, Kentucky, North Carolina, Tennessee, South Carolina, Georgia, Alabama, Mississippi, Arkansas, Oklahoma, Florida, Louisiana, and Texas) at the time of the survey were included in the statistical analyses. Participation was limited to southern U.S. states due to evidence of regional differences in meat consumption.[38,44] Upon completion of the survey, participants were able to enter into a raffle with a 1 in 25 chance to win a $25 Amazon gift card.

Measures

Before presenting the survey questions regarding meat, participants were provided a definition of meat for the purpose of the survey using the following statement, "Please keep in mind when answering survey questions that the word 'meat' refers to red and white meats (beef, lamb, pork, chicken, turkey, fish, shrimp, seafood, etc.) that are either unprocessed (chicken breast, steak, fish filet, etc.) or processed (sausage, lunch meats, hot dogs, chicken nuggets, crab cakes, etc.)" (**Appendix B**). Participants were then asked to rank their average meat intake frequency on a 6-point scale, with 1 = Never, 2 = Less than one time per week, 3 = One time per week, 4 = Several times per week, 5 = Every day, and 6 = Several times per day.[45] After, participants answered two prompts regarding their willingness to reduce meat intake, consisting of, "I would be willing to reduce or continue reducing how much meat I eat in the near future." and "I would be willing to eat a more plant-based diet or continue eating a plant-based diet in the near future." These prompts used a 7-point Likert agreement scale, ranging from 1 = strongly disagree to 7 = strongly agree.[45]

The Meat Attachment Questionnaire (MAQ) was developed by Graça et al. to assess and measure meat attachment as a psychological construct of meat consumption.[42] Prompts from the MAQ were used to assess the construct of meat attachment.[42] The MAQ has consistently performed well in predicting willingness to reduce meat consumption among participants from New Zealand,[43,45] China,[45] Portugal,[42] and the U.S.[42] It includes sixteen prompts within four subscales and a second-order, global scale of meat attachment. Higher scores in the subscales of Hedonism, Affinity, Entitlement, and Dependence refer to a person perceiving meat as a source of pleasure, having a greater affinity toward eating meat, feeling entitled to eating meat, and feeling dependent on eating meat, respectively. A higher global score indicates a greater overall level of meat attachment. Attitudes toward meat, subjective norms related to meat intake, habits related to eating meat, and beliefs about human supremacy were found to be significantly correlated to the scores in each subscale. In addition, MAQ scores were significantly positively correlated to identifying as a meat eater and omnivore and negatively correlated to identifying as a vegetarian and vegan.[42] The 7-point Likert agreement scale was used for responses to the MAQ prompts. Scale reduction resulted in the question, "I would feel fine with a meatless diet" being removed due to studies indicating that it had high cross-loadings with other items.[46,47] To evaluate the 15-item structure of the MAQ, factor analysis was used to confirm that the MAQ prompts had acceptable loadings on the designated subscales. Cronbach's alpha was used to evaluate the reliability of each subscale and the global scale. Each group of prompts was averaged to determine the subscale scores, and all of the prompts were averaged to determine a global scale score.

After completing the MAQ prompts, participants were asked to provide sociodemographic and socioeconomic information. Data on participants' gender identity, age, household size, annual household income, educational attainment, race/ethnicity, and U.S. state of residence were collected.

Participant Groups

Participants were categorized into dichotomous gender, age, income, education, and meat intake frequency groups based on their responses to corresponding survey questions and the distribution of participants among variables. Those who were age 35 years or younger were categorized as younger adults, and those who were over 35 years of age were categorized as older adults. To create the education groups, educational attainment was divided into those who had a 2-year college degree or lower and those who had 4-year college degree or higher. Using household income and size and 2023 federal poverty guidelines,[48] a low-income group (<131% of the 2023 federal poverty line) and a higher-income group (≥131% of the 2023 federal poverty line) were determined. Meat intake frequency groups were defined as those who consumed meat less than once per day (a response of 1-4 on the scale) and those who consumed meat at least once per day (a response of 5-6 on the scale).

Statistical Analysis

IBM SPSS software (Chicago, IL, U.S.) was used for statistical analyses. Only participants with complete survey data were used for analyses. Descriptive statistics were performed to determine means and standard deviations. Significance was set *a priori* as a two-sided p-value ≤0.05. Factor analysis with maximum likelihood estimation and direct oblimin rotation was performed to verify the conceptual structure and assess the four factor model fit of the MAQ.[42] Acceptable factor loadings were set at >|0.40|, and acceptable cross-loadings were set at |0.2-0.3|.[49] The Kaiser-Meyer-Olkin measure and Bartlett's test of sphericity were performed to determine the adequacy of the data for factor analysis. The ratio χ^2/df was used to assess model fit, with a value of ≤3 considered acceptable.[50] Cronbach's alpha was used to assess reliability among the 15-item global scale and the subscales, and values >0.70 were considered acceptable.[51]

Using G*Power 3.1, an *a priori* power analysis was conducted for independent t-tests and determined that a sample size of at least 172 was adequate to provide a power of 90%, effect size d of 0.5 (medium effect), and type 1 error probability of 0.05. Independent t-tests were used to determine significant differences for MAQ subscales and the global scale, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet between gender, age, education, and income groups. Significant differences for MAQ subscales and the global scale and willingness to reduce meat intake and follow a more plant-based diet were assessed via an independent t-test for the meat intake frequency groups.

RESULTS

The analytical sample size was 328 after removing 25 individuals with incomplete data and seven respondents for not living in a southern U.S. state. Participants took an average of seven minutes to complete the survey. The majority of participants were female (80.8%, n=265), white (67.4%, n=221), and graduates of a 4-year college or higher (70.4%, n=231), with a fairly even distribution across ages and incomes (**Table 1**). Most participants were residents of the state of Virginia (n=316), with other participants (n=12) living in the District of Columbia, Maryland, North Carolina, South Carolina, Tennessee, Florida, and Texas. One participant provided an invalid response for household size and was excluded from the independent t-test between income groups. Participants that identified their gender as non-binary or other were excluded from the analysis by gender due to small sample size (n=6). The most common level of self-reported meat intake frequency was several times per day (n=118), with the average response for meat intake frequency closest to the value of every day on the scale [mean±standard devation (M±SD) = 4.8±1.3 out of 6].

Table 1. Respondent (n=328) characteristics for the survey examining meat attachment via the Meat Attachment Questionnaire (MAQ) and willingness to reduce meat intake

		Sample	
Variable	**Category**	**n**	**%**
Gender	Male	57	17.4
	Female	265	80.8
	Non-binary/other	6	1.8
Age, years	18-26	76	23.2
	26-35	88	26.8
	36-55	79	24.1
	>55	85	25.9
Race/ethnicity	Non-Hispanic White	221	67.4
	Non-Hispanic Black	33	10.1
	Non-Hispanic Asian	37	11.3
	Non-Hispanic Multiracial	14	4.3
	Hispanic	23	7.0
Highest level of education	11th grade or less	4	1.2
	GED[a] or High School Diploma	51	15.5
	Graduated 2-year college	42	12.8
	Graduated 4-year college or higher	231	70.4
Household size	1	95	29.0
	2-3	155	47.3
	4-5	59	18.0
	≥6	18	5.5
Household income, annual	<$25,000	63	19.2
	$25,000-49,999	127	38.7
	$50,000-74,999	53	16.2
	≥$75,000	85	25.9
Meat intake frequency	Never	14	4.3
	Less than one time per week	10	3.0
	One time per week	13	4.0
	Several times per week	83	25.3
	Every day	90	27.4
	Several times per day	118	36.0

[a]GED: general equivalency diploma

The Kaiser-Meyer-Olkin measure of sampling adequacy for factor analysis resulted in a value of 0.93, and Bartlett's test of sphericity was significant ($p \leq 0.0001$). Factor analysis supported the four factor MAQ model, accounting for 68% of the total variance (**Table 2**). Two prompts within the Dependence subscale had loadings that were acceptable but slightly low

(<0.50) and cross-loadings that were acceptable but slightly high (>0.25).[49] The chi-square goodness-of-fit value was acceptable at $\chi^2/df = 1.37$. Standardized Cronbach's alpha for the global scale was acceptable at 0.94, as well as the subscales, with standardized Cronbach's alpha values of 0.92, 0.87, 0.80, 0.88 for Hedonism, Affinity, Entitlement, and Dependence, respectively.

Table 2. Exploratory factor analysis results for the 15-item Meat Attachment Questionnaire (MAQ) using survey data (n=328)

	Factors[a]				
Survey Measurements	**1**	**2**	**3**	**4**	***h*[2b]**
To eat meat is one of the good pleasures in life.	**0.79**	0.01	0.07	-0.02	0.72
I love meals with meat.	**0.90**	0.06	0.03	0.06	0.84
I'm a big fan of meat.	**0.93**	-0.03	-0.03	-0.09	0.92
A good steak is without comparison.	**0.56**	0.06	0.08	-0.14	0.57
By eating meat I'm reminded of the death and suffering of animals.*	0.01	**0.87**	-0.04	0.03	0.71
To eat meat is disrespectful towards life and the environment.*	-0.05	**0.73**	0.25	0.00	071
I feel bad when I think of eating meat.*	-0.04	**0.86**	-0.04	-0.14	0.80
Meat reminds me of diseases.*	0.22	**0.54**	-0.03	0.02	0.44
To eat meat is an unquestionable right of every person.	0.00	-0.04	**0.65**	-0.10	0.48
According to our position in the food chain, we have the right to eat meat.	0.11	0.00	**0.84**	0.10	0.72
Eating meat is a natural and indisputable practice.	-0.03	0.12	**0.64**	-0.11	0.57
I don't picture myself without eating meat regularly.	0.26	0.17	0.11	**-0.47**	0.71
If I couldn't eat meat I would feel weak.	-0.03	-0.03	0.03	**-0.74**	0.54
If I was forced to stop eating meat I would feel sad.	0.26	0.03	0.17	**-0.49**	0.67
Meat is irreplaceable in my diet.	0.09	0.10	-0.01	**-0.78**	0.78
Cumulative Variance	0.50	0.57	0.64	0.68	---

[a]Factor loadings >|0.40| are bolded.
[b]h^2: item communalities.
*Items are reverse-scored.

The mean values for the MAQ subscales and the global scale had skewness values between -0.95 and -0.05 and kurtosis values between -0.88 and 0.28, falling within the acceptable ranges for normality (i.e., ±2).[52] The average participant scores were in agreement with most of the MAQ prompts, indicated by a score over four on the Likert scale, with the exception of the prompts within the Affinity subscale and the prompts, "If I couldn't eat meat I would feel weak" and "Meat is irreplaceable in my diet" (**Table 3**). On average, participants were also on the side of agreement for the willingness to reduce meat intake prompt (M±SD = 4.5±2.0) and the willingness to follow a more plant-based diet prompt (M±SD = 4.6±1.9). The highest score in agreement was the average Entitlement subscale at 6.0±1.4, and the prompt, "Meat reminds me of diseases" had an equally as high score in disagreement.

Table 3. Average responses for each Meat Attachment Questionnaire (MAQ) prompt and the corresponding subscales and global scale for the full survey sample (n=328)

Meat Attachment Questionnaire Measure	Average Response Mean±SD[a]
Hedonism (1 = Strongly disagree, 7 = Strongly agree)	4.7±1.6
To eat meat is one of the good pleasures in life.	4.6±1.7
I love meals with meat.	5.1±1.6
I'm a big fan of meat.	4.8±1.8
A good steak is without comparison.	4.5±2.1
Affinity (1 = Strongly agree, 7 = Strongly disagree)	5.5±1.4
By eating meat I'm reminded of the death and suffering of animals.	5.1±1.9
To eat meat is disrespectful towards life and the environment.	5.5±1.6
I feel bad when I think of eating meat.	5.4±1.8
Meat reminds me of diseases.	6.0±1.4
Entitlement (1 = Strongly disagree, 7 = Strongly agree)	6.0±1.4
To eat meat is an unquestionable right of every person.	4.7±1.8
According to our position in the food chain, we have the right to eat meat.	4.6±1.7
Eating meat is a natural and indisputable practice.	5.0±1.6
Dependence (1 = Strongly disagree, 7 = Strongly agree)	3.9±1.7
I don't picture myself without eating meat regularly.	4.3±1.9
If I couldn't eat meat I would feel weak.	3.4±1.9
If I was forced to stop eating meat I would feel sad.	4.2±2.1
Meat is irreplaceable in my diet.	3.8±1.9
Global Meat Attachment	4.7±1.3

[a]SD: standard deviation

Comparisons by gender did not result in any significant differences. Females had slightly lower scores compared to males for the Hedonism and Dependence subscales (M±SD = 4.7±1.6 and 3.9±1.7 vs. 5.0±1.7 and 4.0±1.8, respectively) and the global scale of meat attachment (M±SD = 4.7±1.3 vs. 4.8±1.5), with equal scores for the Entitlement subscale (M±SD = 4.8±1.4) and slightly higher scores for the Affinity subscale (M±SD = 5.5±1.4 vs. 5.3±1.7) and meat intake frequency (M±SD = 4.8±1.3 vs. 4.5±1.3). Females tended to be more willing to reduce meat intake and eat a more plant-based diet than males (M±SD = 4.6±2.0 and 4.7±1.8 vs. 4.1±2.2 and 4.3±2.2, p=0.264 and 0.236, respectively).

Adults ≤ 35 years of age tended to have lower scores for the MAQ measures compared to adults >35 years of age, with significant differences for the Affinity and Entitlement subscales (**Table 4**). In addition, adults >35 years of age had significantly more frequent meat intake and were significantly less willing to follow a more plant-based diet.

Table 4. Differences in mean scores for the Meat Attachment Questionnaire (MAQ) subscales and global scale, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet by age (n=328)

Survey Dimension	Age ≤ 35 years n = 164 Mean±SD	 > 35 years n = 164 Mean±SD[a]	Mean Difference Mean±SE[b]	Significance *p*-value[c]
Hedonism	4.7±1.7	4.8±1.6	-0.1±0.2	0.412
Affinity	**5.3±1.5**	**5.7±1.4**	**-0.4±0.2**	**0.013**
Entitlement	**4.6±1.4**	**5.0±1.5**	**-0.4±0.2**	**0.022**
Dependence	3.8±1.7	4.0±1.5	-0.2±0.2	0.319
Global Meat Attachment	4.6±1.3	4.9±1.3	-0.3±0.1	0.065
On average, how often do you eat meat and products that have meat in them?	**4.6±1.4**	**4.9±1.1**	**-0.3±0.1**	**0.030**
I would be willing to reduce or continue reducing how much meat I eat in the near future.	4.7±2.0	4.2±2.1	0.5±0.2	0.051
I would be willing to eat a more plant-based diet or continue eating a plant-based diet in the near future.	**4.9±1.8**	**4.3±2.0**	**0.6±0.2**	**0.005**

[a]SD: standard deviation
[b]SE: standard error
[c]Bolded values indicate significance at p≤0.05.

There were significant differences between educational attainment levels for Entitlement and Dependence subscales and the global scale, with graduates of a 4-year college or higher having lower scores (**Table 5**). Those with a higher level of educational attainment also had significantly less frequent meat intake and were more willing to follow a more plant-based diet.

Table 5. Differences in scores for the Meat Attachment Questionnaire (MAQ) subscales and global scale, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet by education level (n=328)

	Education Level		**Mean Difference**	**Significance**
Survey Dimension	**Graduated 2-year college or lower n = 97 Mean±SD**	**Graduated 4-year college or higher n = 231 Mean±SD[a]**	**Mean±SE[b]**	***p*-value[c]**
Hedonism	4.9±1.5	4.7±1.7	-0.2±0.2	0.248
Affinity	5.7±1.3	5.4±1.5	-0.3±0.2	0.091
Entitlement	**5.2±1.2**	**4.6±1.5**	**-0.6±0.2**	**0.001**
Dependence	**4.2±1.6**	**3.8±1.7**	**-0.4±0.2**	**0.031**
Global Meat Attachment	**5.0±1.2**	**4.6±1.3**	**-0.4±0.2**	**0.020**
On average, how often do you eat meat and products that have meat in them?	**5.0±1.2**	**4.7±1.3**	**-0.4±0.2**	**0.020**
I would be willing to reduce or continue reducing how much meat I eat in the near future.	4.2±2.0	4.6±2.1	0.4±0.2	0.142
I would be willing to eat a more plant-based diet or continue eating a plant-based diet in the near future.	**4.0±2.0**	**4.9±1.9**	**0.9±0.2**	**<0.001**

[a]SD: standard deviation
[b]SE: standard error
[c]Bolded values indicate significance at p≤0.05.

Those with incomes less than 131% of the 2023 federal poverty level[48] generally had higher scores for the MAQ subscales and global scale as compared to individuals with higher incomes, but differences were not significant (**Table 6**). Both income groups reported a mean meat intake frequency closest to the value of every day. Individuals with lower incomes were significantly less willing to reduce meat intake.

Table 6. Differences in scores for the Meat Attachment Questionnaire (MAQ) subscales and global scale, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet by income (n=327)

	Poverty Income Ratio (PIR)		**Mean Difference**	**Significance**
Survey Dimension	**PIR <1.31 n = 90 Mean±SD**	**PIR ≥1.31 n = 237 Mean±SD[a]**	**Mean±SE[b]**	***p*-value[c]**
Hedonism	4.9±1.5	4.7±1.7	-0.3±0.2	0.201
Affinity	5.6±1.5	5.5±1.4	-0.1±0.2	0.549
Entitlement	4.9±1.5	4.7±1.4	-0.2±0.2	0.381
Dependence	4.1±1.7	3.8±1.7	-0.3±0.2	0.171
Global Meat Attachment	4.9±1.3	4.7±1.3	-0.2±0.2	0.206
On average, how often do you eat meat and products that have meat in them?	4.8±1.3	4.8±1.3	0.0±0.2	0.930
I would be willing to reduce or continue reducing how much meat I eat in the near future.	**4.0±2.1**	**4.6±2.0**	**0.6±0.3**	**0.017**
I would be willing to eat a more plant-based diet or continue eating a plant-based diet in the near future	4.3±2.0	4.7±1.9	0.5±0.2	0.058

[a]SD: standard deviation
[b]SE: standard error
[c]Bolded values indicate significance at $p \leq 0.05$.

All of the scores within the MAQ subscales, the global scale, and the willingness to reduce meat intake dimension were significantly different between those that reported consuming meat less than once per day on average and those who reported consuming meat at least once per day on average (**Table 7**).

Table 7. Differences in scores for the Meat Attachment Questionnaire (MAQ) subscales and global scale, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet by meat intake frequency (n=328)

	Meat Intake Frequency		**Mean Difference**	**Significance**
Survey Dimension	**<Once per day n = 120 Mean±SD**	**≥Once per day n = 208 Mean±SD[a]**	**Mean±SE[b]**	***p*-value[c]**
Hedonism	**3.9±1.9**	**5.2±1.2**	**-1.4±0.2**	**<0.001**
Affinity	**4.8±1.7**	**5.9±1.1**	**-1.1±0.2**	**<0.001**
Entitlement	**4.4±1.5**	**5.0±1.3**	**-0.7±0.2**	**<0.001**
Dependence	**3.1±1.6**	**4.4±1.5**	**-1.3±0.2**	**<0.001**
Global Meat Attachment	**4.0±1.4**	**5.1±1.0**	**-1.1±0.1**	**<0.001**
I would be willing to reduce or continue reducing how much meat I eat in the near future.	**5.0±2.1**	**4.1±2.0**	**0.9±0.2**	**<0.001**
I would be willing to eat a more plant-based diet or continue eating a plant-based diet in the near future	**5.4±1.7**	**4.1±1.9**	**1.3±0.2**	**<0.001**

[a]SD: standard deviation
[b]SE: standard error
[c]Bolded values indicate significance at p≤0.05.

DISCUSSION

This is the first study, to the authors' knowledge, to assess differences in MAQ scores, willingness to reduce meat intake, and meat intake frequency by multiple sociodemographic and socioeconomic characteristics in a U.S. population. Significant differences for multiple MAQ subscales and the global meat attachment scale were found by age, education level, and meat intake frequency. Specifically, younger adults, those with higher educational attainment, and those who eat meat less than once per day had significantly lower scores for multiple MAQ measures as compared to older adults, those with less educational attainment, and those who eat meat at least once per day, respectively. Lower scores are indicative of a weaker attachment or positive bond toward eating meat.[42] Consumers with lower meat attachment may be the most receptive to campaigns that encourage meat reduction and substitution, whereas research suggests that those with higher meat attachment may become defensive about eating meat and more resistant to change.[53,54] The results of this study have identified differences in meat attachment and willingness to reduce meat intake among sociodemographic and socioeconomic groups, helping to better inform the methodology and strategies for these types of interventions.

Consistent with the findings that younger individuals and those with higher levels of educational attainment tend to be more likely to identify as vegetarian[55,56] and more likely to be accepting of plant-based meat alternatives,[57,58] younger adults and those with higher levels of educational attainment were more willing to follow a more plant-based diet. They also reported lower meat intake frequency; however, the average frequency of meat consumption was still relatively high and closest to the value of every day on the scale. In contrast to these findings, other studies have found that as individuals in Germany and the U.S. get older, they consume less meat.[23-27] These apparent contradictions may be explained by younger people generally consuming more food overall, and thus, they would be expected to eat higher amounts of meat than older adults on average.[24]

Among the socioeconomic variables assessed, educational attainment proved to have a stronger impact on differences in meat attachment as compared to income level. Graduates of a

4-year college or higher had significantly lower scores for the Entitlement and Dependence subscales and the global meat attachment scale, lower meat intake frequency, and greater willingness to follow a more plant-based diet, whereas, there was only a significant difference for willingness to reduce meat intake among the income groups. These findings are similar to the results of another study that showed higher educational attainment to be strongly associated with less frequent animal product consumption, with income having a weaker association.[59] Other studies have also consistently found higher educational attainment to be related to lower meat intake.[23,24,28-31]

Individuals with low incomes were found to be significantly less willing to reduce their meat intake and have the same meat intake frequency as individuals with higher incomes. Research has indicated that meat may be of particular importance to individuals with low incomes, with study participants describing meat as the most important component of a meal and spending the greatest portion of their food budget on meat.[60-62] Chan and Zlatevska also found subjective low socioeconomic status to be linked to greater meat preference, with greater desire for social status mediating this effect.[63] While MAQ scores were slightly higher among individuals with low incomes as compared to individuals with higher incomes, results were not significant; therefore, meat attachment may not be a relevant psychological construct driving differences in willingness to reduce meat intake by income. Lowering meat consumption among individuals with low incomes may be especially important due to evidence that they purchase more red and processed meats,[35-37] which have been associated with significant negative environmental impacts[2,9,10] and health effects.[11-20] Additional studies with larger, more nationally representative sample sizes should be conducted to further explore meat attachment as a barrier to reducing meat intake among individuals with low incomes.

Unlike previous studies using the MAQ,[42,43,64] significant differences in meat attachment were not found between males and females. Males have been shown to have higher meat attachment in studies conducted among U.S., New Zealand, and Australian consumers,[42,43,64] which may stem from the sociocultural association between meat and masculinity.[41,65-67] Males did have higher scores for two of the MAQ subscales and the global scale in this study, and the lack of significant differences between males and females may be due to the relatively small number of male participants. The average male participant was also significantly younger at 32.9 years of age compared to the average female participant at 41.8 years of age. This may have skewed the mean male response toward lower meat attachment and meat intake frequency than expected due to younger adults having significantly lower scores for multiple MAQ subscales and meat intake frequency.

Lower scores on the MAQ have been shown to be predictive of greater willingness to reduce meat intake[42,43,45] and identifying as a vegetarian or vegan.[42] Other studies have also indicated that lower meat attachment is associated with greater likelihood of purchasing plant-based meat alternatives[68] and greater willingness to engage in meat substitution.[69] Consistent with these findings, participants in this study with lower self-reported meat intake frequency had significantly lower meat attachment, were more willing to reduce meat intake, and were more willing to follow a more plant-based diet. These results suggest that reducing meat intake to an average of less than once per day may require significant reductions in individuals' meat attachment. Future studies should develop and implement interventions focused on reducing meat attachment in order to increase the likelihood of individuals adopting more sustainable dietary patterns.

Results supported the 15-item structure of the MAQ for use in a U.S. population, with acceptable results from the factor analysis. Assessment of reliability using Cronbach's alpha resulted in the global scale and the Hedonism subscale having a value higher than 0.90, which may point to potential redundancies in the measures.[51] Reducing the Dependence subscale to four prompts, which is more consistent with the number of prompts in the other subscales, may have helped to reduce redundancies, while maintaining appropriate results for model fit statistics. In addition, prompts within the Dependence subscale have demonstrated issues with cross-loading onto other factors in this study and others,[45-47] and the average participant in this survey sample was on the side of disagreement on the Likert scale for multiple of the prompts, in contrast to the other subscales. Thus, the Dependence subscale and prompts may need additional consideration in future studies.

This study had several limitations, including a relatively small sample size with unequal distribution among multiple variables of interest. However, the study was adequately powered, with the final sample size surpassing the adequate sample size of 172 determined by a power analysis. A more diverse sample with participants from other U.S. states would allow the results to be more generalizable and provide greater detail in the differences among sociodemographic and socioeconomic characteristics. Additionally, the present study relied on self-reported meat intake frequency and hypothetical willingness to reduce meat intake and follow a more plant-based diet. Using 24-hour recalls or food frequency questionnaires for these measures alongside the MAQ would provide a better indication of participants' actual dietary behavior in relation to meat attachment. Lastly, some participants may have demonstrated social desirability bias (i.e., a desire to exhibit socially desirable traits and deny socially undesirable traits)[70] due to the nature of the prompts and topic. However, before completing the survey, participants were informed that they should answer each question as honestly and completely as they can.

The results of this study can help inform dietary interventions designed to reduce meat intake by identifying which consumers may be more likely to have strong attachments to meat and be less willing to reduce their meat intake. Age and educational attainment were identified as the two characteristics most associated with differences among meat attachment measures, and these characteristics should be considered when implementing studies that are intervening on the construct of meat attachment. Results also suggest that younger adults, those with higher educational attainment, and individuals with higher incomes are more willing to reduce their meat intake. This study has provided a better understanding of how meat attachment, meat intake frequency, and willingness to reduce meat intake and follow a more plant-based diet differs among U.S. consumers, which will aid in the development of nutrition education, research, and programs that aim to promote plant-based dietary patterns for human and planetary health.

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Chapter 5: Conclusions

INTRODUCTION

The world is facing a triple threat of climate change, obesity, and undernutrition, with these three co-occurring pandemics referred to as The Global Sydemic.[1] The present food system is contributing to The Global Syndemic by generating negative environmental impacts;[2-5] producing products in accordance with the "nutrition transition" toward processed, energy-dense, and animal-based foods;[6-9] generating large quantities of food waste,[9-11] and distributing food inequitably among populations.[12,13] Climate change is also expected to exacerbate undernutrition.[1,14,15] Adoption of sustainable and healthy dietary patterns is an avenue to improve food system sustainability, aid in the mitigation of climate change, promote food security, and reduce obesity and non-communicable diseases.[2,8,16,17]

Evidence indicates that diets made up of predominately plant-based foods are health promoting[18-22] and more sustainable due to the production of most plant-based foods generating less greenhouse gases and requiring less land and water than animal-based foods, especially meat from ruminant animals.[2,3,23] To establish a reference sustainable dietary pattern, The EAT-*Lancet* Commission on Healthy Diets from Sustainable Food Systems developed the Planetary Health Diet.[16] The pattern consists of mostly healthy plant-based foods, including whole grains, fruits, vegetables, and legumes; moderate amounts of animal-based foods; and limited added sugars, saturated fats, and red and processed meats.[16] The EAT-*Lancet* commission estimated that by the year 2050, shifts from current dietary patterns to the Planetary Health Diet could reduce greenhouse gas emissions by about 50%, reduce the use of nitrogen and phosphorous fertilizers by about 10%, and prevent about 11 million adult deaths from diet-related diseases per year.[16] However, it is less certain what will motivate or cause consumers to make these dramatic shifts in dietary patterns, especially among U.S. consumers, as most studies assessing consumers' attitudes regarding meat consumption and willingness to reduce meat intake have been conducted in Europe.[24,25]

To determine what aspects of the American diet could be improved to meet Planetary Health Diet recommendations, we developed and evaluated the Planetary Health Diet Index for the United States (PHDI-US) based on the PHDI validated in the Brazilian population.[26] The PHDI-US was used to measure current levels of American adherence to the Planetary Health Diet and identify differences in adherence among sociodemographic and socioeconomic groups. The disparities identified among PHDI-US scores helped inform what sociodemographic and socioeconomic characteristics to use for the assessment of differences in meat attachment (i.e., a positive bond toward eating meat)[27] and willingness to reduce meat intake in a U.S. population.

MAJOR FINDINGS

The evaluation of the PHDI-US resulted in acceptable validity and reliability, indicating that it could be a useful tool to quantitatively measure American adherence to the Planetary Health Diet recommendations in research, public health, and epidemiological settings. The PHDI-US scores were calculated for the American population using nationally representative dietary data from the National Health and Nutrition Examination Survey (NHANES) 2017-2018. The scores revealed that overall, Americans are far from adhering to Planetary Health Diet recommendations.[16] The average score on the PHDI-US was very low at 38.7 out of 150, and even at the 99^{th} percentile, the mean total PHDI-US score was only about half of the maximum score. Disparities in PHDI-US scores were identified by race/ethnicity, income, smoking status, gender, and age.

The average scores within each PHDI-US component indicated that Americans could consume less added sugars, saturated fats, and red and processed meats and consume more whole grains, legumes, and nuts and peanuts to improve adherence. Additionally, Americans need to eat greater quantities of fruits and vegetables and diversify the types of vegetables consumed. The large gaps identified between current American diets and a sustainable and healthy dietary pattern is cause for concern given the urgency needed to address the climate and obesity crises. As the nutrition transition has unfolded toward dietary patterns made up of processed, palatable, and animal-based foods in many parts of the world,[6-9] the hypothesized shift toward healthy dietary patterns has yet to be realized.[9] Dietary patterns can be slow and difficult to substantially change,[1,28] and there are two diverging approaches to improving dietary quality. The small-changes approach focuses on small, incremental health behavior changes that may be more feasible or realistic to achieve, gradually leading to sustained, larger impacts.[29,30] Alternatively, the necessity for a more transformational approach could be justified due to the exigency for reducing environmental impacts and improving human health.[16] The Planetary Health Diet reflects this transformative concept,[31] with the PHDI-US demonstrating that typical dietary intakes are largely discrepant from many recommendations.[16] To achieve these sustainable dietary goals, consumers will need to be supported through public policies, governmental regulations, and food environments that make choosing plant-based products appealing, easy, and normalized.[1,32] Additionally, diets made up of an abundance of plant-based foods need to be affordable and accessible to meet the true definition of sustainable.[33] The PHDI-US identified that individuals with low incomes had significantly lower PHDI-US scores than individuals with higher incomes, regardless of participation in the Supplemental Nutrition Assistance Program (SNAP). While this may raise concerns about the affordability of the Planetary Health Diet, scores by income were overall very similar, and other studies have demonstrated that the Planetary Health Diet could be less expensive than typical dietary patterns in certain countries, including the U.S.[34-36] Beginning with targeted reductions and substitutions of specific foods could also be an effective strategy for incrementally accomplishing healthier and more sustainable diets.[37] Stylianou et al. found that if Americans replaced only 10% of daily calories from beef and processed meat with the same number of calories from fruits, vegetables, nuts, legumes, and certain types of seafood, they could reduce their dietary carbon footprint by 33% and improve health indicators.[37]

Reducing meat consumption is critical for achieving a sustainable food system;[2,3,16,23] however, meat is largely regarded as a special food with socially developed meaning beyond its nutritional use,[27,38-40] which may make motivating consumers to reduce meat intake particularly challenging. Meat attachment as a psychological construct helps describe this positive affective connection toward meat that can impede individuals' willingness to reduce meat intake.[27,41-43] The Meat Attachment Questionnaire (MAQ) was used to assess meat attachment and willingness to reduce meat intake in an American population by age, income, gender, and educational attainment, and we found age and educational attainment to be the two sociodemographic and socioeconomic characteristics most associated with differences in MAQ scores. Younger adults and graduates of a 4-year college or higher had significantly lower scores for multiple MAQ subscales, lower meat intake frequency, and were more willing to follow a more plant-based diet compared to older adults and those with lower educational attainment, respectively. Consistent with the conceptual construct of meat attachment, participants with more frequent meat intake had significantly higher meat attachment and were less willing to reduce their meat intake.

These findings are useful for informing the design of interventions focused on reducing meat consumption by identifying which consumers may the most receptive or conversely the most resistant to changes in meat intake. Rothgerber has demonstrated that when individuals are reminded that they eat animals, they may utilize mechanisms to reduce meat-related cognitive dissonance, which occurs when one's consumption of meat contradicts beliefs, attitudes, or values related to the negative consequences of eating meat, such as harm to animals or the environment.[44,45] Information-based interventions to reduce meat intake may be ineffective for those with high levels of meat attachment, as these individuals may be more resistant to reducing meat intake and provide justifications for continuing this behavior.[41,44-46] In contrast, women, who tend to have lower meat attachment,[27,42] may be more receptive to these types of messages and thus more responsive to interventions trying to elicit reduced meat intake.[46] Therefore, targeting those with lower meat attachment and increasing feelings of meat-related cognitive dissonance may be effective strategies for encouraging lower meat consumption.[41,44-46] By identifying differences in meat attachment by sociodemographic and socioeconomic characteristics, different approaches can be utilized for various consumers to improve intervention efficacy and promote behavior change.

FUTURE DIRECTIONS

The connection between plant-based diets, positive health effects, and lower environmental impacts is well-established,[1,3,4,8,16,23] but research on how to effectively elicit adoption of plant-based diets is still emerging. The PHDI-US could allow for the measurement of changes in American diets toward a sustainable and healthy dietary pattern. Having this tool will help to quantitively monitor adherence to the Planetary Health Diet[16] among the U.S.

population over time and after research interventions. Future studies are needed to evaluate the predictive validity of the PHDI-US. Determining the association between scores and indicators of metabolic syndrome and obesity will help to identify if higher PHDI-US scores can predict better health outcomes. Results from the validation of the PHDI in Brazil show promise for the predictive validity of the PHDI-US.[47] After predictive validity is established, the PHDI-US can be utilized more broadly as a dietary assessment tool in studies intervening on adherence to Planetary Health Diet recommendations.[16] Furthermore, developing interventions and educational programs for those participating in SNAP-Education[48] may be an important first step in promoting overall diet quality and sustainability and reducing the disparities between individuals with low incomes and individuals with higher incomes as identified by the PHDI-US.

More research interventions focused on reducing actual, long-term meat intake are needed.[49,50] As preliminary studies have established evidence on consumers' meat intake and meat attachment using hypothetical measures of willingness to reduce meat intake and self-reported meat intake frequency, future studies should utilize measures of dietary intake and quantity.[27,42,43,49,50] Using 24-hour recalls and longer follow ups would help determine if interventions have resulted in actual long-term dietary behavior change.[49] Lastly, studies intervening on the construct of meat attachment that also consider the moderating effects of sociodemographic and socioeconomic characteristics are needed, as these factors have been shown to play an important role in willingness to reduce meat consumption and follow a more plant-based diet.[50] Through expanding this research, a better understanding of how to encourage consumers to adopt more sustainable dietary patterns will be gained, helping to address The Global Syndemic[1] and improve the health of humans and the environment.

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Appendix A: Virginia Tech Institutional Review Board Study Approval Letter

Division of Scholarly Integrity and Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
http://www.research.vt.edu/sirc/hrpp

MEMORANDUM

DATE: November 10, 2022

TO: Valisa Ellen Hedrick, Sarah Anne Misyak, Molly Parker

FROM: Virginia Tech Institutional Review Board (FWA00000572)

PROTOCOL TITLE: Assessment of Meat Attachment and Willingness to Reduce Meat Intake

IRB NUMBER: **22-961**

Effective November 10, 2022, the Virginia Tech Human Research Protection Program (HRPP) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104 (d) category(ies) 2(ii).

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit an amendment to the HRPP for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As: **Exempt, under 45 CFR 46.104(d) category(ies) 2(ii)**
Protocol Determination Date: **November 10, 2022**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this protocol is to cover any other grant proposals, please contact the HRPP office (irb@vt.edu) immediately.

Appendix B: Survey and Meat Attachment Questionnaire

This survey is designed to help better understand individuals' experiences and views regarding eating meat. The results from this survey may be published in an academic journal. Your participation is voluntary. Your identity will be kept anonymous. Please answer honestly and as completely as you can. This survey should take about 10-20 minutes of your time. You may exit the survey at any time if you do not wish to continue. There is no more than minimal risk involved with completing this survey. You will first be asked questions to see if you are eligible to participate in this study. If you are eligible, after completing the survey you can choose to provide your contact information to be entered into a raffle with a 1 in 25 chance of winning a $25 Amazon gift card. Your information will only be used for the raffle and will not be connected to your survey responses.

If you have any questions about this study, please contact the study coordinator or principal investigator for this study:

Molly Parker, MS
pmolly95@vt.edu
-or-
Valisa Hedrick, PhD, RDN
vhedrick@vt.edu
-or-
You may also contact Virginia Tech's Institutional Review Board at irb@vt.edu or 540-231-3732.

Your consent to participate in this study will be implied by clicking start and beginning the survey.

Complete the Captcha to continue.

Are you 18 years of age or older?

1. Yes
2. No

Please keep in mind when answering survey questions that the word “meat” refers to red and white meats (beef, lamb, pork, chicken, turkey, fish, shrimp, seafood, etc.) that are either unprocessed (chicken breast, steak, fish filet, etc.) or processed (sausage, lunch meats, hot dogs, chicken nuggets, crab cakes, etc.).

On average, how often do you eat meat and products that have meat in them?

1. Several times per day
2. One time per day
3. Several times per week
4. One time per week
5. Less than one time per week
6. Never

Choose the answer that best describes your feelings about each statement:

	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
I would be willing to reduce or continue reducing how much meat I eat in the near future.	❑	❑	❑	❑	❑	❑	❑
I would be willing to eat a more plant-based diet or continue eating a plant-based diet in the near future.	❑	❑	❑	❑	❑	❑	❑

Choose the answer that best describes your feelings about each statement:

	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly Agree
To eat meat is one of the good pleasures in life.	❑	❑	❑	❑	❑	❑	❑
I love meals with meat.	❑	❑	❑	❑	❑	❑	❑
I'm a big fan of meat.	❑	❑	❑	❑	❑	❑	❑
A good steak is without comparison.	❑	❑	❑	❑	❑	❑	❑

Choose the answer that best describes your feelings about each statement:

	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly Agree
By eating meat, I'm reminded of the death and suffering of animals.	❑	❑	❑	❑	❑	❑	❑
To eat meat is disrespectful towards life and the environment.	❑	❑	❑	❑	❑	❑	❑
I feel bad when I think of eating meat.	❑	❑	❑	❑	❑	❑	❑
Meat reminds me of diseases.	❑	❑	❑	❑	❑	❑	❑

Choose the answer that best describes your feelings about each statement:

	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly Agree
To eat meat is an unquestionable right of every person.	❑	❑	❑	❑	❑	❑	❑
According to our position on the food chain, we have the right to eat meat.	❑	❑	❑	❑	❑	❑	❑
Eating meat is a natural and indisputable practice.	❑	❑	❑	❑	❑	❑	❑

Choose the answer that best describes your feelings about each statement:

	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly Agree
I don't picture myself without eating meat regularly.	❑	❑	❑	❑	❑	❑	❑
If I couldn't eat meat I would feel weak.	❑	❑	❑	❑	❑	❑	❑
If I was forced to stop eating meat I would feel sad.	❑	❑	❑	❑	❑	❑	❑
Meat is irreplaceable in my diet.	❑	❑	❑	❑	❑	❑	❑

How old are you in years? Example response: 31

Choose the answer that best describes your gender:

1. Male
2. Female
3. Non-binary
4. Other

Including yourself, how many people are in your household? Example response: 1

About how much money in dollars does your household make in one year, NOT including any income from federal programs like SNAP or WIC? Example response: 25,000

What is the highest grade you have completed?

1. Grade 11 or less
2. Grade 12 or GED
3. Graduated 2-year college
4. Graduated 4-year college or higher

Are you Hispanic or Latino?

1. Yes
2. No

Please check ALL of the racial identities that apply to you:

1. American Indian or Alaskan Native
2. Asian
3. Black or African American
4. Native Hawaiian or Other Pacific Islander
5. White

What state do you live in?