The Intersection Of Diet, Health And The Environment: Plant Based Diets And Public Health

Christine E. Jovanovic
UTHealth School of Public Health

THE INTERSECTION OF DIET, HEALTH AND THE ENVIRONMENT:

PLANT BASED DIETS AND PUBLIC HEALTH

by

CHRISTINE E. S. JOVANOVIC

APPROVED:

_____

ALEXANDRA E.M. VAN DEN BERG, PHD,
MPH

Deanna M. Hoelscher

DEANNA M. HOELSCHER, PHD, RDN, LD,
CNS, FISBNPA

Baojiang Chen

BAOJIANG CHEN, PHD, MS

_____

DEAN, THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH

DEDICATION
To William J. Schaak

THE INTERSECTION OF DIET, HEALTH AND THE ENVIRONMENT:

PLANT BASED DIETS AND PUBLIC HEALTH

by

CHRISTINE JOVANOVIC
BA, University of Illinois at Urbana-Champaign, 1993
MPH, University of Texas School of Public Health at Austin, 2016

Presented to the Faculty of The University of Texas

School of Public Health

in Partial Fulfillment

of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH
Houston, Texas
May 2020

ACKNOWLEDGEMENTS

THE INTERSECTION OF DIET, HEALTH AND THE ENVIRONMENT:

PLANT BASED DIETS AND PUBLIC HEALTH

Christine E Jovanovic, PhD, MPH
The University of Texas
School of Public Health, 2020

Dissertation Chair: Alexandra E. M. van den Berg, PhD, MPH

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

v

CHAPTER 1: BACKGROUND

Introduction

Both globally and within the United States, chronic disease has become a major driver of mortality and morbidity. In the United States in 2017, the top ten causes of mortality accounted for 74% of all deaths [2]; of these causes, half are closely linked to diet (heart disease, cancer, stroke, Alzheimer's and diabetes). [3] In 2013, Ioannidis estimated that 26% of deaths and 14% of disability adjusted life years (DALYs) in the United States may be attributable to dietary risk factors, controlling for obesity. [4]

At the same time, diet also has an important impact on the environment. Direct emissions from food production contribute 9% to global Greenhouse Gas (GHG) emission totals, while the livestock sector contributes 50% to that total [5]. Indirect impacts from land use and habitat destruction are also influential, reducing the ability of the environment to sequester carbon while contributing to widespread species extinction. Incorporating both direct and indirect mechanisms, Herrero (2013) estimates that switching from the current dietary pattern to a plant-based dietary pattern may reduce global Greenhouse Gas (GHG) emissions by 28% [6].

Clearly, there is a need to define and encourage dietary patterns that reduce the risk of chronic diseases while also protecting the environment from the threats of climate change and mass extinction. Proposed solutions must address both proximal impacts, such as human health outcomes, as well as distal outcomes, such as climate change and biodiversity loss. In order to do so, any proposed remedy must also be feasible and equitable for diverse

populations. A plant-based diet may offer the best option for achieving these multi-factorial goals. Because animal products are reduced rather than eliminated, a plant-based diet may be more acceptable to a greater number of individuals. In addition, including some animal products in the diet can reduce the likelihood of nutrient deficiencies (B12 and Vitamin D) that are associated with total elimination of animal products from the diet. Finally, advocating for a plant-based diet is less likely to become mired in the ever-changing and confusing minutiae of dietary advice, allowing for a simple message that allows for great variation and adaptability across cultures and socioeconomic circumstances. Therefore, this dissertation intends to assess the impact and the utility of a plant-based diet as a means of improving health and mitigating the environmental impacts of diet.

This literature review aims to first explore the association of a plant-based diet to several prevalent chronic disease outcomes: obesity, cardiovascular disease (CVD), type II diabetes (T2D), and cancer. In addition, the impact of consuming meat in the diet will be explored separately, as this has been found to be separate both behaviorally and physiologically. Next, the intersection of diet and the environment will be assessed, with particular focus on the impact of a plant-based diet on GHG emissions, land use and biodiversity. The implications on climate and health equity are also addressed, since these aspects of the current system, as well as the potential impacts of policies intended to influence diet, must be examined in order to ensure all populations may participate and benefit. Finally, the psychosocial determinants of behaviors around consumption of both plants and animals are explored, with the intention to understand how best to intervene and possibly improve dietary patterns at the population level.

Literature Review

Plant-based Diets

Plant-based diets have been defined by Leah & Worsley (2006) as "…an eating pattern that is dominated by fresh or minimally processed plant foods and decreasing consumption of meat, eggs and dairy products." There are several dietary patterns that are often conflated with plant-based diets, especially vegan and vegetarian (including lacto-vegetarian, ovo-vegetarian, and variations thereof). While these dietary patterns are often considered healthy and beneficial, plant-based diets are more similar to the Mediterranean diet in terms of being less restrictive and potentially more feasible for a range of populations (Karlsen, 2017). Particularly compared to strict veganism, a plant-based diet avoids potential nutritional deficiencies associated with the total elimination of animals and animal products from the diet, especially insufficient B12 (Herrmann, 2017). In addition, adherence to a vegan dietary pattern may be difficult and unattractive to many, whereas a plant-based diet may be more accessible and acceptable.

Table 1 provides Tuso et al.'s (2015) definitions of the most common plant-based diets in the United States. [7]. It is important to highlight that plant-based diets do not exclude any food groups; instead, a plant-based diet emphasizes whole foods that are mostly plants, with smaller amounts of animal-based foods and less fat. In the United States in 2016, a Harris poll of 2,015 adults commissioned by the Vegetarian Resource Group found 3.3% self-identified as vegetarians and 1.5% as vegans [8].

Table1.1: Definitions of Dietary Patterns

NAME	REDUCED	ELIMINATED	ENCOURAGED

Vegan		All animals and animal products (i.e., meat, poultry, fish, eggs, and dairy)	
Raw-food vegan		All animals and animal products and foods cooked above 118˚F	
(Lacto-ovo) Vegetarian		Excludes all animals (meat, poultry, fish); may include animal products (eggs and dairy)	
Lacto-vegetarian		All animals and animal products, except for dairy	
Ovo-vegetarian		All animals and animal products, except for eggs	
Pesco-vegetarian		All animals except for fish; may include eggs and dairy.	
Mediterranean	Animals and animal products		Whole foods, especially plants; fish and olive oil.
Plant-based	Animals and animal products, total fat		Whole foods, especially plants; fruits, vegetables, legumes, seeds and nuts

Plant-Based Diets and Health

Obesity

There is evidence that consuming a plant-based diet is associated with lower BMI and

may offer a feasible approach to lowering obesity at the population level. A meta-analysis of

40 (mostly observational) studies discovered more than half reported significant associations

between vegetarian and vegan diet patterns and lower BMI, with BMI 4% to 20% lower for

vegans or vegetarians compared to those who consumed animal-based foods(29 studies),

while nine studies found non-significant associations[9]. Sabaté and Wien (2010) conducted

a meta-analysis of 60 studies and found significant reductions in weight for both men and

women (-7.7 kg, $P < 0.0001$ and -3.3 kg, $P = 0.007$, respectively) and a 2-point lower BMI were associated with higher fruit and vegetable consumption [10].

While these analyses offer intriguing associations, problems of confounding, especially the link between unhealthy diets and other lifestyles factors such as smoking and lack of physical activity may obscure true relationships. However, several large studies of the Seventh Day Adventists, who generally avoid tobacco, alcohol and caffeine, offer an opportunity to detect associations that are less likely to be confounded by unhealthy habits. One such study found that the fewer animal products in the diet, the lower the BMI, detecting a significant difference in BMI between the vegan group (least animal products) and the group that consumed the most animal products of -5.5 kg/m^2 [11]. A similar inverse and dose-response association between plant-based diets and BMI was found in the European Prospective Investigation into Cancer and Nutrition (EPIC) study of 37,875 adults. The largest differences in BMI were found between vegan (22.49 kg/m^2 in men, 21.98 kg/m^2 in women) and meat-eating groups (24.41 kg/m^2 in men, 23.52 kg/m^2 in women), with lacto-ovo and pesco-vegetarians in between. These associations were found to remain after other lifestyle factors (smoking, physical activity and education) were controlled, suggesting that a plant-based diet may impact BMI through changes in macronutrient profile [12].

While the size and geographic diversity of these study populations lends strong support to the inverse association of plant-based diets and lower BMI, further study of ethnic and age variation is warranted. In addition, it may be important to better understand the role of specific fruits and vegetables that may be most beneficial for weight loss. A secondary analysis of prospective cohort studies tracking 133,468 adults found inverse associations

between consumption and weight loss for total fruits (-0.53 lb. per daily serving, 95% CI: -0.61, -0.44), berries (-1.11 lb., -1.45, -0.78), and apples/pears (-1.24 lb., -1.62, -0.86), as well as total vegetables (-0.25 lb. per daily serving, 95%: CI -0.35, -0.14), tofu/soy (-2.47 lb., -3.09, -1.85) and cauliflower (-1.37 lb., -2.27, -0.47). At the same time, starchy vegetables such as peas, corn and potatoes were associated with weight gain [13].

Cardiovascular Disease

The relationship between a plant-based diet and the incidence of CVD appears to mirror other chronic diseases, with lower levels of meat consumption associated with lower risk. In a small (n=28) prospective randomized controlled trial, Ornish (1990) followed patients diagnosed with severe coronary atherosclerosis, randomized to a vegan treatment group (vegan, low-fat) or an American Heart Association (AHA) diet treatment group. After 1 year, those in the vegan treatment group saw the average diameter of stenosis regress from 40.0 (SD 16.9) to 37.8, while the AHA diet treatment group' stenosis progressed from 42.7 (15.5) to 46.1 [14]. A study of 6,555 adults in India offered access to a high percentage of lacto-vegetarians (35%) to evaluate associations with CVD risk factors. A multivariate analysis revealed that vegetarians had significantly lower levels of cholesterol, triglycerides, LDL and lower diastolic blood pressure compared to non-vegetarians [15]. These may be part of the mechanisms that underlie the findings of a meta-analysis of pooled cohort studies, which used Bradford Hill criteria to conclude there was strong evidence for causal relationship between plant-based dietary patterns and reduced risk of CVD (RR 0.63, 95% CI: 0.45, 0.81) [16].

Type II Diabetes

There is convincing evidence for the benefits of a plant-based diet on the incidence

and treatment of Type II diabetes (T2D), which was diagnosed in 8.6% of adults in the U.S.

in 2016 [17] and was the 7th leading cause of death in 2017 [2]. A recent (2019) meta-

analysis of 9 prospective cohort studies (n=307,099) found a significant inverse association

between adherence to a plant-base diet and risk of T2D (RR 0.77, 95% CI: 0.71, 0.84) [18].

Similar to findings regarding CVD, the Adventist Health Study 2 (n = 60,903) found that

prevalence of T2D declined as the proportion of the diet given to plants increased, suggesting

a dose-response relationship. These associations remained after adjusting for important

confounders including BMI, demonstrating the continuum of lowest risk for T2D to highest

from vegans (OR 0.51, 95% CI: 0.40, 0.60), lacto-ovo vegetarians (0.54, 95% CI: 0.49, 0.60),

pesco-vegetarians (0.70, 95% CI: 0.61, 0.80) and semi-vegetarians (0.76, 95% CI: 0.65,0.90)

compared to non-vegetarians [11]. Using data from three prospective studies totaling

4,102,369 person years of follow-up, researchers found large differences in the risk for

incidence of T2D depending on dietary pattern. This secondary analysis of men and women

(n=135,588) in the Nurses' Health Study and the Health Professionals Follow-up Study

created healthy and unhealthy plant-based diet indices, giving positive scores to healthy plant

foods (whole grain, fruits and vegetables, nuts and legumes, oils, tea and coffee) and reverse

scores to less healthy plants foods such as juices and sweetened beverages, refined grains,

potatoes and fries, and sweets. For those following a healthy plant-based diet, hazard ratios

for extreme deciles (most plant-based foods versus least plant-based foods) was 0.55 (95%

CI: 0.51, 0.59, p-trend < 0.001), while an unhealthy plant-based diet was found to be

positively associated with incidence of T2D [19]. These relationships are illustrated in

Figure 1.

Figure 1.1: Pooled hazard ratios (85% Cis) for T2D according to deciles of the overall, healthful, and unhealthful plant-based diet indices.
https://doi.org/10.1371/journal.pmed.1002039.g001
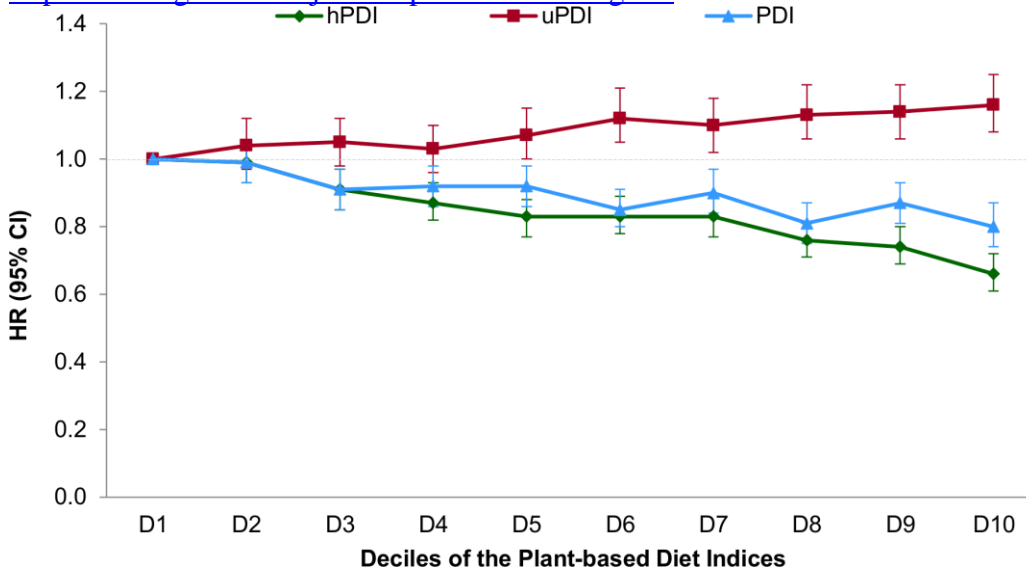
Further support for the benefits of a plant-based diet on markers of T2D comes from a

small (n=56), randomized controlled trial investigating the impact of a vegetarian diet versus

a conventional diabetic diet on insulin resistance, visceral fat, and enzymatic oxidative stress

markers. Daily calories and physical activity were the same between groups. For all

outcomes, those on a vegetarian diet showed significantly greater improvement, resulting in

43% of the experimental (vegetarian) group reducing diabetes medication, versus 5% in the

control (diabetic diet) group (p<0.001) [20]. These effects appear to have several plausible

biological mechanisms, including decreased BMI, increases in fiber and phytonutrients,

8

food-microbiome interactions, and decreases in saturated fat, advanced glycation end products, nitrosamines, and heme iron [21].

Cancer

The relationship between plant-based diets and cancer risk appears similar to that found for CVD and T2D. A 2017 meta-analysis reported a significant protective effect of a vegetarian diet for the incidence of and/or mortality from ischemic heart disease (−25%) and incidence from total cancer (−8%), while a vegan diet was found to confer a significant reduced risk (−15%) of incidence from total cancer [22]. In particular, the 1976 - 1988 Adventist Health Study (n = 34,192) found that risks for colon and prostate cancer appear to be elevated in non-vegetarians compared to vegans (RR of 1.88 and 1.54, respectively). This study also found significantly lower risk for lung, prostate and pancreatic cancer associated with higher consumption of fruit and dried fruit [23]. This pattern of association is similar to that found between dietary patterns and BMI, with less meat progressively associated with lower risk for total cancer. However, Craig (2009) has speculated as to why these associations are not stronger, given the plausibility of the biological mechanisms (i.e., anti-oxidative effects) of fruit and vegetable consumption [24]. There is some evidence that strict veganism can lead to lower intakes of vitamins B12 and D (p-values < 0.001) [22], which may raise the risk of some cancers and attenuate the effect of consuming a plant-based diet in large epidemiological studies.   In addition, not all plant-based diets are created nutritionally equal, since it is possible to avoid animal-based foods while also consuming vegan or vegetarian junk foods, refined grains, and sugary drinks and desserts [25].

Benefits of reducing meat consumption

While a plant-based diet can offer protection from chronic disease via increased consumption of fruits and vegetables [26], reducing meat may have separate and distinct health benefits. Several large prospective cohort studies have explored association between consumption of meat and processed meat, and cancer in humans. A 2011 meta-analysis of large prospective cohort studies found a positive dose-response relationship between each 50g/day increase in processed meat intake and colorectal cancer (RR 1.18, 95% CI: 1.10, 1.28) and for colon cancer (1.24, 95% CI: 1.13, 1.35) [27]. Several mechanisms have been suggested to explain this relationship, including the formation of carcinogenic *N*-nitroso compounds in the gastrointestinal tract, as well as the abundance of heme iron in red meat, which may also become a promotor of *N*-nitroso compound formation. Processed meats often carry nitrites before consumption, which, in conjunction with the pro-nitrite function of red meat alone, would increase nitrite load and, thusly, carcinogenicity [27].

Other researchers have assessed the association of consumption of processed meat and the incidence and outcomes of breast cancer diagnoses. Parada et al. (2017) found that women in the highest category of processed meat consumption had higher all-cause (HR 1.17, 95% CI: 0.99-1.38, p trend = 0.10) and breast cancer-specific (1.23, 95% CI: 0.95, 1.60, p trend = 0.09) than those in the lowest category [28]. These studies, and more than 775 others, led the International Agency for Research on Cancer (IARC) in 2015 to classify processed meat as "carcinogenic to humans" (Group 1) for colorectal and stomach cancer. In addition, the IARC classified red meat as "probably carcinogenic to humans" (Group 2A) for colorectal, pancreatic and prostate cancer [29]. However, a recent re-analysis

Environmental Impacts

While diet is fundamental to human health, there are other important perspectives from which to view dietary patterns. One of the most important may be the consideration of environmental impact of food choice. Each calorie we consume has been produced via an input of energy, has used certain resources, produces different outputs, and each calorie provides varying degrees of nourishment. Aligning dietary patterns with the most sustainable choices will be critical to supporting a world population expected to increase from 7.6 billion to 9 billion by 2050 [30]. In addition to predicted higher demand for food generally, the ongoing nutrition transition—the switch from traditional diets to those characterized by increased processed foods and meat—exacerbate the global impact on both disease incidence and environmental degradation. [31, 32] Given the current and future nutritional needs of billions of humans and the finite nature of global resources, a more holistic understanding of the implications of dietary choices on the environment is essential to a healthy and sustainable future.

Efficiency

The current agricultural system in the United States and many other parts of the world can be a seen as a miracle of industrialization, meeting growing demand for food throughout the Twentieth century with the Green Revolution. By leveraging the use of petroleum-based fertilizers, genetic and hybridized seed production, mono-cropping and petroleum-fueled machinery, industrial agriculture increased yields globally by 150-200% between 1960 and 2010 [33]. Today, the world's agricultural system produces 150% of the world's nutritional needs; an inarguable success and the foundation for widespread decreases in hunger [34, 35].

However, these gains have not been evenly distributed nor without cost. In fact, current industrial practices are extremely resource-intensive, reducing the efficiency of food production. Viewing food from the perspective of inputs versus outputs, food production in the United States yields an energy efficiency ratio of $> 7:1$, in part due to heavy dependence on chemical fertilizers and pesticides, which account for 40% of agricultural production energy [36].

Comparing plant to animal foods reveals vast differences in efficiency of production, reflecting the fundamental nature of movement along the trophic chain. For example, when grains are used to feed people directly, this represents a ratio of 1:1. However, when the same grain is used to feed animals that are then eaten by humans, that ratio changes dramatically and differentially, from 2.3 for chicken to 13.0 for beef. It is important to note that this comparison is crude, and is not able to capture the systems-level effects of animals that graze on land unsuitable for crop production. Another useful perspective is to evaluate how efficiently foods provide protein as a function of fossil fuel inputs. Here, chicken provides a 4:1 ratio, while beef provides a highly inefficient ratio of 40:1 [37]. Compared to animal-based foods, plant-based foods are intrinsically more efficient mechanisms for producing calories and most nutrients.

Impacts of Dietary Patterns on Greenhouse Gas Emissions and Land Use

Current estimates for the proportion of global greenhouse gas (GHG) emissions attributable to agriculture in the United States vary from 9% [38] to 18% [6]. Of these, approximately 50% are caused directly by production of livestock [5], and are attributable to methane production as a by-product of ruminant animal digestion, manure management and

the production of grain as feed for animals.   However, direct emissions from livestock

production do not capture systemic impacts, especially those associated with land use.   In

2010, clearing of tropical forests for livestock production contributed 12% of the world's

GHG emissions [39], and in August 2019, out of control slash and burn clearing activities in

the Amazon are estimated to have produced 140 million metric tons of CO_2, while also

destroying the carbon-capture capacity of lost tropical forest [40].   This more holistic

accounting of the impacts of livestock production suggests larger impacts on GHG

production, as well as greater opportunities for mitigation. When accounting for both direct

and land-use mitigation effects from switching to a plant-based diet, it is estimated that such

a change may eliminate 28% of total GHG emissions [6, 41].

The potential for reducing GHG emission via diet appear viable, but estimating the

effect of a population-level shift to plant-based diets is quite different. Several studies have

attempted to quantify the complexities of human behavior and dietary patterns in relationship

to GHG emissions. At the individual level, a study of various dietary patterns in the UK

estimated that totally eliminating meat (i.e., a vegan diet) would cut GHG emission from

food by 40.2%, compared to diets high in meat [42]. At the household level, food generates

16.2% of GHG emissions, following transportation (40.0%) and housing (30.0%) [43]. As

quantified by Eshel and Martin (year), eating a plant-based diet versus an animal-based diet

is similar to the difference between owning a sedan and a sport utility vehicle [44].

To evaluate the possible impacts of reducing meat in the diet at the national level,

White and Hall year created a model that eliminated production of animal foods in the United

States and estimated GHG from agriculture would decrease by 28%, reducing domestic GHG

emissions by 2.6% (Figure 2). The plants-only scenario also produced 230% of protein and

energy requirements for the population of the United States. However, micronutrient

requirements in the plants-only modeled outcomes were not met, specifically those for

Choline, Calcium, vitamins A and B_{12}, EPA, DHA and arachidonic acid. This may be caused

by the model's assumption that 77% of the calories from animal products would be replaced

with corn, which does not appear to be realistic and would account for a majority of the

deficiencies reported [5]. A 2016 meta-analysis of 63 studies found the median projected

decrease in GHG emissions from agriculture due to shifting to a plant-based diet to be 22%,

while a vegan diet had a median reduction of 45% [45]. Regardless of the methodology, it

seems that eating less meat would reduce GHG emissions. However, all of these estimates

are theoretical and should be treated with caution.

Figure 1.2: GHG emissions associated with food production in a system representative of the current United States and a modeled system in which animal-derived food inputs are eliminated.
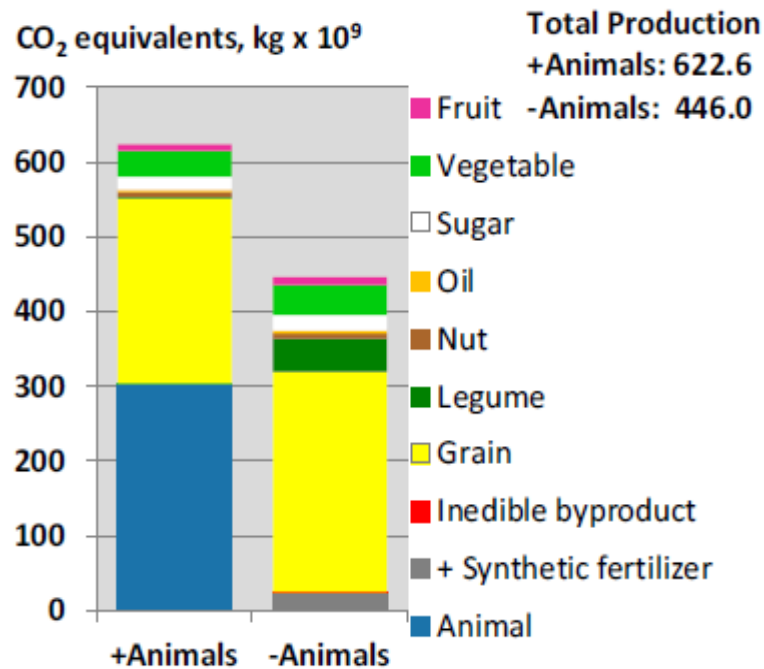
Loss of Biodiversity

As the world's population trends towards 9 billion people by 2050, the demand for animal products is predicted to increase, and the output of the global agricultural system will need to double to meet demand if current dietary patterns persist [41, 46]. It is difficult to overstate the potentially catastrophic impacts of doubling current agricultural output on the earth's ecosystems. By just one metric, land use, the scale of the problem becomes clear. In 2011, the FAO estimated that agriculture occupies 38% of the Earth's terrestrial surface, and this is the largest use of land on our planet [39, 47]. More than 15 years ago, global agriculture had already claimed 70% of grasslands, 50% of savannas, 45% of temperate

15

deciduous forests, and 27% of our tropical forests [47]. In the simplest terms, we have eliminated habitats for wild creatures and native plants at a large scale.

While the proposed solutions to this urgent problem are multi-sectorial and complex, a large-scale shift to plant-based diets may be one of several necessary changes required to preserve biodiversity. Livestock production accounts for nearly three-quarters of all agricultural land use, and is the leading cause of tropical deforestation [41]. In addition, livestock consume one-third of global cereal production [39], displacing crops that could be more efficiently used for human nourishment. In the context of an ongoing nutritional transition that demands ever more animal products [48], these trends become catastrophic. Although a plant-based diet would require more acreage given to plants, net land use would decrease [49].

Equity in Health and Climate

Currently, the FAO conservatively estimates 795 million people are chronically undernourished, while 1 billion experience malnutrition [50], and 2 billion are obese [51]. It seems logical that lower-income groups would be disproportionately affected by severe undernourishment and malnutrition, and indeed, this is the case. It might also seem logical that more highly resourced communities experience higher incidence rates of obesity, but both global and national data contradict this. Globally, low-income and middle-income countries (i.e., Brazil sub-Saharan Africa, China, India) experience the highest rates of obesity and associated chronic disease, and these rates are expected to rise [52]. In the United States, similar patterns exists, with the prevalence of obesity and associated chronic disease highest among lower-income populations. These disparities are reflected in mortality

rates that rise as income declines. Using U.S. Census and CDC data, Chetty et al. discovered

that the gap in life expectancy between those in the highest percentile versus those in the

lowest percentile of income was 14.6 years for men (95% CI: 14.4, 14.8) and 10.1 years for

women (95% CI: 9.9, 10.2), and these differences have increased since 2001 [53].

Social Justice, Climate Justice

The impact of global warming and environmental degradation (such as loss of

biodiversity and water scarcity) are also disproportionately experienced by lower-income

populations and countries [54]. In 2014, the most recent report from the IPCC on climate

change highlighted the special vulnerability of underprivileged communities to climate,

climate variability and extreme weather events: "…the adverse impacts of weather events

and climate increasingly threaten and erode basic needs, capabilities, and rights, particularly

among poor and disenfranchised people…" [55](p. 798). Women, especially, are vulnerable

to the impacts of climate change as they attempt to provide food, water and fuel in changing

climates. Children, always vulnerable, are especially prone to poor health outcomes and loss

of educational opportunities as a consequence of climate change [56, 57]. Even within

wealthier nations, the same pattern of vulnerability to climate change among lower-income

communities can be seen. For instance, in the United States, the devastation following

hurricanes Katrina, Harvey and Maria has disproportionately affected low-income

communities, delivering a double blow of initial damage followed by a lack of resources for

recovery.

While these countries and populations are most vulnerable to the negative impacts of

climate change, they are also the least responsible for the problem, having consumed

relatively fewer resources and produced relatively fewer GHG emissions. It is a matter of human rights and a moral imperative that those nations that have contributed the majority of CO_2 and other GHG, whether directly via emissions or indirectly via demand for GHG-emitting products, should also now be at the leading edge of finding and implementing meaningful solutions.

Health Equity in the United States

In the United States, it has been said that an individual's zip code is more predictive of health outcomes than their genetic code. For example, obesity rates among Hispanic adults (47%) are significantly higher than those among White adults (38%) [58], while hypertension (systolic BP [SBP] ≥140 mm Hg, diastolic BP ≥90 mm Hg, or taking antihypertensive medication) disproportionately affects African Americans (40%) compared to White adults (30%) [59].

While the causes of these disparities are multifactorial and complex, one important mechanism may be differences in consumption of fruits and vegetables. An indication that fruit and vegetable consumption varies by income is provided by Wolfson and Bleigh's research, which found SNAP recipients consumed fewer fruits (35% vs. 46%), p = 0.001) and vegetables (35% vs. 47%, p < 0.001) than those who were not eligible for SNAP [60]. Despite the evidence and in contrast to official guidance, data from NHANES 2007-2010 suggest that 87% of the U.S. population age 1 year and older consume less than the recommended amount of fruits and vegetables [61]. This proportion is not consistent across all Americans, and these differences are important for guiding the distribution of resources and understanding the etiology of disease. An analysis of 2013-2016 NHANES data used

categories of consumption of fruits and vegetables (None, Low, Moderate and High) and found significant associations across demographic groups. Those identifying as Hispanic (compared to Asian), less affluent, less educated or obese were significantly less likely to be in the "High" category of fruit and vegetable consumption [62]. A similar pattern can be detected in the prevalence of obesity and diabetes in the Hispanic population of the U.S. (47% and 9.1%, respectively) as compared to non-Hispanic Whites (37.9% and 7.9%, respectively) [17, 63].

Affordability

In resource-rich nations, where a switch to plant-based diets would have the greatest positive impact on GHG emissions, the needs and challenges within low-income communities must be an integral part of any solution, both from a practical standpoint and from a social equity perspective. Research suggests that plant-based diets can be affordable as well as protective of health and the environment. White and Hall's simulated least-cost diet without animal foods totaled $2.69 per meal, versus cost of current American dietary pattern of $4.00 [5]. Similar findings were discovered in a 7-day comparison of a low-cost version of the MyPlate diet ($53.11/week) versus a plant-based diet that featured olive oil ($38.75/week) (Flynn, 2015).   Because a plant-based diet can be affordable as well as beneficial to health, this strategy may be effective for reducing the impact of climate change, reducing prevalence of chronic diseases and cancer, while also addressing health disparities.

Shifting to a Plant-Based Diet: Psychosocial Determinants and Dietary Patterns

Shifting to a plant-based diet can improve nutrition, protect the environment and offer lower-income populations a realistic (e.g., affordable, equitable) approach.   Further, diet is a

modifiable factor, making it a priority for policymakers and individuals seeking to improve health and environment in the near term. Although some data suggest increasing interest in plant-based diets among the American public (Aramark Corporation, 2005), adoption rates remain extremely low (< 3.5%) (The Vegetarian Resource Group, 2016). In order to effectively shift dietary patterns, it is necessary to understand how to design and implement interventions that are intended to increase plant-based diets with a focus on equity. While this approach may be feasible, it is also a formidable challenge, requiring large changes in current dietary patterns in order to be effective. A recent model of the effects of reducing the GHG emissions of various diets, while also maximizing nutritional value, found that GHG emission reduction tied to diet were limited without significant dietary shifts (Perignon, 2016).   It is, therefore, critically important to understand current attitudes towards diet with a focus on defining barriers and benefits in diverse populations.

Attitudes, Culture, and Meat

Meat consumption is deeply rooted in human diet and culture, especially in Western societies, serving as symbol of wealth, health, and masculinity. American English is littered with terms that provide a glimpse into these deeply embedded attitudes: Phrases such as "couch potato" or "vegging out" imply a lack of energy, while "beefed up" denotes power. To borrow Chiles and Fitzgeralds' useful framing to examine this phenomenon, meat's utility can be viewed as biophysical and/or political-economic [64]. Biophysical arguments for consuming meat include the idea that a diet high in meat is healthy and that a diet without meat cannot be healthy. This is contrary to current evidence, which suggests it is neither necessary to good nutrition nor advantageous to good health, to consume large quantities of

meat. In addition, political-economic forces have converged to associate the consumption of meat with masculinity and strength, and to obscure the environmental cost of industrial livestock production from consumers.

Meat was, and is, associated with wealth and celebration, precisely because it was expensive to produce, environmentally as well as economically. It can be argued that this same paradigm is at work today, where the health risks of meat consumption are clear, as are the associated environmental and animal harms. Despite this, or perhaps because of it, meat consumption is generally viewed as desirable, healthy, and delicious. Understanding the motivations and meanings behind high meat consumption is critical to addressing these norms, both conscious and unconscious, underlying the continued high demand for and consumption of meat in the United States, and to moving towards a plant-based diet for the health of the planet, and of all who inhabit it.

Evolutionary Nutrition

The term "evolutionary nutrition" encompasses several popular ideologies and diets that all share a premise that human diets were at their ideal sometime in the Paleolithic Era, prior to the advent of agriculture, when uncooked meat and gathered fruit and vegetables constituted the majority of the diet. Besides the questionable anthropological assumption that human biology has not evolved in 10,000 years, health benefits are yet to be established (Pitt). Nonetheless, this idea has found a large audience, catalyzed by the success of diets such as Paleo, Adkins, the Zone, and South Beach, and supported by athletes and celebrities extolling the virtues of a meat-based diet. There is a special Paleo diet for CrossFit enthusiasts, an Adkins diet tailored to post-menopausal women, and a version of the Zone

diet designed for post-natal women. All share an approach to health and weight loss that emphasizes increasing the consumption of animal-based protein and reducing carbohydrates. However, these diets confound the risks of a dietary pattern high in animal-based foods with the benefits of protein consumption on weight status and health.

Protein, regardless of whether it comes from plant or from animal sources, is an important part of a healthy diet, providing amino acids that are essential to human health (Karlsen, 2017).   There is some evidence that a high-protein diet can help address several important diseases, as well as precursors of diet-related disease. For example, a controlled trail followed pre-diabetic men and women who were randomized to a low (30% protein, 30% fat, 40% carbohydrate; n=12) or high protein diet (15% protein, 30% fat, 55% carbohydrate; n=12.) After 6 months, 100% of those on the high protein group had remission to normal glucose levels, while only 33% of those on low protein diet had remission. In addition, those on the high protein diet showed improvements in insulin sensitivity (p=0.001), (2) cardiovascular risk factors (p=0.04), (3) inflammatory cytokines (p=0.001), (4) oxidative stress (p=0.001), (5) increased percent lean body mass (p=0.001) compared with the low protein diet at 6 months [65]. There has been great interest in the utility of a high protein diets for weight loss, partly fueled by the popularity of popular diets such as Adkins. The evidence suggests that isocaloric diets that differ in protein level may not improve weight loss, but may improve important plasma markers for chronic disease such as tumor necrosis factor-a (21.8 vs. 20.9 pg/mL, P , 0.0001), IL-6 (21.3 vs. 20.4 pg/mL, P , 0.0001), free fatty acid (20.12 vs.0.16 mmol/L, P = 0.0002), REE (259 vs. 26 kcal, P , 0.0001), insulin sensitivity (4 vs. 0.9, P ,0.0001), and b-cell function (7.4 vs. 2.1, P , 0.0001)

[66]. A meta-analysis of 87 studies detected significantly greater weight loss for low-carb ($\leq$ 35% of total calories) versus high carb diets -6.56 kg, 95% CI: 3.78, 9.34), but no differences by protein level [67].

There is some evidence that the benefits of a high protein diet sourced from plants, rather than from animals, confers additional benefits. A prospective study of 38 individuals diagnosed with type II diabetes and non-alcoholic fatty liver disease (NAFLD) assigned half to either a high animal protein or a high plant protein diet. Both groups experienced significant improvements in measures of liver fat, insulin resistance and hepatic necroinflammation, regardless of protein source or adiposity [68]. A critical gap in almost all of the literature assessing macronutrients and weight loss is the lack of differentiation between highly processed and refined carbohydrates and whole, unrefined carbohydrates. This may be a critical factor in explaining the outcomes observed.

Worldview and Meat

Underlying many of the positive attitudes towards consuming meat, and resistance to a plant-based diet, is a fundamental framework for understanding the role of humanity in the larger context of the earth and its systems. The Judeo-Christian tradition firmly places man above beast, and encourages man to exploit the world for his own benefit as part of the divine plan. In Genesis 1:26-28, God directs man to "Be fruitful and increase in number; fill the earth and subdue it. Rule over fish in the ocean and birds in the sky, and over every living creature that moves on the ground." In contrast, several Eastern traditions suggest a more harmonious relationship with nature and focus on nonviolence to all living creatures. Both Buddhism and Hinduism promote (although they do not require) vegetarianism as a method

to avoid violence and to live a healthy and balanced life [69]. In the United States, it appears that social and cultural reasons for meat consumption are dominant over concerns about increased risk for incidence of chronic disease, negative impacts on the environment and treatment of animals. Currently, the average American consumes 43 pounds of pork, 56 pounds of beef, and 72 pounds if poultry annually, second in per capita meat consumption only to Australia, and 30 times more than India [70].

Now That We're Men: Masculinity and Meat

Although data suggest only slight differences in meat consumption between men and women in the United States [71], eating meat has become associated with masculinity. As a luxury previously available only to the wealthy, and coveted by the poor, eating meat is connected with wealth and power, and, in a patriarchal society such as that in the United States, with masculinity. Consuming meat is widely believed to be necessary for male (but not female) strength and virility, as embodied in rationing during World War II, which diverted meat to the troops (men) at the expense of those on the home front (women and children). As quoted by Chiles and Fitzgerald from a WWII rationing pamphlet, meat was "an important part of a military man's diet, it gives him the energy to out fight the enemy." (Chiles, 2018) Ruby and Heine (2010) explored how omnivores and vegetarians are perceived by themselves and each other, and found both groups rated vegetarians as more virtuous and less masculine [72]. Not surprisingly, a 2106 study by Ruby et al. found that in the United States, men held more positive attitudes towards beef than women, who were had ambivalent or negative attitudes (Ruby, 2016). These trends were similar to those found in Brazil, Argentina, and France.   In an assessment of linkages between attitudes towards

adoption of plant-based diets among 204 college students, Wyker and Davison found that women had significantly more positive attitudes towards a adopting a plant-based diet than men (0 < 0.001) (Wyker, 2010).

As evidence for the benefits of avoiding the consumption of meat accumulates, a conflict between older (pro-meat) and newer (anti-meat) attitudes toward meat consumption develops. In the face of these conflicts, omnivores must justify eating meat when health, environmental and animal rights concerns argue against the practice. Rothgerber (2013) investigated these justifications, and found that they cluster around perceptions of masculinity, with males omnivores more likely to choose meat-eating justifications such as proclaiming a pro-meat attitude ("Meat tastes too good to worry about what all the critics say."), hierarchical justification ("Humans are at the top of the food chain and meant to eat animals."), religious justification ("It is God's will that humans eat animals."), or a human destiny/fate justification ("It violates human destiny and evolution to give up eating meat."). Women omnivores, on the other hand, were more likely to use avoidance ("I try not to think about what goes on in slaughterhouses."), disassociation ("When I look at meat, I try hard not to connect it to an animal.") or denial ("Animals don't really suffer when being raised and killed for meat.") to justify consuming meat (Rothgerber, 2013).

Given the complex social and cultural factors at play and the persistent prevalence of a meat-based diet, it is critical that we gain a better understanding of the motivations and barriers to adopting a plant-base diet. Several studies have sought to understand the motivations and determinants of choosing a plant-based diet. Wyker and Davison (2010) compiled an index of salient beliefs based on the Health Belief Theory, which posits that

behaviors are the result intentions formed by outcome beliefs, normative beliefs and control beliefs. The most important benefits of a plant-based diets for both men and women were "Improved health" (34%, 14%, respectively) and "Weight loss" (14%, 20%, respectively), while the most important disadvantages were "Lack of protein" (32%, 32%, respectively) and "Nutritiously deficient" (16%, 24%, respectively) (Wyker, 2010). This study was limited by not offering environmental reasons for adopting a plant-based diet, which may be an important motivation, and did not offer demographic information beyond gender. Based on Theory of Planned Behavior constructs (i.e., attitudes, subjective norm, and control beliefs), Graça and Oliveira (2015) developed a Meat Attachment Questionnaire (MAQ), which offered good reliability (Cronbach's $\propto$ = 0.92), and then asked a diverse sample of 318 American adults to complete it.   Survey items also included eating habits, dietary identity score (meat eater, omnivore, vegetarian, vegan), and asked participants to "Please indicate your willingness to (1) reduce meat consumption, (2) follow a plant-based diet)", using a Likert scale response option ranging from 1(not willing at all) to 5 (very willing). Feeling of dependence toward meat consumption appeared to explain the highest degree of variance compared with hedonism (enjoyment of meat), affinity (positive affect towards meat), or entitlement (feeling a "right" to eat meat) (Graça, 2015). In a related qualitative study, Graça, Oliveira and Calheiros (2016) examined the association between attachment to meat and willingness to adopt a plant-based diet. A stronger attachment to meat was associated with less willingness to adopt a plant-based diet, and men were more likely to express a positive attachment, suggesting that a positive affect towards meat, particularly among men, may be a significant barrier to the adoption of a plant-base diet (Graça, 2016). Following a

guided group discussion about climate change and diet, Macdiarmid, Douglas and Campbell (2016) asked 87 Scottish adults, "Would you be willing to reduce the amount of meat you eat for the sake of the environment?" Using a Grounded Theory approach, three central themes were found: 1.) Many participants were either unaware or underestimated the effect of diet on climate. 2.) It was common to express skepticism of how much of an impact personal food choices could have on climate change. 3.) Resistance to the idea of reducing meat consumption [73]. These results suggest that any efforts to shift to a plant-based diet in the United States, where we have seen similar attachment to the idea and practice of a meat-based diet, must address social and cultural framing, rather than merely increase awareness of the linkage.

Several studies with particular relevance come from Australia, which is the only nation with higher per capita meat consumption than the United States (Ritchie, 2017). Utilizing the Transtheoretical Model (TTM) to frame their investigation, Lea, Crawford and Wolsey surveyed 415 randomly selected adults, asking about individual's status in the TTM stages of change for eating a plant-based diet, current consumption of fruits and vegetables, and perceived benefits and barriers to consuming a plant-based diet. More than half of participants were in the precontemplation stage, and reported little or no awareness of the benefits of a plant-based diets, coupled with high barriers such as simple unwillingness to reduce meat consumption (either their or their family's), concerns about sufficient iron and protein intake, and issues around the ability to procure and prepare plant-based foods (Lea, 2006). Based on these finding, efforts to increase consumption of plant-based diets may do well to focus on education and family-friendly strategies. More research to understand how

attitudes and culture influence dietary choices in the United States is needed, particularly among diverse and/or disadvantaged populations.

Current Trends in Fruit, Vegetable, and Meat Consumption in the United States

Despite solid evidence supporting the benefits of increasing the consumption of fruits and vegetables, Americans continue to fall far short of RDA recommendations. The 2015-2020 Dietary Guidelines for Americans recommends that all Americans consume more fruits and vegetables as part of a healthy dietary pattern, suggesting adults consume 1.2 to 2 cup equivalents of fruit and 2 to 3 cups of vegetables daily [74]. The USDA MyPlate echoes this advice, suggesting Americans make half their plate fruits and vegetables. Healthy People 2020 is also aligned with the goal of increasing fruit and vegetable consumption in the United States (NWS-14, NWS-15)[75]. However, data from the 2013 and 2015 Behavioral Risk Factor Surveillance System (BRFSS) suggests that most Americans fall short of recommended levels, reporting 12.2% of adults meet guidelines for consumption of fruit, and 9.3% for vegetables. This rate varied by state and demographic factors, so that women were more likely to meet recommendations than men for fruit (15.1%) and vegetables (10.9%), while Hispanics were more likely to meet guidelines for fruit (15.7%), and those with higher income more likely to meet recommendations for vegetables (11.4%). In Texas, the percentage meeting recommendation for fruit (12.1%) was close to the national average, while more Texans met requirements for vegetables (10.9%) [76].

The inverse of this relationship can be observed for consumption of protein in the United States, where average consumption is higher than recommended. The US Recommended Daily Allowance for protein is 0.8g per kg of body weight for healthy adults

[74]. This translates to about 46 g per day for the average American adult female, and 56 g per day for the average American adult male. A 2011 analyses of NHANES data concluded that the average American consumes 128 grams of animal protein per day, and 22% of this is from processed meats. There was some variation across ethnicities, with Black adults consuming more poultry relative to White and Hispanic adults, while Hispanic adults consumed less processed meats than other groups. Women consumed slightly more poultry and less red meat than men, but overall level of consumption of animal-based protein was similar [71]. Another analysis of NHANES dietary 24 hour recall data found slightly lower average protein consumption from all sources for men and women, at 82.3 ± 0.8 gm/day and 98.6 ± 1.1 gm/day, respectively. The study also assessed protein source in the American diet and found that 46% came from meat, 13% from dairy and 30% from plants (8% of intake could not be classified) [77]. It is important to note that, among plant sources of protein, breads were ranked as the first and second most important sources in the current diet. These grain-based sources of plant protein are less dense than legumes or nuts, and this may have implications for the quality and quantity of protein derived from plants in the current American diet [77].

Conceptual Model:

As members and influencers of the natural systems in which we live, humans are engaged in a perpetual and multi-directional relationship between their individual health, their diet, and their environment. This model illustrates the complex relationships among these domains, and shows that diet, human health and environmental health can be optimized where they intersect. By evaluating and promoting a plant-based diet, human health may be

improved while simultaneously mitigating the harmful effects of climate change and environmental degradation.

Public Health Significance

Eating a plant-based diet may have several important advantages over traditional Western (i.e., meat-based) dietary patterns. Consumption of fruits and vegetables has been shown to have important health benefits, including increased protection for chronic diseases such as cardiovascular disease (Ferdowsina & Banard, 2009; Maskarenic et al., 2006; Tuso, Stoll & Li, 2015), type-II diabetes (De Natale et al., 2009), certain cancers (Lampe, 2009) and neurodegenerative diseases (Pistollato & Mauriizio, 2014). Increasing the proportion of the diet given to fruits and vegetables may have the follow-on effect of reducing the amount of meat and dairy consumed, which may have additional and distinct health benefits, including reduced exposure to red and processed meats, which have been identified as "probably carcinogenic to humans" and "carcinogenic to humans," respectively (Bouvard et al., 2016). Further, the consumption of more fruits and vegetables, and a decrease in consumption of animal-based foods, is more environmentally sustainable than a diet high in animal-based foods, due to the comparatively fewer resources used and comparatively fewer greenhouse gases emitted (Johnston, Fanzo & Cogill, 2014; Sabaté &` Soret, 2014) in the production of plant-based foods.

Despite these many benefits, estimates of the prevalence of adults in the United States who identify as vegetarian (avoiding all meat) range from 2.4% (Jaacks, et al., 2016) to 5% (Gallup, 2012), while 10% describe themselves as following a "vegetarian-inclined" diet (Vegetarianism, 2008).   Increasing the proportion of U.S. adults who eat a plant-based diet

may be a highly effective means of decreasing the prevalence of chronic diseases and certain cancers at the population level, while simultaneously decreasing negative environmental impacts of food production. However, the role of meat, and protein source more generally, is a culturally sensitive topic. Encouraging a healthy shift in dietary patterns among the population in the United States is both necessary and daunting, requiring a significant paradigm shift in terms of how and why Americans eat as they do.

Figure 1.3: Conceptual Model: The intersection of diet, health and the environment
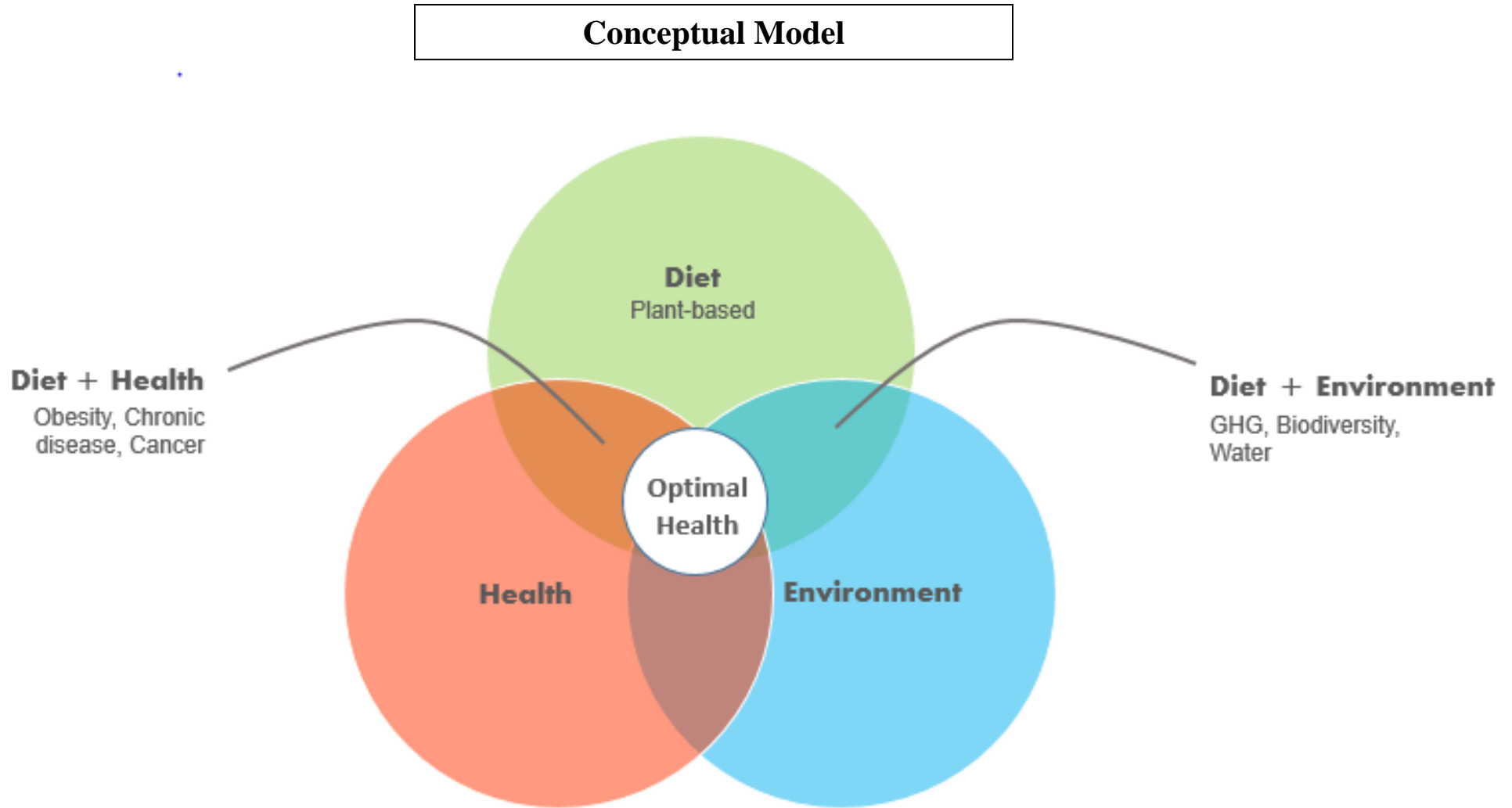
Specific Aims

Paper#1

While much research has suggested an association between plant-based diet and reduced risk for chronic disease and cancer, there is a paucity of research examining these associations in a nationally representative dataset. In addition, no study has assessed the impact of "dosage" of plants in the diet in relation to Metabolic Syndrome.

Aim 1: Quantify association of proportion of plants in the diet (PPD) with Metabolic Syndrome (MetS) criteria and MetS in NHANES participants.

Hypothesis 1: Lower PPD will be associated with higher odds for presence of five MetS criteria, adjusted for confounders (sex, age, income, race/ethnicity):
> *Abdominal obesity (waist circumference)*
> *Hyperglycemia*
> *Hypertriglyceridemia*
> *Hypertension.*
> *Low HDL*

Hypothesis 2: Lower PPD will be associated with higher odds for presence of MetS (i.e., ≥ 3 MetS criteria) adjusted for confounders (sex, age, income, race/ethnicity).

Paper #2

The dichotomy of, on the one hand, a growing body of evidence for the benefits of adopting a plant based diet, and, on the other hand, the entrenched and persistent meat-based diets and pro-meat attitudes among Americans, creates a need for well-designed and effective policies and interventions to encourage a dietary shift. In, particular, understanding motivations among minority and/or disadvantage populations, who may have fewer resources and often have higher prevalence of certain diet-driven chronic diseases, is critical to supporting plant-based diets that are equitable and advantageous to all.

34

Aim 1: Examine associations between demographic variables (sex, race/ethnicity, language, and income) and motivations (environment, health, cost) for willingness to reduce meat consumption.

Hypothesis 1a. -- Willingness to reduce meat for the environment (Q33) will be significantly associated with being female, being White, speaking English, and higher (> $25,000) income.

Hypothesis 1b. -- Willingness to reduce meat for reasons of affordability (Q34) will be significantly associated being female, being White, speaking English, and higher (> $25,000) income.

Hypothesis 1c. -- Willingness to reduce meat for health (Q35) will be significantly associated being female, being White, speaking English, and higher (> $25,000) income.

Aim 2: Examine associations between willingness to reduce meat consumption (Meat Reduction Score or MRS) and weekly servings of meat (Meat per Week). NOTE: Meat Reduction Score (MRS) is a composite score combining Q33, Q34 and Q35.

Hypothesis 2a. – Higher consumption of meat will be associated with lower score on MRS.

Hypothesis 2b. – Higher consumption of meat will be associated with lower score on MRS, with confounders (sex, race/ethnicity, language at home, and income) included.

Aim 3: Evaluate associations between willingness to reduce meat consumption (MRS) and FV consumption.

Hypothesis 3a. – Higher consumption of FV will be associated with higher score on MRS.

Hypothesis 3b. – Higher consumption of FV will associated with a higher score on the MRS, with confounders (sex, race/ethnicity, language at home, and income) included.

Paper #3

  As the obligation to encourage plant-based diets becomes more evident, efficient and accurate methods to measure dietary patterns are needed. In keeping with best practices of nutritional epidemiology and evaluation research, measurement (as well as programming) must be tailored to specific populations and initiatives to enhance accuracy.

Aim 1: Assess the validity of a truncated Food Frequency Survey for measuring meat, fruit and vegetable consumption among a diverse (~50% Hispanic, low-income) population.

Hypothesis 1: Correlation of fruit consumption between FFQ and 24hDR, adjusted for energy intake, will be > 0.50.

Hypothesis 2: Correlation of vegetable consumption between FFQ and 24hDR, adjusted for energy intake, will be > 0.50.

Hypothesis 3: Correlation of meat consumption between FFQ and 24hDR, adjusted for energy intake, will be > 0.50.

Hypothesis 4: Correlation of fruits and vegetables consumption between FFQ and 24hDR, adjusted for energy intake, will be > 0.50.

Conclusion

Diet is a major determinant of human health, and a critical driver of the continuing degradation of the earth's natural systems. The detrimental impacts of increasing population, coupled with higher demand for a Western-style diet dominated by animal products and processed foods, threatens both human and planetary health. Increasing incidence of chronic disease, rising GHG emissions, catastrophic climate change and biodiversity loss are the inevitable result of continuing current dietary patterns. Solutions must be found in order to encourage and support a beneficial dietary shift. Plant-based diets offer a potentially feasible, equitable and effective means of supporting the twin goals of healthy people in a healthy world. Therefore, the following studies are intended to 1.) further understanding of the health effect of plant-based diets by examining the association between increasing the proportion of the diet given to plants and important markers of chronic disease risk (i.e., Metabolic Syndrome); 2.) improve efficacy and tailoring of interventions intended to

increase consumption of plant-based diets by describing motivations to reduce consumption of meat in a low-income, diverse population and correlates thereof; and 3.) provide a viable "usual intake" dietary assessment tool via validation of a food frequency questionnaire (FFQ) designed to assess fruit and vegetable consumption in a low-income, diverse population.

References

1.	Murphy, S.L., et al., *Mortality in the United States, 2017.* 2018.
2.	Statistics, N.C.f.H., *Health, United States, 2017: With special feature on mortality.* 2018.
3.	Ioannidis, J.P., *Implausible results in human nutrition research.* 2013, British Medical Journal Publishing Group.
4.	White, R.R. and M.B. Hall, *Nutritional and greenhouse gas impacts of removing animals from US agriculture.* Proceedings of the National Academy of Sciences, 2017. **114**(48): p. E10301-E10308.
5.	Herrero, M., et al., *Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems.* Proceedings of the National Academy of Sciences, 2013. **110**(52): p. 20888-20893.
6.	Tuso, P., S.R. Stoll, and W.W. Li, *A plant-based diet, atherogenesis, and coronary artery disease prevention.* The Permanente Journal, 2015. **19**(1): p. 62.
7.	The Vegetarian Resource Group. *How many adults in the U.S. are vegetarian and vegan?* 2016; Available from: https://www.vrg.org/nutshell/Polls/2016_adults_veg.htm.
8.	Berkow, S.E. and N. Barnard, *Vegetarian diets and weight status.* Nutrition Reviews, 2006. **64**(4): p. 175-188.
9.	Sabaté, J. and M. Wien, *Vegetarian diets and childhood obesity prevention.* The American journal of clinical nutrition, 2010. **91**(5): p. 1525S-1529S.
10.	Tonstad, S., et al., *Type of vegetarian diet, body weight, and prevalence of type 2 diabetes.* Diabetes care, 2009. **32**(5): p. 791-796.
11.	Spencer, E., et al., *Diet and body mass index in 38 000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans.* International journal of obesity, 2003. **27**(6): p. 728.
12.	Bertoia, M.L., et al., *Changes in intake of fruits and vegetables and weight change in United States men and women followed for up to 24 years: analysis from three prospective cohort studies.* PLoS medicine, 2015. **12**(9): p. e1001878.
13.	Ornish, D., et al., *Can lifestyle changes reverse coronary heart disease?: The Lifestyle Heart Trial.* The Lancet, 1990. **336**(8708): p. 129-133.
14.	Shridhar, K., et al., *The association between a vegetarian diet and cardiovascular disease (CVD) risk factors in India: the Indian Migration Study.* PloS one, 2014. **9**(10): p. e110586.
15.	Mente, A., et al., *A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease.* Archives of internal medicine, 2009. **169**(7): p. 659-669.
16.	Bullard, K.M., et al., *Prevalence of diagnosed diabetes in adults by diabetes type—United States, 2016.* Morbidity and Mortality Weekly Report, 2018. **67**(12): p. 359.
17.	Qian, F., et al., *Association Between Plant-Based Dietary Patterns and Risk of Type 2 Diabetes: A Systematic Review and Meta-analysis.* JAMA internal medicine, 2019.

18. Satija, A., et al., *Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies.* PLoS medicine, 2016. **13**(6): p. e1002039.

19. Kahleova, H., et al., *Vegetarian diet improves insulin resistance and oxidative stress markers more than conventional diet in subjects with Type 2 diabetes.* Diabetic Medicine, 2011. **28**(5): p. 549-559.

20. McMacken, M. and S. Shah, *A plant-based diet for the prevention and treatment of type 2 diabetes.* Journal of geriatric cardiology: JGC, 2017. **14**(5): p. 342.

21. Dinu, M., et al., *Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies.* Critical reviews in food science and nutrition, 2017. **57**(17): p. 3640-3649.

22. Fraser, G.E., *Associations between diet and cancer, ischemic heart disease, and all-cause mortality in non-Hispanic white California Seventh-day Adventists.* The American journal of clinical nutrition, 1999. **70**(3): p. 532s-538s.

23. Craig, W.J., *Health effects of vegan diets.* The American journal of clinical nutrition, 2009. **89**(5): p. 1627S-1633S.

24. Elorinne, A.-L., et al., *Food and nutrient intake and nutritional status of Finnish vegans and non-vegetarians.* PloS one, 2016. **11**(2): p. e0148235.

25. Millen, B.E., et al., *The 2015 Dietary Guidelines Advisory Committee scientific report: development and major conclusions.* Advances in nutrition, 2016. **7**(3): p. 438-444.

26. Chan, D.S., et al., *Red and processed meat and colorectal cancer incidence: meta-analysis of prospective studies.* PloS one, 2011. **6**(6): p. e20456.

27. Parada, H., et al., *Grilled, barbecued, and smoked meat intake and survival following breast cancer.* JNCI: Journal of the National Cancer Institute, 2017. **109**(6).

28. Bouvard, V., et al., *Carcinogenicity of consumption of red and processed meat.* Lancet Oncology, 2015. **16**(16): p. 1599.

29. Samir, K. and W. Lutz, *The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100.* Global Environmental Change, 2017. **42**: p. 181-192.

30. Popkin, B.M., *Relationship between shifts in food system dynamics and acceleration of the global nutrition transition.* Nutrition reviews, 2017. **75**(2): p. 73-82.

31. Clonan, A., K.E. Roberts, and M. Holdsworth, *Socioeconomic and demographic drivers of red and processed meat consumption: implications for health and environmental sustainability.* Proceedings of the Nutrition Society, 2016. **75**(3): p. 367-373.

32. McIntyre, B.D., *International assessment of agricultural knowledge, science and technology for development (IAASTD): Synthesis report with executive summary: A synthesis of the global and sub-global IAASTD reports.* 2009.

33. Gliessman, S.R., *Agroecology: the ecology of sustainable food systems.* 2014: CRC press.

34. Hazel, P., *Green revolution: Curse or blessing?* 2002.

35. University of Michigan. *U.S. Food Systems Factsheet*. Available from: http://css.umich.edu/factsheets/us-food-system-factsheet.

36. Pimentel, D. and M. Pimentel, *Sustainability of meat-based and plant-based diets and the environment.* The American journal of clinical nutrition, 2003. **78**(3): p. 660S-663S.

37. United States Environmental Protection Agency. *Sources of Greenhouse Gas Emissions*. 9/7/19]; Available from: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

38. Foley, J.A., et al., *Solutions for a cultivated planet.* Nature, 2011. **478**(7369): p. 337.

39. Woods Hole Research Center. *New data: Amazaon Fires Have Released 140-141 Metric Tons of CO2*. 2019; Available from: http://whrc.org/new-data-brazilian-amazon-fires-have-released-104-141-million-metric-tons-of-co2/.

40. Tilman, D., et al., *Forecasting agriculturally driven global environmental change.* science, 2001. **292**(5515): p. 281-284.

41. Scarborough, P., et al., *Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK.* Climatic change, 2014. **125**(2): p. 179-192.

42. Jones, C.M., *A Lifecycle Assessment of US Household Consumption: The Methodology and Inspiration Behind the "Consumer Footprint Calculator".* 2005.

43. Eshel, G. and P.A. Martin, *Diet, energy, and global warming.* Earth interactions, 2006. **10**(9): p. 1-17.

44. Vetter, S.H., et al., *Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation.* Agriculture, ecosystems & environment, 2017. **237**: p. 234-241.

45. Food and A.O.o.t.U.N.G.P.S. Unit, *World agriculture: towards 2030/2050: prospects for food, nutrition, agriculture and major commodity groups*. 2006: Food and Agriculture Organization of the United Nations, Global Perspective ….

46. Ramankutty, N., et al., *Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000.* Global biogeochemical cycles, 2008. **22**(1).

47. Popkin, B.M., L.S. Adair, and S.W. Ng, *Global nutrition transition and the pandemic of obesity in developing countries.* Nutrition reviews, 2012. **70**(1): p. 3-21.

48. Machovina, B., K.J. Feeley, and W.J. Ripple, *Biodiversity conservation: The key is reducing meat consumption.* Science of the Total Environment, 2015. **536**: p. 419-431.

49. McGuire, S., *FAO, IFAD, and WFP. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. Rome: FAO, 2015*. 2015, Oxford University Press.

50. Friedrich, M., *Global obesity epidemic worsening.* Jama, 2017. **318**(7): p. 603-603.

51. Kelly, T., et al., *Global burden of obesity in 2005 and projections to 2030.* International journal of obesity, 2008. **32**(9): p. 1431.

52. Chetty, R., et al., *The association between income and life expectancy in the United States, 2001-2014.* Jama, 2016. **315**(16): p. 1750-1766.

53. Mendelsohn, R., A. Dinar, and L. Williams, *The distributional impact of climate change on rich and poor countries.* Environment and Development Economics, 2006. **11**(2): p. 159-178.

54. Olsson, L.M.O.P.T.A.A.S.E.S.M.L.P.a.S.Z., *Climate Change 2014: Impacts, Adaptations, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. 2014: Cambridge, United Kingdom and New York, NY, USA. p. 793-832.

55. Levy, B.S. and J.A. Patz, *Climate change, human rights, and social justice.* Annals of global health, 2015. **81**(3): p. 310-322.

56. The Center for International Environmental Law, *Climate & Human Rights: A Primer*.

57. Hales, C.M., et al., *Differences in obesity prevalence by demographic characteristics and urbanization level among adults in the United States, 2013-2016.* Jama, 2018. **319**(23): p. 2419-2429.

58. Whelton, P.K., et al., *Research needs to improve hypertension treatment and control in African Americans.* Hypertension, 2016. **68**(5): p. 1066-1072.

59. Wolfson, J.A. and S.N. Bleich, *Fruit and vegetable consumption and food values: National patterns in the United States by Supplemental Nutrition Assistance Program eligibility and cooking frequency.* Preventive medicine, 2015. **76**: p. 1-7.

60. U.S. Department of Agriculture. *Current Eating Patterns in the United States*. 2015; Available from: https://health.gov/dietaryguidelines/2015/guidelines/chapter-2/current-eating-patterns-in-the-united-states/.

61. Martin, C., et al., *Demographic Characteristics Associated with Variety of Fruit and Vegetable Intake: What We Eat in America, NHANES 2013–2016 (FS02-06-19).* 2019, Oxford University Press.

62. Hales, C.M., et al., *Prevalence of obesity among adults and youth: United States, 2015–2016.* 2017.

63. Chiles, R.M. and A.J. Fitzgerald, *Why is meat so important in Western history and culture? A genealogical critique of biophysical and political-economic explanations.* Agriculture and human values, 2018. **35**(1): p. 1-17.

64. Stentz, F.B., et al., *Remission of pre-diabetes to normal glucose tolerance in obese adults with high protein versus high carbohydrate diet: randomized control trial.* BMJ Open Diabetes Research and Care, 2016. **4**(1): p. e000258.

65. Kitabchi, A.E., et al., *Effects of high-protein versus high-carbohydrate diets on markers of β-cell function, oxidative stress, lipid peroxidation, proinflammatory cytokines, and adipokines in obese, premenopausal women without diabetes: a randomized controlled trial.* Diabetes care, 2013. **36**(7): p. 1919-1925.

66. Krieger, J.W., et al., *Effects of variation in protein and carbohydrate intake on body mass and composition during energy restriction: a meta-regression.* The American journal of clinical nutrition, 2006. **83**(2): p. 260-274.

67.   Markova, M., et al., *Isocaloric diets high in animal or plant protein reduce liver fat and inflammation in individuals with type 2 diabetes.* Gastroenterology, 2017. **152**(3): p. 571-585. e8.

68.   Rosen, S., *Essential Hinduism*. 2006: Greenwood Publishing Group.

69.   Ritchie, H. and M. Roser, *Meat and seafood production & consumption.* Our World in Data, 2017.

70.   Carrie, D., et al., *Trends in meat consumption in the United States.* Public Health Nutrition, 2011. **14**(4): p. 575-583.

71.   Ruby, M.B. and S.J. Heine, *Meat, morals, and masculinity.* Appetite, 2011. **56**(2): p. 447-450.

72.   Macdiarmid, J.I., F. Douglas, and J. Campbell, *Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet.* Appetite, 2016. **96**: p. 487-493.

73.   DeSalvo, K.B., R. Olson, and K.O. Casavale, *Dietary guidelines for Americans.* Jama, 2016. **315**(5): p. 457-458.

74.   Office of Disease Prevention and Health Promotion. *Nutrition and Weight Status*. 2015; Available from: https://health.gov/dietaryguidelines/2015/guidelines/chapter-2/current-eating-patterns-in-the-united-states/#figure-2-1-desc-toggle.

75.   Lee-Kwan, S.H., et al., *Disparities in state-specific adult fruit and vegetable consumption—United States, 2015.* MMWR. Morbidity and mortality weekly report, 2017. **66**(45): p. 1241.

76.   Pasiakos, S., et al., *Sources and amounts of animal, dairy, and plant protein intake of US adults in 2007–2010.* Nutrients, 2015. **7**(8): p. 7058-7069.

Paper #1: Plant-based Diet and odds of Metabolic Syndrome and Metabolic Syndrome Criteria

by

Jovanovic CES, Hoelscher DM, Chen B, Ranjit N, van den Berg AE

Background

A wealth of studies suggests that, over the long term, diet has a profound effect on health, and is strongly correlated to the most common chronic diseases. In the United States in 2017, the top ten causes of mortality accounted for 74% of all deaths; of these deaths, half are closely linked to diet (heart disease, cancer, stroke, Alzheimer's and type 2 diabetes) [2]. Research has found associations between consumption of a plant-based diet and lower risk for obesity[9, 10], heart disease [15, 16], cancer[22, 25], and type 2 diabetes[11, 78]. There is evidence that consumption of a plant-based diet may improve stenosis (7.9% improvement after 5 years) and reduce risk for adverse cardiac events (RR 2.47 for control versus treatment, 95% CI: 1.49, 4.2) in patients with coronary heart disease, hinting at biological mechanisms by which diet may influence chronic disease outcomes[79]. The relations between a plant-based diet and reduced risk for chronic disease may be further explored via the association of a plant-based diet with Metabolic Syndrome, or MetS.

For diagnostic purposes, the National Cholesterol Education Adult Program Treatment Panel III (NCEP ATP III) (2005) has defined MetS as the presence of 3 or more of the following conditions: hyperglycemia (glucose $\geq$100 mg/dl), abdominal obesity (waist circumference $\geq$88 cm in women and $\geq$102 cm in men), hypertriglyceridemia ($\geq$150 mg/dl), hypertension ($\geq$130/85 mm Hg or on treatment for hypertension) and/or low-HDL cholesterol (<40 mg/dl in women and <50 mg/dl in men) [80]. Globally, the prevalence of MetS is 25%, while in the United States that number is 34.3%[81] A 2014 study of Canadian adults found a significant association with the incidence of CVD fatality and type 2 diabetes and MetS[82]. MetS has also been found

to predict both all-cause mortality and CVD morbidity and mortality in 2173 primarily Latino residents of San Antonio, TX (HR for CVD = 2.01; 95% CI: 1.13, 3.57, HR for all-cause = 1.47; 95% CI: 1.13, 1.92) [83].

Diet appears to be an important and modifiable risk factor for MetS. Using dietary data from a Food Frequency Questionnaire (FFQ) conducted as part of the Adventist Health Study-2, prevalence of MetS was found to be 25.2% among vegetarians, 37.6% among semi-vegetarians, and 39.7% among non-vegetarians (trend p-value <0.001)[84]. This was not a nationally representative sample, and utilized an FFQ, which may be less accurate than other dietary assessment methods, such as the 24 hour dietary recall (24hDR)[85]. Similar significant and inverse associations between plant-based diet and MetS have been found in Chinese adults[86] , Iranian adults with impaired glucose tolerance[87], and a non-representative sample of the US population [88]. A meta-analysis by Godos et al. (2018) found an inverse relationship between adherence to the Mediterranean diet and incidence of MetS[89],. The linkage between diet, MetS and the risk for chronic disease suggests several potential mechanisms by which consumption of a plant-based diet may reduce risk for the incidence of leading causes of mortality. For example, elevated iron stores have been associated with increased incidence of diabetes, most likely via β cell failure and insulin resistance[90, 91]. Heme iron, found exclusively in animal products, is highly bioavailable and increases iron uptake, while the iron found in plants-based foods is more easily regulated. Thus, avoiding meat may decrease iron stores, improving insulin resistance, reducing blood glucose, and reducing risk for type 2 diabetes.

A 2017 narrative review found associations between plant-based diets and reduced risk for chronic disease, as well as for MetS [92]. In addition to preventive effects, several prospective studies have discovered that plant-based diets may also be effective in the treatment of type 2 diabetes and CVD [84, 93]. However, because most of the large studies examining plant-based diets and chronic disease have been conducted among Seventh Day Adventists or other sub-populations in the United States, there is a lack of evidence of the association of consumption of plant-based foods and MetS in a nationally representative sample. In addition, most studies have used arbitrary definitions of diet (i.e., lacto-ovo vegetarian, vegan), rather than a continuous measure of the proportion of the diet consumed as plant foods. Because diet is so complex, this approach may not adequately quantify potential dose-response relations between proportion of plants in the diet and MetS. Further, this approach may not reflect "real world" behavior, where strict adherence to any researcher-defined diet is both rare and often unsustainable. For example, Amimi et al.'s 2010 study or Iranian adults defined 5 distinct dietary patterns detailing consumption or avoidance foods such as mayonnaise, organic meat, and high-fat yogurt: western, prudent, vegetarian, high-fat dairy, chicken and plant[87]. In addition, most studies have used food frequency questionnaires to assess diet, which may be less accurate than repeated 24-hour dietary recalls (24hDR). To our knowledge, no study has examined the association between proportion of diet given to plants and MetS, using repeated 24hDR to assess diet in a nationally representative population in the United States. It is our intention, therefore, to examine these associations using NHANES repeated 24hDR to measure the proportion of plants in

the diet (PPD) in association with MetS risk factors and MetS in a nationally representative sample.

Methods

Study Design

This study is a secondary analysis of National Health and Nutrition Examination Survey (NHANES) 2015-2016 cross sectional data. NHANES is conducted annually by the Centers for Disease Control and Prevention (CDC) in 2 year increments, and is intended to assess the health and nutritional status of adults and children in the United States [3]. The study includes surveys (demographic, socioeconomic, dietary and health-related questions), two repeated 24hDRs, and a physical examination (medical, dental, and physiological measurements), as well as laboratory tests on plasma and urine samples collected via NHANES Mobile Examination Centers (MECs). Each year, the study sample target is 5,000 people distributed across 15 counties in the United States, selected to be nationally representative across age group, sex, low-income status, race and Hispanic origin. Oversampling of select subgroups (Hispanics, African Americans, Asians, people >185% of federal poverty income levels, and people over 60) and sampling weights are used to ensure representative data [3]. Sampling is based on a multistage design that progresses from primary sampling unit (PSU) level, household clusters, specific households and, finally, individuals. To reduce large variance estimates associated with single-year data, all NHANES datasets include 2 years of data (i.e., 2015 – 2016). In 2015-2016, the total sample was 9,544 adults, with an overall cumulative response rate of 58.7%.   .

Data Preparation

Proportion of Plants in the Diet (PPD) Variable

Using the USDA Food and Nutrient database for Dietary Studies (FNDDS) provided by NHANES[94], which contains 8,690 separate food codes, foods were categorized as plant-based or not. The first digit of the FNDDS code is associated with one of nine major food commodity groups: Milk and Milk Products; Meat, Poultry, Fish, and Mixtures; Eggs; Dry Beans, Peas, Other Legumes, Nuts, and Seeds; Grain Products; Fruits; Vegetables; Fat, Oils, and Salad Dressings; Sugars, Sweets, Beverages. Then, foods are further divided into 155 individual food categories combined into 15 main groups: Milk and Dairy; Protein Foods; Mixed Dishes; Grains; Snacks and Sweets; Fruit; Vegetables; Beverages, Nonalcoholic; Alcoholic Beverages; Water; Fats and Oils; Condiments and Sauces; Sugars; Infant Formula and Baby Foods; and Other. Within the main groups are subgroups (Milk, Flavored Milk. Dairy Drinks and Substitutes, Cheese, and Yogurt) characterized by similar food-related properties[95] . Foods are mutually exclusive, so that cheese pizza is associated with only one food code, and never disaggregated into crust, sauce, and cheese.

Because the smallest unit of food was the combined food and not its constituent parts, mixed dishes that contained both plants and non-plants were categorized as non-plant-based. All other food categories were grouped as follows: fruits, vegetables, nuts, seeds, legumes, and non-dairy milk products were categorized as plant-based foods, while all others (meat, poultry, fish and shellfish, dairy products, and mixed dishes) were categorized as non-plant-based. To ensure the sorting was accurate, two experts in

nutrition reviewed each code. The complete set of sorted FNDDS food codes are available in Appendix A.

Once categorization was complete, every observation in both days of the NHANES 24hDR were then coded as 1 = plant-based or 0 = not plant-based. Next, observations were collapsed by participant and Plant Code, so that each participant had two separate calorie counts for each day, one plant-based and the other not. At this point, Day 1 and Day 2 data were merged, so that each participant had a combined calorie count for plant-based foods over 2 days, a combined calorie count of non-plant-based foods over 2 days, and total combined calories over 2 days. The final step was then to divide the combined calories from plant-based foods by the total calories to arrive at the PPD, a measure of the proportion of plants in the diet.

Metabolic Syndrome Variables

Data from the physical examination and laboratory dataset were used to assess MetS criteria outcome variables (hyperglycemia, abdominal obesity, hypertriglyceridemia, hypertension, low HDL,), as well as overall MetS, which is at least three of these variables. From NHANES physical examination data and laboratory data, and using the cut points provided by the NCEP ATP III, MetS criterion outcomes were coded as dichotomous variables where 0 = within guidelines and 1 = above guidelines (Table 2.1). A variable for MetS was created, where the occurrence of $\geq$ 3 Mets criteria was coded 0 = no MetS and 1 = MetS. All data were joined using the Respondent Sequence Number (SEQL) provided in all NHANES datasets.

Table 2.1: Metabolic Syndrome (MetS) criteria variables and coding

METS CRITERIA	CUT POINT	CODING
Hyperglycemia	glucose $\geq$ 100 mg/dl or treatment	

Abdominal obesity	waist circumference $\geq$ 88 cm (women), $\geq$ 102 cm (men)	0 = below cut point,
Hypertriglyceridemia	$\geq$ 150 mg/dl or treatment	1 = at or
Hypertension	$\geq$ 130/85 mm Hg or on treatment for hypertension	above cut point
Low HDL	(< 40 mg/gl in women and < 50 mg/dl in men or treatment	

Analyses

The exposure variable for all tests in the analysis was PPD, and outcome variables were MetS criteria and MetS. All NHANES data were weighted as directed in NHANES analytic guidelines, using weights provided in the laboratory dataset as this was the smallest of the merged datasets (wtsaf2yr), as well as appropriate sampling unit, stratum and VCE variables[96] as provided in the Demographic file. Referent categories for confounders were "Female," "40–59 years," "$25-$65,000," and "Non-Hispanic White." in regression analyses. Logistic regression was performed on each criterion of MetS separately. Another logistic regression was used to assess the relations between PPD and the presence of MetS, defined as the presence of $\geq$ 3 MetS criteria. A second series of regressions was run including confounders (sex, age, income, and race/ethnicity), both separately and together. Goodness-of-fit was assessed using the Hosmer and Lemeshow test. Marginal probabilities were generated for the final adjusted model. All tests were conducted with a significance level of $\alpha = 0.05$, using Stata/SE 14.2 (Stata Corp, 4905 Lakeway Dr., College Station, Texas.)

Results

Demographic data are reported in Table 2.2, including age, sex, income and race/ethnicity. The unweighted sample was almost evenly divided between males and females, but weighting resulted in a slightly higher proportion of females. The weighted

and unweighted age distributions were similar, but slightly more participants were 59 years or younger after weighting. The differences between weighted and unweighted sample distributions for income and race/ethnicity were greater, reflecting purposeful oversampling of these demographics in the NHANES sampling design. Those reported annual incomes < $25,000 were a higher proportion of the unweighted compared to the weighted sample, as were all race/ethnicities except White. Weighted mean PPD is provided by demographic characteristics, and indicates participants consume between 16.57% (those earning < $25,000 annually) and 21.89% (60 years and older) of the diet captured by the repeated 24hDRs is plant-based.

Table 2.2: Descriptive statistics for demographic variables, unweighted and weighted for NHANES 2015-2016 participants

	CRUDE N (%)	WEIGHTED (%)	WEIGHTED MEAN PPD % (SD)
Gender			
Male	4,892 (49.06)	48.51	18.14 (0.10)
Female	5,079 (50.94)	51.49	20.55 (0.11)
Age			
20-39 years	1,953 (34.15)	36.00	19.30 (0.10)
40-59 years	1,846 (32.61)	35.91	17.36 (0.10)
60 years and over	1,901 (33.24)	28.09	21.89 (0.11)
Income			
< $25K	2,387 (24.80)	15.31	16.57 (0.12)
$25K - $65K	3,395 (35.27)	34.35	18.40 (0.11)
>$65K	3,844 (39.93)	50.34	20.84 (0.09)
Race/Ethnicity			
Mexican-American	1,921 (19.27)	8.98	19.31 (0.17)
Other Hispanic	1,308 (13.12)	7.02	20.21 (0.16)
White	3,066 (30.75)	62.46	19.34 (0.08)
Black	2,129 (21.35)	11.73	19.28 (0.14)
Other	1,547 (15.51)	9.81	20.06 (0.13)

Metabolic criteria varied across demographics (Table 2.3). Men had a higher incidence of all MetS criteria (hyperglycemia, hypertriglyceridemia, hypertension, Low HDL) except for waist circumference, where women had a higher incidence. The incidence of all MetS criteria increased as age increased, with the exception of low HDL, which was highest in the youngest age category (37.88% for those 20-39 years.) Income did not appear to effect the incidence of MetS criteria or MetS with, all categories generally tracking with the weighted proportions in the sample. Whites had higher incidence of high waist circumference and hypertriglyceridemia compared to other ethnic groups, while Blacks had a higher incidence of hypertension. Mexican-Americans had higher incidence of hyperglycemia compared to other ethnic groups, which was different than Other Hispanics, which had a higher incidence of low HDL. Compared to the weighted sample proportion, only Whites had a higher than proportionate incidence of MetS.

Table 2.3: Unweighted sample size, weighted mean and standard deviations (SD) for dependent and independent variables

	UNWEIGHTED n	WEIGHTED MEAN	WEIGHTED SD
Day 1 PPD	4,128	0.22	0.16
Day 2 PPD	4,039	0.18	0.14
Combined (2 day) PPD	6,780	0.19	0.13
Waist Cir.	9,368	100.35	14.44
Glucose	3,191	107.80	31.98
Triglycerides	2,723	175.16	79.47
Low HDL	7,256	38,67	16.25
Blood Pressure (Systolic)	7,790	120.76	17.35
Blood Pressure (Diastolic)	7,790	67.95	112.80

Table 2.4: Descriptive statistics for demographic variables, unweighted and weighted; and weighted PPD, weighted Mets criteria, and weighted MetS by demographic variables for NHANES 2015-2016 participants

	CRUDE n (%)	WEIGHT-ED % (SE)	WEIGHTED MEAN PPD % (SD)	HYPER-GLYCEMIA % (SE)	WAIST CIRCUM. % (SE)	HYPER-TRIGLYCERI-DEMIA % (SE)	HYPER-TENSION % (SE)	LOW HDL % (SE)	METABOLIC SYNDROME % (SE)
Gender									
Male	4,892 (49.06)	48.51 (0.01)	18.14 (0.10)	55.59 (0.02)	39.88 (0.02)	56.43 (0.03)	50.24 (0.02)	86.65 (0.02)	57.21 (0.02)
Female	5,079 (50.94)	51.49 (0.01)	20.55 (0.11)	44.41 (0.01)	60.12 (0.01)	43.57 (0.03)	49.76 (0.02)	13.35 (0.02)	42.79 (0.02)
Age									
20-39 years	1,953 (34.15)	36.00 (0.01)	19.30 (0.10)	24.67 (0.02)	29.44 (0.01)	17.41 (0.02)	15.77 (0.01)	37.88 (0.03)	19.6 (0.02)
40-59 years	1,846 (32.61)	35.91 (0.01)	17.36 (0.10)	38.10 (0.02)	38.33 (0.01)	38.68 (0.02)	39.28 (0.02)	37.11 (0.03)	40.29 (0.02)
60 years and over	1,901 (33.24)	28.09 (0.02)	21.89 (0.11)	37.24 (0.02)	32.23 (0.02)	43.91 (0.02)	44.94 (0.02)	25.01 (0.01)	40.11 (0.02)
Income									
< $25K	2,387 (24.80)	15.31 (0.01)	16.57 (0.12)	17.15 (0.02)	15.10 (0.02)	16.14 (0.02)	17.82 (0.02)	14.51 (0.01)	16.62 (0.02)
$25K - $65K	3,395 (35.27)	34.35 (0.01)	18.40 (0.11)	34.67 (0.01)	35.53 (0.02)	36.20 (0.03)	34.89 (0.01)	36.52 (0.02)	36.32 (0.02)
>$65K	3,844 (39.93)	50.34 (0.02)	20.84 (0.09)	48.18 (0.02)	49.37 (0.02)	47.66 (0.03)	47.29 (0.02)	48.97 (0.03)	47.06 (0.03)
Race/Ethnicity									
Mexican-American	1,921 (19.27)	8.98 (0.02)	19.31 (0.17)	9.12 (0.02)	8.53 (0.02)	7.79 (0.02)	6.93 (0.02)	9.96 (0.02)	8.05 (0.02)
Other Hispanic	1,308 (13.12)	7.02 (0.01)	20.21 (0.16)	6.33 (0.01)	5.93 (0.01)	5.61 (0.01)	5.65 (0.01)	8.11 (0.01)	5.92 (0.01)
White	3,066 (30.75)	62.46 (0.04)	19.34 (0.08)	65.47 (0.04)	67.97 (0.04)	69.15 (0.03)	63.48 (0.05)	64.78 (0.04)	67.79 (0.03)
Black	2,129 (21.35)	11.73 (0.03)	19.28 (0.14)	9.16 (0.02)	10.90 (0.02)	7.75 (0.02)	14.43 (0.03)	7.26 (0.02)	9.68 (0.02)
Other	1,547 (15.51)	9.81 (0.01)	20.06 (0.13)	9.92 (0.01)	6.67 (0.01)	9.70 (0.01)	9.51 (0.01)	9.90 (0.01)	8.57 (0.01)

Table 2.4 summarizes crude and adjusted p-values, odds ratios, and 95% confidence intervals for crude and adjusted models of the association between PPD and MetS criteria and MetS. None of the crude model estimates was significant for the association of MetS criteria or MetS with PPD. However, after adding in sex, age, income, and ethnicity, the PPD was significantly associated with hypertension (p=0.02) and with MetS (p=0.02). Holding other covariates constant, the PPD was associated with a 3% lower risk for having hypertension as defined by ATP III (2005) criteria. In the adjusted model, each one unit (1%) increase in PPD was associated with a 2% reduction in the risk of having MetS. Following logistic regressions of the complete model, the Hosmer-Lemeshow test results are reported in Table 4, and suggest that all of the adjusted models are well calibrated, and should not be rejected.

Table 2.5: Odds Ratios (OR), p-values, 95% Confidence Intervals (CI), and Homer-Lemeshow goodness-of-fit statistics for Crude and Adjusted outputs from logistic regression analysis of PPD on Metabolic Syndrome Criteria and Metabolic Syndrome

Outcome Variable	CRUDE			ADJUSTED			HOSMER-LEMESHOW
	OR	*p-*value	95% CI	OR	*p-*value	95% CI	*F* (*p*-value)
Hyperglycemia	1.00	0.76	0.99 – 1.01	01.00	0.75	0.98 – 1.01	0.87 (0.59)
Waist Circumference	1.00	0.59	0.99 – 1.02	0.99	0.53	0.97 – 1.01	0.38 (0.91)
Hypertriglyceridemia	0.99	0.34	0.98 – 1.01	0.99	0.11	0.97 –1.00	0.67 (0.72)
Hypertension	0.83	0.66	0.34 – 2.04	0.97	0.02	0.95 – 0.99	0.44 (0.87)
Low HDL	0.99	0.06	0.98 – 1.00	1.00	0.74	0.98 – 1.03	0.73 (0.41)
MetS	0.99	0.13	0.97 – 1.00	0.98	0.02	0.96 – 0.99	0.26(0.97)

MetS is defined as the presence of 3 or more of the following: hyperglycemia (glucose $\geq$100 mg/dl), abdominal obesity (waist circumference $\geq$88 cm in women and $\geq$102 cm in men), hypertriglyceridemia ($\geq$150 mg/dl), hypertension ($\geq$130/85 mm Hg or on treatment for hypertension) and/or low-HDL cholesterol (<40 mg/dl in women and <50 mg/dl in men) [80] PPD: Proportion of plants in the diet

Marginal probabilities (Table 2.5) provide further insight into the association between PPD and MetS, with females having 55% lower odds of MetS compared to males, and

increasing age from < 29 years to 30 to 60 years conferring an 3.19 times greater probability

of having MetS. Similarly, being 60 years old or older compared to <29 years old increased

the probability of having MetS by more than eight times.

Table 2.2: Marginal probabilities for the association of Proportion of Plants in the Diet (PPD) with Metabolic Syndrome (MetS) following logistic regression of the fully adjusted model

`	P-VALUE	ODDS RATIO	95% CI
PPD	0.02	0.98	0.96 – 0.99
Sex			
Female	<0.01	0.45	0.3 – 0.67
Age			
40 to 59 years	<0.01	3.19	1.6 – 6.39
60 years and over	<0.001	8.40	4.29 – 16.47
Race/Ethnicity			
Mexican American	0.39	1.27	0.72 – 2.23
Other Hispanic	0.28	0.68	0.32 – 1.42
Non-Hispanic Black	0.96	0.99	0.57 – 1.7
Other	0.32	0.76	0.43 – 1.34
Income			
< $25,000	0.51	1.18	0.7 – 1.99
> $65,000	0.13	0.64	0.35 – 1.16

Discussion

In our study, increased PPD was significantly associated with reductions in both

hypertension and MetS in adjusted models.   Several covariates (sex, age) were shown to be

significantly associated with the presence of MetS and PPD. While the effect size of the

association between PPD and MetS was small (OR=0.98), this 2% reduction in risk for each

1-unit (1%) change in PPD translates into a substantial effect for small changes in diet for

MetS outcomes. For the average American consuming 2,000 calories per day and eating the

average 2.7 servings of FV daily[97], a 1% increase would mean consuming 0.67 teaspoons (1% of 2.7 servings) more fruits or vegetables daily to decrease the risk for MetS outcomes by 2%.

Our results suggest that increasing the proportion of the diet given to plants may improve hypertension and MetS, but no other criteria of MetS were significantly associated with changes in PPD. This is in line with other research that has found associations of a plant-based diet with improved blood pressure in adult female Buddhists in Taiwan [98], Adventists in the U.S. [84], and Taiwanese adults [99]. Although this analysis did not detect improvements in hyperglycemia in association with increased PPD, other studies have found associations between a plant-based dietary pattern (i.e., vegan or vegetarian eating patterns) and improved fasting glucose [84, 100, 101]. This may be due to study designs that assessed only differences between extremely different dietary patterns, such as vegan versus Western diet, whereas our study utilized a continuous measure of the proportion of diet given to plants via the PPD. Fewer studies have found association between plant-based diets and improvements in hypertriglyceridemia or waist circumference and none have found associations with improved HDL levels[91, 102]. It is important to note that none of these studies utilized a nationally representative sample or 24hDR to assess diet.

Limitations of this study include a lack of precision in categorizing foods consumed as either plant-based or not, dictated by the granularity offered by the FNDDS food codes. As Satija et al. (2014) found in their analysis of the association between plant-based diets and type 2 diabetes, the healthfulness of the diet, whether plant-based or otherwise, may be a critical factor in chronic diseases and, by deduction, MetS[103]. To avoid mis-categorization of foods,

mixed dished that could not be disaggregated were included in the non-plant-based category. Therefore, foods such as food code 258162110 "stuffed pepper with rice and meat" were considered non-plant-based, despite the presence of peppers and rice. . Similarly, the FNDDS food codes did not allow clear differentiation between whole and refined grains. Therefore, too avoid including highly caloric or "unhealthy" foods, such as sweets, grains were not included in plant-based category. These challenges to accurate classification of foods may have obscured associations between PPD and MetS criteria and/or MetS in our analyses.

Future research into associations between plant-based diets, chronic disease, and chronic disease risk factors may benefit from careful examination of USDA food codes, as well as more detailed food codes to allow for classification that is more precise. Given the importance of diet to health, the increasing understanding of the importance of diet to the environment, and the need to better understand how best to improve nutrition at the population level, further research exploring the association between plant-based diet and chronic disease risk factors and chronic disease is imperative. Building upon the results of this research, future inquiry may benefit from more precise categorization of plant-based foods and stratified analyses. Larger randomized control trails (RCTs) to assess the impact of plant-based diets on MetS criteria and MetS are needed to better understand the mechanisms by which this relationship may operate, and well as to provide better guidance for the support and encouragement of optimal diets for various populations.

References

1. Murphy, S.L., et al., *Mortality in the United States, 2017.* 2018.
2. Berkow, S.E. and N. Barnard, *Vegetarian diets and weight status.* Nutrition Reviews, 2006. **64**(4): p. 175-188.
3. Sabaté, J. and M. Wien, *Vegetarian diets and childhood obesity prevention.* The American journal of clinical nutrition, 2010. **91**(5): p. 1525S-1529S.
4. Shridhar, K., et al., *The association between a vegetarian diet and cardiovascular disease (CVD) risk factors in India: the Indian Migration Study.* PloS one, 2014. **9**(10): p. e110586.
5. Mente, A., et al., *A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease.* Archives of internal medicine, 2009. **169**(7): p. 659-669.
6. Dinu, M., et al., *Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies.* Critical reviews in food science and nutrition, 2017. **57**(17): p. 3640-3649.
7. Elorinne, A.-L., et al., *Food and nutrient intake and nutritional status of Finnish vegans and non-vegetarians.* PloS one, 2016. **11**(2): p. e0148235.
8. Tonstad, S., et al., *Type of vegetarian diet, body weight, and prevalence of type 2 diabetes.* Diabetes care, 2009. **32**(5): p. 791-796.
9. Satija, A., et al., *Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies.* PLoS medicine, 2016. **13**(6).
10. Ornish, D., et al., *Intensive lifestyle changes for reversal of coronary heart disease.* Jama, 1998. **280**(23): p. 2001-2007.
11. Stone, N.J., S. Bilek, and S. Rosenbaum, *Recent national cholesterol education program adult treatment panel III update: adjustments and options.* The American journal of cardiology, 2005. **96**(4): p. 53-59.
12. Moore, J.X., N. Chaudhary, and T. Akinyemiju, *Peer reviewed: Metabolic syndrome prevalence by race/ethnicity and sex in the United States, National Health and Nutrition Examination Survey, 1988–2012.* Preventing chronic disease, 2017. **14**.
13. Rao, D., et al., *Metabolic syndrome and chronic disease.* Chronic diseases and injuries in Canada, 2014. **34**(1).
14. Hunt, K.J., et al., *National Cholesterol Education Program versus World Health Organization metabolic syndrome in relation to all-cause and cardiovascular mortality in the San Antonio Heart Study.* Circulation, 2004. **110**(10): p. 1251-7.
15. Rizzo, N.S., et al., *Vegetarian dietary patterns are associated with a lower risk of metabolic syndrome: the adventist health study 2.* Diabetes care, 2011. **34**(5): p. 1225-1227.
16. Freedman, L.S., et al., *Combining a food frequency questionnaire with 24-hour recalls to increase the precision of estimation of usual dietary intakes—Evidence from the validation studies pooling project.* American journal of epidemiology, 2018. **187**(10): p. 2227-2232.

17.	Chuang, S.-Y., et al., *Vegetarian diet reduces the risk of hypertension independent of abdominal obesity and inflammation: a prospective study.* Journal of hypertension, 2016. **34**(11): p. 2164-2171.

18.	Amini, M., et al., *Relationship between major dietary patterns and metabolic syndrome among individuals with impaired glucose tolerance.* Nutrition, 2010. **26**(10): p. 986-992.

19.	Rumawas, M.E., et al., *Mediterranean-style dietary pattern, reduced risk of metabolic syndrome traits, and incidence in the Framingham Offspring Cohort.* The American journal of clinical nutrition, 2009. **90**(6): p. 1608-1614.

20.	Godos, J., et al., *Adherence to the Mediterranean diet is inversely associated with metabolic syndrome occurrence: a meta-analysis of observational studies.* International journal of food sciences and nutrition, 2017. **68**(2): p. 138-148.

21.	Lowell, B.B. and G.I. Shulman, *Mitochondrial dysfunction and type 2 diabetes.* Science, 2005. **307**(5708): p. 384-387.

22.	Kahn, S., *The relative contributions of insulin resistance and beta-cell dysfunction to the pathophysiology of type 2 diabetes.* Diabetologia, 2003. **46**(1): p. 3-19.

23.	Mattioli, A.V., et al., *Mediterranean diet impact on cardiovascular diseases: a narrative review.* Journal of Cardiovascular Medicine, 2017. **18**(12): p. 925-935.

24.	Kahleova, H., S. Levin, and N. Barnard, *Cardio-metabolic benefits of plant-based diets.* Nutrients, 2017. **9**(8): p. 848.

25.	Statistics, N.C.f.H., *Health, United States, 2017: With special feature on mortality.* 2018.

26.	CDC. *NHANES 2015-2016 Data Documentation, Codebook, and Freqeuncies.* July 2018 11/5/2019]; Available from: https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/DRXFCD_I.htm#Appendix_2.

27.	Group, U.F.S.R. *Dietary Methods Research.* 2019; Available from: https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/dmr-food-categories/.

28.	CDC. *National Health and Nutrition Examination Survey: Anlaytic guidleines, 2011-2014 and 2015-2016.* 2018 3/28/2020]; Available from: https://wwwn.cdc.gov/nchs/data/nhanes/analyticguidelines/11-16-analytic-guidelines.pdf.

29.	Moore LV, T.F. *Adults Meeting Fruit and Vegetable Intake Recommendations -- United States, 2013.* Morbidity and Mortality Week Report (MMWR) 2015 4/26/2020]; Available from: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6426a1.htm#tab.

30.	Chiang, J.-K., et al., *Reduced risk for metabolic syndrome and insulin resistance associated with ovo-lacto-vegetarian behavior in female Buddhists: a case-control study.* PloS one, 2013. **8**(8).

31.	Shang, P., et al., *Veganism does not reduce the risk of the metabolic syndrome in a Taiwanese cohort.* Asia Pacific journal of clinical nutrition, 2011. **20**(3): p. 404.

32.	Gadgil, M.D., et al., *Dietary patterns in Asian Indians in the United States: an analysis of the metabolic syndrome and atherosclerosis in South Asians Living in*

America study. Journal of the Academy of Nutrition and Dietetics, 2014. **114**(2): p. 238-243.

33.   Kim, M.-H. and Y.J. Bae, *Postmenopausal vegetarians' low serum ferritin level may reduce the risk for metabolic syndrome.* Biological trace element research, 2012. **149**(1): p. 34-41.

34.   Turner-McGrievy, G.M., et al., *Differences in environmental impact and food expenditures of four different plant-based diets and an omnivorous diet: results of a randomized, controlled intervention.* Journal of hunger & environmental nutrition, 2016. **11**(3): p. 382-395.

35.   Satija, A., et al., *Healthful and unhealthful plant-based diets and the risk of coronary heart disease in US adults.* Journal of the American College of Cardiology, 2017. **70**(4): p. 411-422.

PAPER #2:   ASSOCIATIONS OF WILLINGESSS TO REDUCE CONSUMPTION OF MEAT WITH FRUIT, VEGETABLE, AND MEAT CONSUMPTION BEHAVIORS IN A LOW-INCOME, HISPANIC POPULATION

Jovanovic CES, Nielsen A, Hoelscher DM, Chen B, Ranjit N, van den Berg AE

Background

Healthy dietary patterns are critical to both human and planetary health. Consuming adequate fruits and vegetables (FV) is protective for several chronic diseases, such as cardiovascular disease (CVD), stroke, type 2 diabetes (T2D,) and certain cancers [104-106]. However, fruit and vegetable consumption may not be the only important component of a health-promoting diet. A 2017 systematic review by Micha et al. found 10 foods or nutrients that had causal evidence for protection against cardio-metabolic disease: fruit, vegetables, legumes/beans, nuts and seeds, whole grains, fish, yogurt, seafood omega-3 fatty acids, polyunsaturated fats, and potassium. In addition, similar evidence for elevated risk for chronic diseases was associated with consuming unprocessed red meats, processed meats, sugar-sweetened beverages, glycemic load, *trans*-fatty acids, and sodium [105]. This suggests that reducing consumption of red meat and processed meats, as well as increasing consumption of FV, may be important characteristics of a health-promoting diet.

Increased risk for CVD, stroke, T2D and cancer is strongly associated with poor diet and, specifically associated with a diet high in animal-based food sources [107, 108]. Song et al. (2016) analyzed data from the prospective cohort Nurses' Health Study (n=131,342) and found that hazard ratios (HR) for all- cause mortality were 0.66 (95% CI, 0.59-0.75) when 3% of energy from plant protein was substituted for an equal amount of animal protein [86, 109]. Specifically, there are indications that consumption of red meat and processed meat are associated with elevated risk for CVD and T2D. A meta-analysis and systematic

review of over 20 studies found weak evidence for the association between red meat and chronic diseases, while consumption of processed meat was associated with a 42% higher CVD risk for each 50 g/d increase in intake [110]. Similarly, a prospective study of over half a million people aged 51 – 70 years enrolled in the National Institutes of Health–AARP (formerly known as the American Association of Retired Persons) Diet and Health Study found elevated risk for all-cause mortality for the highest versus lowest quintile of consumption of red meat (HR=1.31, 95%CI: 1.27-1.35, and HR=1.36, 95% CI: 1.30-1.43) and processed meat (HR=1.16, 95% CI: 1.12-1.20, and HR=1.25, 95% CI: 1.20-1.31) for men and women, respectively [111]. These results indicate that an optimal dietary pattern may include less red and processed meat.

Among Hispanics, heart disease is the leading cause of mortality, affecting roughly a third of Mexican-American men and 31% of women [112]. Diabetes also disproportionately affects Hispanics in the United States (U.S.), with a 66% higher risk of diagnosis compared to Whites[113]. Given the association of lower meat consumption with reduced risk for CVD and T2D, these statistics suggest that encouraging a reduction in consumption of meat may be of particular benefit in these populations.

Dietary patterns are also a critical factor driving climate change and environmental degradation on a global scale. Utilizing life cycle analysis (LCA) to evaluate the Global Warming Potential (GWP) of various foods, Clune (2017) found that the same foods found to be protective for chronic disease risk had lower GWP, while foods associated with higher risks for chronic disease and cancer also had higher GWP (Table 3.1). Fruits, vegetables, cereals, legumes and nuts were low in GWP, while lamb and beef were high[1]. As a sector,

livestock production is estimated to contribute 15% of annual anthropogenic GHG emissions, with ruminants contributing 80% of that total, due largely to methane emissions as a by-product of digestion [114]. Further, estimates of long-term greenhouse gas emissions from agriculture suggest reducing livestock production and structural changes in human diets are necessary to achieve target emissions goals, potentially reducing annual GHG emissions from a projected 13 Gton CO_2eq/year to 7.7 Gton CO_2eq/year by 2070 [115]. For example, a study modeling the impact of reducing beef consumption in Italy from the current average of 406 g/week to 150g/week (consistent with Mediterranean Diet recommendations) found significant impacts on both human health and GHG emissions. Compared to baseline, reducing beef consumption would result in an increase in life expectancy of 7 months and reduce GHG emissions an average of 263 KgCO2eq per person annually[116]. In the Netherlands, where average weekly meat consumption is even higher (1,064g, 90% red or processed meat), a 75% reduction in meat consumption was predicted to reduce GHG emission by 1,405 KgCO2eq per person annually, while benefiting health via reduced saturated fat intake and total calories[117] . Reducing the consumption of meat has the potential for simultaneously improving health and reducing GHG emission.

Table 3.1: Summary of GWP values (kg CO2eq/kg produce or bone free meat) across broad food categories

Food	Median	Mean	Stdev	Deviation from mean	Min	Max
Vegetables (all field grown vegetable)	0.37	0.47	0.39	83%	0.04	2.54
Fruits (all field grown fruit)	0.42	0.50	0.32	64%	0.08	1.78
Cereals	0.50	0.53	0.22	42%	0.11	1.38
Legumes and Pulses	0.51	0.66	0.45	67%	0.15	2.46
Passive greenhouse fruit and vegetable	1.10	1.02	0.49	48%	0.32	1.94
Tree nuts combined	1.20	1.42	0.93	66%	0.43	3.77
Milk world average	1.29	1.39	0.58	41%	0.54	7.50

Heated greenhouse fruit and vegetable	2.13	2.81	1.61	57%	0.84	7.4
Rice	2.55	2.66	1.29	48%	0.66	5.69
Eggs	3.46	3.39	1.21	36%	1.30	6.00
Fish: all species combined	3.49	4.41	3.62	82%	0.78	20.86
Chicken	3.65	4.12	1.72	42%	1.06	9.98
Cream	5.64	5.32	1.62	31%	2.10	7.92
Pork: world average	5.77	5.85	1.63	28%	3.20	11.86
Prawns/shrimp	7.80	14.85	12.37	83%	5.25	38.00
Cheese	8.55	8.86	2.07	23%	5.33	16.35
Butter	9.25	11.52	7.37	64%	3.70	25.00
Lamb: world average	25.58	27.91	11.93	43%	10.05	56.70
Beef: world average	26.61	28.73	12.47	43%	10.74	109. 5

GWP valuations were estimated from a meta-analysis of a large body of LCA studies across regions and methodologies. Findings reflect hierarchies of GHG impacts consistent with comparative literature. Median values used to comparatively estimate GHG impacts.[1]

In addition to significant contributions to GHG emissions, livestock production is the leading cause of deforestation and, consequently, loss of biodiversity. In the Amazon, 70% of cleared land is being used for grazing, while a significant portion of the remainder is covered in feed crops [118-121]. Producing meat also uses a disproportionate amount of water compared to other foods, with a kilogram of animal protein requiring 100 times more water than a kilogram of plant protein [37, 122, 123]. Water pollution from livestock is also problematic, as animals produce more waste than humans in the United States, and this waste is left untreated, often contaminating drinking water with high levels of nitrites and phosphorus, and causing deadly algal blooms [121, 124-127]. For any or all of these reasons, reducing the consumption of meat may be critical to addressing climate change and the environmental impacts of the food system.

Despite the mounting evidence suggesting that eating less meat is important for both human and planetary health, consumption of meat in the United States (U.S.) remains high. In 2017, per capita meat consumption in the United States was 217 pounds, or about 3 times the global average[128]. In 2012, males in the US age 20 and over consumed an average of

98.8 grams of protein per day from all sources [129, 130], well above 56 grams recommended in the 2015-2020 Dietary Guidelines for Americans [131] . Most of this protein is from animal sources [132], which contributes to the environmental harms associated with the production of meat and increases the risk for chronic disease.

Identifying attitudes towards reducing the consumption of meat are critical for developing effective and tailored interventions. In the U.S., studies suggest regional differences in preference for red meat; consumers in the South Central region purchased a per capita average of 21 pounds of beef in 2019, while those in California purchased 13 pounds [133]. Patterns of meat consumption also exhibit significant differences for income (higher income preferred less red meat), race/ethnicity (African Americans preferred less red meat), family characteristics (those with children preferred more meat and more red meat), education (high school or higher preferred more meatless meals and less red meat), and nutritional concerns (cholesterol, sugar, and fat in order of importance)[134]. A 2016 study by Ruby et al. found that in the U.S., men held more positive attitudes towards consuming beef than women, who had ambivalent or negative attitudes [135].

These differences may be important to the design and implementation of interventions and/or policies aimed at reducing consumption of meat. However, no previously published studies have assessed attitudes and motivations for meat consumption among low-income, Hispanic populations in the United States. Understanding the motivations for willingness to reduce meat consumption, and how this willingness varies among sub-populations, is critical to reducing meat consumption and improving population health. In particular, exploring the attitudes of population groups most at risk for metabolic

diseases, such as Hispanic populations, may be useful in designing interventions to reduce meat consumption, reducing morbidity and mortality from these causes. In addition, it may be important to understand whether motivations to reduce meat consumption are associated with meat consumption and FV consumption behaviors. This paper has three specific aims: 1) to evaluate motivations for reducing meat consumption by socio-demographic factors, 2) to determine associations between motivations to reduce meat consumption and meat consumption, and 3) to determine associations between motivations to reduce meat consumption and FV consumption among a diverse and economically disadvantaged population in Austin, TX.

Methods

This is a secondary data analysis of cross sectional data from the Go Austin! Vamos Austin! (GAVA) study conducted in the 78745 and 78744 zip codes of Austin, Texas. The GAVA study was a five year, coalition-driven, evidence-based health initiative that targeted multiple levels of health determinants for children in a predominantly Hispanic, low-income area of Austin with a high prevalence of childhood obesity. Data were collected from households on randomly selected streets around locations where GAVA was implemented during 2017-2018. Trained researchers administered surveys to residents with questions on participants' FV intake, meat consumption, levels of physical activity, psychosocial measures, perceived community cohesion, the physical and social environment, and access to healthy foods and physical activity opportunities. Program descriptions and baseline results have been published elsewhere [136].

Inclusion criteria for the participants were: (1) responsibility for food shopping in household, (2) ability to communicate in English or Spanish, (3) not participating in the GAVA cohort study, and (4) a resident of two low-income neighborhoods in Austin, TX. If eligible, the resident was asked to sign a Consent Form and complete the study instrument. All study participants received a gift of $10. A total sample of 306 individuals completed the survey. All materials and procedure were approved by the University of Texas Health Science Center's Institution Review Board (HSC-SPH-13-0108).

Data Preparation

A Meat Reduction Score (MRS) was created by combining three GAVA survey questions (Table 2), resulting in a continuous variable with higher scores indicating a higher willingness for reducing meat consumption. These questions were sourced from MacDiarmid's 2016 qualitative study exploring attitudes and cultural/ social values pertaining to meat consumption among adults in Scotland[73], and echo the wording used by Graća in research that explored motivations for willingness to reduce meat consumption among Portuguese adults[137]. A summary continuous variable to capture FV consumption was also coded based on the sum of two items asking about fruit and vegetable consumption. Each ½-cup serving was counted as "1," resulting in a continuous variable that is a count of servings. Responses for meat consumption items were recoded (Table 3), and median categories were used to generate a measure of weekly meat consumption as follows: 0 = "I do not eat meat," 2 = "Almost no meat (1-3 times)," 5="Few times per week (4-6 times)," 8= Most of main meals (7-10 times)", and 11="Majority of meals (10 or more)."   The recoded

variable, Meat per Week, is an ordinal variable. Categorical variables were created for

income and food insecurity. Sex, race/ethnicity, and language at home were analyzed as

categorical variables. Generated variables and their constituent survey questions are

presented in Table 3.2.

Table 3.2: Recoded Summary Variables Meat Reduction Score (MRS), Total FV Servings
and Meat per Week from GAVA survey questions

Q#	QUESTION	RESPONSE OPTIONS	RECODED VARIABLE	N MEAN (SD)	MIN, MAX
33	I would be willing to reduce the amount of meat I eat for the sake of the environment.	Strongly disagree (0), Somewhat disagree (1), Neither (2), Somewhat agree (3), Strongly agree (4)	Meat Reduction Score (MRS)	N=306 8.45(3.15)	Min: 0, Max: 12
34	I would be willing to reduce the amount of meat I eat if I could save money.				
35	I would be willing to reduce the amount of meat I eat for the sake of my health.				
40	What is the total amount of fruit you eat each day? (1/2 cup equals approximately 1 handful.)	0 cups (0), ½ cup (1), 1 cup (2), 1 ½ cup (3), 2 cups or more (4)	Total FV Servings	N=306 4.49(1.83)	Min: 0, Max: 8
42	What is the total amount of vegetables you eat each day? (1/2 cup equals approximately 1 handful.)				
46	On average, how many times per week do you eat meat? This includes all meat-based products (e.g., chicken, beef, pork, etc.), except fish.	I eat meat… …for the majority of my meals (including breakfast, lunch and dinner)—more than 10 times per week (11) …for most of my main meals—about 7-10 times per week (8) …a few times per week—about 4-6 times per week (5) …almost no meat—about 1-3 times per week (2) I do not eat meat (0)	Meat per Week	N=303 5.78(3.38)*	Min: 0, Max: 11

*Ordinal variable

Descriptive statistics for sample demographics, Total FV Servings, and Meat per

Week, as well as the three questions that comprise the MRS, were generated. To better

understand variations in attitudes towards reducing consumption of meat, each motivation (environment, health and cost) was evaluated for associations across demographic variables (sex, race/ethnicity, language at home, and income) via chi2 tests. Resulting frequencies and p-values are presented in Table 4. For all regressions, the reference groups were male for sex, White for race/ethnicity, < $25,000/year for income, English for language at home, and "almost never or never" for food insecurity. Linear regression estimates for the MRS and Total FV Servings, and ordered logistic regression for Meat per Week were generated across demographic variables, and these results were used to assess potential confounding (Table 5). Confounders were identified for inclusion in the final model using the "modified disjunctive cause criteria" as described by VanderWeele (2019), which suggest that variables associated with either exposure or both exposure and outcome, be included. To detect the moderating effect of food insecurity, two adjusted linear regression models for the effect of MRS on Total FV Servings were implemented: one including sex, income, race/ethnicity, language at home and food insecurity, and one with all cofounders except food insecurity. Regression diagnostics to assess normality of residuals (Kernel density plot, Shapiro Wilk test), heteroescadicity (Breusch-Pagan/Cook-Weisberg test), and collinearity (Variance Inflation Factor (VIF)) were generated.

Analysis

Because Meat per Week is an ordinal variable, ordered logistic regression was used to assess the association with the MRS. Confounders were applied in the same way as described for Total FV Servings; namely, a crude model was run without confounders, then a fully adjusted model was run with all confounders (sex, income, ethnicity, language at home,

and food insecurity), and a final model was run with all confounders except food insecurity. Confounders were chosen based their potential to define and enhance effective communication of the importance of decreasing meat consumption in diverse populations. Inclusion in the final model was based on significant association of each demographic variable on Total FV Servings and Meat per Week.

Results

Descriptive statistics of the sample are presented in Table 3.3. The sample contained more women than men, due to the inclusion criteria for completing the GAVA survey that the person be responsible for household food shopping, and this is more commonly a female. The sample was ethnically diverse, with a majority identifying as Hispanic (53.92%). The language at home variable reflected this diversity, with 43% of the sample speaking Spanish at home. One-fifth of the sample had incomes below $25,000 per year, and one quarter was "Sometimes "or "Always/Almost always" food insecure.

Table3.3: Descriptive Statistics for demographic variables

	Total Sample (n = 306)
SEX	n (%)
Male	105(34.31)
Female	201(65.69)
AGE	
Mean (SD)	44.87 (0.91)
ETHNICITY	
White	107 (34.97)
Black	18 (5.88)
Hispanic	165 (53.92)
Other	16 (5.23)
INCOME	
< $25,000/year	61 (20.00)
≥$25,000/year	172 (56.39)
Did Not Disclose	72 (23.61)
LANGUAGE	
Spanish	77 (25.16)
English	174 (58.86)
Spanish/English	55 (17.972)
FOOD INSECURE	
Almost never or never	227 (74.67)
Sometimes or Always/almost always	77 (25.53)

The components of the MRS score varied significantly across demographic variables. As shown in Figure 3.1, females were more likely to be willing to reduce their consumption of meat for all reasons, but cost motivation as captured by "Somewhat" or "Strongly Agree" was twice as frequent compared to males (p<0.001). Motivations for reducing consumption of meat also varied significantly

71

across ethnicity, with Hispanics being more willing to reduce meat consumption for all three reasons (environment($p=0.04$), health ($p<0.01$), cost($p<0.001$)). For Black participants, the environment was the least important motivation, compared to Hispanic, White and Other groups ($p=0.01$).   This pattern—that Hispanic participants were significantly more likely to be more willing to reduce meat consumption for all three reasons-- was also observed for the language at home variable, where those speaking mostly Spanish at home reported significantly higher motivations across all three factors (environment ($p<0.001$), health ($p<0.01$), cost ($p<0.001$)).   Unsurprisingly, saving money was more important for those making $\leq$ \$25,000 annually ($p<0.001$). More unexpected was the finding that significantly more participants in the lower income category agreed ("Strongly" or "Somewhat") that they would be willing to reduce their consumption of meat for health reasons ($p=0.049$). For those who were food insecure, health reasons were significantly less important than for those who were not food insecure ($p=0.03$). Across all demographics except food insecurity, participants strongly or somewhat agreed that they would be willing to reduce the amount of meat they ate for health reasons. All motivations were generally higher for Hispanics, primarily Spanish speakers, and those making $\leq$ \$25,000 annually (Table 3.4).

Figure 3.1: "Strongly Agree" or "Somewhat Agree" for MRS component motivations (environment, cost, health) by demographic variables (sex, ethnicity, income, language at home, and food insecurity)
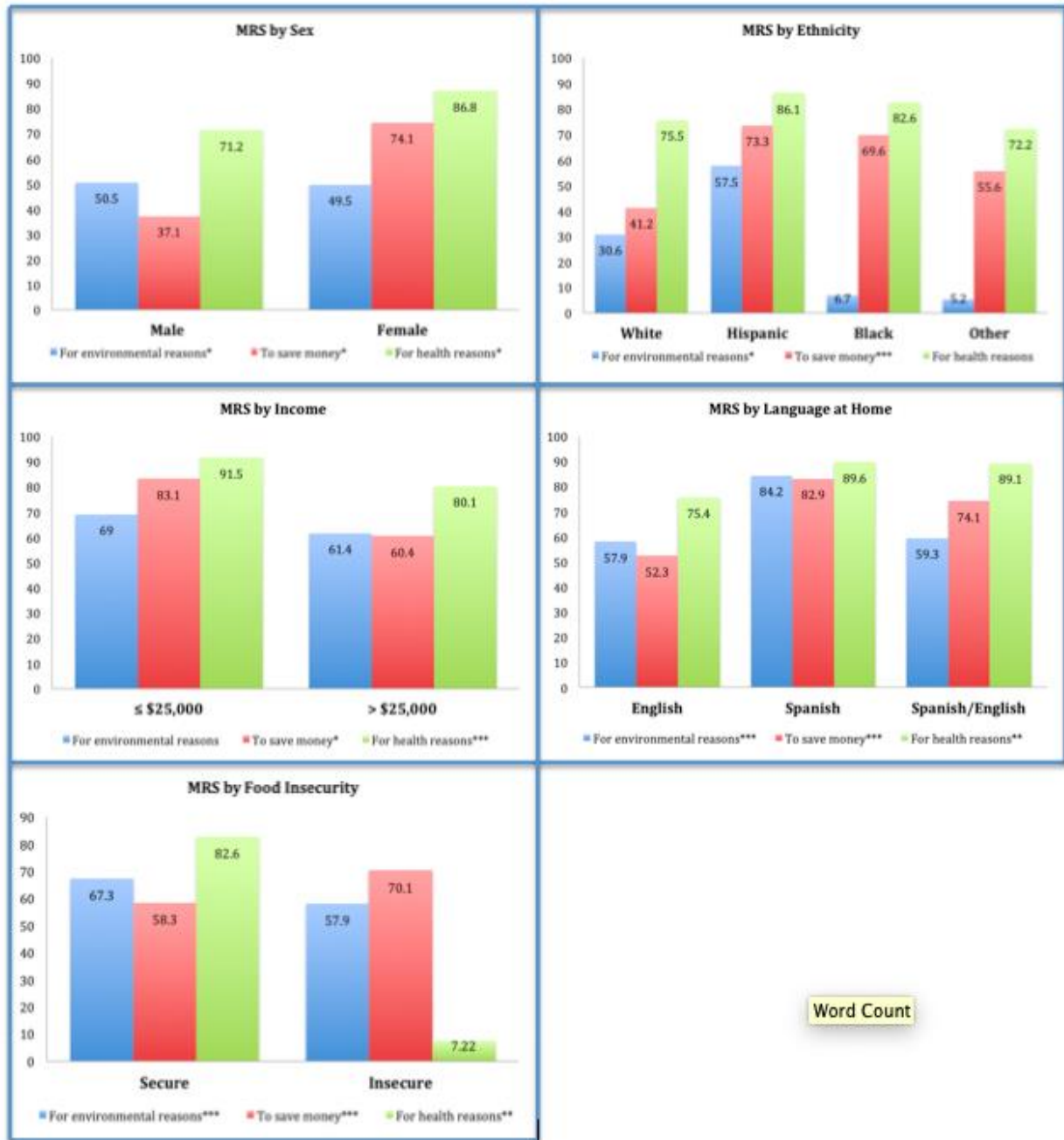
*p<0.05, **p<0.01, ***p<0.001. MRS: Meat Reduction Score, FV: Fruit and Vegetables*

Table 3.4: Components of the MRS (environment, health, cost), Total FV Servings, and Meat

	ENVIRONMENT Strongly/ Somewhat agree n n (%)	HEALTH Strongly/ Somewhat agree n (%)	COST Strongly/ Somewhat agree n (%)	TOTAL FV SERVINGS Mean Servings (SD)	MEAT PER WEEK Mean Servings (SD)
SEX					
Male	52 (50.49)***	74 (71.15)**	39 (37.14)***	4.59 (0.17)	6.91 (0.33)***
Female	51 (49.51)***	173 (86.93)**	146 (74.11)***	4.44 (0.13)	5.18 (0.23)***
ETHNICITY					
White	60 (57.69)*	79 (75.96)*	42 (40.38)	4.92 (0.18)	6.52 (0.32)
Black	9 (50.00)	15 (83.33)	12 (66.67)	3.83 (0.39)	7.56 (0.85)
Hispanic	117 (71.78)*	142 (86.06)**	121 (73.38)***	4.24 (0.13)*	5.18 (0.25)**
Other	9 (56.25)	11 (68.75)	10 (62.50)	5.06 (0.51)	5.00 (1.08)
INCOME					
< $25,000	40 (68.97)	54 (91.53)*	49 (83.05)***	4.27 (0.23)	5.57 (0.39)
≥ $25,000	111 (64.91)	139 (81.29)	91 (53.22)***	4.73 (0.14)	6.24 (0.26)
Not Disclosed	44 (61.97)	54 (75.00)	45 (63.38)	4.15 (0.20)	4.79 (0.39)**
LANGUAGE AT HOME					
English	99 (57.89)	129 (75.44)**	82 (52.33)*	4.67 (0.14)	6.73 (0.26)
Spanish	64 (84.21)***	69 (89.61)**	63 (82.89)***	4.01 (0.17)*	3.95 (0.30)***
Spanish/English	32 (59.26)**	49 (89.09)**	40 (76.92)***	4.60 (0.27)	5.38 (0.45)**
FOOD INSECURE					
Never/Almost never	150 (67.26)	185 (82.59)*	130 (58.30)*	4.73 (0.12)**	5.90 (0.23)
Sometimes/Always	44 (57.89)	61 (7.22)	54 (70.13)*	3.81 (0.21)***	5.40 (0.37)

per Week presented by demographic characteristics

*p<0.05, **p<0.01, ***p<0.001. MRS: Meat Reduction Score, FV: Fruit and Vegetables

Demographic differences were also apparent on outcomes of linear regressions with

MRS as dependent variable (Y) for each demographic characteristic as the independent

variable (X) (Table 3.5). This analysis revealed that being female (p<0.001), being Hispanic

(p<0.001), speaking Spanish (p<0.001) and speaking Spanish and English equally (p=0.01),

were all significantly associated with higher MRS.   For the linear regression of demographic

variables on Total FV Servings as the dependent variable (Y), being Black (p=0.02) or

Hispanic (p<0.01), and speaking Spanish (p<0.01) were all positively and significantly

associated, while food insecurity was significantly and negatively associated (p<0.001). When demographic variables were analyzed using ordered logistic regression on the Meat per Week (dependent variable (Y)), being female (p<0.001), being older (p<0.01), and being Hispanic (p<0.01) were negatively and significantly associated, suggesting that people with these characteristics may eat meat fewer time per week. Speaking Spanish (p<0.001) was positively associated with servings of meat per week.

Next, a series of linear regressions were fit with Total FV Servings as the dependent variable (Y) and MRS as the independent variable (X) for each demographic variable (covariates). This association was significant and negative for being Black (p=0.02) or Hispanic (p<0.01), for speaking Spanish (p<0.01) and for being Food Insecure (p<0.001). Finally, a series of ordered logistic regressions was used to assess the effect of MRS (independent variable (X)) on Meat per Week (dependent variable (Y)), and being female (p=0.02), being older (p=0.02), and speaking Spanish at home (p<0.001) were negatively and significantly associated (Table 3.5).

Table 3.5: Output of MRS (linear regression), Total FV Servings (linear regression), Meat per Week (ordered logistic regression), MRS (X) on Total FV Servings (Y) (linear regression), and MRS (X) on Meat per Week (Y) (ordered logistic regression), across potential confounder (demographic) variables,

	MRS	Total FV Servings	Meat per Week	MRS on Total FV Servings	MRS on Meat/Week
SEX (reference: male)					
Female	2.13***	–0.15	–0.95***	–0.23	–0.28***
AGE	–0.01	–0.01	–0.02**	–0.01	–0.03***
RACE/ETHNICITY (reference: White)					
Black	0.25	–1.08*	1.33	–1.10*	0.78
Hispanic	1.78***	–0.68**	–3.27**	–0.78**	–0.34
Other	0.22	0.15	–1.86	0.13	–1.13*

INCOME (reference: <$25,000)					
≥ $25,000	–0.99*	0.45	0.35	0.48	0.06
ND	–0.74)	–0.13	–0.48	–0.10	–0.85
LANGUAGE AT HOME (reference: English)					
Spanish	2.33***	–0.66**	0.26*	–0.79**	–1.14***
Spanish/ English	1.16**	–0.07	–056	–0.14	–0.56
FOOD INSECURE (reference: Almost never or Never)					
Sometimes/ Always	0.24	–0.93***	–0.26	–0.93***	–0.20

*p<0.05, **p<0.01, ***p<0.001. MRS: Meat Reduction Score, FV: Fruit and Vegetables*

Because age was not associated with either MRS or Total FV Servings, it was

dropped from the analysis. Food insecurity appears to be associated strongly with Total FV

Servings, but not with the MRS, suggesting that food insecurity moderates the relations

between MRS and total FV Servings. Based on these findings, three regression models were

fitted for the association between MRS and Total FV Servings: one crude, one with all

confounders included (sex, race/ethnicity, income, language at home, and food insecurity),

and, based on the hypothesis that food insecurity may act as a moderating variable, a third

model with all variables except food insecurity [138, 139]. As seen in Table 3.6, the

association of MRS and Total FV servings was not significant in the crude and the fully

adjusted model.   However, when food insecurity was removed from the adjusted model,

MRS became significant (p=0.04). In the final model, being Black (p=0.02) and speaking

"Other" language at home (p=0.05) appeared to be significant confounders of the

relationship.

To ensure that the assumptions for valid linear regression were met, post-estimation

diagnostics assessed distribution of residuals for the final model. Both visual examination of

the kernel density plot and standardized normal distribution plots, as well as the Shapiro

Wilk test (p=0.18), suggest residuals for the final adjusted model were normally distributed.

Next, using the Breusch-Pagan/Cook-Weisberg test (p=0.62), no evidence of heteroescadicity

was observed in the final adjusted model. Finally, collinearity was ruled out via the Variance

Inflation Factor (VIF), which was low (mean VIF=1.30). These diagnostics suggest that all

assumptions for linear regression were met, and the final adjusted regression model appears

to provide valid measures of association.

Table 3.6: Adjusted Linear Regression Outcomes for Dependent Variable (Y) = Total FV
Servings, Independent Variable (X) = MRS

	FULLY ADJUSTED MODEL			FULLY ADJUSTED W/OUT FOOD INSECURITY		
	β	95% CI	p	β	95% CI	p
MRS*	**0.07**	**0.00, 0.14**	**0.06**	**0.08**	**0.01, 0.15**	**0.04**
SEX						
Female	0.03	-0.42, 0.49	0.89	-0.01	-0.47, 0.45	0.97
ETHICITY						
Black	**-0.94**	**-0.84, -0.03**	**0.04**	**-1.09**	**-1.99, -0.18**	**0.02**
Hispanic	**-0.52**	**-1.13, 0.08**	**0.09**	**-0.57**	**-1.18, 0.04**	**0.07**
Other	-0.33	-1.36, 0.69	0.52	-0.36	-1.36, 0.64	0.48
INCOME						
≥ $25,000	0.04	-0.52, 0.60	0.9	0.16	-0.40, 0.72	0.57
ND	-0.11	-0.72, 0.51	0.73	-0.03	-0.64, 0.59	0.94
LANGUAGE AT HOME						
Spanish	-0.16	-0.85, 0.53	0.65	-0.17	-0.86, 0.53	0.64
Spanish/English	0.35	-0.32, 1.01	0.31	0.34	-0.332, 1.01	0.32
FOOD INSECURITY						
Sometimes/ Always	**-0.69**	**-1.18, -0.20**	**1**	.	.	.

MRS: Meat Reduction Score

To assess the association of MRS (independent variable (X)) with Meat per Week

(dependent variable (Y)), an ordered logistic regression was utilized to fit a crude and two

77

adjusted models. A fully adjusted model with sex, age, ethnicity, language at home and food insecurity as covariates was performed. Then, based on the results of the individual logistic regressions, those covariates that were significantly associated with either MRS or Meat per Week were included in a final adjusted ordered logistic regression (sex, age, ethnicity, and language at home). In all models, Meat per Week was significantly and negatively associated with the MRS, suggesting that a higher score on the MRS translated into lower meat consumption among our sample (Table 3.7). Age and language at home (Spanish or Spanish/English equally) were significant confounders. Specification error was assessed via the link test, and was found to be nonsignificant (p=0.16), which is an indication that our final model has all relevant predictors in appropriate combinations.

Table 3.7: Adjusted Ordered Logistic Regression Outcomes for Y=Meat per Week, X=MRS

	FULLY ADJUSTED MODEL			FULLY ADJUSTED W/OUT FOOD INSECURITY, INCOME		
	OR	95% CI	p	OR	95% CI	p
MRS*	**0.75**	**-0.69, 0.82**	**<0.01**	**0.768**	**0.76, 0.83**	**<0.001**
SEX						
Female	0.65	0.40, 1.07	0.09	0.68	0.42, 1.09	0.11
AGE						
	0.97	**0.96, 0.99**	**<0.01**	**0.97**	**0.96, 0.99**	**<0.001**
ETHNICITY						
Black	2.26	0.81, 6.33	0.12	2.36	0.85, 6.55	0.10
Hispanic	1.55	0.82, 2.935	0.82	1.48	0.79, 2.77	0.22
Other	**-0.39**	**0.12, 1.22**	**0.10**	**0.454**	**0.15, 1.35**	**0.16**
INCOME						
≥ $25,000	0.84	0.47, 1.52	0.57	.	.	.
ND	0.60	0.31, 1.16	0.13	.	.	.
LANGUAGE AT HOME						

Spanish	**0.28**	**0.14, 0.59**	**<0.01**	**0.27**	**0.14, 0.54**	**<0.001**
Spanish/English	**0.46**	**0.23, 0.93**	**0.03**	**0.47**	**0.24, 0.93**	**0.03**
FOOD INSECURE						
Sometimes/ Always	1.07	0.65, 1.78	0.79	.	.	.

MRS: Meat Reduction Score

Discussion

Consuming large quantities of meat may pose risks to both human and environmental health [140, 141]. In terms of human health, meat consumption may be a risk factor for several chronic diseases, including cancer and CVD [28, 111]. In addition, consuming meat may displace consumption of health-promoting fruits and vegetables [109, 142]. These issues are particularly important in Hispanic populations, which experience elevated risks for both CVD and type 2 diabetes [113]. The present study explored associations between sociodemographic factors, motivations for willingness to reduce meat consumption (health, environmental concerns, and cost) and self-reported weekly meat consumption and daily servings of FV.

The MRS was not significantly associated with Meat per Week in the crude model. However, the addition of confounders (sex, age, ethnicity, language at home) resulted in a significant association. Neither income nor food insecurity were significant in this relationship. These results suggest that ethnicity and/or language at home were important factors in the relations between the MRS and Meat per Week, while measures of income were not. These patterns may indicate that attachment to eating meat is rooted in culture, rather than in affordability. This tracks with other research, such as MacDiarmid, Douglas

and Campbell's (2015) qualitative analysis of Scottish adults, which found eating meat was significantly associated with personal, social, and cultural values, rather than with affordability [73]. García-Jimenéz and Mishra (2011) also found significant differences in meat consumption by ethnicity, with Hispanic and African-American households being more similar in consumption patterns compared to White or Other Minorities. In this study, Hispanics consumed the most meat, although they did not have the highest income, again suggesting that meat consumption may be more closely aligned with culture than with income [143]. The strong and significant association of the MRS with reductions in Meat per Week offers a mechanism by which interventions and policies may seek to encourage reductions in the consumption of meat. By educating people about the environmental, economic and health benefits of eating less meat, it may be that people will subsequently reduce meat consumption, with little influence of affordability issues.

While a significant association between the MRS and Total FV Servings was observed via the fully adjusted model, confounders played a significant role in the relationship, as evidenced by the lack of significance in the crude model. In addition, the moderating behavior of food insecurity, which interfered in the relationship between the MRS and Weekly FV Servings, indicates that affordability and economic access may play a larger role in FV consumption than it does in meat consumption in our sample. A similar association was found between food insecurity and FV consumption among adults in California, with food insecure participants consuming 0.8 fewer servings of FV per day than food secure participants [144].   Further, strong associations for being Hispanic and speaking Spanish at home suggest an important cultural component to FV consumption. Even more

than race/ethnicity, language at home was strongly associated with significantly greater motivation to reduce meat consumption for all reasons, hinting that acculturation to prevailing consumption patterns (i.e., the Western diet) is more important than race/ethnicity in characterizing the relation between the MRS and daily servings of FV.   Other research has found similar relationships between language as a proxy for acculturation and increased FV consumption among Hispanics [145-147].

For both Meat per Week and Total FV Servings, differences in the association by demographic variables offer insight into how interventions to encourage health-promoting behaviors may be tailored. Analysis of the motivations with the MRS by demographic variables provides further detail for crafting messaging and policies, increasing potential efficacy of these efforts. For example, the cost motivation for reducing consumption of meat was more important for those making less than $25,000 annually and for food insecure participants. While this result is unsurprising, the association of affordability was also significantly different by ethnicity. Health reasons and saving money were important for all racial/ethnic groups, but environmental reasons were much less important for Black participants. Cost savings were also significantly less important to males versus females.

Limitations of this study include self-reported data for all variables, which may introduce bias from inaccurate recall or social desirability. Because the data are cross-sectional, no conclusions of causality can be offered, and changes over time are not accessible. The diversity of the study sample is both a strength, in that this offers insight into the psychosocial and behavioral outcomes of a priority (i.e., majority Hispanic, low-income) population, but is also a limitation because external validity to the wider population (i.e., not

majority Hispanic) is truncated. Further research to identify social and cultural associations with meat consumption may be warranted, as this may illuminate important attitudes in the relationship between knowledge, intentions, and meat consumption behavior. In addition, interventions that intend to reduce the economic barriers to FV consumption and/or perception of those barriers, and research into their impact, are suggested.

Overall, the health motivation for willingness to reduce meat consumption was important across all demographic variables except for those who identified as food insecure. This result aligns with other research, such as Schenk, Rössel and Scholz's (2018) study of Swiss adults, which found health reasons were more influential than cost concerns in predicting intended meat consumption frequency [148]. However, among a sample of New Zealand adults, Lentz et al. (2018) found cost to be the most important motivator for reducing consumption of meat, followed by health reasons [149]. While health was a significant motivation in all three studies, variations in motivations to reduce meat suggest that tailoring messages is important. In our study population, emphasizing health benefits may offer the most effective path for communicating the importance of decreasing meat consumption. Hispanic audiences may also be receptive to environmental messaging, and it is important to note that women were much more likely to be motivated by cost issues—an association that may be critical given that women are more likely to manage household food purchasing and preparation.

This study examined the association of the MRS and FV consumption separately from its association with meat consumption, based on evidence that these are different behaviors [150-152]. Understanding how motivations to reduce consumption of meat vary

across diverse populations, and the influence of those motivations on FV and meat

consumption behaviors, offer important details that are critical to the successful design and

implementation of policies and programs intended to increase health promoting behaviors,

specifically increasing FV consumption and decreasing meat consumption. By doing so,

both human health and environmental health may benefit.

References

1. Alissa, E.M. and G.A. Ferns, *Dietary fruits and vegetables and cardiovascular diseases risk.* Critical reviews in food science and nutrition, 2017. **57**(9): p. 1950-1962.
2. Micha, R., et al., *Etiologic effects and optimal intakes of foods and nutrients for risk of cardiovascular diseases and diabetes: systematic reviews and meta-analyses from the Nutrition and Chronic Diseases Expert Group (NutriCoDE).* PloS one, 2017. **12**(4): p. e0175149.
3. Wu, Y., et al., *Fruit and vegetable consumption and risk of type 2 diabetes mellitus: a dose-response meta-analysis of prospective cohort studies.* Nutrition, Metabolism and Cardiovascular Diseases, 2015. **25**(2): p. 140-147.
4. Clune, S., E. Crossin, and K. Verghese, *Systematic review of greenhouse gas emissions for different fresh food categories.* Journal of Cleaner Production, 2017. **140**: p. 766-783.
5. Zhao, D., et al., *Ten-year cardiovascular disease risk of metabolic syndrome without central obesity in middle-aged chinese.* Am J Cardiol, 2007. **100**(5): p. 835-9.
6. Whitmee, S., et al., *Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health.* The Lancet, 2015. **386**(10007): p. 1973-2028.
7. Chuang, S.-Y., et al., *Vegetarian diet reduces the risk of hypertension independent of abdominal obesity and inflammation: a prospective study.* Journal of hypertension, 2016. **34**(11): p. 2164-2171.
8. Song, M., et al., *Association of animal and plant protein intake with all-cause and cause-specific mortality.* JAMA internal medicine, 2016. **176**(10): p. 1453-1463.
9. Micha, R., G. Michas, and D. Mozaffarian, *Unprocessed red and processed meats and risk of coronary artery disease and type 2 diabetes–an updated review of the evidence.* Current atherosclerosis reports, 2012. **14**(6): p. 515-524.
10. Sinha, R., et al., *Meat intake and mortality: a prospective study of over half a million people.* Archives of internal medicine, 2009. **169**(6): p. 562-571.
11. Benjamin, E.J., et al., *Heart disease and stroke statistics-2017 update: a report from the American Heart Association.* Circulation, 2017. **135**(10): p. e146-e603.
12. Gomes, A., et al., *Incidence of diabetes mellitus and obesity and the overlap of comorbidities in HIV+ hispanics initiating antiretroviral therapy.* PloS one, 2016. **11**(8).
13. Steinfeld, H., et al., *Livestock's long shadow: environmental issues and options*. 2006: Food & Agriculture Org.
14. Bälter, K., et al., *Is a diet low in greenhouse gas emissions a nutritious diet?–Analyses of self-selected diets in the LifeGene study.* Archives of Public Health, 2017. **75**(1): p. 17.
15. Farchi, S., et al., *Meat consumption reduction in Italian regions: Health co-benefits and decreases in GHG emissions.* PloS one, 2017. **12**(8).

16.	van de Kamp, M.E., S.M. Seves, and E.H. Temme, *Reducing GHG emissions while improving diet quality: exploring the potential of reduced meat, cheese and alcoholic and soft drinks consumption at specific moments during the day.* BMC public health, 2018. **18**(1): p. 264.

17.	Henning, B., *Standing in Livestock's ''Long Shadow'': The Ethics of Eating Meat on a Small Planet.* Ethics & the Environment, 2011. **16**(2): p. 63-93.

18.	Hiroko Tabuchi, C.R.J.W. *Amazon Deforestation, Once Tamed, Comes Roaring Back* 2017; Available from: https://www.nytimes.com/2017/02/24/business/energy-environment/deforestation-brazil-bolivia-south-america.html.

19.	Bennett, L., *Deforestation and climate change.* A publication of climate institute, 2017. **1400**.

20.	Hu, Y., H. Cheng, and S. Tao, *Environmental and human health challenges of industrial livestock and poultry farming in China and their mitigation.* Environment international, 2017. **107**: p. 111-130.

21.	Pimentel, D. and M. Pimentel, *Sustainability of meat-based and plant-based diets and the environment.* The American journal of clinical nutrition, 2003. **78**(3): p. 660S-663S.

22.	Noya, I., et al., *Water Footprint of Livestock Farming*, in *Environmental Water Footprints*. 2019, Springer. p. 21-54.

23.	van Zanten, H.H., et al., *Global food supply: land use efficiency of livestock systems.* The International Journal of Life Cycle Assessment, 2016. **21**(5): p. 747-758.

24.	Dufour, A. and J. Bartram, *Animal waste, water quality and human health*. 2012: IWA publishing.

25.	Sakadevan, K. and M.-L. Nguyen, *Livestock production and its impact on nutrient pollution and greenhouse gas emissions*, in *Advances in agronomy*. 2017, Elsevier. p. 147-184.

26.	Wen, Y., G. Schoups, and N. Van De Giesen, *Organic pollution of rivers: Combined threats of urbanization, livestock farming and global climate change.* Scientific reports, 2017. **7**: p. 43289.

27.	Cesoniene, L., M. Dapkiene, and D. Sileikiene, *The impact of livestock farming activity on the quality of surface water.* Environmental Science and Pollution Research, 2019. **26**(32): p. 32678-32686.

28.	*Per Capita Meat Consumption in the United States*. Our World in Data; Available from: https://ourworldindata.org/grapher/per-capita-meat-usa.

29.	Archer, E., G. Pavela, and C.J. Lavie. *The inadmissibility of what we eat in America and NHANES dietary data in nutrition and obesity research and the scientific formulation of national dietary guidelines*. in *Mayo Clinic Proceedings*. 2015. Elsevier.

30.	Fehrenbach, K.S., A.C. Righter, and R.E. Santo, *A critical examination of the available data sources for estimating meat and protein consumption in the USA.* Public health nutrition, 2016. **19**(8): p. 1358-1367.

31.	Agriculture, U.S.D.o. *Dietary Guidelines for Americans 2015 - 2020*. 2015; Available from: https://urldefense.proofpoint.com/v2/url?u=https-

3A__health.gov_dietaryguidelines_2015_guidelines_chapter-2D1_a-2Dcloser-2Dlook-2Dinside-2Dhealthy-2Deating-2Dpatterns_-23food-2Dgroups&d=DwIFAg&c=bKRySV-ouEg_AT-w2QWsTdd9X__KYh9Eq2fdmQDVZgw&r=IOFrKQJgz_WYOigAE7D67rpYScpsg EKkehCJaiBPwv7hNVFDhA1eZmc54FyCFbO2&m=301GM67iT4KxGRZQfIUHxS O1PF1E3G4kVGUvHiHZmlo&s=GmrEjJSSJT5KZ2TQSkgxFSTwiHgz39WY1wSJ 3nF2qJU&e=

32. Phillips, S.M., et al., *Commonly consumed protein foods contribute to nutrient intake, diet quality, and nutrient adequacy.* The American journal of clinical nutrition, 2015. **101**(6): p. 1346S-1352S.

33. Krebs, A. *Regional Differences in Consumes' Love of Beef.* 2019; Available from: https://www.perishablenews.com/meatpoultry/regional-differences-in-consumers-love-of-beef.

34. Rimal, A., *Meat labels: consumer attitude and meat consumption pattern.* International Journal of Consumer Studies, 2005. **29**(1): p. 47-54.

35. Ruby, M.B., et al., *Attitudes toward beef and vegetarians in Argentina, Brazil, France, and the USA.* Appetite, 2016. **96**: p. 546-554.

36. Van Den Berg, A., et al., *Design and evaluation of a coalition-led obesity initiative to promote healthy eating and physical activity in low-income, ethnically diverse communities: the Go! Austin/Vamos! Austin initiative.* Archives of Public Health, 2019. **77**(1): p. 25.

37. Macdiarmid, J.I., F. Douglas, and J. Campbell, *Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet.* Appetite, 2016. **96**: p. 487-493.

38. Graça, J., M.M. Calheiros, and A. Oliveira, *Attached to meat?(Un) Willingness and intentions to adopt a more plant-based diet.* Appetite, 2015. **95**: p. 113-125.

39. VanderWeele, T.J., *Principles of confounder selection.* European journal of epidemiology, 2019. **34**(3): p. 211-219.

40. Coffman, D.L. and W. Zhong, *Assessing mediation using marginal structural models in the presence of confounding and moderation.* Psychological methods, 2012. **17**(4): p. 642.

41. Larsson, S.C. and N. Orsini, *Red meat and processed meat consumption and all-cause mortality: a meta-analysis.* American journal of epidemiology, 2014. **179**(3): p. 282-289.

42. Springmann, M., et al., *Mitigation potential and global health impacts from emissions pricing of food commodities.* Nature Climate Change, 2017. **7**(1): p. 69-74.

43. Parada, H., et al., *Grilled, barbecued, and smoked meat intake and survival following breast cancer.* JNCI: Journal of the National Cancer Institute, 2017. **109**(6).

44. Ekmekcioglu, C., et al., *Red meat, diseases, and healthy alternatives: A critical review.* Critical reviews in food science and nutrition, 2018. **58**(2): p. 247-261.

45. García-Jiménez, C.I. and A.K. Mishra, *Role of ethnicity in consumption of meat products.* Applied Economics Letters, 2011. **18**(7): p. 665-669.

46.   Neff, R.A., et al., *Reducing meat consumption in the USA: a nationally representative survey of attitudes and behaviours.* Public health nutrition, 2018. **21**(10): p. 1835-1844.
47.   Dibsdall, L.A., et al., *Low-income consumers' attitudes and behaviour towards access, availability and motivation to eat fruit and vegetables.* Public health nutrition, 2003. **6**(2): p. 159-168.
48.   Ghaddar, S., et al., *Acculturation and healthy lifestyle habits among Hispanics in United States-Mexico border communities.* Revista Panamericana de Salud Publica, 2010. **28**: p. 190-197.
49.   Norman, S., et al., *Comparing acculturation models in evaluating dietary habits among low-income Hispanic women.* Ethnicity and Disease, 2004. **14**(3): p. 399-404.
50.   Schenk, P., J. Rössel, and M. Scholz, *Motivations and constraints of meat avoidance.* Sustainability, 2018. **10**(11): p. 3858.
51.   Lentz, G., et al., *Gauging attitudes and behaviours: Meat consumption and potential reduction.* Appetite, 2018. **127**: p. 230-241.
52.   Moreira, P.A. and P.D. Padrão, *Educational and economic determinants of food intake in Portuguese adults: a cross-sectional survey.* BMC public health, 2004. **4**(1): p. 58.
53.   Arbit, N., M. Ruby, and P. Rozin, *The Meaning of Food in Life Scale: Evidence for Links with Healthy Eating, a Positive Relationship to Food, and Established Determinants of Healthy Eating Behavior.* Journal of Nutrition Education and Behavior, 2017. **49**(7): p. S5-S6.
54.   Vandermoere, F., et al., *Meat Consumption and Vegaphobia: An Exploration of the Characteristics of Meat Eaters, Vegaphobes, and Their Social Environment.* Sustainability, 2019. **11**(14): p. 3936.

PAPER # 3: VALIDATION OF THE FRESH AUSTIN FOOD FREQUENCY QUESTIONNAIRE USING MULTIPLE 24-HOUR DIETARY RECALLS

Jovanovic CES, Whitefield J, Diaz MP, Hoelscher DM, Chen B, Ranjit N, van den Berg AE

Introduction

Evaluating dietary outcomes of community-based interventions is challenging, requiring both measurable change at the individual level, and the instruments to detect that change. Often, because effects of community-level interventions are broad and diffuse, individual-level outcomes are difficult to capture. Historically, dietary assessment generally has focused on producing precise measures of micronutrients in an effort to discover epidemiological relations with disease outcomes. More recently, however, the focus has shifted to assessing changes in habitual dietary patterns at the food group level (e.g., fruits, vegetables, meat) [153-155]. This reflects the intention of community-based interventions to increase/decrease consumption of specific foods or food groups (i.e., increase consumption of fruits and vegetables (FV)), rather than targeting a change in micronutrient consumption (i.e., higher potassium intake)[156]. Among the variety of dietary assessment methods available, the Food Frequency Questionnaire (FFQ) may be the best method for assessment of community-based program evaluation, as it captures usual intake in a cost-effective and minimally burdensome process [157]. Best practice recommends that FFQs be tailored to both the study aims and the study population, so that the foods queried reflect the outcomes of interest, as well as the culture and usual diet of study subjects[158]. These adaptations may change the validity of the instrument, however, and ideally instruments should be validated when adapted to new studies[159, 160].

The intent of this study was to examine the validity of a Food Frequency Questionnaire utilized in the FRESH Austin study, designed to evaluate changes in the consumption of FV in diverse low-income communities in Austin, TX. In alignment with

well-established dietary assessment protocols, repeated 24-hour dietary recalls (24hDRs) serve as the criterion measure [161-163] .

Methods

Subjects

Because the purpose of this study was to validate the FRESH Austin FFQ, subjects were recruited to mimic the demographic characteristics of the larger FRESH Austin cohort. FRESH Austin is the evaluation of the Fresh for Less (FFL) initiative, which aims to improve access to healthy, affordable food in ethnically diverse and economically disadvantaged communities through organizational support of local mobile markets in Austin, TX. By decreasing barriers to healthy food access, FFL is intended to affect purchasing behaviors and, ultimately, increase consumption of fresh FV in the target communities. Because increased consumption of fresh FV is the primary outcome of interest, the FRESH Austin survey includes an FFQ that will be administered to a cohort of 400 residents over a three-year period. Adapted from the previously validated FFQ (the Block questionnaire), the FRESH Austin FFQ food list was aligned with the goals of the intervention, focusing on assessing the consumption of FV, rather than the entire diet.   Inclusion criteria for both FRESH Austin and the validation study were the same: at least 18 years old, not pregnant or breast feeding, and able to speak English or Spanish.

Data Collection Protocol

Recruitment was conducted at sites within the FRESH Austin study area. People at a community health clinic, a local health center, and a YMCA within the FRESH Austin study area were approached by trained and certified data collectors, and invited to participate in the

validation study. In accordance with approved IRB protocol, subjects were given an information sheet, were invited to ask questions, and, if they were willing to participate, signed an IRB-approved consent.

Research shows that correlations between FFQs and reference methods such as repeated 24hDRs are higher for interviewer-conducted FFQs, as compared to those that are self-administered[164, 165]. However, no difference in correlation has been found between FFQs conducted via telephone interview with a qualified researcher and those conducted in person[165, 166]. Therefore, the FRESH Austin protocol included either in-person or telephone interviews with trained personnel. This also aligns with the protocol used in the FRESH Austin study for data collection. Three 24hDRs were administered to each participant, followed by the FFQ. At the time of recruitment, the first 24hDR was administered in person, and arrangements were made for the second 24hDR via telephone interview. At the time of the second 24hDR, a day and time for the third 24hDR was arranged. After three 24hDRs were completed, the FRESH Austin FFQ was conducted either in person or over the phone, depending on the availability and preference of the participant, and incentives were delivered. In all, 69 people were recruited; four chose not to continue after the first interview, five after the second, and three chose not to complete the FFQ, resulting in a final sample size of 57. Participants were classified as dropped from the study after four attempts to reach the participant were made, or the participant requested to leave the study. Participants received $20 in gift cards for completing all four assessments.

FRESH Austin Validation Study Survey

Besides the questions focused exclusively on FV consumption, the FRESH Austin survey contains items to assess shopping behaviors, food access, demographic information, neighborhood and retail environment, and attitudes towards shopping for and consuming FV. The FFQ in the FRESH Austin survey was adapted from the Block FFQ, which is used in the NHANES annual survey and has been widely validated [167-169]. The foods in the FRESH Austin survey were chosen to capture the most commonly consumed FV in the study population (diverse, low-income population in Austin, TX), taking into account local sales data as well as feedback from promotoras. The question stems were, "Over the last month, how many times per month, week, or day did you eat the following fruit/vegetable?" and, "When you ate the fruit/vegetable, how much did you usually eat?" The FV listed were: apples, citrus, bananas, berries, grapes, melon, lettuce, dark leafy greens, broccoli or cauliflower, carrots, tomatoes, avocadoes, sweet potatoes, potatoes (not sweet), cabbage, peppers, corn, zucchini or other squash, and onions. In addition, respondents were given an option to mention up to four additional fruits and four additional vegetables not included in this listing.

To create the Fresh Austin Validation Study survey, the FV FFQ and demographic questions from the FRESH Austin survey were combined with a question about meat consumption and questions about attitudes towards reducing meat consumption. This validation study examines only the FRESH Austin FFQ (Figure 1), along with pertinent demographic questions. In all, the FRESH Austin Validation Study survey contained 22 questions, and was administered in either Spanish or English, as preferred by the participant.

Figure 4.1: Components of the FRESH Austin survey and the FRESH Austin Validation Study survey

Survey Components
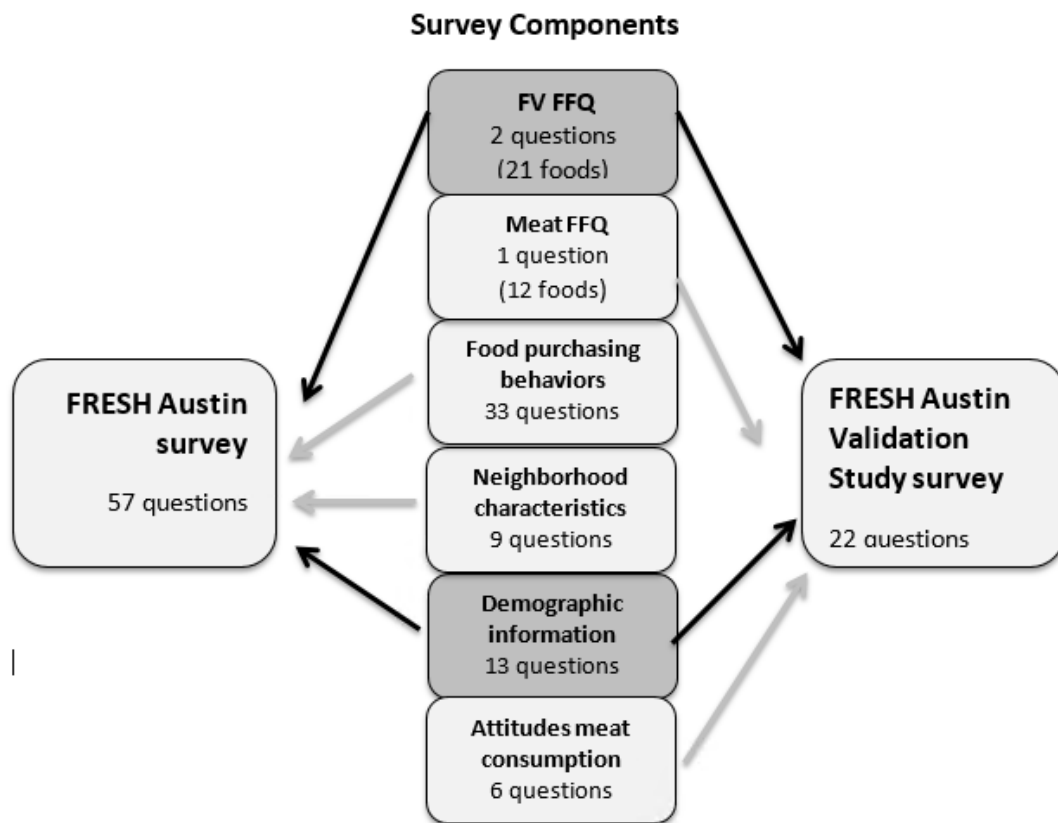
Twenty-four Hour Dietary Recalls

The USDA five-step multiple-pass 24hDR method has been shown to capture dietary energy and macronutrient intake within 10% of actual intake, as determined by estimated energy requirements (EER) and basal metabolic rate (Burkeholder-Cooley et al., 2017). This allows the 24hDR to be used as the "gold standard" against which the accuracy of the FFQ can be measured [170]. Our study utilized three 24hDRs, conducted using the five-step multiple pass method, and guided by scripts adapted from those provided by NDSR. To ensure that the data covered the same time period defined in the FRESH Austin FV FFQ (i.e., the thirty days), three recalls were completed in a period of thirty days, with two recalls of

weekdays and one of a weekend day. All participants were provided with a printed measuring guide, which was also used in the FRESH Austin data collection. Recall protocols were adapted from the Nutrition Data Systems for Research (NDSR), then entered and analyzed using NDSR software (version 2008, Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN, USA)(NCCR, 2018). The NDSR utilizes the USDA food composition database, which is maintained by the Agricultural Research Division (ARS) [171].

Data Preparation

To minimize discrepancies in data entry, all 24hDR records were entered by two trained personnel (MD and JW), then crosschecked in their entirety, and disagreements resolved collaboratively. In consultation with the FRESH Austin team, which includes experts in nutritional sciences, final categories of FV were chosen based on congruence between the FFQ and 24hDR. For example, the "Deep Yellow" vegetable category from the 24hDR was mapped to sweet potatoes and carrots from the FFQ, while the "Dark Green" category from the 24hDR was mapped to cooked dark leafy greens from the FFQ (Table 4.1.) All quantities reported are expressed in servings per day. In accordance with USDA convention, servings are defined as: ½ cup of any cooked or raw vegetable or fruit, or 1 cup of raw leafy greens. For a person on a 2,000-calorie-per-day diet, the Recommended Dietary Guidelines for Americans 2015-2020 suggests 2.5 cups of vegetables and 2 cups of fruit per day, or 9-10 servings total[26]. Servings per day for each FV were generated by converting weekly or monthly consumption to daily, and multiplying this by servings as defined above. All variables are continuous measures of servings per day. Data were examined for outliers.

Any values +/- two standard deviations were re-examined for plausibility and data collectors

queried to confirm accuracy of all extreme values.

Table 4.1: Validation study food categories and their components from FFQ and 24hDR data

VALIDATION STUDY CATEGORY	FFQ ITEM(S)	NDSR DEFINITION
Citrus	Citrus (oranges, grapefruit, etc.)	Citrus fruit (oranges, grapefruit, tangerines, lemons)
Non-citrus Fruits	Apples, bananas, berries, grapes, melon, other non-citrus	Fruit excluding citrus fruit
Avocados	Avocados	Avocados
Dark Green	Lettuce or raw dark leafy greens, cooked dark leafy greens, broccoli or cauliflower	Spinach, collards, romaine, broccoli
Deep Yellow	Carrots, sweet potatoes	Carrots, sweet potatoes, pumpkin, winter squash
Tomatoes	Tomatoes	Tomatoes
White Potatoes	Potatoes (not sweet)	White potatoes, fried potatoes
Starchy	Corn, peas, jicama	Peas, corn, cassava, jicama
Other Vegetables	Other	Other

Analysis

Demographic characteristics of participants in the Validation Study and the FRESH

Austin Cohort subjects were compared using Pearson or Spearman correlation tests for age,

sex, ethnicity and income (Table 1). In addition, scatterplots comparing categories of FV for

the FFQ versus the 24hDR were generated for each of the nine food categories, and

examined for linearity. Crude mean and standard deviation for categories of FV, separately

and together, were computed (Table 4.2). Shapiro-Wilks tests assessed normality of each

food category variable. Non-normal variables were log-transformed and re-checked via

Shapiro-Wilks. For non-normal variables, Spearman's ρ was reported, and Pearson's *r* was

reported for normally distributed variables. Because the paired t-test is robust to non-normal

distributions in larger (n>30) samples, this was used to assess differences between mean

values for each food category variable, p-values reported [172].

Correlation estimates (Pearson's r or Spearman's ρ) provide a measure of the

relationship between the FFQ and the 24hDR. However, correlations can be inaccurate if

they are caused by a widespread sample (as when disagreement between methods is large but

linear), and only provide an indication of the strength of the linear relationship between

variables, rather than defining agreement. Therefore, we also present Bland-Altman plots,

which plot the difference of paired variables versus their average, allowing estimates of fixed

bias via mean difference. This bias is deemed significant based on its variance from zero.

Limits of agreement (LOA) (i.e., mean difference $\pm$ 1.96 SD of the difference) provide an

estimate of variability of the agreement between the two methods, and describe the range of

values in which agreement between methods will fall for 95% of the sample [173].   Bland-

Altman plots were also used to explore proportional bias, which occurs when differences

between methods vary across the sample.

Borrowing from methods used in time series forecast analyses, Mean Absolute

Percentage Errors (MAPE) provide a measure of error between the paired FFQ and 24hDR

observations, which can be indicative of prediction accuracy, and are included in Table 4.3.

These estimates use the 24hDR as the criterion or actual value, and the FFQ as the forecast or

predicted value, scaled to each category. Lower estimates suggest lower error, and better

prediction, of the FFQ from the 24hDR. Finally, the Bland-Altman method was used to

produce graphs that plot the mean of the two methods against the difference for each

variable, allowing visual comparisons of agreement between the two methods (Figure4.2.)

Significance was set at $\alpha = 0.05$ for all tests, and all analyses were performed using STATA

SE 14.2 (College Station, TX.)

Results

The subjects in the Validation Study were similar to those in the FRESH Austin

Cohort with respect to age, ethnicity, and income, with no significant differences in these

characteristics between study populations. Validation Study participants were significantly

more female and spoke different languages at home, especially a language other than

English, Spanish, or English and Spanish equally (Table 2.)

Table 4.2: Comparison of selected demographic characteristics of Validation Study and
FRESH Austin Cohort participants

	VALIDATION STUDY (%)	COHORT (%)	P-VALUE
GENDER			
Female	45 (83.33)	282 (70.50)	0.007
AGE in years			
Mean (SD)	43.56 (1.89)	43.89 (0.68)	0.869
ETHNICITY			
Hispanic	12 (22.22)	127 (31.99)	
Black	3 (5.56)	32 (8.06)	
White	29 (53.70)	203 (51.13)	
Other	10 (18.52)	35 (8.82)	0.094
INCOME			
Less than $25,001	12 (23.53)	89 (23.30)	
$25,001 - $45,000	21 (41.18)	112 (29.32)	
$45,001 - $65,000	8 (15.69)	70 (18.32)	
> $65,000	10 (19.61)	111 (29.06)	0.299
LANGUAGE AT HOME			
Only/mostly English	24 (44.44)	236 (59.15)	
Both English and Spanish	10 (18.52)	51 (12.78)	
Only/mostly Spanish	16 (29.63)	109 (27.32)	
Mostly other	4 (7.41)	3 (0.75)	0.001

A comparison of crude estimates of FFQ and 24hDR servings per day indicates that "Non-Citrus Fruits" and "Other Vegetables" have the highest values, reflecting the inclusion of a variety of FV in each category. The FFQ and 24hDR produced similar estimates of average total servings per day across FV (6.68 and 6.40 servings per day, respectively,) as well as for FV categories separately. Further analyses of crude estimates via the paired t-test reveal that there were no significant mean differences between Total Fruit, Total Vegetables and Total FV. In all, no FV categories had significant mean differences (Table 4.3.)

Table 4.3: Crude mean servings and standard deviation (SD) for each food category (per day) by assessment method (FFQ and 24hDR), and paired t-test

FOOD CATEGORY	FFQ		24HDR		PAIRED T-TEST
	MEAN	SD	MEAN	SD	P-VALUE
Citrus	0.68	0.12	0.30	0.08	0.17
Non-citrus Fruits	2.06	0.20	2.29	0.21	0.32
AVG Total Fruit	**2.74**	**0.21**	**2.59**	**0.17**	**0.20**
Avocados	0.28	0.05	0.13	0.04	0.35
Dark Green	0.41	0.09	0.61	0.10	0.28
Deep Yellow	0.44	0.07	0.37	0.05	0.08
Tomatoes	0.46	0.07	0.54	0.07	0.88
White Potatoes	0.25	0.06	0.30	0.05	0.12
Starchy	0.22	0.05	0.15	0.03	0.11
Other Vegetables	1.88	0.21	1.71	0.14	0.49
AVG Total Vegetables	**3.94**	**0.13**	**3.81**	**0.10**	**0.26**
AVG Total FV	*6.68*	*0.14*	*6.40*	*0.13*	*0.51*

Across categories of FV, the FRESH Austin FFQ provided moderately correlated outcomes compared to the repeated 24hDR, with correlations above 0.30 for all food groups, except white potatoes (Table 4.4). The highest correlations were observed for "Non-Citrus Fruits" and "Other Vegetables," which were both above 0.50. All correlations were

significant, except for "White Potatoes" and "Avocados," and 55% of food categories had

correlations above 0.40.

Because our interest is in a measure of error that does not penalize larger magnitude

errors more than smaller magnitude errors, the MAPE is utilized to provide further insight.

MAPE values were small for all FV, suggesting the variance of the error estimates are also

small.   In addition, these data indicate that the errors are small in both the negative and the

positive direction, which is important to the assessment of agreement between the two

methods, where either a positive or a negative difference would be of interest.   Of particular

importance are the small MAPE values for "Non-Citrus Fruits" and "Other Vegetables,"

since consumption of these are most likely to be targeted by programs and interventions and,

therefore, most likely to be used as critical measures of intervention efficacy. Further, the

larger values generated for "Avocados," and "White Potatoes" suggest that larger errors in

assessment may make it more difficult to capture significant changes for these categories.

Table 4.4: Pearson's *r* or Spearman's ρ and Mean Absolute Percentage Error (MAPE), n = 56

FOOD CATEGORY	SPEARMAN ρ/ PEARSON'S *R*	P-VALUE	MAPE	SD
Citrus	0.48	<0.01	3.0%	0.06
Non-citrus Fruits	0.57	<0.001	0.9%	0.10
TOTAL Fruit	**0.64**	**<0.001**	**2.2%**	**0.05**
Avocados	0.38	0.38	3.5%	0.05
Dark Green	0.33	0.02	0.7%	0.03
Deep Yellow	0.51	<0.01	1.1%	0.06
Tomatoes	0.47*	<0.01	0.9%	0.05
White Potatoes	0.01	0.93	2.6%	0.10
Starchy	0.30	0.03	1.5%	0.03
Other Vegetables	0.59*	<0.001	0.4%	0.10
TOTALVegetables	**0.74**	**<0.001**	**1.7%**	**0.06**
TOTAL FV	**0.69**	**0.02**	**0.7%**	**0.06**

Finally, Bland-Altman plots (Figure 4.2) provide greater detail for assessing the degree to which the two methods agree. Each plot shows the line of equality, or the line upon which all points would appear if the FFQ and the 24hDR produced the exact same measure [173, 174]. For every category, the plots show the grouping of data points for smaller values to be closer together, while outliers are only found at larger values. Mean differences were less than 0.50 servings per day for all categories, including the "Non-Citrus" and "Other Vegetables" categories, which have larger crude values due to the inclusion of a greater variety of FV. Given that the values in these summary categories are higher, the mean difference of 0.50 servings per day suggests these estimates substantially agree. Limits of Agreement for each food category describe the range of agreement among the FFQ and 24hDR for 95% of individuals assessed[175].

Figure 4.2: Bland-Altman plots comparing differences between FFQ and 24hDR estimates to average of FFQ and 24hDR values for all FV categories

Discussion

In previous studies, the FFQ generally overestimates usual intake [158-160, 167, 176, 177], and yields correlations of between 0.40 – 0.70 across food groups and nutrients, compared to 24hDRs [178]. In our study, we found correlations between 0.01 for "Potatoes"

and 0.59 for "Other Vegetables," indicating that the FRESH Austin FFQ provides moderately valid measures for FV surveyed, except "Potatoes."

The central question of this study is whether the FRESH Austin FFQ provides a valid measure of FV consumption, compared to the 24hDR [179]. The 24hDR is often used as the reference method for several reasons: it has less reliance on long-term memory (requiring recall of only the previous day,) utilizes a trained interviewer to enhance details and accuracy, and elicits a detailed record of consumption, including methods of preparation and details of brands and sources[159, 167, 180]. A consistent agreement of the FRESH FV FFQ and repeated 24hDRs allows the use of the less burdensome option, in this case the FFQ, to be deemed reliable and effective at detecting important changes in consumption in the population of interest [176, 181]. In addition, the pattern observed via the Bland-Altman plots, showing closer agreement at smaller quantities and greater discrepancies at higher quantities, argues for the careful examination and possible exclusion of outliers in pre-/post-assessments. These values may be "true," in the sense that large quantities of a specific food were eaten, but "untrue" as an indicator of habitual consumption.

Because measures of agreement are distributed both above and below the line equality, no systematic bias is detected. However, the LOA were wide, suggesting that the FFQ may lead to important under- or over-estimation of actual intake. Similar to the results found by Bautista, Herran and Pryer (2014), we conclude our findings of limited precision precludes a reliable estimate of epidemiological associations with disease, but allows for valid comparisons of cohort designs [182]. This FFQ could be useful to provide estimates of

changes in consumption over time, where the outcome of interest is not a measure of true intake, but rather an assessment of changes in consumption.

Our study found correlations in line with similar research, such as Hebden et al.'s (2013) comparison of a tailored FFQ to repeated food records. In that study, fruit servings were correlated ($r = 0.58$) in line with our results ("Citrus" $r = 0.48$, "Non-Citrus" $r = 0.57$), as were vegetable servings ($r = 0.57$) in comparison to "Other Vegetables" $r = 0.59$ [183]. As found in other studies, the FFQ slightly underreported consumption of FV compared to the criterion measure [157, 158, 161, 183, 184]. This may be attributed to social desirability bias, as subjects may report habitual intake to resemble their own intended consumption, or their perceptions of the interviewer's expectations, rather than actual intake. The 24hDR recall may reduce this bias by asking more immediate questions of recent intake, providing less opportunity to edit consumption to align with intentions. Further, as noted by Bloucher at al. (2005), higher numbers of recall days are associated with greater correlations with FFQ values, suggesting that for some food categories, more than 2 or 3 recalls are required to account for daily variance in consumption[177]. While the brevity of the FRESH Austin FFQ reduced survey burden, it also eliminated the ability to calculate total energy, since the entire diet was not evaluated. This limitation would be important for any investigations into associations with disease, since consumption cannot be scaled by total energy, but is appropriate for studies intended to capture changes in consumption, rather than de-attenuated values [185, 186].

Every FV group assessed by the FRESH Austin FFQ showed acceptable levels of association between FFQ and 24hDR, with the exception of potatoes and avocadoes,

suggesting that this tailored FFQ is able to capture usual consumption with sufficient accuracy to enable valid assessment of changes in FV intake. The FFQ minimizes respondent burden, which is especially important condition for retention in cohort studies, and helps ensure sufficient sample sizes and power to detect changes in outcomes. In addition, the FRESH FV FFQ focus on whole foods is aligned with evaluation of community-based interventions, such as Austin's Fresh for Less program, aimed at improving access in high-need communities [187-189]. As in other community-level programming, the outcomes of interest are changes in patterns of consumption, specifically increases in FV intake. This FFQ aligns evaluation with implementation, providing a measure of change that is important for program evaluation, as well as for assessment of an important determinant of desired health outcomes.

References

1. Clune, S., E. Crossin, and K. Verghese, *Systematic review of greenhouse gas emissions for different fresh food categories.* Journal of Cleaner Production, 2017. **140**: p. 766-783.
2. Murphy, S.L., et al., *Mortality in the United States, 2017.* 2018.
3. Statistics, N.C.f.H., *Health, United States, 2017: With special feature on mortality.* 2018.
4. Ioannidis, J.P., *Implausible results in human nutrition research.* 2013, British Medical Journal Publishing Group.
5. White, R.R. and M.B. Hall, *Nutritional and greenhouse gas impacts of removing animals from US agriculture.* Proceedings of the National Academy of Sciences, 2017. **114**(48): p. E10301-E10308.
6. Herrero, M., et al., *Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems.* Proceedings of the National Academy of Sciences, 2013. **110**(52): p. 20888-20893.
7. Tuso, P., S.R. Stoll, and W.W. Li, *A plant-based diet, atherogenesis, and coronary artery disease prevention.* The Permanente Journal, 2015. **19**(1): p. 62.
8. The Vegetarian Resource Group. *How many adults in the U.S. are vegetarian and vegan?* 2016; Available from: https://www.vrg.org/nutshell/Polls/2016_adults_veg.htm.
9. Berkow, S.E. and N. Barnard, *Vegetarian diets and weight status.* Nutrition Reviews, 2006. **64**(4): p. 175-188.
10. Sabaté, J. and M. Wien, *Vegetarian diets and childhood obesity prevention.* The American journal of clinical nutrition, 2010. **91**(5): p. 1525S-1529S.
11. Tonstad, S., et al., *Type of vegetarian diet, body weight, and prevalence of type 2 diabetes.* Diabetes care, 2009. **32**(5): p. 791-796.
12. Spencer, E., et al., *Diet and body mass index in 38 000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans.* International journal of obesity, 2003. **27**(6): p. 728.
13. Bertoia, M.L., et al., *Changes in intake of fruits and vegetables and weight change in United States men and women followed for up to 24 years: analysis from three prospective cohort studies.* PLoS medicine, 2015. **12**(9): p. e1001878.
14. Ornish, D., et al., *Can lifestyle changes reverse coronary heart disease?: The Lifestyle Heart Trial.* The Lancet, 1990. **336**(8708): p. 129-133.
15. Shridhar, K., et al., *The association between a vegetarian diet and cardiovascular disease (CVD) risk factors in India: the Indian Migration Study.* PloS one, 2014. **9**(10): p. e110586.
16. Mente, A., et al., *A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease.* Archives of internal medicine, 2009. **169**(7): p. 659-669.
17. Bullard, K.M., et al., *Prevalence of diagnosed diabetes in adults by diabetes type— United States, 2016.* Morbidity and Mortality Weekly Report, 2018. **67**(12): p. 359.

18.   Qian, F., et al., *Association Between Plant-Based Dietary Patterns and Risk of Type 2 Diabetes: A Systematic Review and Meta-analysis.* JAMA internal medicine, 2019.

19.   Satija, A., et al., *Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies.* PLoS medicine, 2016. **13**(6): p. e1002039.

20.   Kahleova, H., et al., *Vegetarian diet improves insulin resistance and oxidative stress markers more than conventional diet in subjects with Type 2 diabetes.* Diabetic Medicine, 2011. **28**(5): p. 549-559.

21.   McMacken, M. and S. Shah, *A plant-based diet for the prevention and treatment of type 2 diabetes.* Journal of geriatric cardiology: JGC, 2017. **14**(5): p. 342.

22.   Dinu, M., et al., *Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies.* Critical reviews in food science and nutrition, 2017. **57**(17): p. 3640-3649.

23.   Fraser, G.E., *Associations between diet and cancer, ischemic heart disease, and all-cause mortality in non-Hispanic white California Seventh-day Adventists.* The American journal of clinical nutrition, 1999. **70**(3): p. 532s-538s.

24.   Craig, W.J., *Health effects of vegan diets.* The American journal of clinical nutrition, 2009. **89**(5): p. 1627S-1633S.

25.   Elorinne, A.-L., et al., *Food and nutrient intake and nutritional status of Finnish vegans and non-vegetarians.* PloS one, 2016. **11**(2): p. e0148235.

26.   Millen, B.E., et al., *The 2015 Dietary Guidelines Advisory Committee scientific report: development and major conclusions.* Advances in nutrition, 2016. **7**(3): p. 438-444.

27.   Chan, D.S., et al., *Red and processed meat and colorectal cancer incidence: meta-analysis of prospective studies.* PloS one, 2011. **6**(6): p. e20456.

28.   Parada, H., et al., *Grilled, barbecued, and smoked meat intake and survival following breast cancer.* JNCI: Journal of the National Cancer Institute, 2017. **109**(6).

29.   Bouvard, V., et al., *Carcinogenicity of consumption of red and processed meat.* Lancet Oncology, 2015. **16**(16): p. 1599.

30.   Samir, K. and W. Lutz, *The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100.* Global Environmental Change, 2017. **42**: p. 181-192.

31.   Popkin, B.M., *Relationship between shifts in food system dynamics and acceleration of the global nutrition transition.* Nutrition reviews, 2017. **75**(2): p. 73-82.

32.   Clonan, A., K.E. Roberts, and M. Holdsworth, *Socioeconomic and demographic drivers of red and processed meat consumption: implications for health and environmental sustainability.* Proceedings of the Nutrition Society, 2016. **75**(3): p. 367-373.

33.   McIntyre, B.D., *International assessment of agricultural knowledge, science and technology for development (IAASTD): Synthesis report with executive summary: A synthesis of the global and sub-global IAASTD reports.* 2009.

34.   Gliessman, S.R., *Agroecology: the ecology of sustainable food systems.* 2014: CRC press.

35.   Hazel, P., *Green revolution: Curse or blessing?* 2002.
36.   University of Michigan. *U.S. Food Systems Factsheet*. Available from: http://css.umich.edu/factsheets/us-food-system-factsheet.
37.   Pimentel, D. and M. Pimentel, *Sustainability of meat-based and plant-based diets and the environment.* The American journal of clinical nutrition, 2003. **78**(3): p. 660S-663S.
38.   United States Environmental Protection Agency. *Sources of Greenhouse Gas Emissions*. 9/7/19]; Available from: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
39.   Foley, J.A., et al., *Solutions for a cultivated planet.* Nature, 2011. **478**(7369): p. 337.
40.   Woods Hole Research Center. *New data: Amazaon Fires Have Released 140-141 Metric Tons of CO2*. 2019; Available from: http://whrc.org/new-data-brazilian-amazon-fires-have-released-104-141-million-metric-tons-of-co2/.
41.   Tilman, D., et al., *Forecasting agriculturally driven global environmental change.* science, 2001. **292**(5515): p. 281-284.
42.   Scarborough, P., et al., *Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK.* Climatic change, 2014. **125**(2): p. 179-192.
43.   Jones, C.M., *A Lifecycle Assessment of US Household Consumption: The Methodology and Inspiration Behind the "Consumer Footprint Calculator".* 2005.
44.   Eshel, G. and P.A. Martin, *Diet, energy, and global warming.* Earth interactions, 2006. **10**(9): p. 1-17.
45.   Vetter, S.H., et al., *Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation.* Agriculture, ecosystems & environment, 2017. **237**: p. 234-241.
46.   Food and A.O.o.t.U.N.G.P.S. Unit, *World agriculture: towards 2030/2050: prospects for food, nutrition, agriculture and major commodity groups*. 2006: Food and Agriculture Organization of the United Nations, Global Perspective ….
47.   Ramankutty, N., et al., *Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000.* Global biogeochemical cycles, 2008. **22**(1).
48.   Popkin, B.M., L.S. Adair, and S.W. Ng, *Global nutrition transition and the pandemic of obesity in developing countries.* Nutrition reviews, 2012. **70**(1): p. 3-21.
49.   Machovina, B., K.J. Feeley, and W.J. Ripple, *Biodiversity conservation: The key is reducing meat consumption.* Science of the Total Environment, 2015. **536**: p. 419-431.
50.   McGuire, S., *FAO, IFAD, and WFP. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. Rome: FAO, 2015*. 2015, Oxford University Press.
51.   Friedrich, M., *Global obesity epidemic worsening.* Jama, 2017. **318**(7): p. 603-603.
52.   Kelly, T., et al., *Global burden of obesity in 2005 and projections to 2030.* International journal of obesity, 2008. **32**(9): p. 1431.
53.   Chetty, R., et al., *The association between income and life expectancy in the United States, 2001-2014.* Jama, 2016. **315**(16): p. 1750-1766.

54. Mendelsohn, R., A. Dinar, and L. Williams, *The distributional impact of climate change on rich and poor countries.* Environment and Development Economics, 2006. **11**(2): p. 159-178.

55. Olsson, L.M.O.P.T.A.A.S.E.S.M.L.P.a.S.Z., *Climate Change 2014: Impacts, Adaptations, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. 2014: Cambridge, United Kingdom and New York, NY, USA. p. 793-832.

56. Levy, B.S. and J.A. Patz, *Climate change, human rights, and social justice.* Annals of global health, 2015. **81**(3): p. 310-322.

57. The Center for International Environmental Law, *Climate & Human Rights: A Primer*.

58. Hales, C.M., et al., *Differences in obesity prevalence by demographic characteristics and urbanization level among adults in the United States, 2013-2016.* Jama, 2018. **319**(23): p. 2419-2429.

59. Whelton, P.K., et al., *Research needs to improve hypertension treatment and control in African Americans.* Hypertension, 2016. **68**(5): p. 1066-1072.

60. Wolfson, J.A. and S.N. Bleich, *Fruit and vegetable consumption and food values: National patterns in the United States by Supplemental Nutrition Assistance Program eligibility and cooking frequency.* Preventive medicine, 2015. **76**: p. 1-7.

61. U.S. Department of Agriculture. *Current Eating Patterns in the United States*. 2015; Available from: https://health.gov/dietaryguidelines/2015/guidelines/chapter-2/current-eating-patterns-in-the-united-states/.

62. Martin, C., et al., *Demographic Characteristics Associated with Variety of Fruit and Vegetable Intake: What We Eat in America, NHANES 2013–2016 (FS02-06-19).* 2019, Oxford University Press.

63. Hales, C.M., et al., *Prevalence of obesity among adults and youth: United States, 2015–2016.* 2017.

64. Chiles, R.M. and A.J. Fitzgerald, *Why is meat so important in Western history and culture? A genealogical critique of biophysical and political-economic explanations.* Agriculture and human values, 2018. **35**(1): p. 1-17.

65. Stentz, F.B., et al., *Remission of pre-diabetes to normal glucose tolerance in obese adults with high protein versus high carbohydrate diet: randomized control trial.* BMJ Open Diabetes Research and Care, 2016. **4**(1): p. e000258.

66. Kitabchi, A.E., et al., *Effects of high-protein versus high-carbohydrate diets on markers of β-cell function, oxidative stress, lipid peroxidation, proinflammatory cytokines, and adipokines in obese, premenopausal women without diabetes: a randomized controlled trial.* Diabetes care, 2013. **36**(7): p. 1919-1925.

67. Krieger, J.W., et al., *Effects of variation in protein and carbohydrate intake on body mass and composition during energy restriction: a meta-regression.* The American journal of clinical nutrition, 2006. **83**(2): p. 260-274.

68. Markova, M., et al., *Isocaloric diets high in animal or plant protein reduce liver fat and inflammation in individuals with type 2 diabetes.* Gastroenterology, 2017. **152**(3): p. 571-585. e8.

69. Rosen, S., *Essential Hinduism.* 2006: Greenwood Publishing Group.

70. Ritchie, H. and M. Roser, *Meat and seafood production & consumption.* Our World in Data, 2017.

71. Carrie, D., et al., *Trends in meat consumption in the United States.* Public Health Nutrition, 2011. **14**(4): p. 575-583.

72. Ruby, M.B. and S.J. Heine, *Meat, morals, and masculinity.* Appetite, 2011. **56**(2): p. 447-450.

73. Macdiarmid, J.I., F. Douglas, and J. Campbell, *Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet.* Appetite, 2016. **96**: p. 487-493.

74. DeSalvo, K.B., R. Olson, and K.O. Casavale, *Dietary guidelines for Americans.* Jama, 2016. **315**(5): p. 457-458.

75. Office of Disease Prevention and Health Promotion. *Nutrition and Weight Status.* 2015; Available from: https://health.gov/dietaryguidelines/2015/guidelines/chapter-2/current-eating-patterns-in-the-united-states/#figure-2-1-desc-toggle.

76. Lee-Kwan, S.H., et al., *Disparities in state-specific adult fruit and vegetable consumption—United States, 2015.* MMWR. Morbidity and mortality weekly report, 2017. **66**(45): p. 1241.

77. Pasiakos, S., et al., *Sources and amounts of animal, dairy, and plant protein intake of US adults in 2007–2010.* Nutrients, 2015. **7**(8): p. 7058-7069.

78. Satija, A., et al., *Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies.* PLoS medicine, 2016. **13**(6).

79. Ornish, D., et al., *Intensive lifestyle changes for reversal of coronary heart disease.* Jama, 1998. **280**(23): p. 2001-2007.

80. Stone, N.J., S. Bilek, and S. Rosenbaum, *Recent national cholesterol education program adult treatment panel III update: adjustments and options.* The American journal of cardiology, 2005. **96**(4): p. 53-59.

81. Moore, J.X., N. Chaudhary, and T. Akinyemiju, *Peer reviewed: Metabolic syndrome prevalence by race/ethnicity and sex in the United States, National Health and Nutrition Examination Survey, 1988–2012.* Preventing chronic disease, 2017. **14**.

82. Rao, D., et al., *Metabolic syndrome and chronic disease.* Chronic diseases and injuries in Canada, 2014. **34**(1).

83. Hunt, K.J., et al., *National Cholesterol Education Program versus World Health Organization metabolic syndrome in relation to all-cause and cardiovascular mortality in the San Antonio Heart Study.* Circulation, 2004. **110**(10): p. 1251-7.

84. Rizzo, N.S., et al., *Vegetarian dietary patterns are associated with a lower risk of metabolic syndrome: the adventist health study 2.* Diabetes care, 2011. **34**(5): p. 1225-1227.

85.   Freedman, L.S., et al., *Combining a food frequency questionnaire with 24-hour recalls to increase the precision of estimation of usual dietary intakes—Evidence from the validation studies pooling project.* American journal of epidemiology, 2018. **187**(10): p. 2227-2232.

86.   Chuang, S.-Y., et al., *Vegetarian diet reduces the risk of hypertension independent of abdominal obesity and inflammation: a prospective study.* Journal of hypertension, 2016. **34**(11): p. 2164-2171.

87.   Amini, M., et al., *Relationship between major dietary patterns and metabolic syndrome among individuals with impaired glucose tolerance.* Nutrition, 2010. **26**(10): p. 986-992.

88.   Rumawas, M.E., et al., *Mediterranean-style dietary pattern, reduced risk of metabolic syndrome traits, and incidence in the Framingham Offspring Cohort.* The American journal of clinical nutrition, 2009. **90**(6): p. 1608-1614.

89.   Godos, J., et al., *Adherence to the Mediterranean diet is inversely associated with metabolic syndrome occurrence: a meta-analysis of observational studies.* International journal of food sciences and nutrition, 2017. **68**(2): p. 138-148.

90.   Lowell, B.B. and G.I. Shulman, *Mitochondrial dysfunction and type 2 diabetes.* Science, 2005. **307**(5708): p. 384-387.

91.   Kahn, S., *The relative contributions of insulin resistance and beta-cell dysfunction to the pathophysiology of type 2 diabetes.* Diabetologia, 2003. **46**(1): p. 3-19.

92.   Mattioli, A.V., et al., *Mediterranean diet impact on cardiovascular diseases: a narrative review.* Journal of Cardiovascular Medicine, 2017. **18**(12): p. 925-935.

93.   Kahleova, H., S. Levin, and N. Barnard, *Cardio-metabolic benefits of plant-based diets.* Nutrients, 2017. **9**(8): p. 848.

94.   CDC. *NHANES 2015-2016 Data Documentation, Codebook, and Freqeuncies*. July 2018 11/5/2019]; Available from: https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/DRXFCD_I.htm#Appendix_2.

95.   Group, U.F.S.R. *Dietary Methods Research*. 2019; Available from: https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/dmr-food-categories/.

96.   CDC. *National Health and Nutrition Examination Survey: Anlaytic guidleines, 2011-2014 and 2015-2016*. 2018 3/28/2020]; Available from: https://wwwn.cdc.gov/nchs/data/nhanes/analyticguidelines/11-16-analytic-guidelines.pdf.

97.   Moore LV, T.F. *Adults Meeting Fruit and Vegetable Intake Recommendations -- United States, 2013*. Morbidity and Mortality Week Report (MMWR) 2015 4/26/2020]; Available from: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6426a1.htm#tab.

98.   Chiang, J.-K., et al., *Reduced risk for metabolic syndrome and insulin resistance associated with ovo-lacto-vegetarian behavior in female Buddhists: a case-control study.* PloS one, 2013. **8**(8).

99.   Shang, P., et al., *Veganism does not reduce the risk of the metabolic syndrome in a Taiwanese cohort.* Asia Pacific journal of clinical nutrition, 2011. **20**(3): p. 404.

100. Gadgil, M.D., et al., *Dietary patterns in Asian Indians in the United States: an analysis of the metabolic syndrome and atherosclerosis in South Asians Living in America study.* Journal of the Academy of Nutrition and Dietetics, 2014. **114**(2): p. 238-243.

101. Kim, M.-H. and Y.J. Bae, *Postmenopausal vegetarians' low serum ferritin level may reduce the risk for metabolic syndrome.* Biological trace element research, 2012. **149**(1): p. 34-41.

102. Turner-McGrievy, G.M., et al., *Differences in environmental impact and food expenditures of four different plant-based diets and an omnivorous diet: results of a randomized, controlled intervention.* Journal of hunger & environmental nutrition, 2016. **11**(3): p. 382-395.

103. Satija, A., et al., *Healthful and unhealthful plant-based diets and the risk of coronary heart disease in US adults.* Journal of the American College of Cardiology, 2017. **70**(4): p. 411-422.

104. Alissa, E.M. and G.A. Ferns, *Dietary fruits and vegetables and cardiovascular diseases risk.* Critical reviews in food science and nutrition, 2017. **57**(9): p. 1950-1962.

105. Micha, R., et al., *Etiologic effects and optimal intakes of foods and nutrients for risk of cardiovascular diseases and diabetes: systematic reviews and meta-analyses from the Nutrition and Chronic Diseases Expert Group (NutriCoDE).* PloS one, 2017. **12**(4): p. e0175149.

106. Wu, Y., et al., *Fruit and vegetable consumption and risk of type 2 diabetes mellitus: a dose-response meta-analysis of prospective cohort studies.* Nutrition, Metabolism and Cardiovascular Diseases, 2015. **25**(2): p. 140-147.

107. Zhao, D., et al., *Ten-year cardiovascular disease risk of metabolic syndrome without central obesity in middle-aged chinese.* Am J Cardiol, 2007. **100**(5): p. 835-9.

108. Whitmee, S., et al., *Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health.* The Lancet, 2015. **386**(10007): p. 1973-2028.

109. Song, M., et al., *Association of animal and plant protein intake with all-cause and cause-specific mortality.* JAMA internal medicine, 2016. **176**(10): p. 1453-1463.

110. Micha, R., G. Michas, and D. Mozaffarian, *Unprocessed red and processed meats and risk of coronary artery disease and type 2 diabetes–an updated review of the evidence.* Current atherosclerosis reports, 2012. **14**(6): p. 515-524.

111. Sinha, R., et al., *Meat intake and mortality: a prospective study of over half a million people.* Archives of internal medicine, 2009. **169**(6): p. 562-571.

112. Benjamin, E.J., et al., *Heart disease and stroke statistics-2017 update: a report from the American Heart Association.* Circulation, 2017. **135**(10): p. e146-e603.

113. Gomes, A., et al., *Incidence of diabetes mellitus and obesity and the overlap of comorbidities in HIV+ hispanics initiating antiretroviral therapy.* PloS one, 2016. **11**(8).

114. Steinfeld, H., et al., *Livestock's long shadow: environmental issues and options*. 2006: Food & Agriculture Org.

115. Bälter, K., et al., *Is a diet low in greenhouse gas emissions a nutritious diet?– Analyses of self-selected diets in the LifeGene study.* Archives of Public Health, 2017. **75**(1): p. 17.
116. Farchi, S., et al., *Meat consumption reduction in Italian regions: Health co-benefits and decreases in GHG emissions.* PloS one, 2017. **12**(8).
117. van de Kamp, M.E., S.M. Seves, and E.H. Temme, *Reducing GHG emissions while improving diet quality: exploring the potential of reduced meat, cheese and alcoholic and soft drinks consumption at specific moments during the day.* BMC public health, 2018. **18**(1): p. 264.
118. Henning, B., *Standing in Livestock's ''Long Shadow'': The Ethics of Eating Meat on a Small Planet.* Ethics & the Environment, 2011. **16**(2): p. 63-93.
119. Hiroko Tabuchi, C.R.J.W. *Amazon Deforestation, Once Tamed, Comes Roaring Back* 2017; Available from: https://www.nytimes.com/2017/02/24/business/energy-environment/deforestation-brazil-bolivia-south-america.html.
120. Bennett, L., *Deforestation and climate change.* A publication of climate institute, 2017. **1400**.
121. Hu, Y., H. Cheng, and S. Tao, *Environmental and human health challenges of industrial livestock and poultry farming in China and their mitigation.* Environment international, 2017. **107**: p. 111-130.
122. Noya, I., et al., *Water Footprint of Livestock Farming*, in *Environmental Water Footprints*. 2019, Springer. p. 21-54.
123. van Zanten, H.H., et al., *Global food supply: land use efficiency of livestock systems.* The International Journal of Life Cycle Assessment, 2016. **21**(5): p. 747-758.
124. Dufour, A. and J. Bartram, *Animal waste, water quality and human health*. 2012: IWA publishing.
125. Sakadevan, K. and M.-L. Nguyen, *Livestock production and its impact on nutrient pollution and greenhouse gas emissions*, in *Advances in agronomy*. 2017, Elsevier. p. 147-184.
126. Wen, Y., G. Schoups, and N. Van De Giesen, *Organic pollution of rivers: Combined threats of urbanization, livestock farming and global climate change.* Scientific reports, 2017. **7**: p. 43289.
127. Cesoniene, L., M. Dapkiene, and D. Sileikiene, *The impact of livestock farming activity on the quality of surface water.* Environmental Science and Pollution Research, 2019. **26**(32): p. 32678-32686.
128. *Per Capita Meat Consumption in the United States*. Our World in Data; Available from: https://ourworldindata.org/grapher/per-capita-meat-usa.
129. Archer, E., G. Pavela, and C.J. Lavie. *The inadmissibility of what we eat in America and NHANES dietary data in nutrition and obesity research and the scientific formulation of national dietary guidelines*. in *Mayo Clinic Proceedings*. 2015. Elsevier.
130. Fehrenbach, K.S., A.C. Righter, and R.E. Santo, *A critical examination of the available data sources for estimating meat and protein consumption in the USA.* Public health nutrition, 2016. **19**(8): p. 1358-1367.

131. Agriculture, U.S.D.o. *Dietary Guidelines for Americans 2015 - 2020*. 2015; Available from: https://urldefense.proofpoint.com/v2/url?u=https-3A__health.gov_dietaryguidelines_2015_guidelines_chapter-2D1_a-2Dcloser-2Dlook-2Dinside-2Dhealthy-2Deating-2Dpatterns_-23food-2Dgroups&d=DwIFAg&c=bKRySV-ouEg_AT-w2QWsTdd9X__KYh9Eq2fdmQDVZgw&r=IOFrKQJgz_WYOigAE7D67rpYScpsgEKkehCJaiBPwv7hNVFDhA1eZmc54FyCFbO2&m=301GM67iT4KxGRZQfIUHxSO1PF1E3G4kVGUvHiHZmlo&s=GmrEjJSSJT5KZ2TQSkgxFSTwiHgz39WY1wSJ3nF2qJU&e=

132. Phillips, S.M., et al., *Commonly consumed protein foods contribute to nutrient intake, diet quality, and nutrient adequacy.* The American journal of clinical nutrition, 2015. **101**(6): p. 1346S-1352S.

133. Krebs, A. *Regional Differences in Consumes' Love of Beef*. 2019; Available from: https://www.perishablenews.com/meatpoultry/regional-differences-in-consumers-love-of-beef.

134. Rimal, A., *Meat labels: consumer attitude and meat consumption pattern.* International Journal of Consumer Studies, 2005. **29**(1): p. 47-54.

135. Ruby, M.B., et al., *Attitudes toward beef and vegetarians in Argentina, Brazil, France, and the USA.* Appetite, 2016. **96**: p. 546-554.

136. Van Den Berg, A., et al., *Design and evaluation of a coalition-led obesity initiative to promote healthy eating and physical activity in low-income, ethnically diverse communities: the Go! Austin/Vamos! Austin initiative.* Archives of Public Health, 2019. **77**(1): p. 25.

137. Graça, J., M.M. Calheiros, and A. Oliveira, *Attached to meat?(Un) Willingness and intentions to adopt a more plant-based diet.* Appetite, 2015. **95**: p. 113-125.

138. VanderWeele, T.J., *Principles of confounder selection.* European journal of epidemiology, 2019. **34**(3): p. 211-219.

139. Coffman, D.L. and W. Zhong, *Assessing mediation using marginal structural models in the presence of confounding and moderation.* Psychological methods, 2012. **17**(4): p. 642.

140. Larsson, S.C. and N. Orsini, *Red meat and processed meat consumption and all-cause mortality: a meta-analysis.* American journal of epidemiology, 2014. **179**(3): p. 282-289.

141. Springmann, M., et al., *Mitigation potential and global health impacts from emissions pricing of food commodities.* Nature Climate Change, 2017. **7**(1): p. 69-74.

142. Ekmekcioglu, C., et al., *Red meat, diseases, and healthy alternatives: A critical review.* Critical reviews in food science and nutrition, 2018. **58**(2): p. 247-261.

143. García-Jiménez, C.I. and A.K. Mishra, *Role of ethnicity in consumption of meat products.* Applied Economics Letters, 2011. **18**(7): p. 665-669.

144. Neff, R.A., et al., *Reducing meat consumption in the USA: a nationally representative survey of attitudes and behaviours.* Public health nutrition, 2018. **21**(10): p. 1835-1844.

145. Dibsdall, L.A., et al., *Low-income consumers' attitudes and behaviour towards access, availability and motivation to eat fruit and vegetables.* Public health nutrition, 2003. **6**(2): p. 159-168.

146. Ghaddar, S., et al., *Acculturation and healthy lifestyle habits among Hispanics in United States-Mexico border communities.* Revista Panamericana de Salud Publica, 2010. **28**: p. 190-197.

147. Norman, S., et al., *Comparing acculturation models in evaluating dietary habits among low-income Hispanic women.* Ethnicity and Disease, 2004. **14**(3): p. 399-404.

148. Schenk, P., J. Rössel, and M. Scholz, *Motivations and constraints of meat avoidance.* Sustainability, 2018. **10**(11): p. 3858.

149. Lentz, G., et al., *Gauging attitudes and behaviours: Meat consumption and potential reduction.* Appetite, 2018. **127**: p. 230-241.

150. Moreira, P.A. and P.D. Padrão, *Educational and economic determinants of food intake in Portuguese adults: a cross-sectional survey.* BMC public health, 2004. **4**(1): p. 58.

151. Arbit, N., M. Ruby, and P. Rozin, *The Meaning of Food in Life Scale: Evidence for Links with Healthy Eating, a Positive Relationship to Food, and Established Determinants of Healthy Eating Behavior.* Journal of Nutrition Education and Behavior, 2017. **49**(7): p. S5-S6.

152. Vandermoere, F., et al., *Meat Consumption and Vegaphobia: An Exploration of the Characteristics of Meat Eaters, Vegaphobes, and Their Social Environment.* Sustainability, 2019. **11**(14): p. 3936.

153. Cummins, S., et al., *Large scale food retailing as an intervention for diet and health: quasi-experimental evaluation of a natural experiment.* Journal of Epidemiology & Community Health, 2005. **59**(12): p. 1035-1040.

154. McCormack, L.A., et al., *Review of the nutritional implications of farmers' markets and community gardens: a call for evaluation and research efforts.* Journal of the American Dietetic Association, 2010. **110**(3): p. 399-408.

155. Sharpe, P., et al., *Evaluation of a Food Hub Initiative's Effect on Food Shoppers' Perceptions, Shopping Behavior, Diet, and Weight in a Community of Low Income and Low Access to Healthy Food (OR16-06-19).* Current developments in nutrition, 2019. **3**(Supplement_1): p. nzz051. OR16-06-19.

156. Kim, D.J. and E.J. Holowaty, *Brief, validated survey instruments for the measurement of fruit and vegetable intakes in adults: a review.* Preventive medicine, 2003. **36**(4): p. 440-447.

157. Rodrigo, C.P., et al., *Food frequency questionnaires.* Nutricion hospitalaria, 2015. **31**(3): p. 49-56.

158. Willett, W. and E. Lenart, *Reproducibility and validity of food-frequency questionnaires.* Nutritional epidemiology, 2013. **3**.

159. Subar, A.F., et al., *Comparative validation of the Block, Willett, and National Cancer Institute food frequency questionnaires: the Eating at America's Table Study.* American journal of epidemiology, 2001. **154**(12): p. 1089-1099.

160. Cade, J., et al., *Development, validation and utilisation of food-frequency questionnaires–a review.* Public health nutrition, 2002. **5**(4): p. 567-587.

161. Jackson, M.D., et al., *Use of a food frequency questionnaire to assess diets of Jamaican adults: validation and correlation with biomarkers.* Nutrition journal, 2011. **10**(1): p. 28.

162. Fraser, G.E., et al., *Biomarkers of dietary intake are correlated with corresponding measures from repeated dietary recalls and food-frequency questionnaires in the Adventist Health Study-2.* The Journal of nutrition, 2016. **146**(3): p. 586-594.

163. Boeing, H., et al., *The relative validity of vitamin intakes derived from a food frequency questionnaire compared to 24-hour recalls and biological measurements: results from the EPIC pilot study in Germany. European Prospective Investigation into Cancer and Nutrition.* International journal of epidemiology, 1997. **26**(suppl_1): p. S82.

164. Thompson, F.E., et al., *Comparison of interviewer-administered and automated self-administered 24-hour dietary recalls in 3 diverse integrated health systems.* American journal of epidemiology, 2015. **181**(12): p. 970-978.

165. Hughes, A.R., et al., *Comparison of an interviewer-administered with an automated self-administered 24 h (ASA24) dietary recall in adolescents.* Public health nutrition, 2017. **20**(17): p. 3060-3067.

166. Harnack, L.J. and M.A. Pereira, *Strategies for Improving the Validity of the 24-hour Dietary Recall and Food Record Methods*, in *Advances in the Assessment of Dietary Intake*. 2017, CRC Press. p. 67-84.

167. Block, G., et al., *Comparison of two dietary questionnaires validated against multiple dietary records collected during a 1-year period.* Journal of the American Dietetic Association, 1992. **92**(6): p. 686-693.

168. Lutz, L.J., et al., *Serum and Erythrocyte Biomarkers of Nutrient Status Correlate with Short-Term A-Carotene, B-Carotene, Folate, and Vegetable Intakes Estimated by Food Frequency Questionnaire in Military Recruits.* Journal of the American College of Nutrition, 2019. **38**(2): p. 171-178.

169. Tanner, K.J. and R.P. Watowicz, *Development of a tool to measure the number of foods and beverages consumed by children using National Health and Nutrition Examination Survey (NHANES) FFQ data.* Public health nutrition, 2018. **21**(8): p. 1486-1494.

170. Conway, J.M., L.A. Ingwersen, and A.J. Moshfegh, *Accuracy of dietary recall using the USDA five-step multiple-pass method in men: an observational validation study.* Journal of the American Dietetic Association, 2004. **104**(4): p. 595-603.

171. Ahuja, J., et al., *USDA Food and Nutrient Database for Dietary Studies, 5.0–Documentation and User Guide.* US Department of Agriculture, Agricultural Research Service, Food Surveys Research Group: Beltsville, MD, USA, 2012.

172. Rasch, D. and V. Guiard, *The robustness of parametric statistical methods.* Psychology Science, 2004. **46**: p. 175-208.

173. Bland, J.M. and D.G. Altman, *Measuring agreement in method comparison studies.* Statistical methods in medical research, 1999. **8**(2): p. 135-160.

174. Bland, J.M. and D. Altman, *Statistical methods for assessing agreement between two methods of clinical measurement.* The lancet, 1986. **327**(8476): p. 307-310.

175. Bunce, C., *Correlation, agreement, and Bland–Altman analysis: statistical analysis of method comparison studies.* American journal of ophthalmology, 2009. **148**(1): p. 4-6.

176. Shatenstein, B. and H. Payette, *Evaluation of the relative validity of the short diet questionnaire for assessing usual consumption frequencies of selected nutrients and foods.* Nutrients, 2015. **7**(8): p. 6362-6374.

177. Boucher, B., et al., *Validity and reliability of the Block98 food-frequency questionnaire in a sample of Canadian women.* Public health nutrition, 2006. **9**(1): p. 84-93.

178. Willett, W.C., *Future directions in the development of food-frequency questionnaires.* The American journal of clinical nutrition, 1994. **59**(1): p. 171S-174S.

179. Bingham, S.A., et al., *Comparison of dietary assessment methods in nutritional epidemiology: weighed records v. 24 h recalls, food-frequency questionnaires and estimated-diet records.* British Journal of Nutrition, 1994. **72**(4): p. 619-643.

180. Shim, J.-S., K. Oh, and H.C. Kim, *Dietary assessment methods in epidemiologic studies.* Epidemiology and health, 2014. **36**.

181. Thompson, F.E. and A.F. Subar, *Dietary assessment methodology*, in *Nutrition in the Prevention and Treatment of Disease*. 2017, Elsevier. p. 5-48.

182. Bautista, L.E., O.F. Herran, and J.A. Pryer, *Development and simulated validation of a food-frequency questionnaire for the Colombian population.* Public health nutrition, 2005. **8**(2): p. 181-188.

183. Hebden, L., et al., *Validity and reproducibility of a food frequency questionnaire as a measure of recent dietary intake in young adults.* PloS one, 2013. **8**(9).

184. Dehghan, M., et al., *Relative validity of an FFQ to estimate daily food and nutrient intakes for Chilean adults.* Public health nutrition, 2013. **16**(10): p. 1782-1788.

185. Do, M., et al., *Low-income young adults report increased variety in fruit and vegetable intake after a stage-tailored intervention.* Nutrition research, 2008. **28**(8): p. 517-522.

186. Pearson, N., et al., *A family-based intervention to increase fruit and vegetable consumption in adolescents: a pilot study.* Public health nutrition, 2010. **13**(6): p. 876-885.

187. Resnicow, K., et al., *A motivational interviewing intervention to increase fruit and vegetable intake through Black churches: results of the Eat for Life trial.* American journal of public health, 2001. **91**(10): p. 1686-1693.

188. Haire-Joshu, D., et al., *High 5 for Kids: the impact of a home visiting program on fruit and vegetable intake of parents and their preschool children.* Preventive medicine, 2008. **47**(1): p. 77-82.

189. Yoder, A.B.B., et al., *Farm to elementary school programming increases access to fruits and vegetables and increases their consumption among those with low intake.* Journal of Nutrition Education and Behavior, 2014. **46**(5): p. 341-349.

CONCLUSION

This dissertation is composed of three papers intended to explore aspects of the intersection of diet, health, and the environment. In the first, we used a nationally representative dataset from NHANES to examine the association of proportion of plants in the diet (PPD) to Metabolic Syndrome (MetS) criteria and MetS. Results suggest that increasing the PPD significantly decreases the risk for hypertension and for MetS. In the second paper, data from the Go Austin! Vamos Austin! (GAVA) study was used to assess the relationship of three potential motivations (health, environment, cost) for willingness to reduce meat consumption in a diverse population, and associations of the composite Meat Reduction Score (MRS) with daily fruit and vegetable consumption, as well as with weekly servings of meat. The cost motivation was strongest for women, and the health motivation was important to all race/ethnicities and income groups. Daily servings of fruits and vegetables were significantly and positively associated with higher scores on the MRS, while weekly serving of meat were significantly and negatively associated, suggesting that changing attitudes towards reducing the consumption of meat may result in higher fruit and vegetable consumption and lower meat consumption in this population. Finally, the third paper validated a truncated Food Frequency Questionnaire (FFQ) compared to three 24-hour Dietary Recalls. The FFQ provided good correlation and agreement, and may be sufficiently accurate to provide valid measure of fruit and vegetable consumption, while also reducing survey burden in diverse (majority Hispanic) populations.

Shifting dietary patterns to include a greater proportion of plant-based foods may provide protection from chronic disease, while reducing harmful impacts of the food system

on the environment. This research offers further evidence for the health benefits of increasing the proportion of plants in the diet, then suggests potentially effective approaches to instigating behavioral change, and finally provides a feasible method for capturing consumption behavior in diverse populations.

Each study had limitations, such as a lack of granularity in food codes in Paper #1, potential bias from self-reported data in Paper #2, and reduced power from limited sample size in Paper #3. Further research to accurately define the characteristics of a beneficial plant-based diet may help researchers and policy-makers fine tune efforts to improve chronic disease outcomes in a variety of populations. There is also a paucity of research into the psychosocial determinants of reducing the consumption of meat, which is distinct from the relatively well-studied determinants of fruit and vegetables consumption. Further research into best practices for increasing awareness of the benefits of reducing meat consumption may be warranted. Finally, feasible and accurate dietary assessment continues to be a challenge that may benefit from further research and technological innovation.

Dietary patterns have the potential to support human and environmental health, or to undermine it. Given the high cost of chronic disease, most recently illustrated by the devastating effect of COVID-19 on those who present with pre-existing co-morbidities, and the unrelenting challenge of climate change, the alignment of dietary patterns to benefit both personal health and global environmental concerns seems more imperative than ever before. This work is offered as a small step forward in the effort to support individuals and organizations in their work to realize the goal of healthy people in a healthy world.

Appendix A

2015-2016 PPD
FoodCode FINAL.xls

Appendix B

Appendix C