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DIETARY FERMENTABLE CARBOHYDRATE (FC) CONSUMPTION AND ASSOCIATIONS WITH DIET QUALITY AND HEALTH PARAMETERS

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DIETARY FERMENTABLE CARBOHYDRATE (FC) CONSUMPTION AND ASSOCIATIONS WITH DIET QUALITY AND HEALTH PARAMETERS

BY

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ABSTRACT

Excessive body fat and related dysmetabolic complications concern both emerging and developed countries. An important environmental cause of these conditions is the altered composition of gut microbiota, which is influenced by the host diet. A number of clinical trials target gut microbiome composition or functions with fermentable carbohydrates (FCs) to promote a healthier profile. Total dietary fiber, which includes both FC and non-fermentable carbohydrates, is considered a promising tool for the prevention of chronic diseases. This has led to significant changes in food and health recommendation with an increase in dietary fiber intake advised. However, reference to other FCs such as resistant starches, non-starch polysaccharides, polyols (lactitol, sorbitol, mannitol, etc.), soluble dietary fibers (SDF), and oligosaccharides (fructo- and galacto-oligosaccharides, etc.) are still lacking. Intakes of FC in free-living adults remain largely under-investigated, but the limited work to date suggests that they tend to be low. Determining overall dietary components and patterns associated with FCs might allow adjustment for diet in many future studies and can eventually help increase the habitual consumption of all FCs. Identifying the average consumption of all types of FCs and their associations with health outcomes in free-living populations might inform treatment practices that include all types of FCs to improve clinical outcomes and help to include them in dietary guidelines than just dietary fiber. Based on this background, the objectives, hypotheses, methods, and results of this dissertation are threefold:

Manuscript-1: The goal of this study was to analyze the association between the consumption of FCs and the total healthy eating index 2015 (HEI-2015) as well as

HEI-2015 components. The study involves a US college student population, considering they are at the decisive stage of their dietary choices and at high risk of developing metabolic diseases. The Diet History Questionnaire-II (DHQ-II) was used to estimate dietary intake of FCs, and a simple HEI algorithm scoring method, which is a publicly available statistical code from the Division of Cancer Control and Population Sciences of the National Cancer Institute, was used to calculate the HEI-2015 total score and component scores. The relationship between FC intake and total HEI-2015 and the component score was assessed using a simple linear regression model. The result concluded that the higher total FCs intake was related to a higher HEI-2015 score and hence higher diet quality. Furthermore, the HEI adequacy components such as vegetables, sea/plant proteins, and fruits (total and whole) are associated with a higher intake of FCs, whereas total dairy showed an inverse association. Additionally, the association between moderation components and FC intake was not as strong as the adequacy components.

Manuscript-2: The purpose of this cross-sectional study was to examine the intake of quantified FCs (e.g., SDF and polyols, etc.), in US college students and to explore possible health differences between higher and lower consumers. Short-term laboratory studies show that FCs positively influence health through energy homeostasis., However, consumption of these FCs in college students has not been thoroughly investigated and their possible health benefits have not been well elucidated. The study included anthropometric, demographic, and dietary intake data from 587 students at the University of Rhode Island. A median split was used to classify higher and lower FC consumers. Stepwise multiple linear regression evaluated the differences in FC consumption and health outcomes while controlling for confounders. The results showed that the consumption of FC and subclasses (SDF and polyol) were low compared to the quantity used in intervention studies. Despite this fact, the results suggest that there was an inverse association between FC intake and blood glucose levels, percent body fat, blood pressure, and LDL-c levels in this population.

Manuscript-3: This cross-sectional study aimed to analyze the consumption of FCs and subclasses in plant-based (PT) and meat-based (MT) diet groups in US adults. We also compared the diet quality in PT- *vs* MT-based diet and explored whether diet quality alters the FC consumption in PT and MT diets. Prior research focused on the abundance of FCs in plant-based diets (e.g. vegan, vegetarian) and potential relations with health outcomes, however, limited evidence exists that compares the varying FC intake in PT *vs* MT diets. We hypothesized that perhaps FCs are related to a high-quality diet and not just plant-based diets. Data were collected through online surveys from participants who adhered to PT-diets (no consumption of animal flesh) and MT-diet (≥7 times animal flesh/week) for at least the prior three months. An independent-sample t-test was used to observe the mean difference in FC consumption in PT and MT diet groups and stepwise multiple regression was used to analyze the diet quality of these two diet groups. Study results suggest that eating better-quality diets, either plant-based or animal-based, was associated with higher consumption of FCs among US adults, and the lowest FC consumption was observed in low-quality MT-based diet groups.

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DEDICATION

I would like to dedicate this dissertation to my family.

To my husband, Ajinkya who is the greatest support I have here in the U.S., his dedication to help me and to answer my unending questions mesmerizes me in many ways. Thank you for showing faith in me.

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PREFACE

This dissertation is presented in the Manuscript Format. These projects are three chapters that are from two different studies through the University of Rhode Island, in the pursuit of finding new ways to improve public health through healthy eating. Upon completion of the final dissertation submission, each of the three manuscripts presented will be submitted for publication to the specified journal highlighted on each manuscript title page. This dissertation was focused on evaluating the average consumption of fermentable carbohydrates, along with their relationships to health outcomes and diet quality of free-living US adults. It is an honor to provide even a small contribution that might improve public health. It is hoped that this research adds meaningful information to the body of literature around gut microbiome research and healthy eating.

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Manuscript 1 "Dietary contributors to fermentable carbohydrate intake in healthy American college students"

by

will be submitted to the *Journal of American College Health*

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ABSTRACT

Objective: College students are at the decisive stage of their dietary choices. Because their average diet quality tends to be low, they are at high risk of developing metabolic diseases. Some of these metabolic consequences result from low diet quality leading to altered gut microbiota composition. Dietary fermentable carbohydrates (FCs) are known to somewhat normalize this altered microbiota and eventually improve health. Though, research has not yet established which dietary components of food groups are associated with increased FC consumption and whether FCs are related to high-quality diets in college students. Diet quality assessed by the healthy eating index 2015 (HEI-2015) has adequacy components (higher intake is beneficial) and moderation components (lower intake is beneficial) and has been issued to correspond to the 2015-2020 United States Dietary Guidelines (USDG). The proposed cross-sectional study examined the association between the consumption of FCs and subclasses (such as soluble dietary fibers and polyols) with the HEI-2015, HEI components, and dietary food groups that might contribute to the increased FC intake in healthy US college students. We also evaluated the habitual consumption of FCs in this college student population as an exploratory aim. The primary hypothesis was that FC consumption positively predicts HEI scores, and the secondary hypothesis was that HEI adequacy components are associated with increased FC consumption.

Methods: This is a cross-sectional secondary data analysis. The Diet History Questionnaire (DHQ II), a web-based food frequency questionnaire was used to quantify the consumption of total FCs and subclasses such as soluble dietary

fibers (SDF) and polyols. The consented students who are ≥18 years old and energy intake was 500 to 3500 kcal/day for women and 800-4000 kcal/day for men were included, whereas pregnancy, and non-compliance with fasting were the exclusion criteria. To quantify total FCs (in grams) consumption, all available types of fermentable carbohydrates (e.g. SDF, polyol) were added together. We used the publicly available simple HEI algorithm scoring method provided by the national cancer institute (NCI) to calculate the HEI-2015 total score and component scores. Association between FC consumption and HEI-2015 total and HEI component score were tested with unadjusted linear regression and the Spearman correlation between the dietary food groups and FC intake was calculated.

Results: A sample of 571 students enrolled in introductory nutrition classes at the University of Rhode Island volunteered for the study, of which 96% of students were between 18 and 24 years old 80.7% were female, and 84.5% were white with a mean HEI-2015 score of 65.5±10.7 and average energy intake was 1789±709 kcal. The average daily intake of FC was 7.1±3.6g, SDF 6.2±3.2g, and polyol 1.0±0.8g. Average daily consumption of FCs statistically significantly predicted HEI-2015 score, $F(1, 568) = 116.7$, $p < 0.0005$, accounting for 17% of the variation in total HEI-2015 score with adjusted $R^2 = 16.9\%$, a medium-size effect according to Cohen. Pearson correlation coefficient (R)= 0.41 indicated a moderate-strength correlation. An extra gram daily FCs consumption was associated with a 1.24 (95% CI, 1.02-1.47) point increase in the total HEI-2015 score. Similarly, average daily consumption of SDF $F(1, 568) = 88.04$, $p < 0.0005$ and polyol $F(1, 568) = 129.6$, $p < .0005$ (both are types of FCs) statistically significantly predicted total HEI-2015 score accounting for 14% and 19% of the variation in total HEI score respectively. An extra gram daily SDF intake was associated with a 1.26 (95% CI, 0.99 to 1.52) higher total HEI-2015 score, and an extra gram daily of polyol consumption was associated with a 6.06 (95% CI, 5.02 to 7.11) point higher total HEI-2015 score.

Of the HEI-2015 components, total vegetable consumption [β=0.91 (95% CI, 0.69–1.13)], total fruit 0.86 (0.66–1.06) and whole fruit 0.83 (0.61–1.05), showed a higher association with FCs intake compared to other HEI components. Similarly, Sea/plant protein [0.75 (0.53–0.96)], greens/bean [0.69 (0.51-0.87)] and total protein [0.57 (0.31-0.84)] also showed fairly-strong significant associations with FCs consumption. Whereas, total dairy, from the adequacy components, was inversely related to FCs consumption −0.32, (-0.42- -0.21). Of the HEI-2015 moderation components, refined grains 0.18 (0.07-0.29), saturated fat 0.35 (0.25–0.45) and added sugar 0.21 (0.11-0.32) showed positive associations with FCs consumption. Additionally, Pearson correlation showed the total red and orange vegetables (0.62), dark green vegetables (0.58), and whole fruit (0.63) showed a strong positive correlation with FC intake.

Conclusion: The study concluded the total grams of average daily FC and subclasses consumption was low in this population of college students compared to the grams used in intervention studies for health benefits. Higher total FCs intake was related to a higher HEI-2015 score as well as adequacy components of HEI-2015 such as vegetables and fruits (total and whole) whereas inversely associated with total dairy. Additionally, the association between moderation components and FC intake was not as strong as the adequacy components. These findings emphasize the increased consumption of vegetables and fruits in college students not only improves their diet quality but also increases their FC intake.

1. Introduction

The prevalence of overweight and obesity has dramatically increased in young adults over the last 20 years[1-3]. Unhealthful dietary behaviors during the first semester of college are considered as one of the main causes contributed towards weight gain[4]. Recent evidence suggests that diets higher in fermentable carbohydrates (FCs) help to improve metabolic conditions by influencing host-microbiota symbiosis[5, 6]. FCs are a diverse group of complex indigestible carbohydrates; mostly including resistant starches, non-starch polysaccharides, indigestible oligosaccharides, polyols (e.g. sorbitol, mannitol, erythritol, xylitol, pinitol, etc.), plant cell wall polysaccharides, and soluble dietary fibers[7]. FCs are neither hydrolyzed nor absorbed in the upper part of the human gastrointestinal tract but are metabolized by the number of beneficial bacteria present in the gastrointestinal tract into short-chain fatty acids (SCFAs)[5, 6] which are known to help modulate energy intake and attenuate weight gain[8-11]. FCs are considered the main energy source for gut microbiota, with higher dietary FCs promoting a beneficial microflora[5]. Despite this knowledge about the potential health benefits of FCs, the habitual consumption in college students is unknown.

Additionally, the relationship of FC to diet quality has never been explored. Diet quality is useful to assess the overall healthfulness of total diets[12]. The Healthy Eating Index (HEI) is one measure of diet quality, which is based on healthy consumption of nutrients or food groups and reflects adherence to the United States Dietary Guidelines (USDG). The USDG were not designed with any FCs in mind; therefore, it remains unknown how well adherence to the USDG is associated with higher total FC intake and intake of FC subclasses such as soluble dietary fibers (SDF), oligosaccharides, and polyols. In addition, very limited research has been conducted on the identification of specific dietary components of HEI, and food groups (e.g., fruits, vegetables, grains (whole/refined), etc.) that contribute most towards FC intake.

The Dietary Reference Intakes (DRIs) include total dietary fibers which are commonly classified as soluble and insoluble dietary fibers; of which SDFs are a subclass of FCs (but insoluble dietary fibers are not)[13, 14]. Previous research mainly focused on total dietary fibers and has shown that the adequate intake of dietary fiber is important for health[15-17] as well as prevention of chronic diseases[18-21], however, college students are not meeting the minimum recommended dietary guidelines for fiber intake[22, 23]. College students do not consume adequate amounts of dietary fiber from dietary sources such as fruits and vegetables[24, 25] which is also a major source of non-fiber FCs, therefore it is very likely that they are also not consuming enough FCs. Additionally, some fruits (such as strawberries and nectarines) and vegetables (mushrooms, garlic, onion, and scallion) are also high in FCs, but not the significant sources of dietary fibers[26, 27].

Published evidence suggests that 4-8 g/d of non-fiber FC intake[28] (includes polyols and oligosaccharides but excludes SDF) may be required to observe a significant impact on health. Polyols included in this study are also called 'sugar alcohols' and are the most prevalent low digestible carbohydrate in the US food supply, with low caloric density, sweet taste, and low glycemic index[29-31]. They are naturally found in fruits (such as strawberries, plums, and cherries) and vegetables (cauliflower and mushrooms)[29, 30]. Oligosaccharides (OS) consist of 3-10 monosaccharide units linked by β-glycosidic bonds and include two subtypes: 1) fructo-oligosaccharides (FOS) and 2) galacto-oligosaccharides (GOS)[32]. FOS can be found in scallions, fruits, artichokes, grains, onions, and pasta and GOS can be found in peas, soy, lentils, and beans[33]. These non-fiber FCs may elicit health benefits even after small consumption[34, 35], however, there is no consistent reference intake amount in the literature, as there is for dietary fiber. Therefore, it is important to evaluate habitual consumption of FCs in college students, which includes other non-fiber FCs (polyols and oligosaccharides), not just total dietary fibers, while taking a whole diet component approach in free-living populations. Additionally, the western lifestyle, which usually has low diet quality, decreases the overall consumption of FCs[35-37]. Unfortunately, young adults easily adapt to western lifestyle[38]. Consequently, lower consumption of dietary fiber in college students (10.5 ± 5.6g/1000kcal) than recommended by the USDG (14g/100kcal)[39], along with low FCs, might be one of the reasons that their average diet quality tends to be low[40, 41]. However, associations of FCs and their subclasses with dietary quality and the USDG have not been investigated in college students[40, 41].

Therefore, the study aimed to: (1) analyze the association between intake of FCs and subclasses and diet quality (assessed by HEI-2015), (2) identify the HEI components and food groups that are associated with increased FC intake, and (3) describe the food items that contributed towards these food groups in the US college students. The study also aimed to quantify the habitual consumption of FCs and subclasses in college students for the first time.

2. Methods

For this cross-sectional study, we used data from an ongoing research program conducted at the University of Rhode Island (URI). Institutional Review Board [42] approval was obtained for the study and all participants sign IRB-approved consent forms if they want to permit their data to be used for research.

2.1 Subjects and Recruitment: URI students enrolled in an introductory nutrition course (NFS210) completed the dietary, anthropometric, biochemical, and health assessments as mandatory course activities. The course teaching assistants and the research assistant involved in this study check the eligibility of the students to participate, provide detailed information about the study, conduct the consenting process, and collect signed consent forms from those who accept the invitation to participate. This data collection first started in fall 2015 and it is still an ongoing process in the Nutrition and Food Sciences Department. This present study included a total of nine cross-sections between the fall 2015 to spring 2020 semesters. Consented students who completed the data collection process and were ≥18 years of age were included (n=711). Current pregnancy/lactation was an exclusion criterion. Female participants who reported consuming <500-3500 kcal< and male participants <800-4000kcal< energy intake[43] per day (n=81) and incomplete dietary questionnaires (n=60) were also excluded from the analysis[44] leaving a final analytic sample of n=571.

2.2 Data Collection Procedure

2.2.1 Descriptive Data: Students completed survey assessments online at the start of the semester and during their regular lab periods. Participants completed a brief standardized demographic survey where information regarding age, sex, smoking habits (yes/no), and ethnicity was collected. Physical activity was calculated using the International Physical Activity Questionnaire (IPAQ)[45] and descriptive results included an average of moderate and vigorous physical activity days/week. The Dietary History Questionnaire-II (DHQ-II) was used to collect information regarding total energy consumption and FC intake (details are below). Teaching assistants of the course measured height duplicate on a digital wall-mounted stadiometer (SECA 240, Hamburg, Germany), to 0.1 cm, with an average of the two measures recorded and weight on a digital scale (SECA 700, Hamburg, Germany), to 0.1 kg, with the average of the two measurements recorded which was used to calculate body mass index (BMI) as kg/m^2. These data points were used for the descriptive purposes of the study population.

2.2.2 Diet History Questionnaire (DHQ-II): DHQ-II is an electronic food frequency questionnaire (FFQ) that consists of 124 food items, including both portion size and dietary supplement questions. This validated DHQ provides nutrient estimates, takes about 45 minutes to complete, and is designed based on cognitive research findings, to be easy to use. Participants cannot submit the DHQ if any item is left incomplete.

2.2.3 Calculate FC consumption: Diet*Calc software was used to generate the nutrient estimates from the DHQ data using the food and nutrient database. Diet*Calc consists of three main components- 1) food frequency data ii) data dictionary to interpret the DHQ data files and iii) database utility, which allowed us to import nutrient data into the Diet*Calc food database. Estimated FCs by the DHQ-II included soluble dietary fibers (SDF, which includes oligosaccharides) and polyols such as Erythritol, Lactitol, Inositol, Pinitol, Sorbitol, Xylitol, Isomaltose, Maltitol, and Mannitol. To quantify total FCs consumption (in grams), all available types of fermentable carbohydrates data (e.g., SDF, all polyols) were added together.

2.2.4 Diet Quality: Diet quality was assessed using HEI-2015, a multi-component scoring method to assess individuals' diet quality[46]. HEI-2015 reflects adherence to the US Dietary Guidelines ranging from 1 to 100, with higher scores reflecting greater adherence and diet quality[47]. The maximum score of 100 is the sum of 9 adequacy and 4 moderation component scores. The a*dequacy components* represent the food groups, subgroups, and dietary elements that are encouraged. For these components, **higher** scores reflect **higher** intakes, because higher intakes are desirable. *Moderation components* embody the dietary elements and food groups for which there are recommended restrictions for intake. For moderation components, **higher** scores are associated with **lower** intakes, because lower intakes are more desirable. Overall, a higher total HEI score indicates a diet that aligns better with dietary recommendations, particularly the USDG[48].

2.2.5 HEI-2015 Total and Component Scoring Method: For HEI scoring methods all HEI components were weighted equally. The 13 HEI components are scored on a density basis out of 1000 calories, except for fatty acids, which is a ratio of unsaturated to saturated fatty acids[47]. Total fruits, greens and beans, total vegetables, whole fruits, protein-containing foods, and seafood and plant proteins score 5 for the highest consumption and 0 for the lowest consumption. The highest score is 10 for the consumption of three components, dairy, whole grains, and fatty acids[47, 49] (ratio of poly- and monounsaturated fatty acids to saturated fatty acids), and is 0 for the lowest consumption. Whereas the remaining four components (refined grains, added sugars, sodium, and saturated fats) score 0 for the highest consumption and 10 for the lowest consumption[47,50]. Component scores were summed to yield a total score ranging from 0 to 100, with a higher score indicating greater adherence to the USDG. We used the simple HEI algorithm scoring method, which is a publicly available statistical code from the Division of Cancer Control and Population Sciences of the National Cancer Institute to calculate the HEI-2015 total score and component scores[51].

2.2.6 Food groups in DHQ-II: The food group variables available in the DHQ-II database are based on the U.S. Department of Agriculture's (USDA) MyPyramid Equivalents Database (MPED) and Food Pattern Equivalent Database (FPED). The FPED (current name of former MPED) variables used in this study convert foods and beverages into 9 major food groups. These 9 food groups include vegetables, fruits, dairy, protein, grain, added sugar, fats, oils, and alcohol. The food groups are defined as the number of cup equivalents of vegetables, fruit, and dairy; ounce equivalents of protein and grain foods; teaspoon equivalents of added sugars; gram equivalents of oils and solid fats; and the number of alcoholic drinks. In FPED, many food groups are subdivided into food items such as the Red and Orange Vegetable component is sub-divided into Tomato and Other Red Vegetables, Starchy Vegetables into Potatoes (white) and Other Starchy Vegetables; the Meat, Poultry, and Seafood component is subdivided into Meat, Poultry, Organ Meat, Cured Meat, Seafood high in n-3 fatty acids, and Seafood low in n-3 fatty acids to provide in-depth data analysis. These subgroups aggregate into a total of 37 food items used in this study analysis to further tease apart the food items that contribute most towards the FC intake.

(Appendix I contains a detailed list of foods included in each of the 37 Food items in FPED).

2.3 Statistical analysis:

Before analyses, the research staff double-checked all the data for data entry errors, missing data, etc. All data were analyzed for normality assessment by skewness and kurtosis. Descriptive statistics were used to summarize demographics using frequencies and percentages to present categorical variables and mean±standard deviation for continuous variables. Statistical tests were conducted with a 2-tailed α (alpha) and significance accepted at $p < 0.05$.

Unadjusted simple linear regression was run to understand the relationship between FCs consumption and total HEI-2015 score. To assess linearity a scatterplot of HEI-2015 score against FCs consumption with a superimposed regression line was plotted. The beta coefficients [with 95% confidence intervals (CIs) and *p*-values] were calculated to examine associations. To measure the strength of associations between dependent and independent variables we reported the Pearson correlation coefficient (R) and the percentage of variance that is also the estimate of effect size represented by adjusted (R^2)[52].

The relationship between the HEI-2015 component score and the FCs consumption was assessed using an unadjusted linear regression model as described above. We further analyzed the correlations among the 37 food items, and FC intake was assessed by bivariate correlation coefficient. All statistical analyses were performed with SPSS version 24 (Statistical Package for Social Sciences, IBM-SPSS Inc., Armonk, New York).

3. Results

3.1 Demographic characteristics:

The study included a total of 9-cross sections of the ongoing data collection between Fall 2015-Spring 2020, except spring 2018. We collected demographic and nutrient consumption data from a total of 711 consented students (figure 1). Of these, 60 did not complete the online DHQ-II and a total of 72 were excluded who reported energy other than 500 to 3500 kcal/day for women and 800-4000 kcal/day for men[43]. There was a total of 9 students who enrolled twice in the course; for these cases, the most complete data set was used for each participant. Finally, data from 571 students have been used in the analysis (table 1) of which 96% of participants were between 18 and 24 years old, 80.7% were female, and 84.5% were white. The mean consumption of total available FCs in this student population was 7.1±3.6g. The total mean SDF consumption was 6.2±3.2g and polyol (non-fiber FC) 1.0±0.8g (table 1). According to the DHQ-II data, on average students consumed 1789±709 kcal/day and the HEI of this population was 65.5±10.7 out of 100. The details of the mean HEI component scores are presented in Table-1**.**

In examining this student population's mean HEI-2015 component scores, the lowest mean score from the adequacy components was for whole-grain intake 2.3±1.4 (out of 10), whereas the highest mean component score was for total protein 4.3±1.2 and whole fruit consumption 4.2±1.4 (both out of 5), among all 13-HEI component scores. Overall, the mean HEI component scores for fatty acids (5.7±3.2) and total dairy (5.8±2.8) were comparatively low values (both out of 10).

Of the four moderation components, the highest mean score was for refined grains 7.8±2.6 (out of 10) and the lowest mean score was for sodium 5.1 ±2.8 (out of 10). The mean score for added sugar was 7.6±2.8, and for saturated fat was 6.7±2.8, both of which are scored out of 10 points (table 1).

3.3 FC intake and total HEI-2015 score:

Linear regression was run to understand the relationship between the average daily consumption of FCs and total HEI-2015 scores. Average daily consumption of FCs statistically significantly predicted HEI-2015 score, $F(1, 568) = 116.7$, $p < 0.0005$, accounting for 17% of the variation in total HEI-2015 score with adjusted $R^2 = 16.9\%$, a medium-size effect according to Cohen[53]. Pearson correlation coefficient R= 0.41 indicates a moderate-strength correlation. An extra gram daily FCs consumption was associated with a 1.24 (95% CI, 1.02-1.47) point increase in the total HEI-2015 score.

Similarly, the scatterplot of the HEI-2015 score against the average daily consumption of SDF and polyols (types of FCs) displayed a linear relationship (Figures 3 and 4 respectively). The average daily consumption of SDF, $F(1, 571) = 84.6$, $p < 0.0005$ and polyols $F(1, 571) = 129.6$, $p < 0.0005$ statistically significantly predicted total HEI-2015 score (Table 2). An extra gram daily SDF intake associated with 1.26 (95% CI, 0.99-1.52), and polyol consumption 6.06 (5.02-7.11) point increase in total HEI-2015 score (table 2) in this population.

3.3 FCs and HEI component score

As shown in table 3 there were positive significant associations between most of the adequacy components of HEI-2015 and FC consumption in this population of college students.

Overall Vegetables (β =0.91, 95% CI, 0.69-1.13), total fruits 0.86 (0.66-1.06) and whole fruits 0.83 (0.61-1.05) associated with higher FC intake, followed by sea/plant protein 0.71 (0.52-0.91), greens/beans 0.69 (0.51-0.87), and total protein 0.57 (0.31-0.84). Whereas total dairy from the adequacy components was inversely related to FCs consumption −0.29 (−0.41 to −0.17).

Of the HEI-2015 moderation components, saturated fat 0.35 (0.25–0.45), added sugar 0.21 (0.11-0.32) and refined grain 0.18 (0.07-0.29) were positively associated with FCs consumption. Sodium showed a negative association with FC consumption but was not statistically significant.

3.4 Correlation between Food items and FC intake

Of the 9 food groups, total vegetables (0.69), total fruits (0.67), and oils (0.51) showed strong positive correlations with FC intake. Total protein (0.44) and total grains (0.32) showed moderate positive correlations, and dairy, solid fats, alcohol, added sugar showed weak positive correlations with FC intake.

Of the vegetable groups, red and orange (0.62), dark green (0.58), and other total vegetables (0.57) showed strong correlations with FC intake; much stronger than starchy potatoes (0.07). Of the total fruits, intact fruits (0.63) were more strongly positively correlated with FC intake than fruit juice (0.07). From the total grains, whole grain (0.46) showed a strong positive correlation with FC intake compared to refined grain (0.26). From the total protein food group, plant-based proteins such as legumes (0.47), nuts/seeds (0.42), and soy protein (0.41) were positively correlated with FC intake, while animal proteins such as meat (-0.04) showed weak inverse relationships. The details can be found in correlation table 4

4. Discussion

To our knowledge, the present study is the first to examine the relationships between FCs consumption and total HEI-2015 and HEI component scores in a US college student population. Study findings indicate that average daily FC consumption, including the FC subclasses SDFs and polyols, were associated with an increased total HEI-2015 score. Furthermore, positive significant associations were observed between FC consumption and adequacy components, except dairy consumption was negatively associated. Contrary to our hypothesis, refined grain, saturated fat, and added sugar from the moderation components showed a positive significant association with FCs consumption.

4.1 FCs consumption and total HEI-2015

A novel aspect of this study was to evaluate associations between FC and subclasses (such as SDF and polyols) intake and HEI-2015 scores in US college students. A previous study in US adults examined the relationship between total fiber intake and HEI-2010 and component scores[54], thus including one subclass of FC, SDF, but also adding in insoluble (nonfermentable carbohydrates) and excluding other fermentable carbohydrates such as polyols. Significantly higher (27.7%) HEI-2010 scores were found among the adults meeting or exceeding adequate fiber intakes than the overall population[54]. The current study aligns with these results in college students, predicting that a gram increase of average daily FC consumption was associated with an increase in total HEI-2015 score by 1.24 points. Higher HEI-2015 scores are associated with higher overall diet quality and align with the USDG[48, 55]. To increase the diet quality; consumption of adequacy components of HEI such as total vegetables and fruits are advised, which our findings, along with some previous research, identified as food groups associated with FCs[56, 57].

4.2 Associations between HEI component scores and FCs consumption:

Prior research in NHANES reported primary food group contributors to total fiber intake (insoluble fibers plus SDF) were fruits, vegetables, grain products, dry-beans/seeds/legumes/peas/nuts, and plant proteins[54, 58] similar to what this study concluded. In both the HEI-2015 component analyses and the FPED analysis, vegetables showed the strongest associations with FC intakes, followed by fruits. This could be because vegetables and fruits tend to be rich sources of various FCs[54]. Whole grains, which also predicted FCs intake, but not as strongly as vegetables and fruits, tend instead to be richer sources of insoluble (non-fermentable) fibers[54]. An additional explanation could be that the HEI-2015 component scores for vegetables and fruits were higher in this student population than their whole grain scores. While this should be investigated further, our findings support the need to encourage vegetable intakes in college students to bolster their FC intakes, along with whole grains.

Our study also showed a strong association between the sea/plant protein component and FC intake., Sea/plant protein is comprised of plant proteins and sea proteins; based on previous research in plant-based diets[59-62], along with our food item analyses (discussed below), we postulate that plant proteins have contributed towards the FCs, rather than seafood protein. While more work should be conducted to elucidate this phenomenon, it may have potential implications for people who obtain more of their dietary proteins from animal sources than plants.

The current study found that consumption of all the HEI-2015 adequacy components was positively associated with increased intake of FC except total dairy, which was negatively associated with FCs intake. A possible reason for this is that this study did not include the milk sugar lactose in total FC intake. Lactose can be considered as an FC for individuals with lactose intolerance[5], therefore future research can consider counting lactose as an FC if data of participants' lactose tolerance status is available. Additionally, saturated fats, added sugars, and refined grains from the moderation component groups had weak positive associations with FCs intake. A possible explanation for this could be that consumption of associated foods items that contain FCs along with saturated fat/added sugar/refined grains such as cakes, cookies, and some snack foods[63]. For example, fruit pies have saturated fat, refined grains, and added sugar, but the fruits may contain SDF, oligosaccharides, and polyols[63]. Some other dessert, snack, and sauce products contain naturally occurring polyols and oligosaccharides in addition to refined grains, saturated fats, and added sugars[64]. Additionally, some refined grains, contain small amounts of dietary fiber, such as 100g refined white flour (2-3g) and milled white rice (1-2g)[64]. However, whole grains have significantly higher amounts of dietary fiber (including SDF) than refined grains, which helps explain their stronger relationship with FC intakes[65-67]. Polyols are used as low-caloric sweeteners[68-70], sometimes as a replacement for added sugar in chewing gums, hard candies, baked goods, snack bars, chocolate, and ice-creams[71, 72]. Some of these food items are sources of refined grain and saturated fats, which could be another reason that FCs had a positive association with these moderation components. While these had weak associations with FCs, it is important to emphasize that the adequacy components' associations were much stronger. Given the adverse effects of added sugar, saturated fats, and refined grains on health, these food groups would not be recommended for increasing FC intake.

4.3 Food items correlated with FC intake

This study provided insight into food groups and specific food items that are positively correlated with FC intake in US college students. For example, the food group "total vegetable" was highly correlated with increased FC intake, but only dark green vegetables and red-orange vegetables showed a strong correlation with FC intake and not the starchy vegetables such as white potatoes. Similarly, only intact fruits were strongly correlated with FC intake, and not fruit juices. Plant proteins (Legume, Nuts & Seeds, and Soy) were the main sources of FC in the "total protein" food group, and not animal proteins. Another food group "oil" also showed a strong correlation with FC intake, which included fats naturally present in nuts, seeds, avocados, and olives[73]. As discussed before, nuts and seeds as well as other plant groups (included avocado and olives)[64] were positively correlated with the FC, which might be the reason the food group 'oil' showed a strong positive correlation with FC intake. In alignment with our HEI-2015 analysis, whole grains from the food group "total grain" showed a stronger correlation with FC than refined grains. Studies showed that whole grains are an important source of dietary fibers[74] which includes the major FC group, SDF. Contrary to our hypothesis another food item that positively correlated to FC intake was 'Yogurt', which may have been due to secondary components in yogurts[75] such as coconut, oats, fruits, or nuts, which contain dietary fibers and polyols, but not abundantly, and hence may not contribute greatly to the FC content of yogurt, thus showing only a weak positive correlation. Overall, these findings suggest FC intake could be increased by consuming vegetables such as dark green and red-orange vegetables, intact fruits as well as whole grains, and plant protein foods.

Supporting our HEI-2015 component analysis, “added sugar” and “solid fats” also showed weak positive correlations with FC intake. ‘Added sugar’ does not include sugar substitutes[73] such as sorbitol, xylitol, erythritol (types of polyol), and therefore separate correlation analysis of FC subclasses and added sugar showed a very small correlation with SDF (0.17) and polyols (0.11). However, the ‘added sugar’ includes fruit juice concentrates as well as honey[73] which contains a small amount of dietary fiber (0.2%) according to USDA’s food and nutrient database[64]. Similarly, ‘solid fats’ showed a weak correlation with FCs, perhaps due to combinations of foods consumed. For example, salad dressings and sour cream, which contain considerable amounts of solid fats, are generally eaten with salads and vegetable dishes. They showed strong correlations with FC intake. [64]. Further research is needed to understand the relationship between these food groups and FC intake

4.4 Consumption of total FC

The current study shows the average daily consumption of FCs in this population was low compared to the amounts used in clinical trials[76, 77]. A previous study suggests that 4-8 g/d of non-fiber FC intake[28] (such as polyols and oligosaccharides) might be beneficial for health. This student population consumed 1.1±0.9 g/day of polyols, which is notably lower. In DHQ-II data, oligosaccharides are added together with SDF, so this study does not have a reference specifically to oligosaccharide consumption. Future work should examine oligosaccharides and SDF separately. The USDG does not specify the consumption of total FCs but they recommend the consumption of total dietary fiber, which includes SDF and insoluble fibers, of 14gm/1000kcal[78]. In this population of college students, lower intakes of total dietary fibers (11.8±5.1/1000kcal) were observed. These results align with several other studies that showed low intake of dietary fiber in college students[39]. Future studies may consider focusing specifically on recommendations to increase FCs containing food groups in college students, especially vegetables, fruits, and plant proteins, in addition to insoluble fibers.

Several studies show that the average western gut houses far fewer microbial species compared to individuals eating a diet more similar to our ancestors[79-81]. This is one of the side effects of decreased consumption of FCs[82, 83]. There is great scientific interest in the long-term benefits of FC consumption[84, 85] although these FCs have yet to be studied in college students, and their habitual intake in this population is far less understood. This study provides a first step towards achieving the goal, by quantifying FC consumption in a free-living population of college students and providing an insight into dietary components that might increase the consumption. Further research is needed to elucidate the effect of FC consumption on gut microbiota, and associated health benefits in this population.

In summary, the adequacy components seem to play a strong role in increasing the intake of total FC. The USDG recommends increased consumption of fruits and vegetables as well as whole grains to increase the intake of dietary fiber[63]. This study aligned with those recommendations, while focusing on total FC, SDF, and polyols, finding vegetables to be the strongest contributor in this student population. Intact fruits, plant proteins, and whole grains are also positively correlated with FCs consumption. Even though the USDG currently does not include FCs, the benefits of adhering to the recommended daily dietary fiber allowance by the USDG should not be underestimated, bearing in mind that both non-fermentable fibers and fermentable fibers (SDF) impart health benefits. Based on these results, we can conclude that dietary patterns that do not meet recommended vegetables, fruits, and plant protein intakes might contribute to low intakes of FCs. Further research is warranted to investigate the effects of dietary components that are major contributors to the FCs intake, in more diverse populations.

4.4 Study Strengths and Limitations

This is the first study examining relationships between FCs consumption and total HEI-2015 score as well HEI component scores. A strength of the study is that sources of FCs were assessed in the context of overall dietary patterns, and measured using HEI-2015 and FPED, which reflect the 2015–2020 USDG. An additional study strength is that FCs consumption was calculated using DHQ-II, which is a validated instrument in many research studies[86-89]. However, diet assessment by DHQ does not psyllium fiber which is a valuable source of SDF[90], and hence may have incompletely captured important sources of FC intake. Additionally, the DHQ-II does not separate some of the FCs from SDF, such as oligosaccharides. Instead, they are added together with SDF intake, so DHQ data did not allow us to further understand specific food items contributing towards oligosaccharide intake. Another limitation of the study is the lack of generalizability; the study included a healthy college student population, the majority of them were white females enrolled in a nutrition course. This population of college students was on the higher end of HEI, probably because they are in a nutrition course, so if the study were to be repeated in a non-nutrition course sample of college students, they may have even lower intakes of FC. This is worth perusing future research, along with populations who have greater racial, ethnic, and gender diversity.

5. Conclusion

In conclusion, FC intake in college students predicted HEI scores, and thus aligned with the USDG. Further, higher intakes of vegetables (especially dark green and red-orange), fruits (intact), plant proteins, and whole grains correlated with higher FC intake in this population. Promoting increased dietary FC intake in college student populations might also improve their diet quality, which may improve gut microflora, and reduce the risk of several chronic diseases. Further studies are warranted to investigate the influence of vegetables, fruits, plant proteins, and whole grains on total FCs intake and gut microbiota, along with potential health outcomes in more diverse populations. Although FC intakes were low in this population, students who have higher diet quality consume higher dietary FC. This study helps set a foundation affirming preliminary work, and future studies can examine if FC can be used as a marker for a healthy diet.

Figure 1: Flow diagram of inclusion and exclusion of the study population (final sample=571)

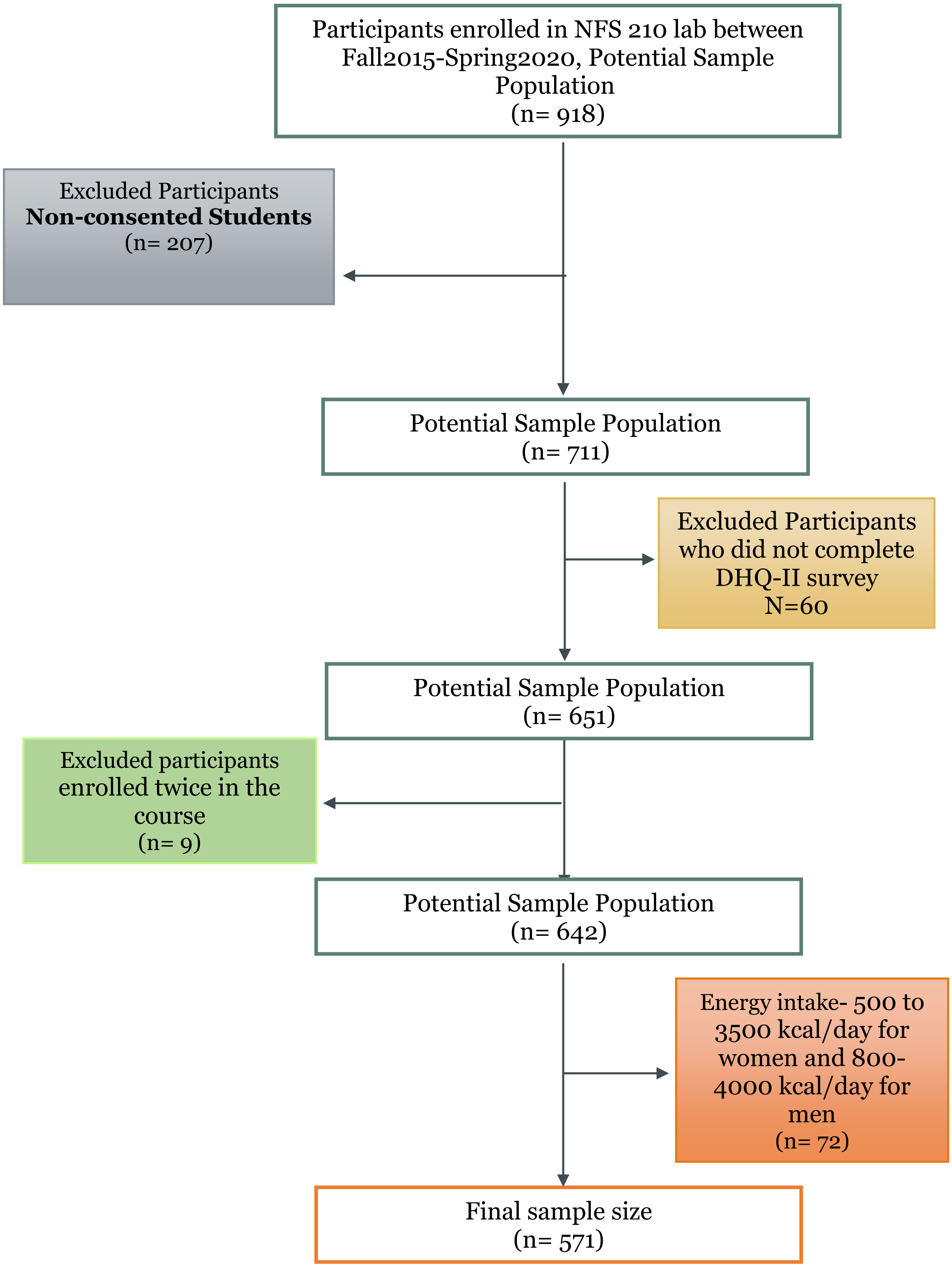

Table 1. Demographic characteristics and habitual consumption of total FCs and subclasses (SDF and Polyol)/1000kcal in the US college students (n=571)

Characteristics	**N**	
		Percentage (%)
Sex (female %)	498	80.7
Race (%)		
White	496	84.5
Non-White		15.5
Smoking	492	
Yes		7.9
No		92.1
		Mean±SD
Age (years)	514	19.5±3.3
BMI (Kg/m^2)	531	23.8±4.2
Physical activity (days/week)	552	4.9±2.6
Energy (kcal)	571	1789±709
Healthy Eating Index (HEI)	571	65.5±10.7
Total Dietary Fiber	571	20.3±4.8
FC consumption		7.1±3.6
SDF		6.2±3.2g
Polyols		1.0±0.8g
HEI component score		
Adequacy Components		
Total Vegetables	571	3.9±1.3
Greens/Beans		3.9±1.6
Total Fruit		3.9±1.5
Whole Fruit		4.2±1.4
Total Protein		4.3±1.2
Sea/plant Protein		4.0±1.5
Fatty Acids		5.7±3.2
Whole Grain		2.3±1.4
Total Dairy		5.8±2.8
Moderation component		
Sodium	571	5.1 ±2.8
Refined Grain		7.8±2.6
Saturated Fat		6.7±2.8
Added sugar		7.6±2.8

Abbreviations: N=Number of participants, **SD**= Standard deviation, **FC**= Fermentable carbohydrate, **SDF**= soluble dietary fiber. **Total score out of 5:** Total Vegetables, Greens/beans, Total Fruit, Whole Fruit, total protein, Sea/plant protein. **Total score out 10:** Fatty Acids, Whole Grain, Total Dairy, Sodium, Refined Grain, Saturated fat, Added Sugar Descriptive data; values represented in either percentage (%) or mean±standard deviation from the descriptive statistics.

Figure 2: Scatterplot of **HEI-2015 score vs FC** in 571 college students based on DHQ-II data by an unadjusted linear regression model

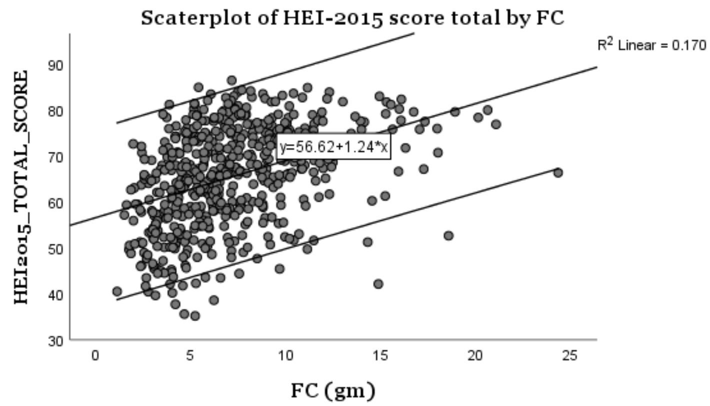

Figure 3: Scatterplot of **HEI-2015 score vs SDF** in 571 college students based on DHQ II data by an unadjusted linear regression model

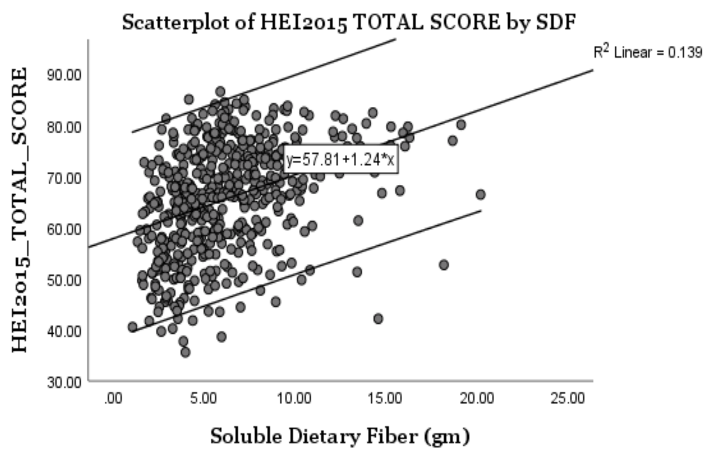

Figure 4: Scatterplot of **HEI-2015 score vs Polyol** in 571 college students based on DHQ-II data by an unadjusted linear regression model

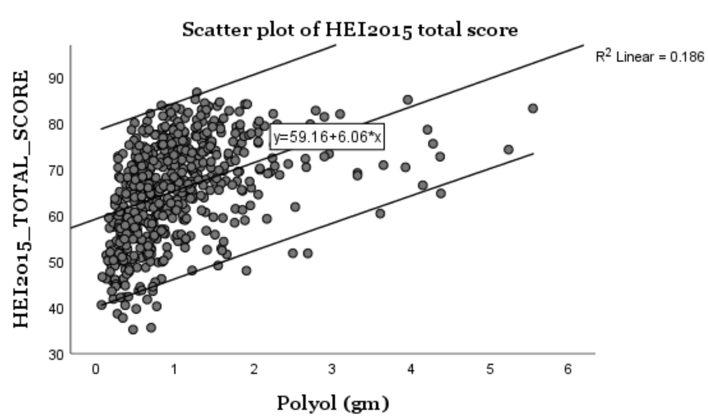

Table 2. Results of the unadjusted linear regression analysis- change in total HEI-2015 score by FC and subclasses consumption in healthy US college student population aged≥18 (n=571)

Explanatory variable (gram)	**N**	**β**	***95% CI***		**Std. error**	**p-value**
			Lower bound	Upper bound		
FC	571	1.24	1.02	1.47	0.12	0.001**
SDF		1.26	0.99	1.52	0.13	0.001**
Polyol		6.06	5.02	7.11	0.53	0.001**

Abbreviations: **N**= Number of participants, **β**=parameter estimate/unstandardized coefficient; **Associations between gram intake of FC and subclasses consumption (primary outcome) with HEI-2015 score were analyzed by multivariate analysis;** **significant p-value <0.01; **95% CI**= 95% Confidence interval

Table 3. Results of the unadjusted linear regression analysis for changes in gram FC intake by increasing HEI-2015 component score healthy US college student population aged ≥18 (*n*=571)

Explanatory variable	N	β	95% CI		Std. error	p-value
			Lower bound	Upper bound		
Adequacy Components						
Total Vegetables	571	0.91	0.69	1.13	0.11	0.00**
Green Bean		0.69	0.51	0.87	0.09	0.00**
Total Fruit		0.86	0.66	1.06	0.10	0.00**
Whole Fruit		0.83	0.61	1.05	0.11	0.00**
Whole Grain		0.43	0.20	0.61	0.11	0.00**
Total Dairy		-0.32	-0.42	-0.21	0.05	0.00**
Total Protein		0.57	0.31	0.84	0.13	0.00**
Sea/plant Protein		0.71	0.52	0.91	0.10	0.00**
Fatty Acids		0.35	0.26	0.44	0.04	0.00**
Moderation Components						
Sodium	571	-0.04	-0.14	0.07	0.05	0.475
Refined Grain		0.18	0.07	0.29	0.06	0.002**
Saturated Fat		0.35	0.25	0.45	0.05	0.00**
Added sugar		0.21	0.11	0.32	0.05	0.00**

Abbreviations: **N**=Number of participants; **β**=parameter estimate/unstandardized coefficient, **Std. error**= Standard error; **Associations between HEI-2015 component score and gram intake of FC (secondary outcome) were analyzed by unadjusted linear regression analysis;** *significant p-value <0.05, **significant p-value <0.01; **95% CI**= 95% Confidence interval; std. error=Standard Error.

Table 4. Bivariate Correlations between FPED food groups and food items with FC intake (grams) in healthy US college students (n=571)

Food Groups	FC	Alcoholic Drinks	Solid Fat	Oils	Total Dairy	Cheese	Yogurt	Milk	Total Protein	Beans, Peas, and Lentils	Nuts and Seeds	Soy Products	Eggs	Total Meat, Poultry, and Seafood	Seafood Low in n-3 Fatty Acids	Seafood high in n-3 Fatty Acids	Poultry	Organ Meat	Cured Meat
FC	**1.000**	**0.06**	**.168****	**.505****	**.122****	**0.07**	**.206****	**0.08**	**.444****	**.471****	**.417****	**.408****	**.255****	**.181****	**.179****	**.223****	**.124****	**.141****	**0.010**
Alcoholic drinks	0.06	1.00	.153**	.12**	.112**	.127**	-0.04	0.08	.117**	0.02	0.04	0.01	0.08	.127**	0.044	0.036	0.06	-0.003	.152**
Solid Fats	.168**	.153**	1.00	.353**	.721**	.748**	.208**	.496**	.370**	.094*	0.03	0.04	.292**	.481**	.206**	0.061	.296**	.193**	.466**
Oils	.505**	.117**	.353**	1.00	.162**	.212**	.162**	0.06	.685**	.375**	.662**	.287**	.362**	.343**	.206**	.180**	.263**	.169**	.185**
Total Dairy	.122**	.112**	.721**	.162**	1.00	.653**	.346**	.814**	.222**	0.02	0.02	0.06	.206**	.319**	.140**	0.072	.183**	0.066	.351**
Cheese	0.066	.127**	.748**	.212**	.653**	1.00	.174**	.264**	.231**	0.08	0.03	0.00	.26**	.309**	.162**	0.039	.206**	.086*	.382**
Yogurt	.206**	-0.04	.208**	.162**	.346**	.174**	1.00	.182**	.255**	0.07	.223**	.168**	.247**	.186**	.224**	.226**	.148**	0.039	.163**
Milk	0.078	0.08	.496**	0.06	.814**	.264**	.182**	1.00	.100*	-0.02	-0.03	0.04	.083*	.228**	.085*	0.047	.092*	0.034	.260**
Total Protein	.444**	.117**	.370**	.685**	.222**	.231**	.255**	.100*	1.00	.297**	.606**	.293**	.568**	.747**	.412**	.374**	.515**	.148**	.417**
Beans, Peas, and Lentils	.471**	0.02	.094*	.375**	0.02	0.08	0.07	-0.02	.297**	1.00	.292**	.399**	.189**	.107*	.142**	.124**	0.068	.176**	0.016
Nuts and Seeds	.417**	0.04	0.03	.662**	0.02	0.03	.223**	-0.03	.606**	.292**	1.00	.340**	.246**	.088*	.144**	.105*	0.061	0.045	0.015
Soy Protein	.408**	0.01	0.04	.287**	0.06	0.00	.168**	0.04	.293**	.399**	.340**	1.00	.194**	0.045	.128**	.107*	0.019	0.073	-0.08
EGGS	.255**	0.08	.292**	.362**	.206**	.256**	.247**	.083*	.568**	.189**	.246**	.194**	1.000	.382**	.219**	.294**	.265**	0.037	.181**
Total meat, poultry, & seafood	.18**	.127**	.481**	.343**	.319**	.309**	.186**	.228**	.747**	.107*	.088*	0.05	.382**	1.000	.484**	.430**	.720**	.163**	.660**
Seafood Low in n-3 Fatty Acids	.179**	0.04	.206**	.206**	.140**	.162**	.224**	.085*	.412**	.142**	.144**	.128**	.219**	.484**	1.000	.784**	.249**	.167**	.241**
Seafood high in n-3 fatty acids	.223**	0.04	0.06	.180**	0.07	0.04	.226**	0.05	.374**	.124**	.105*	.107*	.294**	.430**	.784**	1.000	.240**	0.052	.169**
Poultry	.124**	0.06	.296**	.263**	.183**	.206**	.148**	.092*	.515**	0.07	0.06	0.02	.265**	.720**	.249**	.240**	1.000	0.056	.411**
Organ Meat	.141**	0.00	.193**	.169**	0.07	.086*	0.04	0.03	.148**	.176**	0.04	0.07	0.037	.163**	.167**	0.052	0.056	1.000	.112**
Cured Meat	0.010	.152**	.466**	.185**	.351**	.382**	.163**	.260**	.417**	0.02	0.01	-0.08	.181**	.660**	.241**	.169**	.411**	.112**	1.000
Meat	-0.04	.154**	.565**	.158**	.370**	.394**	.105*	.303**	.404**	0.07	-0.07	-.093*	.180**	.664**	.245**	.118**	.370**	.248**	.476**

Total Grain	.314**	0.07	.704**	.439**	.471**	.536**	.207**	.310**	.442**	.196**	.169**	.185**	.246**	.478**	.159**	0.046	.328**	.246**	.435**
Refined Grain	.260**	0.07	.723**	.413**	.472**	.564**	.183**	.300**	.413**	.162**	.131**	.147**	.226**	.479**	.151**	0.033	.332**	.248**	.440**
Whole Grain	.456**	0.00	.321**	.412**	.272**	.181**	.280**	.222**	.409**	.316**	.329**	.345**	.238**	.282**	.145**	.110**	.187**	.158**	.229**
Beans, Peas, &Lentils	.476**	0.02	.093*	.377**	0.01	0.08	0.07	-0.02	.298**	.994**	.298**	.400**	.189**	.105*	.140**	.122**	0.068	.178**	0.018
Total Veg	.688**	0.02	0.06	.507**	-0.03	0.05	.118**	-0.08	.429**	.455**	.369**	.357**	.247**	.217**	.219**	.285**	.138**	.162**	-0.01
Other Veg	.571**	0.03	0.05	.447**	-0.04	0.06	.132**	-.1*	.405**	.460**	.316**	.292**	.246**	.236**	.234**	.284**	.168**	.158**	0.029
Total Starchy Veg	.330**	0.04	.394**	.355**	.201**	.263**	0.04	.150**	.161**	.259**	0.07	.132**	0.052	.171**	0.043	-0.002	.141**	.197**	.167**
Other Starchy Veg	.432**	-0.06	0.03	.248**	-0.01	-0.02	.097*	0.01	.181**	.342**	.196**	.240**	.092*	0.070	0.074	.138**	0.049	.118**	-0.015
Potatoes	0.072	.106*	.499**	.242**	.256**	.365**	-0.03	.177**	0.06	.096*	-0.06	0.00	-0.003	.160**	0.013	-.098*	.145**	.184**	.249**
Total Red & Orange Veg	.619**	0.04	0.07	.419**	0.02	.117**	.136**	-0.06	.376**	.446**	.361**	.331**	.188**	.187**	.210**	.242**	.100*	.161**	0.038
Other Red & Orange Veg	.521**	-0.05	-.184**	.30**	-.172**	-.118**	.161**	-.16**	.248**	.352**	.354**	.300**	.14**	0.018	.157**	.230**	0.02	0.065	-.11**
Tomatoes	.443**	.121**	.335**	.377**	.211**	.339**	0.08	0.07	.331**	.397**	.221**	.224**	.142**	.281**	.182**	.145**	.140**	.214**	.186**
Dark Green Veg	.577**	0.00	-.110**	.362**	-.141**	-0.08	.097*	-.15**	.334**	.352**	.339**	.308**	.219**	.112**	.204**	.306**	0.051	.100*	-.093*
Total Fruit	.656**	0.03	-0.01	.264**	0.02	-0.02	.198**	0.02	.272**	.264**	.348**	.233**	.134**	0.048	.108**	.140**	0.027	0.050	-0.06
Fruit Juice	0.067	.183**	.281**	-0.02	.231**	.222**	0.03	.235**	0.02	0.04	-.109**	-0.06	-0.03	.154**	.115**	0.066	.094*	.094*	.219**
Other Fruits	.629**	-0.01	-.107*	.292**	-0.05	-.086*	.204**	-0.05	.292**	.284**	.447**	.304**	.149**	0.013	.106*	.172**	0.001	0.018	-.117**
Citrus, Melons & Berries	.483**	0.02	0.00	.246**	-0.02	0.03	.194**	-0.06	.190**	.224**	.274**	.169**	0.06	0.029	.122**	.101*	0.061	0.06	-0.05
Added Sugar	.176**	.160**	.498**	.158**	.454**	.277**	.175**	.434**	.110**	0.03	-0.04	0.00	0.020	.223**	0.065	-0.003	.118**	.105*	.283**

Table 4 (continued). Bivariate Correlations between FPED food groups and food items with FC intake (grams) in healthy US college students (n=571) continued

Food Groups	Meat	Total Grains	Refined Grains	Whole Grains	Beans, Peas, and Lentils	Total Vegetables	Other Vegetables	Total Starchy Vegetables	Other Starchy Vegetables	Potatoes	Total Red and Orange Vegetables	Other Red and Orange Vegetables	Tomatoes	Dark Green Vegetables	Total Fruit	Fruit Juice	Other Fruits	Citrus, Melons, and Berries	Added Sugars
FC	-0.04	.314**	.260**	.456**	.476**	.688**	.571**	.330**	.432**	0.072	.619**	.521**	.443**	.577**	.66**	0.067	.63**	.483**	.176**
Alcoholic drinks	.154**	0.065	0.071	-0.002	0.020	0.017	0.035	0.040	-0.057	.106*	0.045	-0.049	.121**	0.003	0.03	.18**	-0.02	0.019	.160**
Solid Fats	.565**	.704**	.723**	.321**	.093*	0.061	0.047	.394**	0.032	.499**	0.066	-.184**	.335**	-.110**	-0.01	.28**	-.11*	0.01	.50**
Oils	.158**	.439**	.413**	.412**	.377**	.507**	.447**	.355**	.248**	.242**	.419**	.303**	.377**	.362**	.26**	-0.02	.29**	.25**	.158**
Total Dairy	.370**	.471**	.472**	.272**	0.011	-0.03	-0.041	.201**	-0.011	.256**	0.019	-.172**	.211**	-.141**	0.02	.23**	-0.05	-0.02	.45**
Cheese	.394**	.536**	.564**	.181**	0.076	0.048	0.065	.263**	-0.021	.365**	.117**	-.118**	.339**	-0.082	-0.02	.22**	-.09*	0.03	.277**
Yogurt	.105*	.207**	.183**	.280**	0.066	.118**	.132**	0.039	.097*	-0.029	.136**	.161**	0.079	.097*	.20**	0.027	.20**	.194**	.175**
Milk	.303**	.310**	.300**	.222**	-0.02	-0.076	-.098*	.150**	0.006	.177**	-0.061	-.162**	0.072	-.145**	0.02	.24**	-0.05	-0.06	.43**
Total Protein	.404**	.442**	.413**	.409**	.298**	.429**	.405**	.161**	.181**	0.061	.376**	.248**	.331**	.334**	.27**	0.022	.29**	.190**	.110**
Beans, Peas, and Lentils	0.072	.196**	.162**	.316**	.994**	.455**	.460**	.259**	.342**	.096*	.446**	.352**	.397**	.352**	.26**	0.036	.28**	.224**	0.03
Nuts and Seeds	-0.07	.169**	.131**	.329**	.298**	.369**	.316**	0.067	.196**	-0.056	.361**	.354**	.221**	.339**	.35**	-.11**	.45**	.274**	-0.04
Soy Protein	-.093*	.185**	.147**	.345**	.400**	.357**	.292**	.132**	.240**	-0.005	.331**	.300**	.224**	.308**	.23**	-0.06	.30**	.169**	-0.00
Eggs	.180**	.246**	.226**	.238**	.189**	.247**	.246**	0.052	.092*	-0.003	.188**	.136**	.142**	.219**	.13**	-0.03	.15**	0.06	0.02
Tot meat, poultry &seafood	.664**	.478**	.48**	.282**	.105*	.217**	.236**	.17**	0.070	.160**	.187**	0.02	.28**	.112**	0.05	.15**	0.01	0.03	.22**
Seafood low in n-3 fatty-acid	.25**	.16**	.151**	.145**	.140**	.219**	.234**	0.043	0.074	0.013	.210**	.157**	.182**	.204**	.11**	.12**	.106*	.122**	0.07
Seafood high in n-3 fatty acid	.118**	0.046	0.33	.110**	.122**	.285**	.284**	-0.002	.138**	-.098*	.242**	.230**	.145**	.306**	.14**	0.066	.17**	.101*	-0.003
Poultry	.370**	.328**	.332**	.187**	0.068	.138**	.168**	.141**	0.049	.145**	.100*	0.024	.140**	0.051	0.03	.094*	0.001	0.061	.118**
Organ Meat	.248**	.246**	.248**	.158**	.178**	.162**	.158**	.197**	.118**	.184**	.161**	0.065	.214**	.100*	0.05	.094*	0.018	0.06	.105*

Cured Meat	.476**	.435**	.440**	.229**	0.018	-0.001	0.029	.167**	-0.015	.249**	0.038	-.110**	.186**	-.093*	-0.06	.22**	-.12**	-0.05	.28**
Meat	1.0	.504**	.527**	.173**	0.068	0.002	0.048	.231**	0.001	.325**	0.059	-.158**	.297**	-.119**	-.09*	.24**	-.15**	-0.07	.251**
Total Grain	.504**	1.0	.988**	.638**	.193**	.172**	.139**	.375**	.107*	.403**	.238**	-0.040	.444**	-0.006	.097*	.19**	0.04	.101*	.391**
Refined Grain	.527**	.988**	1.0	.532**	.160**	.143**	.115**	.377**	.085*	.426**	.212**	-0.069	.438**	-0.039	0.07	.21**	-0.001	0.081	.401**
Whole Grain	.173**	.638**	.532**	1.0	.313**	.277**	.210**	.226**	.195**	.133**	.283**	.165**	.294**	.198**	.25**	-0.02	.29**	.196**	.172**
Beans, Peas, and Lentils	0.068	.193**	.160**	.313**	1.0	.458**	.461**	.264**	.344**	.098*	.446**	.354**	.394**	.351**	.27**	0.033	.29**	.227**	0.04
Total Vegetables	0.002	.172**	.143**	.277**	.458**	1.0	.874**	.440**	.576**	.124**	.806**	.733**	.560**	.891**	.46**	-0.1	.51**	.42**	-0.06
Other Vegetables	0.05	.139**	.115**	.210**	.461**	.874**	1.0	.310**	.514**	0.032	.704**	.645**	.506**	.732**	.37**	-0.1	.41**	.39**	-0.07
Total Starchy Vegetables	.231**	.375**	.377**	.226**	.264**	.440**	.310**	1.0	.617**	.811**	.322**	.223**	.349**	.176**	.20**	.19**	.14**	.214**	.213**
Other Starchy Vegetables	0.01	.107*	.085*	.195**	.344**	.576**	.514**	.617**	1.0	.136**	.530**	.545**	.334**	.438**	.37**	0.06	.37**	.35**	-0.01
Potatoes	.325**	.40**	.43**	.133**	.098*	.124**	0.032	.811**	.136**	1.0	0.027	-.110**	.224**	-.092*	-0.003	.24**	-.09*	0.05	.277**
Total red & orange veg	0.059	.238**	.212**	.283**	.446**	.806**	.704**	.322**	.530**	0.027	1.0	.801**	.759**	.643**	.46**	0.003	.49**	.419**	-0.05
Other red & orange veg	-.16**	-0.04	-0.07	.165**	.354**	.733**	.645**	.223**	.545**	-.110**	.801**	1.0	.299**	.677**	.44**	-.12**	.51**	.42**	-.19**
Tomatoes	.297**	.444**	.438**	.294**	.394**	.560**	.506**	.349**	.334**	.224**	.759**	.299**	1.0	.367**	.30**	.18**	.27**	.28**	.110**
Dark Green Vegetables	-.12**	-0.01	-0.04	.198**	.351**	.891**	.732**	.176**	.438**	-.092*	.643**	.677**	.367**	1.0	.43**	-.14**	.52**	.393**	-.17**
Total Fruit	-.088*	.097*	0.07	.246**	.266**	.459**	.368**	.203**	.372**	-0.003	.457**	.438**	.300**	.432**	1.0	.26**	.84**	.705**	.114**
Fruit Juice	.244**	.186**	.206**	-0.02	0.033	-0.076	-0.075	.189**	0.059	.239**	0.003	-.120**	.180**	-.139**	.26**	1.0	-0.06	0.04	.297**
Other Fruits	-.15**	0.042	-0.001	.289**	.286**	.512**	.414**	.141**	.374**	-.086*	.488**	.511**	.271**	.518**	.84**	-0.06	1.0	.538**	-0.06
Citrus, Melons, & Berries	-0.07	.101*	0.081	.196**	.227**	.424**	.390**	.214**	.348**	0.045	.419**	.424**	.279**	.393**	.71**	0.04	.54**	1.0	0.06
Added Sugar	.251**	.391**	.401**	.172**	0.036	-0.06	-0.067	.213**	-0.008	.277**	-0.045	-.188**	.110**	-.172**	.11**	.30**	-0.06	0.06	1.0

Abbreviations: FC Included SDF and Polyols such as Erythritol, Lactitol, Inositol, Pinitol, Sorbitol, Xylitol, Isomaltose, Maltitol, and Mannitol.

Food Patterns Equivalents Database Components= Total Fruit: Total intact fruits (whole or cut) and fruit juices (cup eq.), **citrus, Melon, and Berries**: Intact fruits (whole or cut) of citrus, melons, and berries (cup eq**.), Other Fruits:** Intact fruits (whole or cut); excluding citrus, melons, and berries (cup eq.), **Fruit Juices:** Fruit juices, citrus, and non-citrus (cup eq.), **Total vegetables:** Total dark green, red and orange, starchy, and other vegetables; excludes legumes (cup eq.) **Dark green vegetable**s (cup eq.), **Total red and orange vegetables:** Total red and orange vegetables (tomatoes and tomato products + other red and orange vegetables) (cup eq.), **Tomatoes**: Tomatoes and tomato products (cup eq.), **Other red and orange vegetables:** Other red and orange vegetables, excluding tomatoes and tomato products (cup eq.), **Total starchy vegetables:** white potatoes + other starchy vegetables (cup eq.), **Potatoes**: White potatoes (cup eq.), **Other starchy vegetables:** Other starchy vegetables, excluding white potatoes (cup eq.), **Other vegetables:** Other vegetables not in the vegetable components listed above (cup eq.), **Beans, peas, and lentils:** legumes computed as vegetables (cup eq.), **Whole Grains:** Grains defined as whole grains and contain the entire grain kernel the bran, germ, and endosperm (oz. eq.), **Refined Grain:** Refined grains that do not contain all of the components of the entire grain kernel (oz. eq.), **Total Protein Food:** Total meat, poultry, organ meat, cured meat, seafood, eggs, soy, and nuts and seeds; excludes legumes (oz. eq.), **Total Meat, Poultry, and Seafood :** Total of meat, poultry, seafood, organ meat, and cured meat (oz. eq.), **Meat:** Beef, veal, pork, lamb, and game meat; excludes organ meat and cured meat (oz. eq.), **Cured Meat:** Frankfurters, sausages, corned beef, cured ham and luncheon meat that are made from beef, pork, or poultry (oz. eq.), **Organ Meat:** Organ meat from beef, veal, pork, lamb, game, and poultry (oz. eq.), **Poultry:** Chicken, turkey, Cornish hens, duck, goose, quail, and pheasant (game birds); excludes organ meat and cured meat (oz. eq.), **Seafood High in n-3 Fatty Acids:** Seafood (finfish, shellfish, and other seafood) high in n-3 fatty acids (oz. eq.), **Seafood Low in n-3 Fatty Acids:** Seafood (finfish, shellfish, and other seafood) low in n-3 fatty acids (oz. eq.), **Eggs:** Eggs (chicken, duck, goose, quail) and egg substitutes (oz. eq.), **Soy Products:** Soy products, excluding calcium fortified soy milk (soymilk) and products made with raw (green) soybean (oz. eq.), **Nuts and Seeds:** Peanuts, tree nuts, and seeds; excludes coconut (oz. eq.), **Total Dairy:** Total milk, yogurt, cheese, and whey. For some foods, the total dairy values could be higher than the sum of D_MILK, D_YOGURT, and D_CHEESE because the Miscellaneous Dairy component composed of whey is not included in FPED as a separate variable. (cup eq.), **Milk:** Fluid milk, buttermilk, evaporated milk, dry milk, and calcium fortified soy milk (soymilk) (cup eq.), **Oils:** Fats naturally present in nuts, seeds, and seafood; all un-hydrogenated vegetable oils, except palm oil, palm kernel oil, and coconut oils; the fat present in avocado and olives above the allowable amount; 50% of the fat present in stick and tub margarine and margarine spreads (grams), **Solid Fats:** Fats naturally present in meat, poultry, eggs, and dairy (lard, tallow, and butter); fully or partially hydrogenated oils; shortening; palm oil; palm kernel oil; coconut oils; fats naturally present in coconut meat and cocoa butter; and 50% of the fat present in stick, and tub margarine and margarine spreads (grams), **Added sugars:** Caloric sweeteners such as syrups and sugars and others defined as added sugars (tsp. eq.), **Alcoholic Drinks:** Alcoholic beverages and alcohol (ethanol) added to foods after cooking (no. of drinks)

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

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Manuscript 2 “Dietary fermentable carbohydrate consumption and association with cardiometabolic risk markers in college students: a cross-sectional study"

by

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ABSTRACT

Objective: Dietary fermentable carbohydrates (FCs) are resistant to digestion and made available to colonic bacteria to metabolize into beneficial compounds which are well known to improve health. Consumption of these FCs in college students has not been thoroughly investigated and their possible health benefits have not been well elucidated. The primary objective of this study was to determine the consumption of total FCs and the subclasses of soluble dietary fibers (SDF) and polyols in US college students. The secondary objective was to observe differences in health parameters; body mass index [BMI (kg/m^2)], blood glucose, blood pressure, percent body fat, and low-density lipoprotein cholesterol (LDL-c) between groups of high and low FC consumers.

Methods: As a mandatory course requirement of ongoing general nutrition courses at the University of Rhode Island, anthropometric and demographic data are collected from students. The Diet History Questionnaire (DHQ II), a web-based food frequency questionnaire was used to quantify the consumption of total FCs and subclasses such as polyols and soluble dietary fibers (SDF). The consented students who are ≥18 years old are included whereas energy intake over-or under-reporting, pregnancy, and non-compliance with fasting were the exclusion criteria. To quantify total FCs consumption, all types of fermentable carbohydrates (e.g., SDF, polyols) were added together. A median split was used to classify the intake of low and high FC consumer groups. Intake of FCs and subclasses (SDF and polyol) in gram per 1000kcal (g/1000kcal) was also calculated to control for the possibility of increased intake from total consumption. We used multiple linear regression to evaluate differences in health

parameters (BMI, blood glucose, blood pressure, percent body fat, and LDL-c) between low and high FC consumer groups while adjusted for confounders. A separate model for each dependent variable was used. The potential confounding variables based on literature search were entered into the multivariate model in the order of significance from univariate analysis i.e., added most significant variable from univariate analysis first. Finally, variables that show at least a 10% change in beta coefficient were kept in the final model.

Results: The 9-cross-sections (Fall2015-Spring2020) of this data included 571 students of which 95% participants were between 18 and 22 years old, 80.8% were female and 84.5% white with a mean BMI of population 23.9±4.3 kg/m². The average FC intake for low FC groups was 4.6±1.4 and the high FC group was 10.9±4.0 grams with most of the amounts coming from SDF. After controlling for confounders, we observed significantly higher diastolic blood pressure (mmHg) in low FC (β=2.95, p=0.04*), than high consumers. The low SDF group also had significantly higher blood glucose mg/dL (β= 2.65 mg/dL; p=0.02*) than high consumers. Additionally, we also observed low polyol consumers expressed as g/1000kcal had higher BMI kg/m² (β=0.99, p=0.050) than high low polyol consumers, with borderline statistical significance.

Conclusion: The consumption of fermentable carbohydrates and subclasses in this population was low compared to the quantity used in the intervention studies. Despite this fact, the results suggest that there was an inverse association between FC and subclasses intake and diastolic blood pressure, blood glucose levels, and BMI in this population. To further evaluate the potential relationship between FC consumption and cardiometabolic risk factors in this and other populations, long-term mechanistic studies are needed.

1. Introduction

The prevalence of cardiometabolic risk factors has increased in college students[1, 2]. The years between 18 and 24 are generally considered transitional years during which college students experience weight gain may be due to poor diet[3] and declined physical activity (PA)[4-6]. Despite the growing evidence on increasing overweight/obesity, physical inactivity, and risk of developing chronic diseases, college students were still reported as an understudied population[7, 8]. On the other hand, to avoid this risk some studies suggested early intervention in this population is very critical because diet and lifestyle could prevent 80% of this events[9].

Recent studies on the human gut microbiome suggested that consumption of fermentable carbohydrates (FCs) lowers the risk of these cardiometabolic factors[10-14]. In controlled laboratory studies, dietary FCs have shown promising results concerning metabolic outcomes because they influence satiety and insulin/glucose pathways[11, 15-17] which could affect changes in energy balance and body weight[18]. The detailed mechanism between FC intake-improving metabolic outcomes is still under investigation, however, some studies explain that the gut microflora ferment (i.e., break down) these FCs that are otherwise indigestible by the human digestive system[19, 20]. This process produces metabolically active products such as short-chain fatty acids (SCFA) that promote health[20]. These SCFA[21], such as acetate, propionate, and butyrate, generate molecular signals to activate satiety hormones that are associated with decreased hunger and gastric emptying and improve postprandial glucose and insulin sensitivity[22-24].

Past research has also shown consumption of FC-rich food such as legumes, cereals, barley, and oat-bran or other OS-rich foods enhances apparent satiety, decreases energy intake, and improves lipid profiles, and glucose regulation[15, 16, 25, 26]. Dietary FCs include some fibers, polyols, oligosaccharides (OS), and resistant starch, which support the growth of existing gut microflora[27-29]. The dietary FCs are also known to be found in fruits and vegetables primarily, however, studies reported college students to consume an inadequate quantity of fruits and vegetables[30]. Further, total FC intake and possible health benefits in healthy U.S college students have not been investigated[31-33]. Considering college students are at high risk of developing metabolic diseases and they are at the decisive stage of their dietary choices[34, 35], consumption of total FCs and their possible health benefits in healthy U.S college students need to be researched[33, 36].

Some studies have focused on the gut microbiome and gastrointestinal symptoms [37-39] while others on a single type of FC and health by improving microbial composition and activity[40], however estimation of total FC including the subclasses such as soluble dietary fibers (SDFs) and polyols consumption has not been thoroughly investigated in the free-living young US population. Additionally, these are usually short-term laboratory-controlled studies, and the potential impact of these FCs and subclasses on cardiometabolic risk markers have not been well elucidated in the student population. Provided that the FCs may play a major role in lowering cardiometabolic risk factors, advanced research is required to illuminate the possible health effects and average consumption of these carbohydrates[15]. The proposed study aimed to estimate the consumption of total FCs and subclasses in healthy free-living US college students who normally consume typical western diets and the secondary aim was to observe potential differences in cardiometabolic risk factors such as BMI (kg/m^2), blood pressure, blood glucose, and percent body fat (% BF) between groups of high and low FC consumers.

2. Methodology

2.1 Study design and participants

For this cross-sectional study, we used data from an ongoing research program conducted at the University of Rhode Island (URI). Institutional Review Board [41] approval was obtained for the study and all participants sign IRB-approved consent forms if they want to permit their data to be used for research. Demographic and anthropometric data were used in the statistical analysis along with dietary intake measured via the Diet History Questionnaire (DHQ-II)[42] an online food frequency questionnaire.

2.1.1 Recruitment: URI students enrolled in an introductory nutrition course completed the dietary, anthropometric, blood variables, and health assessments as mandatory course activities. The course teaching assistants (TAs) and the research assistant involved in this study check the eligibility of the students to participate, provide detailed information about the study, conduct the consenting process, and collect signed consent forms from those who accept the invitation to participate. This data collection first started in fall 2015 and it is still an ongoing process. This study included a total of 9-cross sections between fall 2015 to spring 2020. The inclusion criteria for the study were the consented students who completed the data collection process, ≥18 years of age, whereas non-compliance with fasting or other data collection protocols as well as current pregnancy/lactation were the exclusion criteria.

2.2 Measures:

Measurements of blood variables and anthropometric data were conducted under the supervision of course faculty and by trained teaching assistants (TAs). Students completed these assessments at the start of the semester and during their regular lab periods, they completed online surveys, including the sociodemographic, physical activity, and dietary questionnaires (DHQ II).

2.2.1 Demographics:

Demographic characteristics were collected during the start of the course through online surveys. Variables of interest included age, sex (male and female), race (white and non-white), smoking (yes/no), physical activity (PA) (vigorous days per week and moderate days per week), and sitting minutes/day. Participants completed a brief standardized demographic survey; where information regarding age, sex, smoking habits, and the race was collected. PA was calculated using International Physical Activity Questionnaire (IPAQ)[43]. The IPAQ survey included a question about days/week participants performed vigorous PA such as 'heavy lifting, digging, aerobics, or fast bicycling' and moderate PA such as 'carrying light loads, bicycling at a regular pace, or doubles tennis'. We summed up these scores out a maximum possible score of 7days/week. These data points were used for descriptive purposes and analysis of covariance when required.

2.2.2 FCs intake*:* The total FC and subclasses intake was calculated from Diet History Questionnaire's (DHQ-II) nutrient output. The DHQ-II is an electronic food frequency questionnaire (FFQ) that consists of 134 food items and 8 dietary supplement questions reflecting the previous year of intake. This validated

DHQ[42] takes about 45 minutes to an hour to complete and is designed, based on cognitive research findings, to be easy to use. Participants cannot submit the DHQ if any item is left incomplete.

Diet*Calc software generates the nutrient estimates from the DHQ data using the food and nutrient database which included FCs and subclasses. These estimated FCs by the DHQ-II included soluble dietary fibers (SDF) and polyols (erythritol, inositol, isomalt, lactitol, maltitol, mannitol, pinitol, sorbitol, and xylitol). All the estimated FCs (in gram) were added together to evaluate the total FC consumption.

2.3.3Exposure Variable(s)*:* To quantify total FCs consumption (in gram), all types of fermentable carbohydrates (e.g., SDF, polyols) were added together and the median split was used to assess the intake of low and high FC consumer groups. Intake of FCs in gram per 1000kcal was also calculated to control for the possibility of increased intake from total consumption. Additionally, we analyzed the consumption of SDF and polyol intake in grams and grams per 1000kcal.

2.2.4 Healthy Eating Index-2015: HEI-2015 is a multicomponent scoring method used to assess diet quality and adherence to US dietary guidelines[44 45]. The HEI-2015 score ranges from 1-100, with a higher score reflecting greater adherence and better diet quality[45]. To calculate HEI-2015 we used publicly available statistical code developed by the Division of Cancer Control and Population Sciences of the National Cancer Institute[46].

2.2.5 Anthropometric and Blood Variables: Teaching assistants of the course followed a standardized protocol to collect the blood variables, which included blood glucose, LDL-c and blood pressure (systolic and diastolic blood pressure), and anthropometric measurements such as height and weight to calculate BMI (kg/m^2) as well as % body fat (a detailed process in an appendix- F and G). All tests were carried out following a 12-hour overnight fast. Height was measured in duplicate on a digital wall-mounted stadiometer (SECA 240, Hamburg, Germany), to 0.1 cm, with an average of the two measures recorded. Weight was measured in duplicate on a digital scale (SECA 700, Hamburg, Germany), to 0.1 kg, with the average of the two measurements recorded, and BMI was calculated as kg/m^2 using these measurements. The segmental multi-frequency bioelectrical impedance analysis (InBody 770)[47] was used to measure the body composition and % BF. The InBody test takes 60 seconds, and the results print automatically after testing.

Blood pressure was measured in duplicate using an electronic sphygmomanometer (Omron Healthcare, Inc), where the first reading was taken after 5 minutes of a participant sitting, and the second and any follow-up measurements subsequently at least 1 minute apart. To evaluate fasting total lipid profile and blood glucose, teaching assistants collected a 40uL sample of capillary blood via finger stick and measured it immediately with the Alere Cholestech LDX System (Serial No. SNAA122881, Alere Inc., Waltham MA).

2.2.6 Covariates*:* Potential confounders were selected based on the literature for the following dependent variables: BMI, % BF, blood glucose, and blood pressure. These potential confounders were: sex (male/female)[48], race (white and non-white) [49], age[50]][51], healthy eating index-2015 (HEI-2015), energy intake (kcal), physical activity (vigorous and moderate days per week), sitting minutes/week, alcohol consumption (in grams) and smoking (yes/no)[52-54]. We also included insoluble dietary fiber as a confounder to make sure the results were not driven by them[55, 56]. All the potential confounders (i.e., independent variables) were tested in univariate models to observe the association with each dependent variable, separately.

2.3 Statistical method:

2.3.1 Descriptive statistics: All statistical analyses were performed with SAS enterprise guide version 9.4. Data were analyzed for normality assessment by skewness and kurtosis. Descriptive statistics were used to summarize demographics, we used frequencies and percentages to present categorical variables and mean±standard deviation for continuous variables for the whole sample. Before analyses, all data were double-checked manually for accuracy (e.g., data entry, missing data, etc.). Statistical tests were conducted with a 2-tailed α (alpha) and significance accepted at $p < 0.05$. A simple HEI algorithm scoring method, which is a publicly available statistical code from the Division of Cancer Control and Population Sciences of the National Cancer Institute was used to calculate the HEI-2015 score. We excluded participants with energy intake <500 to 3500< kcal/day for women and <800-4000< kcal/day for men[57] (n= 72). As well as participants who did not complete the DHQ survey (n=60).

2.3.3 Univariate and multiple regression analyses for secondary aim: The study evaluated high vs. low FC consumption on 6 cardiometabolic risk factors [i.e., the 6 dependent variables: BMI, blood glucose, blood pressure (systolic and diastolic blood pressure), % body fat, and LDL-c]. Comparison of FC group differences on the 6 risk markers was assessed by regressing the binary FC group variable on each of the cardiometabolic risk markers in separate multiple regression (MR) models that control for covariates identified in the literature search.

The initial MR model/base model included the FC group (low vs high) as an independent variable and a single risk marker as a dependent variable, then we refined the model by adding the most significant covariate from the univariate analysis sequentially at a time to the base model and retained those variables in the model that change the β-coefficient by at least 10% or more in the parameter estimate table, and then re-ran the model with next potential variable. We repeated the process until we reach our final model with only variables that change parameter estimates by at least 10% or more. The details of covariates deleted/retained from the analysis can be found in the MR result tables. A separate multivariate linear regression analysis was developed for each independent variable (FC and subclasses expressed as gram and gram/1000kcal) and dependent variables (i.e., BMI, blood glucose, systolic blood pressure, diastolic blood pressure, % body fat, and LDL-c).

3. Results

3.1 Demographics:

The study included a total of 9-cross sections of the data between Fall2015-Fall2019. We collected demographic, anthropometric, blood variables, and nutrient consumption data from a total of 711 consented students (Figure 1). Of these, 60 did not complete the online DHQ-II and missing FC consumption data, hence deleted from the data. There was a total of 9 students who enrolled twice in the course; for these cases, the most complete data set was used for each participant. We only included participants with energy intake 500 to 3500 kcal/day for women and 800-4000 kcal/day for men[57] and deleted participants data outside of this range (n=72) leaving a potential sample data =571 (figure 1).

Data from 571 students were used (Table 1) in the analysis of which 95% of participants were between 18 and 22 years old, 80.8% were female and 84.5% were white. The mean of physical activity days/week was 5.5±2.1. A total of 91% of students identified themselves as current non-smoker. On average students consumed 1788±708 kcal/day and the mean Healthy Eating Index of this population was 65.5±10.7. Participants' mean BMI was 23.9±4.3kg/m^2, blood glucose was 87.7±8.5 (mg/dl), SBP was 112.6±13.2 (mmHg), DBP was 73.9±9.3 (mmHg), % BF was 26.2±8.8 and LDL-c was 87.5±27.9 (mg/dL) (Table 1).

3.2 Average Intake of FCs:

Mean quantified Fermentable carbohydrates intake (FCs) was 7.1±3.6g and 4.1±1.9 g/1000kcal (Table-2). The average intake for SDF was 6.1±3.1g and 3.6±1.7g/1000kcal. Mean polyol intake was 1.0±0.8g and 0.6±0.4 g/1000kcal. The details of FCs intake and its subclasses are listed in Table-2 with their skewness and kurtosis values. Additionally, the mean intake of total dietary fiber with FCs and subclasses for males and females of this population can be found in Table 6.

3.3 Differences between low and high FC, SDF, and Polyol consumers:

3.3.1 Gram intake

The MR analysis for associations between high and low FC consumer groups with cardiometabolic risk markers shown in Tables 3, 4, and 5. The average intake of FC was 4.6±1.4g in the low FC consumer group and 10.9±4.0g in the high FC consumer group; 3.8±1.2g in the low SDF consumer group and

9.4±3.5g in the high SDF consumer group and the total polyol was 0.54±0.2 in the low polyol consumer group and 1.70±0.9g in the high polyol consumer group.

The final MR analysis after adjusting for confounders showed gram intake of FC and SDF were each significantly associated with DBP (β=2.95, p=0.04*, R^2=0.08), % body fat (β=2.91, p=0.01*, R^2=0.37). Additionally, the multivariate model of FC consumer group and % body fat unadjusted for insoluble fiber showed statistically significant higher means of %body fat in low FC consumer group (β=2.91, p=0.01*, R^2=0.37) than high consumers. However, the final model included insoluble fiber was attenuated the main effect and was no longer statistically significant (β=2.41, p=0.06, R^2=0.37). Finally, no other significant differences in other biomarkers were found gram intake of FC, SDF, or Polyol after the final model.

3.3.2 g/1000kcal:

The average intake of total FC was 2.7±0.6g/1000kcal in the low FC consumer group and was 5.6±1.7g/1000kcal in the high FC consumer group; for SDF was 2.3±0.6g/1000kcal in the low SDF consumer group and was 4.8±1.7g/1000kcal in the high SDF consumer group and for polyol was 0.31±0.1g/1000kcal in the low polyol consumer group and was 0.90±0.4g/1000kcal in the high polyol consumer group.

The final MR analyses of polyol/1000kcal and BMI showed a significantly higher mean of BMI (kg/m^2) in the low consumer group (β=0.99, p= 0.050*, R^2 = 0.04) compared to the high consumer group. Finally, no other significant differences in other biomarkers were found in the gram/1000kcal consumer group of FCs, SDF, and Polyol.

4. Discussion

The goal of this study was to evaluate the consumption of FCs and subclasses in a free-living college-aged population and the secondary aim was to compare the differences in cardiometabolic risk factors between low vs high consumer groups. The study concluded the lower intake of FCs and subclasses in this population compared to the amount used in clinical trials, consistent with low fiber intake. Nevertheless, higher FC and SDF intake were each associated with lower DBP and %body fat, and polyol/1000kcal intake was associated with lower BMI, even when controlling for fiber intake. These results conclude that more efforts are needed to increase the consumption of total FCs in the college student population, considering their benefits in improving cardiometabolic risk factors[58, 59].

The global nutrition transition model showed the decrease in fermentable carbohydrate intake as one of the main characteristics that are linked to health risks[60, 61], and increased FC intake from an early stage of life might show long-term health benefits[58, 59]. A randomized controlled trial (RCT) showed a reduced glycemic response in type-2-diabetic patients after 10.5g supplementation of SDF for 8-week intervention[62], similarly, polyol consumption was also associated with decreased blood glucose and insulin secretion[63]. In line with these studies, the current study found lower blood glucose in higher SDF and a non-significant trend in higher polyol consumer groups. The potential mechanism leading to this difference in blood glucose could be related to the increased hormones such as GLP-1 and PYY after consumption of FCs[22]. Prior research in controlled laboratory studies, showed that the dietary FCs influence satiety and insulin/glucose pathways[11, 15, 16]. Human gut microbiota ferments these FCs into SCFA[21], which produces molecular signals to activate satiety hormones that are associated with decreased hunger and gastric emptying and improve postprandial glucose and insulin sensitivity[22-24]. The current study did not measure these hormonal levels; however, this should be a focus in future studies to examine whether the observed differences in blood glucose levels might be explained by such mechanisms.

Consumption of FCs not only increases satiety hormones[18] but has also been shown to decrease plasma ghrelin and energy intake, which may help reduce weight[15].[15]. Similarly, increases in satiety and decreases in energy intake were seen after consumption of 16g oligofructose for 2-weeks in healthy adults age 21-39[24]. Corroborating such prior research, this study observed that higher polyol expressed as g/1000kcal intake was associated with lower BMI. These findings support the conclusions from previous studies that showed a lower caloric value of polyols 0-3 kcal/g compared to 4kcal/g for sugars makes them ideal to use for weight management[64-67].

A recent intervention study suggested that increased intake of FCs may have beneficial effects on obesity after they found that the consumption of oligofructose enriched inulin (8gm/day) for 16 weeks reduces fat mass in children with overweight and obesity[68]. In alignment with this study, the current study also showed lower % body fat in the high FC consumer group than the low consumer group, but the effect was attenuated and no longer significant when adjusted for insoluble dietary fiber. However, throughout the study, the trend of lower % body fat was visible in the high FC/SDF/Polyol consumer group, however not statistically significant. The reason might be that this population was consuming less than half of FCs compared to the amount used in those intervention studies, therefore future work should include a high FC consuming population to observe a significant effect.

In the present study, we did not observe any significant associations with LDL-c and the results had a small effect size. This could be because this study population was healthy, and their baseline lipid levels were normal[69]. Previous research has shown that some of the fermentable carbohydrates such as SDF bind to bile acids and interfere with their resorption[70] which might help to the lower levels, however, the detailed mechanism of fermentable carbohydrates and their byproducts on cholesterol-lowering effects are still being explored [18, 71-74].

Additionally, this study also observed lower DBP in the high FC consumer group and no other exposure variables showed significant associations with blood pressure. The reason might be that the consumption of FC and subclasses in this population was quite low, and blood pressures were mostly within normal ranges in this healthy student population. However, it is important to note that a small change in health parameters can translate to decreased health risk and reduced mortality. For example, a difference of 2mmHg in blood pressure of polyol consumer group or 1% reduction in LDL-C of overall FC and subclasses consumer group in this study can significantly decrease mortality from stroke and CVD[75, 76]. Additionally, if the study were to be conducted in the population at risk, the results could be more evident.

Although there are very few clinical trials that investigated the effects of FCs on blood pressure and the exact mechanism is still unknown, the results of this study are in line with a previous study that concluded the lack of fermentable carbohydrates intake in the diet is a crucial risk factor for the development of clinically meaningful hypertension with the main driver of this outcome might be disruptions to the gut microbiota[77]. Consequently, more studies determined probiotic consumption and its effect on blood pressure. An RCT with probiotic supplementation for 21 weeks showed a 6.7mmHg decrease in SBP and a 3.6mmHg decrease in DBP in hypertensive people[78]. The potential mechanisms responsible for the differences relate to the regulation of angiotensin-converting enzyme (ACE) activity, glucose tolerance, and systemic inflammation[79-81]. Fermented dairy products are known to increase ACE inhibitory activity[82, 83], which is related to decreases blood pressure[84, 85]. However, more investigation is needed to further elucidate this mechanism and determine whether FCs exert similar effects as probiotics.

Additionally, the study results showed different results for absolute and relative intake of FCs and subclasses (i.e., gram and gram/1000kcal). For example, the gram intake of FC and DBP showed a significant association, but not FC/1000kcal and the effect size was small, therefore it's worth exploring whether consuming more total energy would reduce the effectiveness of FCs on DBP. Additionally, the gram intake of FC and %BF showed significant association (without ISDF) with a large effect size, but not FC/1000kcal. This might be due to the small sample size (n=244), and if we had a larger sample size, we may have seen significant associations, but this should be explored in future research. Similarly, SDF showed a significant association with blood glucose, but not SDF/1000kcal, and future work should explore whether absolute or relative amounts of SDF are more important for healthy blood glucose levels. This would be particularly relevant in populations with higher ranges of blood glucose than what was seen in this student population. Furthermore, the polyol models tend to be weak (p-values and R), probably because this student population consumed such low quantities of polyols in general. Overall, the results suggest an absolute amount of polyol (polyol gram model), might be important for blood glucose, whereas, for DBP, the amounts of polyols relative to total caloric intake might be more important. However, given the weak associations, these relationships should be followed up using broader ranges of polyol intakes, as well as in more diverse populations, particularly those at high risk for elevated blood glucose and hypertension.

The strengths of this study are being one of the first studies to examine FCs intake and its association with cardiometabolic health markers in free-living student populations. All health markers were measured by validated instruments and trained researchers, and data collection spanned over a period of 5-years. Additionally, the DHQ-II used in this study is a US-validated FFQ for calculating nutrient intakes[42]. The limitations of this study were a relatively large convenience sample of predominantly female, single university students without significant ethnic diversity. Apart from that this study population mostly included healthy young college students enrolled in a nutrition course, therefore, effects observed in this study may not represent the overall population at risk. Finally, although subjects received education related to portion sizes and data collection, all dietary information was based upon self-report and dependent upon subject participation and diligence. Nonetheless, this cross-sectional study provides compelling preliminary evidence that increased FC intake is associated with improving cardiometabolic risk markers in the college student population, however, prospective studies and RCTs are needed to determine causal relationships.

5. Conclusion

In summary, the average consumption of FC in this large college student population was low, especially in the male students compared to the amount used in clinical trials. After analyzing the differences in health indices by FC consumption, we found significantly lower diastolic blood pressure (mmHg) in high FC consumers, lower fasting blood glucose in high SDF consumers, and lower BMI in the high polyol/1000kcal consumer group than a low consumer group. Given these associations between total FC and subclasses with risk markers even at low levels of consumption and in a healthy population, promotion of increased FC consumption in students should be strongly considered.

Figure 1: Flow diagram of exclusion of the participants based on the study criteria to reach final study sample (n=571)

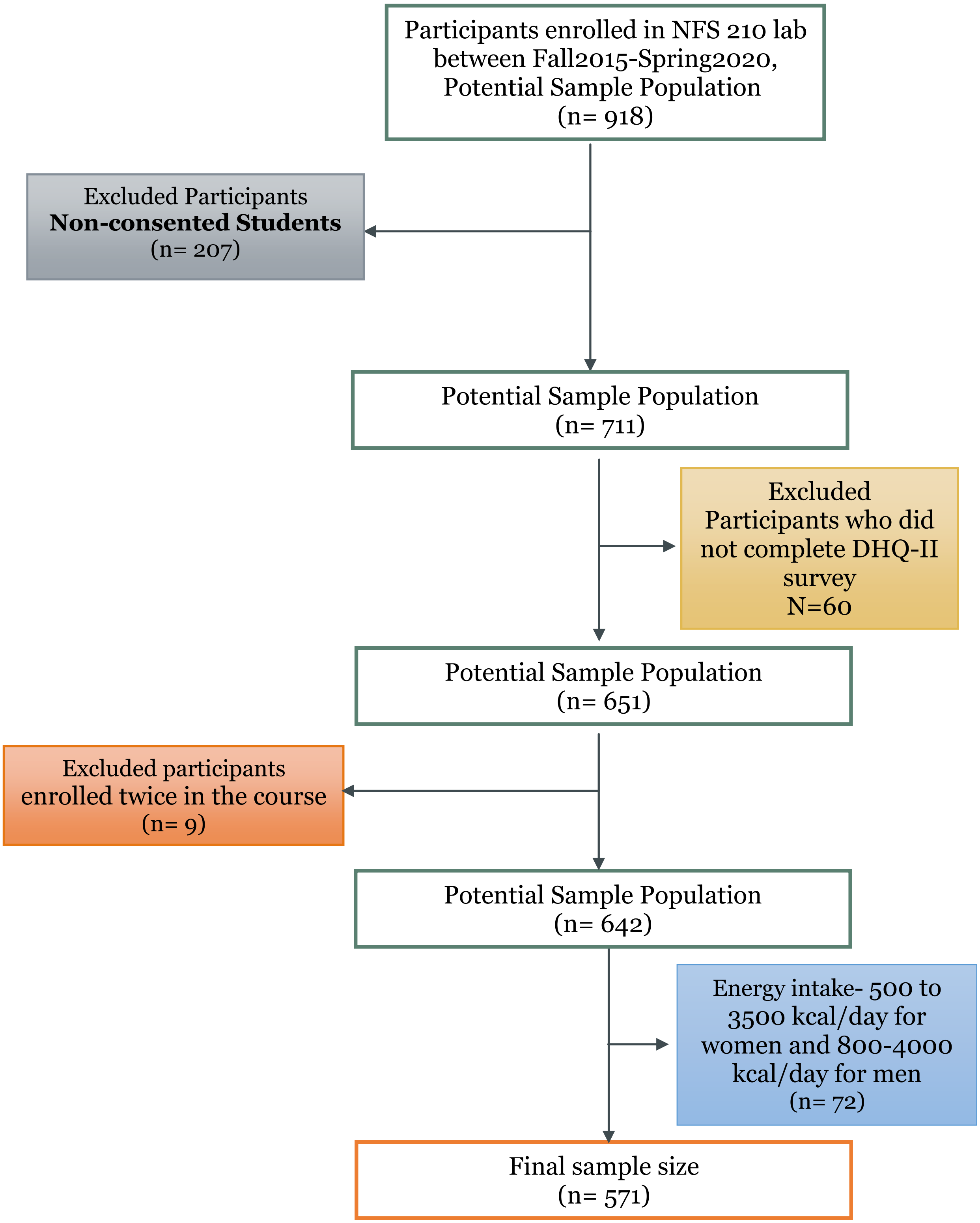

Table 1. Demographic characteristics of 571 consented healthy US college students who enrolled in an introductory nutrition course

Characteristics	N	
		Percentages (%)
Sex (female %)	499	80.8
Race (%)	497	
White		84.5
Non-White		15.5
Smoke Now (%)	501	
Yes		7.5
No		92.5
		Mean±SD
Age (years)	514	19.5±3.3
Physical Activity (days/week)	496	5.5±2.1
Kcal	571	1788±708
Healthy Eating Index (HEI-2015)	571	65.5±10.7
Body Mass Index, (kg/m^2)	442	23.9±4.3
Blood Glucose, (mg/dl)	459	87.7±8.5
Systolic blood pressure (mmHg)	472	112.6±13.2
Diastolic blood pressure (mmHg)	472	73.9±9.3
Body fat (%)	244	26.2±8.8
LDL-c	424	87.5±27.9

Abbreviations: N=total number of participants, **SD**=standard deviation, **kg/m^2**=kilograms over meters squared; **mg/dL**= milligram/deciliter; **mmHg**=millimeter of mercury (manometric unit of pressure); Descriptive statistics.

Table 2. Daily consumption of total FC and subclasses (gram and g/1000kcal) in healthy US college students enrolled in an introductory nutrition course (n=571)

Consumption (g)	Mean±SD	Skewness	Kurtosis
FC consumption	7.1±3.6	1.1	1.8
FC (g/1000kcal)	4.1±1.9	1.4	3.4
SDF	6.1±3.1	1.2	2.1
SDF (g/1000kcal)	3.6±1.7	1.7	5.6
Polyols	1.0±0.8	2.1	6.6
Polyols (g/1000kcal)	0.6±0.4	1.9	5.2

Abbreviations: Min = Minimum, **Max** = Maximum, **Mean±SD**= Mean±Standard deviation,
FC= Fermentable carbohydrate, **SDF**= soluble dietary fiber; Descriptive statistics

Table 3. Differences in cardiometabolic risk markers between groups of Low vs High **FC** consumers (expressed as g and g/1000kcal) of 571 consented healthy US college students enrolled in an introductory nutrition course

Outcome variables	β coefficient	95% CI		Effect size (R^2)	*p-value*
		Lower bound	Upper bound		
FC (g)					
BMI (kg/m2)	0.77	-0.37	1.92	0.10	0.19
GLC (mg/dL)	1.90	-0.47	4.26	0.08	0.12
SBP (mmHg)	0.24	-3.43	3.90	0.21	0.90
DBP (mmHg)	2.95	0.19	5.70	0.08	0.04*
Body Fat (%)	2.41	-0.11	4.94	0.37	0.06
LDL-c (mg/dL)	2.66	-11.47	6.15	0.07	0.55
FC					
BMI (kg/m^2)	0.19	-0.92	1.30	0.1	0.74
GLC (mg/dL)	1.34	-0.91	3.59	0.09	0.99
SBP (mmHg)	0.75	-2.57	4.06	0.21	0.66
DBP (mmHg)	1.70	-0.74	4.14	0.06	0.17
Body Fat (%)	1.36	-0.96	3.68	0.33	0.25
LDL-c (mg/dL)	4.25	-3.10	11.62	0.11	0.26

Abbreviations: N=Number of participants; **FC**=Fermentable carbohydrate; **BMI**=body mass index (kg/m^2); **LDL-C**=low density lipoprotein cholesterol; **GLC**=blood glucose; **SBP**=systolic blood pressure; **DBP**=diastolic blood pressure; **differences in cardiometabolic risk markers between groups of low vs high FC consumers were analyzed by multiple regression model with high consumer group as the reference group.** * significant p value<0.05

A) Regression Analysis controlling for (Gram intake):
1) BMI: Age, sex, race, smoking, alcohol intake, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
2) Blood Glucose: Age, sex, race, smoking, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
3) SBP: Age, sex, alcohol intake, energy intake, HEI-2015, sitting minutes/day, insoluble dietary fiber intake
4) DBP: Age, alcohol intake, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber intake
5) %body fat: Age, sex, alcohol intake, energy intake, physical activity, sitting minutes/day, insoluble dietary fiber intake
6) LDL-c: Age, smoking, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber intake.

B) Regression Analysis controlling for (Gram/1000kcal intake):
1) BMI: Age, sex, race, smoking, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
2) Blood glucose: Age, sex, smoking, alcohol intake, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
3) SBP: Age, sex, race, alcohol intake, energy intake, HEI-2015, physical activity, sitting minutes/day
4) DBP: Age, sex, alcohol intake, HEI-2015, sitting minutes/day, insoluble dietary fiber
5) %Body fat: Age, sex, energy intake, physical activity, sitting minutes/day, insoluble dietary fiber
6) LDL-c: Age, sex, race, energy intake, HEI-2015, physical activity, sitting minutes/day

Table 4. Differences in cardiometabolic risk markers between groups of Low vs High **SDF** consumers (expressed as a g and g/1000kcal) of 571 consented healthy US college students enrolled in an introductory nutrition course

Outcome Variables	β coefficient	95% CI		Effect size (R^2)	*p-value*
		Lower Bound	Upper Bound		
SDF (g)					
BMI (kg/m2)	0.77	14.18	25.81	0.10	0.19
GLC (mg/dL)	2.65	0.48	4.82	0.07	0.02*
SBP (mmHg)	-1.18	-4.74	2.37	0.23	0.51
DBP (mmHg)	2.73	-0.04	5.49	0.11	0.053
Body Fat (%)	0.42	-2.51	3.35	0.2	0.78
LDL-c (mg/dL)	0.92	-11.47	6.15	0.11	0.83
SDF(g/1000kcal					
BMI (kg/m²)	0.46	-0.61	1.54	0.08	0.4
GLC (mg/dL)	1.40	-0.59	3.38	0.06	0.17
SBP (mmHg)	0.05	-3.41	3.31	0.23	0.98
DBP (mmHg)	1.98	-0.38	4.33	0.08	0.10
Body Fat (%)	0.72	-1.54	2.98	0.33	0.53
LDL-c (mg/dL)	4.05	-2.81	10.91	0.11	0.25

Abbreviations: SDF=soluble dietary fiber; **95% CI**= 95% confidence interval; **BMI**=body mass index (kg/m²); **LDL-c**= low density lipoprotein cholesterol; **GLC**=blood glucose; **SBP**=systolic blood pressure; **DBP**=diastolic blood pressure; **differences in cardiometabolic risk markers between groups of low vs high SDF consumers were analyzed by multiple regression model with high consumer group as the reference group.** *significant p-value <0.05

A) Regression Analysis controlling for (Gram intake):
1) BMI: Age, sex, race, smoking, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
2) Blood Glucose: Age, race, smoking, HEI-2015, physical activity, insoluble dietary fiber
3) SBP: Age, sex, alcohol intake, energy intake, HEI-2015, sitting minutes/day, insoluble dietary fiber
4) DBP: Age, alcohol intake, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
5) %body fat: Age, sex, alcohol intake, energy intake, physical activity, sitting minutes/day, insoluble dietary fiber
6) LDL-c: Age, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber

B) Regression Analysis controlling for (Gram/1000kcal intake):
1) BMI: Age, sex, smoking, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
2) Blood Glucose: Age, race, HEI-2015, physical activity, sitting minutes/day
3) SBP: Age, sex, race, smoking, alcohol intake, energy intake, physical activity, sitting minutes/day, insoluble dietary fiber
4) DBP: Age, sex, smoking, alcohol intake, HEI-2015, sitting minutes/day, insoluble dietary fiber
5) %body fat: Age, sex, smoking, HEI-2015, physical activity, insoluble dietary fiber
6) LDL-c: Age, sex, race, HEI-2015, physical activity, sitting minutes/day

Table 5. Differences in cardiometabolic risk markers between groups of Low vs High **Polyol** consumers (expressed as a g and g/1000kcal) of 571 consented healthy US college students enrolled in an introductory nutrition course

Outcome variable	β - coefficient	95% CI		Effect size	*p-value*
		Lower bound	Upper bound		
Polyol (g)					
BMI (kg/m²)	0.43	-0.61	1.47	0.07	0.42
GLC (mg/dL)	1.86	-0.09	3.82	0.04	0.06
SBP (mmHg)	2.67	-0.51	5.85	0.22	.099
DBP (mmHg)	0.39	-2.13	2.91	0.02	0.76
Body Fat (%)	0.09	-2.44	2.61	0.32	0.44
LDL-C (mg/dL)	1.44	-9.26	6.39	0.08	0.72
Polyol (g/1000kcal)					
BMI (kg/m2)	0.99	0.0002	1.97	0.04	0.050*
GLC (mg/dL)	1.40	-0.61	3.42	0.03	0.17
SBP (mmHg)	2.4	-0.74	5.56	0.21	0.13
DBP (mmHg)	1.35	-0.95	3.66	0.03	0.25
Body Fat (%)	0.55	-1.77	2.87	0.30	0.64
LDL-C (mg/dL)	2.86	-4.01	9.74	0.04	0.41

Abbreviations: N=Number of participants; **BMI**= body mass index (kg/m²); **LDL-C**= low-density lipoprotein cholesterol; **GLC**=blood glucose; **SBP**=systolic blood pressure; **DBP**=diastolic blood pressure; **differences in cardiometabolic risk markers between groups of low vs high Polyol consumers were analyzed by multiple regression model with high consumer group as the reference group.** *significant p-value <0.05

A) Regression Analysis controlling for (Gram intake):

1) BMI: Age, alcohol intake, energy intake, HEI-2015, physical activity, sitting minutes/day
2) Blood Glucose: Age, smoking, HEI-2015, insoluble dietary fiber
3) SBP: Sex, energy intake, HEI-2015, sitting minutes/day, insoluble dietary fiber
4) DBP: Alcohol intake, energy intake, HEI-2015, sitting minutes/day, insoluble dietary fiber
5) % Body fat: Sex, race, smoking, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber
6) LDL-c: Age, race, energy intake, HEI-2015, physical activity, sitting minutes/day, insoluble dietary fiber

B) Regression Analysis controlling for (Gram/1000kcal intake):
1) BMI: Sex, smoking, energy intake, sitting minutes/day, insoluble dietary fiber
2) Blood Glucose: Sex, energy intake, sitting minutes/day, insoluble dietary fiber
3) SBP: Sex, HEI-2015, sitting minutes/day
4) DBP: Smoking, alcohol intake, energy intake, HEI-2015, physical activity, insoluble dietary fiber
5) % Body fat: Sex, race, HEI-2015, sitting minutes/day, insoluble dietary fiber
6) LDL-c: Sex, smoking, energy intake, HEI-2015, physical activity, insoluble dietary fiber

Table 6. FC and subclasses consumption stratified sex in consented healthy US college students enrolled in an introductory nutrition course (n=571)

Subgroups	**N**	**(g/1000kcal)**	**Mean±SD**
Sex			
Male	96	FC	3.63±2.0
		TDF	10.42±5.5
		SDF	3.84±1.5
		polyol	0.49±0.3
Female	403	FC	4.27±1.8
		TDF	12.02±4.9
		SDF	3.63±1.6
		Polyol	0.64±0.5

Abbreviations: **N**= Number of Participants, **FC**= Fermentable carbohydrate, **TDF**=Total dietary fiber **SDF**= soluble dietary fiber, **Mean±SD**= Mean± standard deviation, **g/1000kcal**= gram/1000kcal

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Manuscript 3 "Comparison of fermentable carbohydrate (FC) consumption in plant-based vs meat-based diet groups "

by

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ABSTRACT

OBJECTIVE: Fermentable carbohydrates (FC) are indigestible by the human digestive system and through colonic fermentation by gut microbes, may improve human health. Although FCs are abundant in plant foods, limited research has compared the varying intake of FCs in self-selected plant-based (PT) *vs* meat-based (MT) diets. Types of foods chosen within PT and MT diets may vary, which could impact the FC distribution and overall diet quality, but these relationships have not been examined to date. The proposed research quantifies FC intake in diets of free-living adults who self-identify as consuming PT or MT diets and explores relationships with dietary quality as reflected by the Healthy Eating Index (HEI-2015). The primary aim of the study was to calculate the difference in mean FC and subclasses (soluble dietary fiber and polyols) intake (in grams and g/1000kcal) between PT and MT diet groups of free-living adults. The secondary aim was to analyze relationships between PT and MT diet groups and HEI-2015 scores. The exploratory aim evaluated if FC and subclasses intake differed by high and low diet quality in PT and MT diet groups.

METHODS: This was a cross-sectional comparison of 84 free-living adults who consume two different dietary patterns: plant-based (PT) and meat-based (MT) diets. We recruited through social media, listservs, and flyers. Demographic data were collected through an eligibility survey, and dietary intake data were collected through a diet history questionnaire (DHQ-III) reflecting the previous month of intake. DHQ-III provided an average intake of FCs' subclasses in grams (soluble dietary fiber and polyols), which were added together to calculate the total available FC intake. The eligibility criteria for the study were that PT groups

should not consume any animal flesh and MT groups should consume animal flesh on average at least once/day. The exclusion criteria were pregnancy, lactation, and any chronic medical conditions. Independent sample t-tests were used to compare the mean intake of FC and subclasses (in grams and g/1000kcal) of the PT and MT diet groups. We ran multiple regression analysis to compare the diet quality of PT and MT diet groups while adjusting for confounders. For the exploratory aim, we used analysis of variance to evaluate if low and high diet quality (by the median split of HEI-2015 score) influences the relationship between diet group and FC and subclasses (in grams and g/1000kcal) intake.

RESULT: The average intake of FC (g) [PT (9.8±5.2g) vs MT (7.3±3.6g), p=0.014*], SDF (g) [8.3±4.4g vs 6.4±3.1, p=0.02] and polyol (g) [1.5±1.0 vs 1.0±0.6, p=0.008] was significantly higher in the PT diet group than MT diet group. Similarly, the average intake of FC (gram/1000kcal) [6.5±5.9 vs 4.6±3.9, p=0.0001*], SDF (g/1000kcal) [5.5±1.6 vs 4.0±1.6, p=0.0003*] and polyol (g/1000kcal) [1.0±0.6 vs 0.6±0.3, p=0.0006*] was significantly higher in PT than MT. The multiple regression model after controlling for race statistically significantly predicted that the mean HEI-2015 score for the PT-diet group was higher than the MT-diet group [77.9±9.1 vs 64.7±11.4, $p < 0.0001$, adj. R^2 =0.36]. Exploratory findings concluded higher intake of FC (7.1±1.2 vs 3.6±1.3, p=0.0001*), SDF (6.0±1.1 vs 3.1±1.2, p= 0.001*), and polyols (1.1±0.5 vs 0.5±0.3, p=0.001*) in the high-quality PT group than the low-quality MT group.

CONCLUSION: In summary, study results suggest that on average, people who report PT dietary patterns consume more FC and subclasses than those reporting MT. Significantly higher dietary quality was also seen in the PT group than the

MT-group. Importantly, findings also indicate that eating higher-quality diets, either plant-based or meat-based, was associated with a higher intake of FCs and subclasses among these US adults. An understanding of relationships among intake PT- and MT-diets, dietary quality, and FC intake will help articulate strategies that aim to increase FC intake, and enhance understanding of plant-based diet intake, ultimately human health.

1. Introduction

Fermentable carbohydrates (FC), which are indigestible by the human digestive system, are metabolically available to gut microbes and act as the main energy source for gut microbiota[1]. Dietary FC includes the sub-classes of soluble dietary fibers (SDF), oligosaccharides (OS), polyols, and resistant starches[2-6]. These FCs are selectively fermented by beneficial colonic bacteria to promote growth and colonization of more beneficial bacteria[5, 6], and byproducts of this fermentation are known to improve human health[4, 7]. The amount of FC available to gut microbes is affected by common dietary patterns that either increase, decrease, or exclude specific nutrients. While FCs are known to be abundant in plant foods, and plant-based diets are potentially beneficial for gut microbes [8], limited research has compared the varying intake of FCs in self-selected plant-based (PT) *vs* meat-based (MT) diets. Types of foods chosen within PT and MT diets may vary, which could impact the FC distribution and the overall healthfulness of such diets[9, 10]. The proposed research quantifies FC intake in diets of free-living adults who self-identify as consuming PT or MT diets.

Dietary FC maintains diverse and rich microbiota[11-15], which are key moderators of dietary impacts on host metabolic status[16], but direct connections to PT diets in free-living humans remain unexplored. Recent studies show that PT diets may increase the number of beneficial bacteria in the gut[8, 17, 18], possibly due to the presence of FCs in PT diets[1]. Empirical evidence directly comparing this in self-selected PT and MT diets is lacking.

The increasing popularity of PT diets is due, at least in part, to the possibility that they lower risks for chronic diseases[19-23]. However, PT diets do not necessarily always translate to healthy eating patterns[17]. In fact, some PT diets can also include less healthful plant foods such as desserts, sugar-sweetened beverages, and savory snacks as well as highly processed convenience foods, which are directly related to a heightened risk for chronic diseases[24, 25]. Additionally, preference for a PT diet is often interpreted as reduction or elimination of meats. Whether reducing or eliminating MT foods from diets confers health benefits remains controversial[26]. Prior studies that evaluated the diet quality of PT diets did not jointly differentiate the diet quality of MT-diets in relation to FC intake, especially in free-living populations[27]. However, a comparison of the diet quality of PT-diets with MT-diets is important to determine whether PT-diets improve diet quality by adhering to dietary recommendations[28, 29] and subsequently increasing FC intake. Additionally, applying a diet quality indicator such as the healthy eating index (HEI-2015)[30] to self-selected PT diets *vs* MT diets in free-living adults would offer insight into efficacious diet choices and strategies to increase beneficial nutrients such as FC.

Diet quality can be easily calculated and studied[31, 32]. In clinical research, one of the most-used dietary indices to evaluate diet quality is the Healthy Eating Index (HEI, started in 1989)[33]. The HEI closely aligns with the U.S. Dietary Guidelines and has been modified over the years according to Dietary Guidelines revisions. Evaluating the relationships between FC intake in PT *vs* MT diet groups differentiated by diet quality (as indicated by the HEI) has not been done in free-living populations. This approach would provide a basis for understanding the possible role that FC provides in enhancing the diet quality of PT relative to MT diets. Additionally, the role of FC's subclasses such as soluble dietary fibers

(SDF), OS, and polyols in contributing to the diet quality of PT and MT diets has not been studied. This study evaluated the intake of FCs and subclasses (SDF and polyols) in free-living adults self-selecting PT and MT diets, differentiated by high and low diet quality.

A cross-sectional study[34] that included 415 participants to understand the public views for intake of plant-based diets concluded that the majority of the population perceived "associated health benefits" particularly to decrease saturated fat intake and "to increase dietary fiber intake" are the most prominent views for the intake of a plant-based diet. Dietary fibers (DF) benefit human health, but the non-fermentable insoluble fibers do so by different means than SDF due to their differential fermentable properties[35, 36]. Much interest has focused on total and non-fermentable (insoluble) fibers, but less has focused on SDF, along with non-fiber FC such as oligosaccharides and polyols[37]. It is unclear to what degree PT diets are associated with SDF and total FC compared to MT diets; perhaps they are more related to a high diet quality diet than just PT diets. Therefore, work is needed on total FCs and subclasses together with diet intake in free-living populations.

The present cross-sectional study primarily focused on comparing FCs and subclasses intake in self-selected PT- and MT-based diet groups of free-living adults. It further examined the diet quality of PT- and MT-diet groups and evaluated whether the FC intake differed by high and low diet quality (measured by HEI-2015) between PT-based *vs* MT-based diet groups.

2. Methods

This was a cross-sectional comparison of two different dietary patterns: plant-based (PT) and meat-based (MT) diets, as self-selected by free-living adults. The Institutional Review Board (IRB) approval was obtained in March 2020. All research participants signed IRB-approved informed consent forms before starting the data collection (Consent form in Appendix-J).

2.1 Subjects and Recruitment: The advertisement of the study was done through flyers, social media, and class announcements at the University of Rhode Island where the study was conducted. This advertising specified that we seek individuals who have adhered to a PT or MT diet for at least 3 months before the study. Potential participants completed an online eligibility survey with brief dietary screening questions. Information about those who completed the eligibility survey versus those who were enrolled is included in the results section. A total of 84 participants completed the study, of which 43 were in PT, and 41 were in MT diet groups based on their eligibility survey response. Most of the participants were recruited from the university and surrounding areas of Rhode Island and 25 of them were from the other states of the US. The PT group required individuals who do not consume animal flesh, while the MT group consumes animal flesh at least 7-10 times per week or once/day. The inclusion criteria of the study were all genders, races, BMI, and age ≥18 years, who are not pregnant or lactating, free from chronic diseases. The eligible participants were contacted via email to send further information and address questions or concerns (Advertisement flyer in Appendix K).

2.2 Data collection procedure:

2.2.1 Demographic data: The eligibility survey included brief standardized demographic questions and the International Physical Activity (PA) Questionnaire (IPAQ)[38]. The IPAQ survey included a question about days/week participants performed vigorous PA such as 'heavy lifting, digging, aerobics, or fast bicycling' and moderate PA such as 'carrying light loads, bicycling at a regular pace, or doubles tennis. We summed up these scores out a maximum possible score of 7days/week. For example, if the participant was performing 7 days vigorous PA and 7days moderate PA the maximum possible score for his physical activity was 7days/week. The demographic survey included information regarding age, sex, smoking habits, weight, height (BMI later calculated in Excel as kg/m^2) supplement intake, and ethnicity was collected. These data were used for descriptive purposes and as confounders when required (Eligibility Survey in Appendix L).

2.2.2 Dietary Intake Data: After consenting to the study participants were provided with their personal login and password information to start the electronic Dietary History Questionnaire (DHQ-III) reflecting the intake of the previous month where the guidance from research personnel was provided virtually (via email/phone/video call) when needed. Approximately 60-90 minutes were required to complete the survey. The DHQ-III is an electronic food frequency questionnaire (FFQ) that consists of 135 food items and includes both portion size and dietary supplement questions and is designed and validated by the National Cancer Institute[39]. In DHQ-III, HEI-2015 and dietary component intakes based on questionnaire responses were automatically calculated. Two participants were selected by a raffle drawing method to each receive a $100 Amazon gift card, as an incentive for participation.

2.2.3 Fermentable carbohydrate intake: In DHQ-III, nutrient intake was automatically calculated including intake of FCs such as soluble dietary fibers (SDF) and polyols (Erythritol, Lactitol, Inositol, Pinitol, Sorbitol, Xylitol, Isomaltose, Maltitol, and Mannitol). All the estimated FCs (in gram) were added together to evaluate the total available FC intake, which included SDF and OS (combined in DHQ as SDF), as well as polyols. FCs in gram per 1000kcal were also calculated to control for the possibility of increased consumption from total intake. Similarly, SDFs and polyol in gram per 1000kcal were also calculated.

2.2.4 Covariate selection for multivariate analysis: Demographic characteristics of participants were examined as possible covariates were included based on research suggesting an association with dietary patterns (vegetarian, non-vegetarian) and HEI-2015, were (sex (male/female), race (White/non-white/unknown), age, etc.)[40, 41], energy intake, physical activity (vigorous and moderate physical activity/week), smoking (yes/no), and alcohol intake[40-44]. Energy intake (kcal), HEI-2015, and alcohol intake (in grams) were obtained from the DHQ-III whereas physical activity was measured through the IPAQ survey[38]. These covariates were used for the multiple regression analysis models (aim 2) of the study.

2.3 Statistical analysis:

The primary aim of the study was to calculate the difference in mean FC and subclasses (SDF and polyols) intake between PT and MT diet groups. The secondary aim of the study was to analyze relationships between PT and MT diet groups and the HEI-2015 scores. The exploratory aim evaluated if the FC and subclasses intake differed by high and low diet quality in PT and MT diet groups (Figure-1).

2.3.1 Descriptive statistics: Data were assessed for normality by skewness and kurtosis. Descriptive statistics were used to summarize demographics; frequencies and percentages were used to present categorical variables and mean±standard deviation for continuous variables. Before analyses, all data were double-checked manually for accuracy (e.g., data entry, missing data, etc.). Statistical tests were conducted with a 2-tailed α (alpha), and significance was accepted at $p<0.05$. Data are mean±standard deviation unless otherwise stated. All statistical analyses were performed with SAS enterprise guide version 9.4.

For the primary aim to determine whether the (mean) FC intake, measured in grams, differed between two diet groups (PT and MT) we used an independent-sample t-test (aim-1). We also analyzed the mean intake of SDF and polyols; subclasses of FCs between PT *vs* MT diet group. To account for differing total energy intake, these analyses were also conducted with FC, SDF, and polyols expressed as grams per 1000 kcals.

The secondary aim evaluated the association between a dichotomous independent variable representing two diet groups (PT and MT) and HEI-2015 (aim-2), by multiple regression models (forward) controlled for covariates, which were identified in the literature search to be associated with HEI-2015. The preliminary bivariate analyses identified the order of potential covariates entered the regression model i.e., the most significant variables entered first to the base model. The base model included diet groups (PT and MT) as an independent variable and HEI-2015 as a dependent variable. Next, the most significant variable (based on p-value from bivariate analysis) was included and a change in β-coefficient was observed in the parameter estimate table. If the addition of the covariate change β-coefficient by 10% then the variable was retained in the model, if not then the variable was removed from the model, and then the next potential variable was added and re-ran the model. We repeated the process until we reach our final model that only has covariates that cause a 10% change in β-coefficient. The details of covariates retained/deleted from the model can be found in the MR result tables. The models were assessed for multicollinearity by reviewing variance inflation factors (VIFs) value <5.0. Analyses were conducted on the 84 participants who had complete data.

The exploratory aim of this study was to evaluate whether diet quality (HEI-2015 score) can modify the average intake of FCs (in grams and g/1000kcal) in PT- and MT-diet groups. We used the median split of HEI-2015 scores to create high and low diet quality groups of PT and MT diet-based participants and compared the FC and subclasses intake in the respective groups. One-way analysis of variance (ANOVA) was used to examine whether there are any statistically significant differences between the means of FC and subclasses intake (in grams and g/1000kcal) between PT and MT diet groups separated by high and low diet quality. Partial eta squared was calculated to examine the effect sizes.

3. Results

3.1 Demographic characteristics:

Of the 190 participants who filled out the eligibility survey, 28 participants did not meet the meat intake criteria and 13 did not meet PT diet group criteria. Out of the remaining 149 participants, 65 participants did not complete the online DHQ-III survey. Data from 84 participants were used in the analysis, of which 51.2% of participants were in the PT-diet group and 48.8% of participants were in the MT-diet group (table 1). More PT- than MT-diet group participants were female (93.0% vs 68.3%; p=0.005), but other characteristics did not differ significantly. Although not significant, PT-diet group participants had higher mean physical activity days/week (6.0±1.7 vs 5.1±2.2; p=0.11) than those in the MT-diet group. The mean total HEI-2015 score for the PT-diet group was significantly (p<0.001) higher (77.9±9.1), than that of the MT-diet group (64.7±11.4; table 1).

Additionally, the differences in demographic information of study completers and non-completers were analyzed by independent t-test for continuous variables and chi-square test for categorical variables. The results showed that the study completers group was younger (26.8±11.5 vs 33.5±13.7 years of age), with more females (81% vs 10.8%) and less white (60.7% vs 73.8%) population than the study non-completer group (table 2).

3.2 Evaluation by Diet group (PT *vs* MT)

3.2.1 Average intake of total FCs and subclasses between the two diet groups:

a) Gram intake: An independent-samples t-test was run to determine if there were differences in gram intake of FC and subclasses between the 43 PT and 41 MT diet group participants. There were no outliers in the data, as assessed by inspection of a boxplot. FCs intake for each level of diet group was normally distributed, as assessed by Shapiro-Wilk's test (p >0.05), and there was homogeneity of variances, as assessed by Levene's test for equality of variances (p = 0.25).

The average intake of FC was higher in the PT diet group (9.8±5.2g) than the MT diet group (7.3±3.6g), and the difference was statistically significant -2.5g [(95% CI -4.4 to -0.5), p=0.014*]. Similarly, the average intake of SDF [PT (8.3±4.4g) vs MT (6.4±3.8) p=0.02*] and polyol [PT (1.5±1.0) vs MT (1.0±0.6), p=0.008] was significantly higher in the PT diet group than MT diet group. The details of FCs and subclasses intakes are listed in Table 3.

b) Gram/1000kcal intake: There were no outliers in the data, as assessed by inspection of a boxplot. Engagement scores for each level of diet group were normally distributed, as assessed by Shapiro-Wilk's test (p > 0.05), and there was homogeneity of variances, as assessed by Levene's test for equality of variances (p > 0.05). The total FC intake in gram/1000kcal was higher in the PT diet group than the MT diet group [(6.5±5.9 vs 4.6±3.9)], with a statistically significant difference of [-1.8g (95% CI, -2.2 - -0.7), p=0.0001*]. Similarly, the average intake of SDF (g/1000kcal) [4.5±2.0vs 4.0±1.6, (p=0.0003*)] and polyol (g/1000kcal) [1.0±0.6 vs 0.6±0.3, (p=0.0006*)] was significantly higher in PT diet group than MT diet group. The details of FCs intake and its subclasses are listed in Table 4.

3.2.2 Differences in HEI-2015 score by diet group:

The results for MR analysis for associations between PT and MT diet group with HEI-2015 are shown in table 5. A multiple regression model met the assumption of normality as assessed by skewness and kurtosis. The variation inflation factor (VIF) values were less than 5, therefore there was no evidence of multicollinearity. The PT-diet group was associated with a higher mean HEI-2015 score than the MT-diet group (76.8±10.7 vs 64.7±11.4) and the multiple regression model statistically significantly predicted HEI-2015, $F(7, 83) = 13.51$, $p < 0.0001$, adj. $R^2 = 0.35$. Covariate race was retained in the final multivariate model and age, gender, physical activity, alcohol intake, energy consumption, and smoking were removed from the model due to less than 10% effect on β-coefficient. Regression coefficients and standard errors can be found in Table 5 (below).

3.3 Evaluation by diet quality:

A median split of HEI-2015 scores sub-classified PT and MT diet groups into low and high diet quality groups. The cut-off values of HEI-2015 for the median split were 79.3 for PT- and 62.9 for the MT-diet group. The HEI-2015 range for the low diet quality PT group (PT-lowDQ) was 48.3-79.3 and the high diet quality PT (PT-highDQ) range was 79.5-91.4. The low diet quality MT group (MT-lowDQ) HEI-2015 scores ranged 39.5-62.9, and for the high diet quality MT group (MT-highDQ) it was 64.7-89.1.

A one-way ANOVA was run to compare the total FC and subclasses (SDF and polyols) intake among diet groups of low and high diet quality (DG-DQ) PT- and MT-diets. Results showed the mean **FC intake** was statistically significantly different between DG-DQ, Welch's $F(3, 43) = 11.8$, $p < 0.0005$, partial $\eta^2 = 0.23$. Mean FC intake was decreased from PT-highDQ (10.7±3.6) to the MT-highDQ (9.1±3.7), PT-lowDQ (8.9±6.5), and MT-lowDQ (5.5±2.4) groups, in that order. Games-Howell post hoc analysis revealed that the significant differences in FC intake between MT-lowDQ and PT-high-DQ [(-5.2, 95% CI (-8.7 to -1.8), p = 0.001*)]; MT-lowDQ and MT-highDQ [mean difference=-3.7, 95%CI (-7.2 to -0.12) p=0.04], as well as MT-lowDQ and PT-lowDQ [mean difference=-1.7, 95%CI (-6.3 to -1.1) p=0.003].

Similarly, the average intake of **FC expressed as g/1000kcal** was statistically significantly different between DG-DQ; Welch's $F(3, 43) = 25.5, p < 0.0001$, partial $\eta^2 = 0.18$. Games-Howell post hoc analysis revealed significant differences in FC intake expressed as g/1000kcal between MT-lowDQ and PT-lowDQ [mean difference= -1.4, 95% CI (-0.2 to 2.9) p=0.09)], MT-lowDQ and MT-highDQ [-1.5, 95% CI (0.01 to 3.1), p=0.049] as well as MT-lowDQ and PT-highDQ [-3.5, 95% CI (2.0 to 5.1), p = 0.0001)] in that order (figure 2).

A one-way ANOVA for mean **intake of SDF** between DG-DQ was significantly different; Welch's $F(3, 43) = 10.2, p < 0.0001$, partial $\eta^2 = 0.21$. Games-Howell post hoc analysis showed the SDF intake was significantly different between MT-lowDQ and MT-highDQ [-3.1, 95%CI (-6.1 to -0.02) p=0.047*], as well as MT-lowDQ and PT-highDQ [(-4.2, 95% CI (-7.2 to -1.2), p = 0.03*]. Similarly, **SDF expressed as g/1000kcal** was significantly different between DG-DQ group, Welch's $F(3, 43) = 21.5, p < 0.0001$, partial $\eta^2 = 0.27$. Significant difference between observed in SDF/1000kcal intake in MT-lowDQ and PT-lowDQ [-1.7, 95%CI (-3.2 to -0.4) p=0.005*], MT-lowDQ and PT-highDQ [-2.9, 95% CI (-4.2 to -1.5), p=0.0001*] (table-5).

A one-way ANOVA for mean **polyol intake** between DG-DQ was significantly different; Welch's F (3, 42) = 11.7, $p < 0.0001$, partial $\eta^2 = 0.19$. Games-Howell post hoc analysis showed the SDF intake was significantly different between MT-lowDQ and PT-highDQ [-1.0, 95% CI (0.38 to 1.6), p=0.0001*]. Similarly, **polyol expressed as g/1000kcal** was significantly different between DG-DQ group, Welch's F (3, 43) = 11.1, $p < 0.0001$, partial $\eta^2 =$ 0.24. The polyol (g/1000kcal) intake was significantly different between MT-lowDQ and MT-highDQ group [-0.39, 95% CI (-0.8 to -0.01), p=0.04*] and MT-lowDQ and PT-highDQ [-0.7, 95% CI (-1.0 to -0.28), p=0.0001*] group. Overall, the MT-lowDQ group had the lowest intake of FC and subclasses either gram intake or gram/1000kcal intake compared to all other groups (Result in figure 2 below and result table can be found in Appendix M).

4. Discussion

This cross-sectional study compared average FC and subclasses (SDF and polyol) intakes and diet quality (by HEI-2015) between plant-based (PT) and meat-based (MT) diets, to understand the roles of dietary patterns and diet quality in the relationship between PT and MT diets and FC intake. The analysis also included consideration of high- and low-quality PT diets, and high- and low-quality MT diets. Overall, participants in the PT-diet group consumed more grams of fermentable carbohydrates (total FCs, SDF, and polyols) than the MT-diet group. The MT-diet group consumed (non-significantly), higher means of kcal/day, therefore when the analyses were performed separately with energy (kcal) adjustment, the differences in FC intake were significantly higher in the PT-diet group than MT-diet group, which was also observed in the FC subclasses SDF and polyols. These results align with previous research that showed the plant-based diets have a higher amount of total dietary fibers (nonfermentable and fermentable)[45]. This study adds to the literature that plant-based dietary patterns might provide an abundant source of FC (fiber and non-fiber FC), which may modulate intestinal microbiota. Although it is known that greater FC intake impacts the gut microbiota and results in a wide range of health benefits[46, 47], much-published research often focused on either total dietary fibers (insoluble plus soluble) or a single strain of FCs (e.g. either oligosaccharides or polyols)[48, 49]. A holistic approach of comparing the average intake of multiple FCs has never been done before. This study is the first to our knowledge that compared the average intake of FC that accounted for SDF and polyols between PT- and MT-diet groups.

Experts suggest that adopting a plant-based dietary pattern likely offers beneficial health outcomes[22, 50]. However, these diets may not always be synonymous with high-quality eating patterns[24]. For example, some consumers may assume that just by eliminating animal flesh that they are automatically eating healthier, even without considering the types of foods remaining in their diets. Taken together, this study compared the diet quality of PT- and MT-diet groups and found out that the PT-diet group had a significantly higher diet quality [HEI of 76.8±10.7 vs 68.3±12.4, p=<0.0001**] than MT-diet groups. The results were in line with published research, where vegetarians or vegans had higher overall diet quality than meat-consumers[51].

Additionally, the current study observed a significantly higher intake of average FCs and sub-classes intake in diet groups with high diet quality (PT- and MT-diet with higher HEI-2015 scores by median split) irrespective of dietary pattern. These data suggest that FCs are more closely aligned with diet quality than with only plant-based diet categorization. Additionally, high-quality PT diets consumed about twice as much total FC, SDF, and polyols as the MT-low DQ group. All of these 3-dietary patterns were higher in FC and subclasses content than low-quality meat-based diets, but still lower than those used in clinical trial studies to promote health and healthy gut microbiota[52-54].

High diet quality rated diets are those rich in vegetables, whole grain/high fiber foods, and low-fat dairy, moderate in lean meats and fish, and largely devoid of processed meats, fried foods, savory snacks, and sweets including sugared drinks[24]. In the USA and other developed countries, it has become popular to adopt diets focused on a diet premise (e.g., 'keto', 'paleo,' or 'vegan'), rather than on diet quality concepts, in the interest of health[34, 55]. Thus, messaging focused on high-quality diets attributes may lead to more intake of FCs and healthier outcomes than the simple promotion of plant-based diets or other patterns. The data herein suggest that higher FCs intake was not only associated with diet type but more so with high-quality diets.

According to a recent online survey conducted at Tufts University (Boston, MA), 50% of the population totaling 9536 participants reported following a plant-based diet[56]. The main obstacle to adopting a PT-diet was a lack of information about these diets and health benefits[34] whereas, the attraction towards a PT=diet may reflect the communal belief that PT-diets are healthy compared to MT-based diets[57, 58] or increase the intake of fiber[34]. In the present sample, the most favorable group for the higher intake of dietary fiber was noted for the high diet quality subsets of the PT-diet group (figure 2). It is interesting to note that the highest unadjusted intake of FCs was displayed by MT- consuming high-quality diets (MT-highDQ) comparable to the other diet groups (PT-highDQ, PT-lowDQ, MT-lowDQ groups). Additionally, the lowest intake of FCs has been observed in the MT-lowDQ group throughout all the analyses compared to the other groups. However, the MT groups consumed more total kcals, and the overall study population had a higher mean HEI-2015 score (72 vs 59 out of 100) compared to the average HEI-score for Americans[59]. Considering these findings, and published research on PT-diets and health outcomes did not account for diet quality[60, 61], it is possible that the claimed benefits of 'healthful' plant-based diets may be moderated and underreported.

A strength of this study was that intakes of FCs were assessed in the context of two dietary patterns (PT and MT) while considering diet quality. Another strength of this study was the use of the most recent version of the diet history questionnaire (DHQ-III), a US-validated FFQ that has been developed and tested for assessing food intake and calculating nutrient intakes[62]. The study not only included FCs but the FC sub-classes SDF and polyols, which can be considered as a strength since there has been very little human work published on these types of FC in PT and MT-diet groups. Another strength was controlling for potential confounding variables in the multiple regression analysis. The important limitation of this study was that due to the cross-sectional design, the results can only highlight associations between variables and cannot establish causality. Additionally, the evaluation of diet quality was limited by the small sample size, of a comparatively healthy population, with high HEI-2015 scores, and the dietary data were self-reported. Despite broad inclusion criteria, this study's population mostly included a widely white and female sample, which may make it difficult to generalize to other populations. Although, our sample included a wide range of ages (18-67 years), which makes the findings more generalizable to different adult age groups. Of those who met inclusion criteria, 65 participants did not complete the DHQ-III, and they differed from completers by age, sex, and race. They did not respond to offers for assistance with the DHQ-III or email nudges. Future work in this area should seek to understand the reasons for the non-completion of food frequency questionnaires. Another limitation of the study is that the dietary assessment tool does not separate out some of the FCs such as oligosaccharides, however, they tend to be added together with SDF intake.

Despite these limitations, our study was among the first to evaluate the relative importance of the quality of PT- *vs* MT-diets, in association with FC intake among free-living US adults. The findings observed a higher intake of FCs and subclasses expressed as g/1000kcal in PT-diets than MT-diet. They also revealed that self-selected PT-diets had a significantly higher mean HEI-2015 score than MT-based diets. The study indicates that a high-quality diet is an essential factor for increased intake of FC and subclasses. Finding new ways to assess FC intake in dietary patterns is an important step in pursuing the relationship between dietary patterns and increased FC intake, and this study was the first to show that diet quality influences the FC intake in self-selected PT- and MT-based diets. Future work may consider recruiting participants across a broader range of demographics and diet quality and stratifying based on diet quality to further examine the assessment of FC intake by dietary patterns.

5. Conclusion

In summary, our results provide the first efforts to examine free-living FC intake in PT- and MT-diet groups controlled by diet quality. Overall, in self-selected diets, the PT pattern showed higher FCs and subclasses, as well as HEI-2015 scores. Importantly, study results suggest that eating higher-quality diets, either PT- or MT-based, is associated with a higher intake of FCs and subclasses among US adults. Conversely, the low-quality MT-based diets contained the lowest FCs and subclasses. Findings support the current dietary recommendations that promote a high-quality plant-based diet for increased intake of fiber (and other types of FCs), and that diet quality is especially important for people self-selecting MT-based diets. An understanding of the relations of FC intake in self-selected PT- and MT-diets, and the role of diet quality will help articulate strategies that aim to increase fermentable carbohydrate intake. This will set a basis for future research, and potentially influence beliefs about plant food intake, in the interest of promoting health.

Figure 1: Outcomes, Hypotheses, and Data sources for the study which included 84 self-selected PT and MT diet groups.

Outcome	Hypothesis	Data source
Primary Mean FC and subclasses (SDF and Polyol) intake in grams	Participant in the PT-diet group will have more FC and subclasses intake than those in the MT-diet group	Eligibility survey and Nutrient information via Online DHQ-III questionnaire
Secondary Diet Quality (HEI-2015 score)	PT-diet group will have higher diet quality (HEI-2015 score) than MT-diet group	Eligibility survey and Online DHQ-III questionnaire automatically calculate HEI-2015 score
Exploratory FC and subclasses intake	High diet quality group will have higher FC and subclasses intake than low diet quality groups	Eligibility survey and Online DHQ-III questionnaire

Table 1. Demographic characteristics of the study population (n=84) who completed diet history questionnaire-II.

Characteristics	Total Sample N=84	PT group N=43	MT group N=41	p-value
Percentages (%)				
Sex (female)	81.0	93.02	68.29	0.005*
Race White Non-white Unknown	 60.7 8.38 30.95	 62.8 0 39.0	 58.5 0 23.3	0.16
Smoke Now Yes No	 8.3 91.7	 2.33 97.67	 7.32 92.68	0.35
Mean±SD				
Age (years)	26.8±11.5	29.0±13.0	24.5±9.3	0.08
Physical Activity (days/week)	4.1±2.6	6.0±1.7	5.1±2.2	0.11
BMI, (kg/m^2)	23.8±4.9	23.2±4.6	24.4± 5.1	0.25
Kcal/day	1589.8±668.3	1496.9±650.5	1687.2±680.8	0.19
HEI-2015	71.4±12.2	77.9±9.1	64.7±11.4	<.0001**

Abbreviations: N=Number of participants, **FC=** Fermentable carbohydrate, **MT group**= Meat-based diet group, **PT group**= Plant-based diet group, **BMI, (kg/m^2)** = Body Mass Index, (kg/m^2) **Healthy Eating Index-2015**= HEI-2015; **differences in demographic characteristics of PT vs MT diet groups were analyzed by Independent -t-test for continuous variables and chi-square test for categorical variables; *significant p-value <0.05, **significant p-value <0.01**

Table 2. Comparison of demographic characteristics of completers vs non-completers of the study (n=149)

Characteristics	Completers N=84	Non-completers N=65	p-value
Percentage (%)			
Sex (female)	81	10.8	0.001*
Race (%)			
White	60.7	73.8	
Non-white	8.4	23.1	0.001*
Unknown	30.9	3.9	
Smoke Now (%)			
Yes	8.3	9.0	0.34
No	91.7	91.0	
Mean±SD			
Age (years)	26.8±11.5	33.5±13.7	0.001*
Physical Activity (days/week)	4.1±2.6	4.6±2.4	0.28
Diet Type (%)			
PT	51.2	39.7	0.19
MT	48.8	60.3	

Abbreviations: N=Number of participants, **FC=** Fermentable carbohydrate, **MT group**= Meat-based diet group, **PT group**= Plant-based diet group, **to analyze the differences between study completers and non-completers, Independent -t-test for continuous variables and chi-square test for categorical variables were conducted; *significant p-value <0.05, **significant p-value <0.01**

Table 3. Primary Outcome (a): Difference between average gram intake of total FCs and subclasses in participants self-reporting as consuming a mainly plant-based (PT) or meat-based (MT) diet

Intake (g)/diet group (n=84)	PT (n=43)	MT (n=41)	t-test for equality of means			
			Mean diff.	p-value	95% CI	
					LL	UL
Total FC	9.8±5.2	7.3±3.6	-2.5	0.014*	-4.4	-0.5
SDF	8.3±4.4	6.4±3.1	-2.0	0.02*	-3.6	-0.3
Polyol	1.5±1.0	1.0±0.6	-0.5	0.008**	-0.8	-0.3

Abbreviations: N=Number of participants, **Total FC=** Fermentable carbohydrate, **SDF=** Soluble dietary fiber, **MT**= Meat-based diet group, **PT**= Plant-based diet group, **LL**=Lower limit, **UL**=Upper limit; **differences between groups in primary outcome (gram intake) were analyzed by independent sample t-test;** *significant p-value <0.05, **significant p-value <0.01; 95% CI= 95% Confidence interval

Table 4. Primary outcome (b): Difference between average intake of total FCs and subclasses, as expressed by grams/1000kcal in participants self-reporting as consuming a mainly plant-based diet or meat-based (MT)

Intake (g/1000kcal) /diet group (n=84)	PT (n=43)	MT (n=41)	t-test for equality of means			
			Mean diff.	p-value	95% CI	
					LL	UL
Total FC	6.5±5.9	4.6±3.9	-1.8	0.0001**	-2.7	-0.9
SDF	5.5±1.6	4.0±1.6	-1.5	0.0003**	-2.2	-0.7
Polyol	1.0±0.6	0.6±0.3	-0.4	0.0006**	-0.6	-0.2

Abbreviations: N= Number of participants**, Total FC=** Fermentable carbohydrate, **SDF=** Soluble dietary fiber, **MT**= Meat-based diet group, **PT**= Plant-based diet group, **LL**=Lower limit, **UL**=Upper limit; **differences between groups in primary outcome (g/1000kcal) were analyzed by independent sample t-test;** *=significant p-value <0.05, **=significant p-value <0.01; 95% CI= 95% Confidence interval

Table 5. Secondary outcome: Multivariable adjusted Healthy Eating Index (HEI-2015) comparison between PT vs MT diet groups of a total of 84 participants

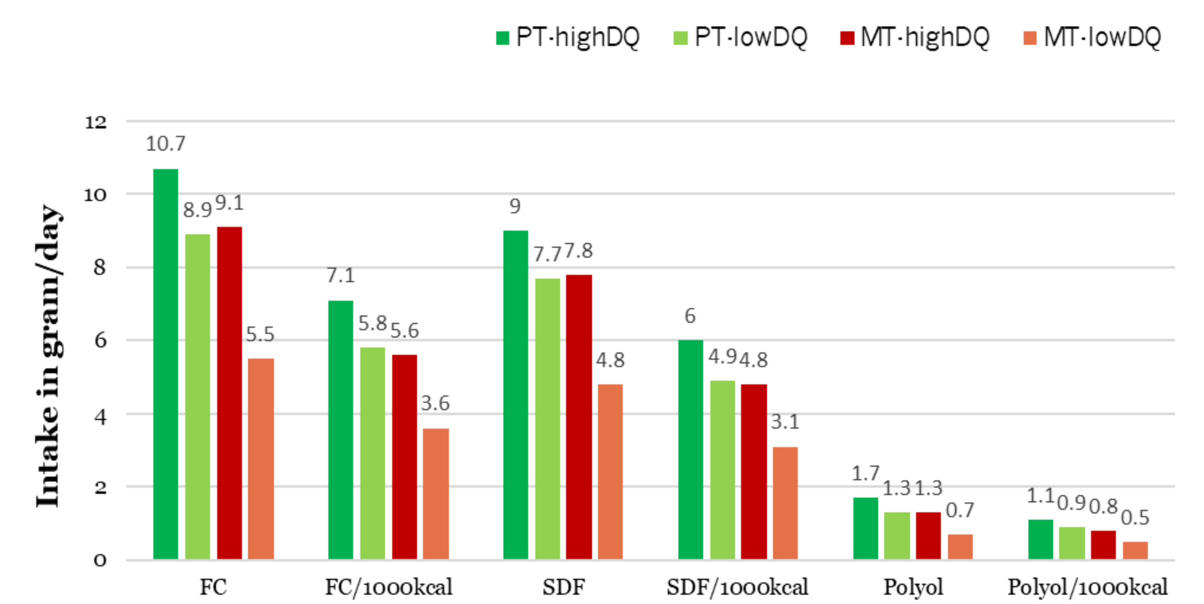
HEI-2015	B-coefficient	95% CI		Standard Error	p-value	R^2
		LL	UL			
Base Model						0.35
Constant	68.07**	64.68	71.45	1.70	<.0001	
PT Diet	13.5**	9.2	17.8	2.2	<.0001	

Abbreviations: **N=** Number of participants, **MT**= Meat-based diet group (reference) **PT**= Plant-based diet group **R^2** = Effect Size, **HEI-2015:** Healthy eating index-2015; **differences in HEI-2015 score between PT and MT-diet groups were analyzed by multiple regression while adjusting for confounders;** *significant p-value <0.05, **significant p-value <0.01, 95% CI= 95% Confidence interval, UL=Upper limit, LL=Lower limit.

*Regression Analysis controlled for **race**

(To retain covariate in the model; the change in β-coefficient of the main effect should be 10%).

Figure 2. Difference between average intake of total FC and subclasses (g and g/1000kcal) in PT vs MT diet group stratified by diet quality (n=84)



p-Value	0.002**	0.0001**	0.004**	0.001**	0.008**	0.001**
partial eta square	0.23[a]	0.18[a]	0.21[a]	0.27[a]	0.19[a]	0.24[a]

FC and subclasses (g and g/1000kcal)

Abbreviations: **FC**=Fermentable carbohydrate, **SDF**=Soluble dietary fiber, **PT-highDQ**= Plant-based diet group with high diet quality, **PT-lowDQ=** Plant-based diet group with low diet quality, **MT-highDQ=** Meat-based diet group with high diet quality**, MT-lowDQ=** Meat-based diet group with low diet quality; **differences between groups in exploratory outcome were analyzed by one-way analysis of variance (ANOVA) for diet group-diet quality.** *significant p-value <0.05, **significant p-value <0.01; [a] = partial eta squared indicating large effect size

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APPENDIX A: List of Abbreviations

Abbreviations	Full form
%BF	Percent Body Fat
BG	Blood Glucose
BMI	Body Mass Index (weight in kilograms/height in meters^2)
BP	Blood Pressure
DF	Dietary Fiber
DGA	Dietary Guidelines for Americans
DHQ-III	Dietary History Questionnaire-III
FC	Fermentable Carbohydrates
FFQ	Food Frequency Questionnaire
GLP-1	Plasma Glucagon-like Peptide 1
HEI-2015	Healthy Eating Index-2015
IPAQ	International Physical Activity Questionnaire
IRB	Institutional Review Board
LDL-c	Low-Density Lipoprotein Cholesterol
MT	Meat Based Diet Group
OS	Oligosaccharide
PT	Plant Based Diet Group
PYY	Peptide YY
SCFA	Short Chain Fatty Acids
SDF	Soluble Dietary Fiber
TA	Teaching Assistant

APPENDIX B: Study 1 and 2 Consent Form

CONSENT FORM FOR RESEARCH: Participant
Version 5: November 2019-December 5 2020

I. Consent Form

THE UNIVERSITY OF RHODE ISLAND
COLLEGE OF HEALTH SCIENCES

THINK BIG WE DO™

DEPARTMENT OF NUTRITION AND FOOD SCIENCES
125 Fogarty Hall, Kingston, RI 02881 USA p: 401.874.2253 f: 401.874.5974 web.uri.edu/nfs

Title of Project: Nutrition Assessment Secondary Data Analysis

INFORMED CONSENT TO PARTICIPATE IN RESEARCH

You are invited to take part in a research project described below. Students enrolled in NFS 210 and NFS 443 currently have anthropometric and biochemical assessments and complete dietary assessment as part of their coursework. These assessments are used for classroom assignments. We are asking you to give us permission to use these data for research. In addition, we are asking you to complete a few additional demographic and dietary questions. The purpose of the research is to validate assessment methodologies and to investigate the relationship between anthropometric, biochemical, and dietary variables that are related to chronic disease risk. If you have questions you may contact the Geoffrey Greene, the person mainly responsible for this study at 874-4028 or email him at gwg@uri.edu.

Description of the Project:
The purpose of the study is to use nutrition assessment data for research to help us understand the relationship between diet and disease risk in college students.

My Participation
You must sign this informed consent form for the data collected as part of this class to be used for research, and must complete the additional brief questionnaire.

What will be done:
If you take part in this study, your information entered into a password protected computer. Your data will be identified by code number only. Once all data have been entered and verified, the link between code number and identifying data will be destroyed. All data analysis will be conducted by code number only. Assessments that we will be using are listed below (these are collected as part of your class and the additional brief demographic questionnaire):

Demographics	✓
Dietary Assessment	✓
Height, Weight	✓
Waist and Hip Circumference	✓

THE UNIVERSITY OF RHODE ISLAND
IRB NUMBER: HU1112-069
IRB APPROVAL DATE: November 27, 2019
IRB EXPIRATION DATE: December 5, 2020

Bioelectric Impedence (InBody)	✓
Sonographic Measurement of the Heel (bone density)	✓
Standard Blood Tests (TG, HDL, LDL, Total Cholesterol, Glucose)	✓

Risks or discomfort:
The risks are minimal. The only risks would be loss of confidentiality and that will be minimized as described below.

Benefits of this study:
You will not receive any direct benefit. Allowing us to use your data and filling out the brief questionnaire will help us with research to better understand the relationship between diet and chronic disease in college students.

Confidentiality:
Your part in this study is confidential. None of the information will identify you name. We will keep all consent forms in a locked cabinet in Room 146 Fogarty for five years. All information collected for the class will be identified by code numbers and will not include any link to your name. This information will be confidential.

Decision to quit at any time:
You have been given the opportunity to decide whether or not to participate in this study. Your decision to participate will not affect your grade in the class or your relationship with your class instructor. Your instructor will not know who is participating in this study. You have the right to stop participating at any time, but once data have been entered and verified and the link between participant and code has been destroyed, we will not be able to remove your data.

Rights and Complaints:
If you are not satisfied with the way this study is performed, you may discuss your complaints with Geoffrey Greene (401-874-4028) anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the Office of Research Integrity, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, RI, telephone: (401) 874-4328.

You have read this Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in the study. Please note that you must be at least 18 years of age in order to participate.

Print Your Name: ____

______________________ ________ ______________________
Signature of Participant Date Signature of Researcher

Please sign both consent forms, keeping one for yourself

THE UNIVERSITY OF RHODE ISLAND

IRB NUMBER: HU1112-069
IRB APPROVAL DATE: November 27, 2019
IRB EXPIRATION DATE: December 5, 2020

APPENDIX C: Nutrition Assessment Survey

Name:_

____

_   Date:_________________

Please Print

<u>Nutrition Assessment Study Survey</u>

1. What is your age?

Less than 18 years

18 years

19 years

20 years

21 years

22 years

23 years

24 years

25 years

26 years

27 years

28 years

29 years

30 years

31 years

32 years

33 years

34 years

35 years

36 years

37 years

38 years

39 years

40 years

41 years

42 years

43 years

44 years

45 years

46 years

47 years

48 years

49 years

50 years

51 years

52 years

53 years

54 years

55 years

56 years

57 years

58 years

59 years

60 or more years

2. What is your gender?

Male

Female

Choose not to answer

3. Which one of the following best applies to you?

White

Black or African American

Hispanic/Latino

Asian

Native Hawaiian or other Pacific Islander

American Indian or Alaskan Native

Mixed

Other (please specify):

Choose not to answer

4. What is your year in school?

Freshman

Sophomore

Junior

Senior

Graduate

5. What is your current major?

Agricultural Sciences

Biological Sciences

Business/Communication

Education

Exercise Science/Kinesiology

Fine Arts/Humanities

Health/Nursing

Nutrition

Social Sciences

Undeclared

Graduate Student

Other (please specify):

Choose not to answer

6. Place of residence during the academic year?

On campus

Off campus

Choose not to answer

7. Green Eating is: Eating locally grown foods, limited amounts of processed/fast foods, eating meatless meals at least one day per week, choosing organic foods as much as possible, and only taking what you plan on eating.

Are you a green eater?

No, and I do not intend to start within the next 6 months

No, but I am thinking about becoming a green eater within the next 6 months

No, but I am planning on becoming a green eater within the next 30 days

Yes, I am a green eater and have been for less than 6 months

Yes, I am a green eater and have been doing so for 6 months or more

I choose not to answer

8. Which of the following best describes the MAJORITY of your meals during the academic year?

I eat meals prepared at home.

I purchase frozen or ready-to-eat meals

I eat at dining halls/restaurants

I get fast food/take-out

Choose not to answer

9. Do you have a campus meal plan?

Yes

No

Choose not to answer

10. What is your usual rate of eating?

Very Slow Medium Fast Very

Choose not to

slow fast answer

1 2 3 4 5 6

11. Do you experience abdominal discomfort such as cramping, bloating, or excess gas? (this refers to gastrointestinal discomfort, NOT menstrual discomfort)

Never or very seldom

Seldom, less than once per month

Occasionally, a few times per month

Fairly often, once or twice per week

Very often, several times per week or daily

Choose not to answer

12. If you experience abdominal discomfort, how severe is it?

I do not experience abdominal discomfort

Very mild –not very noticeable

Moderate – noticeable but not too bad

Somewhat uncomfortable – it's kind of bad, but manageable

Very uncomfortable – I cannot carry out my normal activities

Choose not to answer

13. Please select the answer that BEST describes your usual behavior.

	Barely ever to never	Rarely (25%)	Sometimes (50%)	Often (75%)	Almost always	Choose Not to Answer
- Locally grown foods are grown within 100 miles of your location. Based on this, how often do you eat locally grown foods?	o	o	o	o	o	
- When in season, how often do you shop at farmer's markets?	o	o	o	o	o	
- How often do you choose foods that are labeled certified organic?	o	o	o	o	o	
- How often do	o	o	o	o	o	

you select meats, poultry, and dairy products that are raised without antibiotics or hormones?					
- How often do you select food or beverages that are labeled fair trade certified?	o	o	o	o	o
- How often do you buy meat or poultry products labeled "free range" or "cage free"?	o	o	o	o	o

14. Have you smoked at least 100 cigarettes in your entire life?

Yes

No

I choose not to answer

15. Do you NOW smoke cigarettes every day, some days, or not at all?

Every day

Some days

Not at all

I choose not to answer

16. What would you like to weigh in pounds? ________ Put CNA if you choose not to answer

17. How would YOU describe your current weight?

Very underweight

Slightly underweight

About the right weight

Slightly overweight

Very overweight

I choose not to answer

18. How do you feel about your current weight?

I am happy with my current weight

I don't care about my current weight

I am upset about my current weight

Choose not to answer

19. On average, how many hours of sleep do you get in a 24-hour period? Think about the time you actually spent sleeping or napping, not just the amount of sleep you think you should get. How many hours do you usually get each day and night?

1 hour or less

2 hours

3 hours

4 hours

5 hours

6 hours

7 hours

8 hours

9 hours

10 hours or more

Choose not to answer

20. Are you often sleepy during the day?

Yes

No

Choose not to answer

21. Do you frequently wake up during the time you are asleep?

Yes

No

Choose not to answer

22. How would you evaluate the quality of your sleep?

Not impaired

Moderately impaired,

Severely impaired

Choose not to answer

23. How many hours before bed do you usually eat your last meal or snack?

<1 hour

1 hour

2 hours

3 hours

4 hours

5 hours

6 hours

>6hours

Choose not to answer

24. What is your usual bedtime?

Before 10:00 PM

10:00 PM

11:00 PM

12:00 AM

1:00 AM

2:00 AM

3:00 AM

4:00 AM

After 4:00 AM

Choose not to answer

25. How many days a week do you usually eat breakfast?

0

1

2

3

4

5

6

7

Choose not to answer

26. Stress management includes regular relaxation and physical activity, talking with others and/or making time for social activities.

Do you effectively practice stress management in your daily life?

No, and I do <u>NOT</u> intend to in the <u>next 6 months</u>

No, but I intend to in the in the <u>next 6 months</u>

No, but I intend to in the <u>next 30 days</u>

Yes, but I have been for LESS than 6 months

Yes, and I have been for MORE than 6 months

I choose not to answer

APPENDIX D: International Physical Activity Questionnaire

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ
The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ
Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation
Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ
International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information
More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

APPENDIX E: Diet History Questionnaire

a. More information is available on the DHQ II can be found in the link below:

https://epi.grants.cancer.gov/dhq2/about/

APPENDIX F: Anthropometric Assessment

- **Height Collection Protocol**

Also see Visual Protocols – Appendix C

1. Engineering Controls
    a. Calibrating/zeroing stadiometer.
2. Process
    a. Ask student to remove shoes and socks.
    b. Ask student to remove hair ornaments, buns, or barrettes that prevent the students from placing his/her head against the back of the stadiometer.
    c. Ask the student to step completely under the slide of the stadiometer, making sure that the student is centered with the stadiometer.
    d. Ask the student to stand as straight as possible with feet together and heels, buttock, shoulder blades, and back of head completely touching the wall.
    e. Be sure that the student is looking straight ahead and that there is a horizontal plane from the boney socket of the eye to the notch above the projection of the ear (Frankfurt plane).

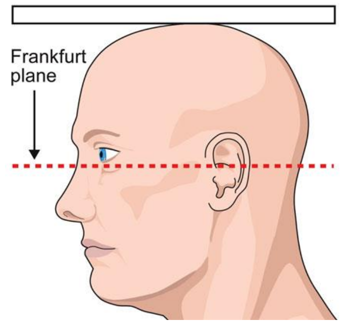

Figure 1 Frankfurt Plane

f. Ask the student to take a deep breath in and hold it to straighten the spine and standardize measurement.

g. When the student inhales, move the height slide to rest lightly on top of the student's head.

h. Fix the height slide in place and ask the student to resume normal breathing.

i. Ask the student to step out from under the slide.

j. Record height to the nearest 0.1 centimeter on the data collection sheet.

    i. Be sure to avoid parallax (angular distortion) by bending down, kneeling, or standing on a stool and reading the height value at eye level.

    ii. Repeat measurement. If there is > 0.2 centimeter difference between measurements, repeat until two measurements are within 0.2 centimeter. These two measurements will be the official measurements.

k. Record all measurements on the data collection sheet. Be sure to cross out any unofficial measurements.

l. Record the average of the two official measurements to two decimal places.

3. Considerations

a. Be sure stadiometer is located in a non-carpeted area.
b. For obese students, it can sometimes be difficult to have four points of contact with the vertical backboard or wall. In this case, it is important to have as many contact points as possible (at least 2), making sure the student is looking straight ahead.
c. To avoid parallax when reading a height measurement, you must be eye level with the person being assessed Have a step stool or chair near when taking height measurements or someone taller.
d. Be sure the same stadiometer is used for baseline and follow-up height measurements.

Weight Protocol

Also see Visual Protocols – Appendix C

1. Engineering Controls

    a. Calibrating/Zeroing the scale.

2. Process

    a. Zero the scale. Balance beam scales must be level prior to weighting the student. The scale must be on a hard, flat surface, not on carpet.
    b. Ask students to empty their bladder prior to being weighed. This is required of all students.

c. Ask students to remove any excess clothing, shoes, and socks prior to weighing. Students must be asked to remove coins, keys, cell phones, or other heavy objects from their pockets prior to measurement.

d. Ask the students to step up onto the scale fully. Make sure that both feet are completely on the scale.

e. Ask the student to stand completely still with arms at their sides and eyes looking straight ahead.

f. Record weight to the nearest 0.1kg on the data collection sheet.

g. Repeat measurement. If there is >0.2kg difference between measurements, repeat until two measurements are within 0.2kg. These two measurements will be the official weight measurements.

h. Record all measurements on data collection sheet. Be sure to cross out any unofficial measurements.

i. Record the average of the two official measurements to two decimal places.)

3. <u>Considerations</u>

a. To measure accurately, scales should be recalibrated on a regular basis and each time a scale is moved to a different location. Review scale manual for proper calibration techniques.

b. Due to natural weight fluctuations that occur during the day, it is desirable to weight the students at the same time of day (within 2 hours) of each assessment.

c. Ensure the same scale is used for all weight measurements.

THE INBODY TEST

TEST PREPARATION

Before each InBody Test, follow these guideliness to ensure your test results are accurate:

Prior to testing, **avoid**:
- x Exercising 6-12 hours prior
- x Eating 3-4 hours prior
- x Consuming alcohol or caffeine 24 hours prior
- x Using a shower or sauna
- x Using lotion or ointment on hands or feet

Prior to testing, **do**:
- o Hydrate well the day before
- o Stand upright for at least 5 minutes
- o Use the bathroom
- o Remove all socks, pantyhose, shoes, articles of heavy clothing (jackets) and metal objects (jewelry, watches, belts)
- o Warm yourself up for 20 minutes if you are testing in cold weather

Please consult a physician before testing if you are menstruating or have medical implants such as pacemakers and other life-sustaining medical implants.

THE INBODY TEST

HOW TO TEST

The InBody unit utilizes voice commands to guide the user through the InBody Test. The following steps are elaborated to provide you with detail to the proper testing procedures.

1. Remove shoes, socks, heavy articles of clothing, and items in pockets if you have not done so already. Wipe hands and feet with an InBody Tissue (optional).

2. Stand on the device barefoot and align heel with the round silver electrodes and the rest of the feet with the foot electrode. Stay still and wait for weight to be measured.

3. After weight is measured, input your Age, Height, and Gender. Entering a unique ID is optional but recommended because using an ID will record and track your progress.

4. When prompted, grab the hand electrodes by placing your thumbs on the thumb electrodes and wrapping your fingers around the bottom electrodes. Keep your arms relaxed and extend slightly away from the torso so that your armpits are not touching one another (roughly 15 degrees).

The InBody Test will take 60 seconds and your results will print automatically after testing.

Remember to test every 2-4 weeks to monitor and track your progress.

4

Blood Lipids, Glucose, Blood Pressure Results

Name ______________ **Participant ID**______________

Your Results:

Are You at Risk?

Place sticker here

BP 1	
BP 2	
BP 3 (if necessary)	
BP 4 (if necessary)	

Blood Pressure:
- Desirable: <120/80 mmHg
- Borderline high: ≥ 130/85 mmHg
- High: ≥140/90 mmHg

Total Cholesterol:
- Desirable: < 200 mg/dL
- Borderline: 200-239 mg/dL
- High: ≥ 240 mg/dL

HDL Cholesterol:
- Low: < 40mg/dL
- High: ≥ 60 mg/dL

LDL Cholesterol:
- Optimal: <100 mg/dL
- Near optimal/above optimal: 100-129 mg/dL
- Borderline high: 130-159 mg/dL
- High: 160-189 mg/dL
- Very high: ≥ 190 mg/dL

Triglycerides:
- Normal: < 150mg/dL
- Borderline high: 150-199 mg/dL
- High: 200-499 mg/dL
- Very high: ≥ 500mg/dL

Glucose:
- Normal fasting glucose: < 100mg/dL
- Impaired fasting glucose: 100-126 mg/dL
- High fasting glucose: ≥ 126 mg/dL

National Cholesterol Education Program Adult Treatment Panel III Guidelines, American Diabetes Association

APPENDIX H: HEI-2015 Component and Scoring standard

HEI-2015[1] Components and Scoring Standards

Component	Maximum points	Standard for maximum score	Standard for minimum score of zero
Adequacy:			
Total Fruits[2]	5	≥0.8 cup equivalent per 1,000 kcal	No Fruit
Whole Fruits[3]	5	≥0.4 cup equivalent per 1,000 kcal	No Whole Fruit
Total Vegetables[4]	5	≥1.1 cup equivalent per 1,000 kcal	No Vegetables
Greens and Beans[4]	5	≥0.2 cup equivalent per 1,000 kcal	No Dark-Green Vegetables or Legumes
Whole Grains	10	≥1.5 ounce equivalent per 1,000 kcal	No Whole Grains
Dairy[5]	10	≥1.3 cup equivalent per 1,000 kcal	No Dairy
Total Protein Foods[4]	5	≥2.5 ounce equivalent per 1,000 kcal	No Protein Foods
Seafood and Plant Proteins[4,6]	5	≥0.8 ounce equivalent per 1,000 kcal	No Seafood or Plant Proteins
Fatty Acids[7]	10	(PUFAs + MUFAs) / SFAs ≥2.5	(PUFAs + MUFAs)/SFAs ≤1.2
Moderation:			
Refined Grains	10	≤1.8 ounce equivalent per 1,000 kcal	≥4.3 ounce equivalent per 1,000 kcal
Sodium	10	≤1.1 grams per 1,000 kcal	≥2.0 grams per 1,000 kcal
Added Sugars	10	≤6.5% of energy	≥26% of energy
Saturated Fats	10	≤8% of energy	≥16% of energy

[1] Intakes between the minimum and maximum standards are scored proportionately.

[2] Includes 100% fruit juice.

[3] Includes all forms except juice.

[4] Includes legumes (beans and peas).

[5] Includes all milk products, such as fluid milk, yogurt, and cheese, and fortified soy beverages.

[6] Includes seafood; nuts, seeds, soy products (other than beverages), and legumes (beans and peas).

[7] Ratio of poly- and mono-unsaturated fatty acids (PUFAs and MUFAs) to saturated fatty acids (SFAs).

APPENDIX I: Detailed Food Patterns Equivalents Database Components

FPED component and SAS variable name	Foods and Units
Total Fruit (F_TOTAL)	Total intact fruits (whole or cut) and fruit juices (cup eq.)
Citrus, Melons, and Berries (F_CITMLB)	Intact fruits (whole or cut) of citrus, melons, and berries (cup eq.)
Other Fruits (F_OTHER)	Intact fruits (whole or cut); excluding citrus, melons, and berries (cup eq.)
Fruit Juice (F_JUICE)*	Fruit juices, citrus and non-citrus (cup eq.)
Total Vegetables (V_TOTAL)	Total dark green, red and orange, starchy, and other vegetables; excludes legumes (cup eq.)
Dark Green Vegetables (V_DRKGR)	Dark green vegetables (cup eq.)
Total Red and Orange Vegetables (V_REDOR_TOTAL)*	Total red and orange vegetables (tomatoes and tomato products + other red and orange vegetables) (cup eq.)
Tomatoes (V_REDOR_TOMATO)	Tomatoes and tomato products (cup eq.)
Other Red and Orange Vegetables (V_REDOR_OTHER)	Other red and orange vegetables, excluding tomatoes and tomato products (cup eq.)
Total Starchy Vegetables (V_STARCHY_TOTAL)*	Total starchy vegetables (white potatoes + other starchy vegetables) (cup eq.)
Potatoes (V_STARCHY_POTATO)	White potatoes (cup eq.)
Other Starchy Vegetables (V_STARCHY_OTHER)	Other starchy vegetables, excluding white potatoes (cup eq.)
Other Vegetables (V_OTHER)	Other vegetables not in the vegetable components listed above (cup eq.)
Beans, Peas, and Lentils (V_LEGUMES)	Beans, peas, and lentils (legumes) computed as vegetables (cup eq.)
Total Grains (G_TOTAL)	Total whole and refined grains (oz. eq.)
Whole Grains (G_WHOLE)	Grains defined as whole grains and contain the entire grain kernel — the bran, germ, and endosperm (oz. eq.)
Refined Grains (G_REFINED)	Refined grains that do not contain all of the components of the entire grain kernel (oz. eq.)
Total Protein Foods (PF_TOTAL)*	Total meat, poultry, organ meat, cured meat, seafood, eggs, soy, and nuts and seeds; excludes legumes (oz. eq.)
Total Meat, Poultry, and Seafood (PF_MPS_TOTAL)	Total of meat, poultry, seafood, organ meat, and cured meat (oz. eq.)

* [illegible]

FPED component and SAS variable name	Foods and Units
Meat (PF_MEAT)	Beef, veal, pork, lamb, and game meat; excludes organ meat and cured meat (oz. eq.)
Cured Meat (PF_CUREDMEAT)	Frankfurters, sausages, corned beef, cured ham and luncheon meat that are made from beef, pork, or poultry (oz. eq.)
Organ Meat (PF_ORGAN)	Organ meat from beef, veal, pork, lamb, game, and poultry (oz. eq.)
Poultry (PF_POULT)	Chicken, turkey, Cornish hens, duck, goose, quail, and pheasant (game birds); excludes organ meat and cured meat (oz. eq.)
Seafood High in *n*-3 Fatty Acids (PF_SEAFD_HI)	Seafood (finfish, shellfish, and other seafood) high in *n*-3 fatty acids (oz. eq.)
Seafood Low in *n*-3 Fatty Acids (PF_SEAFD_LOW)	Seafood (finfish, shellfish, and other seafood) low in *n*-3 fatty acids (oz. eq.)
Eggs (PF_EGGS)	Eggs (chicken, duck, goose, quail) and egg substitutes (oz. eq.)
Soy Products (PF_SOY)	Soy products, excluding calcium fortified soy milk (soymilk) and products made with raw (green) soybean (oz. eq.)
Nuts and Seeds (PF_NUTSDS)	Peanuts, tree nuts, and seeds; excludes coconut (oz. eq.)
Beans, Peas, and Lentils (PF_LEGUMES)*	Beans, peas, and lentils (legumes) computed as protein foods (oz. eq.)
Total Dairy (D_TOTAL)	Total milk, yogurt, cheese, and whey. For some foods, the total dairy values could be higher than the sum of D_MILK, D_YOGURT, and D_CHEESE because the Miscellaneous Dairy component composed of whey is not included in FPED as a separate variable. (cup eq.)
Milk (D_MILK)	Fluid milk, buttermilk, evaporated milk, dry milk, and calcium fortified soy milk (soymilk) (cup eq.)
Yogurt (D_YOGURT)	Yogurt (cup eq.)
Cheese (D_CHEESE)	Cheeses (cup eq.)
Oils (OILS)	Fats naturally present in nuts, seeds, and seafood; all unhydrogentaed vegetable oils, except palm oil, palm kernel oil, and coconut oils; the fat present in avocado and olives above the allowable amount; 50% of the fat present in stick and tub margarines and margarine spreads (grams)
FPED component and SAS variable name	**Foods and Units**
Solid Fats (SOLID_FATS)	Fats naturally present in meat, poultry, eggs, and dairy (lard, tallow, and butter); fully or partially hydrogenated oils; shortening; palm oil; palm kernel oil; coconut oils; fats naturally present in coconut meat and cocoa butter; and 50% of the fat present in stick and tub margarines and margarine spreads (grams)
Added Sugars (ADD_SUGARS)	Caloric sweeteners such as syrups and sugars and others defined as added sugars (tsp. eq.)
Alcoholic Drinks (A_DRINKS)	Alcoholic beverages and alcohol (ethanol) added to foods after cooking (no. of drinks)

* New variable in FPED and is not in MPED 2

APPENDIX J: PT and MT-diet based comparison consent form (Study 3)

THE UNIVERSITY OF RHODE ISLAND

IRB Consent Form for Research

Kathleen Melanson
Department of Nutrition and Food Sciences
Postbiotic Advantages of Vegetarian Eating or Meat-Eating Trends (PAVEMENT) Study

Postbiotic Advantages of Vegetarian Eating or Meat-Eating Trends (PAVEMENT)

We invite you to take part in the 'Postbiotic Advantages of Vegetarian Eating or Meat-Eating Trends' (PAVEMENT) Study at the University of Rhode Island, Department of Nutrition and Food Sciences. You have been asked to participate in this research study that will seek to evaluate and understand the markers of health and biological differences between plant and animal-based diets. This research is a unique study that looks to not only benefit the participant but also the scientific community in the future.

STUDY TITLE
Postbiotic Advantages of Vegetarian Eating or Meat-Eating Trends (PAVEMENT)
PRINCIPAL INVESTIGATORS
Principal Investigator: Kathleen Melanson, PhD, RDN, LDN
Office: (401) 874-4477 Email: kmelanson@uri.edu
Graduate Student Investigator: Ajita Jadhav, MSc

KEY INFORMATION
Important information to know about this research study:

- The purpose of the study is to collect dietary information to compare individuals consuming various degrees of dietary choices.
- If you choose to participate, you will be asked to do the following things:
    - Complete an eligibility questionnaire, prior to your lab visit, on your own time.
    - We will arrange a virtual meeting to assist you through the process of this study in your convenient time and answer your questions and concerns during the meeting before you sign the consent form. Once you agreed to participate you will sign the online (pdf doc) consent form and send it to us.
    - Complete the online food craving questionnaire via shared pdf file.
    - Complete online Food Frequency Questionnaire via survey link.
    - This will take approximately 65-95 minutes total
- There are no known risks to you for being involved in this research study. A benefit included in participation in this research study is that you will be a part of a unique project that has never been conducted before in the scientific community. As a result of the study, you will receive detailed dietary data upon request.
- You will also have a chance to win one of two $100 amazon gift cards for your participation.
- Taking part in this research project is voluntary. You don't have to participate, and you can stop it any time.
- **This consent form is only for the online part of the study.**

INVITATION
You are invited to take part in the PAVEMENT research study. The information in this form is meant to help you decide whether or not to participate. If you have any questions, please ask. Participation in this study is voluntary and you may withdraw at any time. We encourage you to ask questions and raise any concerns should they arise throughout the duration of the study. If you decide to move forward, you must sign this

THE UNIVERSITY OF RHODE ISLAND

IRB NUMBER:	IRB1920-142
IRB APPROVAL DATE:	January 28, 2021
IRB EXPIRATION DATE:	

IRB Consent Form for Research

Kathleen Melanson
Department of Nutrition and Food Sciences
Postbiotic Advantages of Vegetarian Eating or Meat-Eating Trends (PAVEMENT) Study

the beginning of this form. For questions concerning your rights or complaints about the research contact the Institutional Review Board (IRB) or Vice President for Research and Economic Development:

- IRB: (401) 874-4328 / researchintegrity@etal.uri.edu.
- Vice President for Research and Economic Development: at (401) 874-4576

What will happen if you decide not to be in this research study or decide to stop participating once you start?
You can decide not to be in this research study, or you can stop being in this research study ("withdraw") at any time before, during, or after the research begins for any reason. Deciding not to be in this research study or deciding to withdraw will not affect your relationship with the investigator or with the University of Rhode Island.
You will not lose any benefits to which you are entitled.

Documentation of informed consent
You are voluntarily making a decision whether or not to be in this research study. Signing this form means that (1) you have read and understood this consent form, 2) you have had the consent form explained to you, (3) you have had your questions answered, (4) you have decided to be in the research study and (5) you are at least 18 years of age. You will be given a copy of this consent form to keep.

Participant Name:

____
(Name of Participant: Please print)

Participant Signature:

________________________________ ____________
Signature of Research Participant Date

Investigator certification:
My signature certifies that all elements of informed consent described on this consent form have been explained fully to the subject. In my judgment, the participant possesses the capacity to give informed consent to participate in this research and is voluntarily and knowingly giving informed consent to participate.

________________________________ ____________
Signature of Person Obtaining Consent Date

THE UNIVERSITY OF RHODE ISLAND

IRB NUMBER:	IRB1920-142
IRB APPROVAL DATE:	January 28, 2021
IRB EXPIRATION DATE:	

APPENDIX K: Advertisement Flyer (Study-3)

APPENDIX L: Eligibility Survey (Study-3)

PAVEMENT STUDY Eligibility Questionnaire_Animal Based Diet

Start of Block: Default Question Block

Q1 **Email address ***

____

Q2 **First name ***

____

Q3 **Last name ***

____

Q4 **Phone number ***

____

Q5 **Age ***

____

Q6 **Gender** *
Mark only one oval.

○ Female (1)

○ Male (2)

○ Prefer not to say (3)

○ Other: (4)

____

Q7 **What is your race/ethnicity?**

○ White (1)

○ Black or African American (2)

○ American Indian or Alaska Native (3)

○ Asian (4)

○ Native Hawaiian or Pacific Islander (5)

○ Other please specify (6)

____

○ Choose not to answer (7)

Q41 **What is your height?**

____

Q42 **What is your weight?**

____

Q8 **Are you a student?**

- ◯ Yes (1)
- ◯ No (2)
- ◯ Choose not to answer (3)

Q9 **If yes- What is your major? ***

____

Q11 **Do you live on-campus or off-campus?**

- ◯ on campus (1)
- ◯ off campus (2)
- ◯ choose not to answer (3)

Q43 **From which US state are you?**

____

Q12 **Do you chew or smoke tobacco or vaping? ***
Mark only one oval.

◯ Yes (1)

◯ No (5)

Q11 **Are you currently pregnant? ***
Mark only one oval.

◯ Yes (1)

◯ No (2)

Q12 **If yes, are you nursing? ***
Mark only one oval.

◯ Yes (4)

◯ No (5)

Q14 **Do you have any chronic illnesses or diseases? ***
Mark only one oval.

◯ Yes (4)

◯ No (5)

Q15 **If yes, please specify below.**

____
____

Q16 **Do you have any gastrointestinal diseases? (Ex. Crohn's Disease, Inflammatory Bowel Disease, GERD, etc.) ***
Mark only one oval.

◯ Yes (4)

◯ No (5)

Q17 **If yes, please specify below.**

____
____

Q18 **Do you have any malabsorption problems? (ex. lactose or gluten intolerance) ***
Mark only one oval.

◯ Yes (4)

◯ No (5)

Q19 **If yes, please specify below.**

____

____

Q20 **Have you taken any antibiotics in the past 3 months?** *
Mark only one oval.

◯ Yes (1)

◯ No (2)

Q21 **Do you take any probiotic supplements? ***
Mark only one oval.

◯ Yes (4)

◯ No (5)

Q22 **Do you take any fiber supplements? ***
Mark only one oval.

◯ Yes (4)

◯ No (5)

Q23 **During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?** *

Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activites refer to activities that take hard physical effort and make you breather much harder than normal. think only about those physical activites that you did for at least 10 minutes at a time.

Mark only one oval.

- ◯ 1 day (1)
- ◯ 2 days (2)
- ◯ 3 days (3)
- ◯ 4 days (4)
- ◯ 5 days (5)
- ◯ 6 days (6)
- ◯ 7 days (7)
- ◯ No vigorous physical activities (skip next question if not vigorous physical activities) (8)

Q24 **How much time did you usually spend doing vigorous physical activities on one of those days? (___ hours and/or minutes per day)**

____

Q25 **During the past 7 days, on how many days did you do moderate**

physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking. *

Think about all the moderate activites that you did in the last 7 days. Moderate activites refer to activites that take moderate physical effort and make you breather somehwat harder than normal. Think about those physical activties that you did for at least 10 minutes at a time.

Mark only one oval.

◯ 1 day (1)

◯ 2 days (2)

◯ 3 days (3)

◯ 4 days (4)

◯ 5 days (5)

◯ 6 days (6)

◯ 7 days (7)

◯ No moderate physical activities (Skip next question if no moderate physical activities) (8)

Q26 **How much time did you usually spend doing moderate physical activities on one of those days? (__ hours and/or minutes per day)**

____

Q27 **During the last 7 days, on how many days did you walk for at least 10 minutes at a time?** *

Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.
Mark only one oval.

- ◯ 1 day (1)
- ◯ 2 days (2)
- ◯ 3 days (3)
- ◯ 4 days (4)
- ◯ 5 days (5)
- ◯ 6 days (6)
- ◯ 7 days (7)
- ◯ No walking (Skip next question if no walking) (8)

Q28 **How much time did you usually spend walking on one of those days? (___ hours and/or minutes per day)**

____

Q29 **During the last 7 days, how much time did you spend sitting on a week day? (___ hours and/or minutes per day) ***
The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work, and during leisure time. this many include time spent sitting at a desk, vsiting friends, reading, or sitting or laying down to watch television.

____

Q44 **How do you describe your eating pattern?**

- ◯ Vegetarian (1)
- ◯ Vegan (2)
- ◯ Paleo (3)
- ◯ Pescatarian (4)
- ◯ Lacto-ovo-vegetarian (5)
- ◯ Non-vegetarian (6)
- ◯ Other (7) ____

Q30 **Which animal products do you consume, if any? ***
Check all that apply.

- ▢ Red Meat (beef, lamb, pork) (1)
- ▢ Poultry (chicken, turkey, duck) (2)
- ▢ Fish/Shellfish (crab, shrimp, lobster, salmon) (3)
- ▢ Dairy (cheese, milk, yogurt) (4)
- ▢ Eggs (5)
- ▢ Honey (6)
- ▢ Other (7) ____

Q38

If you consume red meat, such as beef, lamb, and pork, approximately how many times per week?

◯ 1-2 times (1)

◯ 2-3 times (2)

◯ 3-4 times (3)

◯ 4-5 times (4)

◯ 5-6 times (5)

◯ 6-7 times (6)

◯ 7-8 times (7)

◯ 8-9 times (8)

◯ 9-10 times (9)

◯ More than 10 times (10)

◯ Other, specify (11) ____

Q40
If you consume poultry, such as chicken, turkey, and duck, approximately how many times per week?

- ○ 1-2 times (1)
- ○ 2-3 times (2)
- ○ 3-4 times (3)
- ○ 4-5 times (4)
- ○ 5-6 times (5)
- ○ 6-7 times (6)
- ○ 7-8 times (7)
- ○ 8-9 times (8)
- ○ 9-10 times (9)
- ○ More than 10 times (10)
- ○ Other, Specify (11) ________________

Q31 **If you consume fish/shellfish, such as crab, shrimp, salmon, and lobster, approximately how many times per week?**
Mark only one oval.

○ 1-5 times (1)

○ 5-10 times (2)

○ More than 10 times (3)

○ Other (4) ____

Q32 **If you consume dairy, such as cheese, milk, and yogurt, approximately how many times per week?**
Mark only one oval.

○ 1-5 times (1)

○ 5-10 times (2)

○ More than 10 times (4)

○ Other (5) ____

Q33 **If you consume eggs, approximately how many times per week?**
Mark only one oval.

○ 1-5 times (1)

○ 5-10 times (2)

○ More than 10 times (3)

○ Other (4) ____

Q34 **If you consume honey, approximately how many times per week?**
Mark only one oval.

○ 1-5 times (1)

○ 5-10 times (2)

○ More than 10 times (3)

○ Other (4) ____

End of Block: Default Question Block

***APPENDIX M: Manuscript-II (*Exploratory outcomes)- Difference between average intake of total FCs and subclasses in high and low diet quality in PT and MT diet groups**

Outcome variable	Diet Group by diet quality	N	Mean± SD	95% CI		p-Value	partial eta square
				Lower Bound	Upper Bound		
FC	PT-highDQ	22	10.7±3.6	9.1	12.2	0.002**	0.23[a]
	PT-lowDQ	21	8.9±6.5	6	11.9		
	MT-highDQ	21	9.1±3.7	7.5	10.8		
	MT-lowDQ	20	5.5±2.4	4.4	6.6		
	Total	84	8.6±4.6	7.6	9.6		
FC_1000kcal	PT-highDQ	22	7.1±1.2	6.6	7.7	0.0001*	0.18[a]
	PT-lowDQ	21	5.8±2.3	4.7	6.8		
	MT-highDQ	21	5.6±2.5	4.5	6.7		
	MT-lowDQ	20	3.6±1.3	3	4.3		
	Total	84	5.6±2.3	5.1	6.1		
SDF	PT-highDQ	22	9.0±3.0	7.6	10.3	0.004**	0.21[a]
	PT-lowDQ	21	7.7±5.6	5.1	10.2		
	MT-highDQ	21	7.8±3.2	6.4	9.3		
	MT-lowDQ	20	4.8±2.2	3.8	5.8		
	Total	84	7.4±3.9	6.5	8.2		
SDF_1000kcal	PT-highDQ	22	6.0±1.1	5.5	6.5	0.001**	0.27[a]
	PT-lowDQ	21	4.9±1.8	4.1	5.7		
	MT-highDQ	21	4.8±2.2	3.8	5.8		
	MT-lowDQ	20	3.1±1.2	2.6	3.7		
	Total	84	4.8±1.9	4.3	5.2		
Polyol	PT-highDQ	22	1.7±0.9	1.3	2.1	0.008**	0.19[a]
	PT-lowDQ	21	1.3±1.1	0.8	1.8		
	MT-highDQ	21	1.3±0.6	1	1.6		
	MT-lowDQ	20	0.7±0.3	0.5	0.9		
	Total	84	1.3±0.8	1.1	1.4		
Polyol_1000kcal	PT-highDQ	22	1.1±0.5	0.9	1.3	0.001**	0.24[a]
	PT-lowDQ	21	0.9±0.6	0.6	1.2		
	MT-highDQ	21	0.8±0.3	0.6	0.9		
	MT-lowDQ	20	0.5±0.3	0.4	0.6		
	Total	84	0.8±0.5	0.7	0.9		

Abbreviations: N= Number of participants**, FC**=Fermentable carbohydrate, **SDF**=Soluble dietary fiber, **PT-highDQ**= Plant-based diet group with high diet quality, **PT-lowDQ**= Plant-based diet group with low diet quality, **MT-highDQ**= Meat-based diet group with high diet quality**, MT-lowDQ**= Meat-based diet group with low diet quality; **differences between groups in exploratory outcome were analyzed by one-way analysis of variance (ANOVA) for diet group-diet quality.** *significant p-value <0.05, **significant p-value <0.01; [a] = partial eta squared indicating large effect size