Human Nutrition & Metabolism 36 (2024) 200258

Contents lists available at ScienceDirect

Human Nutrition & Metabolism

journal homepage: www.sciencedirect.com/journal/human-nutrition-and-metabolism

Consumption of a variety of plant foods, ultra-processed foods, and risk for chronic disease: A dietary intervention

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A R T I C L E I N F O

Keywords:
Plant foods
Ultra-processed foods
Chronic disease

A B S T R A C T

Background: The reliance on ultra-processed foods (UPF) as a source of energy has increased over the last decade. Consumption of UPF is associated with increased calorie intake and increased risk for chronic disease. An intentional increase of a variety of non-ultra-processed plant foods may decrease UPF intake and reduce risk for chronic disease.

Methods: The objective of this study was to determine whether an intervention to increase in the number of varieties of non-ultra-processed plant foods consumed each week along with grocery reimbursement was associated with reduced intake of UPF and reduced risk of chronic disease. An 8-week dietary intervention with the intention for subjects (22 were recruited and started the study, while 19 subjects completed the study) to consume at least 30 varieties of non-ultra-processed plant foods per week was conducted. Subjects watched a weekly educational module, received recipes and grocery lists, and received reimbursement for non-ultra-processed plant foods that were purchased. Diet assessments were conducted by 24-h recall and 3-day diet records. Fasting plasma glucose, C-reactive protein, LDL and HDL cholesterol, and anthropomorphic measurements were assessed at four time points.

Results: The number of different types of non-ultra-processed plant foods consumed each week was significantly increased after the 8-week intervention compared to before (34.7 ± 10.8 vs 23.1 ± 12.1; $p < 0.001$). The number of ultra-processed foods consumed per day was significantly lower during the intervention compared to the control period (5.32 ± 1.65 vs 6.54 ± 2.04; $p = 0.02$). There were no significant changes to biochemical or anthropomorphic following the 8-week intervention.

Discussion: Educating individuals on the importance of the variety of plant foods intake along with reducing the financial barrier for purchasing plant foods may be an effective way to reduce reliance on ultra-processed foods. More research is needed to determine whether an increase in varieties of plant foods and reduction in ultra-processed food intake impacts risk for chronic disease.

1. Introduction

Chronic diseases pose major healthcare challenges and dramatically reduce the quality of life for millions of people. Lifestyle behaviors, including dietary intake, are important determinants of the development of chronic diseases and are the first -line approach for interventions [1]. Intake of ultra-processed foods may be contributing to the epidemic of obesity and other chronic diseases [2,3]. Ultra-processed foods contain sugar, salt, and additives and are associated with adverse health outcomes [4,5].

Since its inception in 2010, the NOVA system has been relied upon in research as a standardized system to categorize foods based on level of processing to study in association with health outcomes [6]. The NOVA system includes 4 levels of processing: unprocessed or minimally processed foods, processed culinary ingredients, processed foods, and ultra-processed foods. Examples of unprocessed or minimally processed

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https://doi.org/10.1016/j.hnm.2024.200258
Received 29 May 2023; Received in revised form 17 February 2024; Accepted 20 February 2024
Available online 1 March 2024

would include fresh produce, herbs, and grains. Processed culinary ingredient examples include vegetable oils, honey, maple syrup, and butter. Examples of processed foods include canned vegetable and legumes, canned fish, and freshly made unpackaged breads and cheeses. Finally, ultra-processed foods include carbonated soft drinks, ready-to eat cereals, and mass-produced ice-cream, breads, crackers, and cookies. The distinction that sets ultra-processed foods apart from the other three categories of foods is that they are designed for convenience and palatability, and that they contain additives for coloring, texturizing, and/or preserving [6].

Intake of processed foods has increased over several decades as people spend less time at home, less time cooking, and more money on convenience foods and foods consumed outside of the home [7]. Cooking skills and consumption of home cooked meals have declined [8]. In addition, access to and affordability of recommended foods varies widely among populations and plays a large role in dietary quality. The increased consumption of ultra-processed foods is likely contributing to low intake of a variety of non-ultra-processed plant foods: fruits, vegetables, legumes, whole grains, nuts, and seeds. Non-ultra-processed plant foods are those plant foods that belong to the first 3 NOVA categories: whole (unprocessed) or minimally processed, processed culinary ingredients or processed plant foods. Distinguishing between ultra-processed and non-ultra-processed plant foods allows for separating the effects that the additives (including sodium and sugar) in plant-based ultra-processed foods may have.

The American Gut Project found that people who consumed more than 30 varieties of plant foods (fruits, vegetables, legumes, nuts, seeds, grains) in a 7-day period had greater gut bacteria diversity compared to those who consumed less than that [9]. Gut bacteria diversity is associated with reduced likelihood of obesity and its associated comorbidities [10]. Dietary behaviors to increase diversity of gut bacteria may be a strategy to reduce risk of chronic disease, however barriers such as cost and education reduce the likelihood of such behaviors.

Cost and availability of non-ultra-processed plant foods are barriers to a balanced dietary pattern for many people [11]. The cost of foods is major food choice determinant and ultra-processed foods may be perceived as more affordable based on pricing strategies and calorie content. In addition, the perception that fruits and vegetables aren't satiating, the required time and labor for preparation, the perishability, and the difficulty to regularly keep on hand, are deterrents to meeting fruit and vegetable recommendations [12]. Education on how to regularly access and consume non-ultra-processed plant foods is needed, along with policy development to improve access and affordability.

Despite the consensus that healthy lifestyle behaviors are critical for long term health, effective methods for promoting dietary patterns associated with positive health outcomes are lacking. Strategies to improve understanding of and access to such dietary patterns are needed. There remains a paucity of effective lifestyle and behavioral interventions for the prevention of chronic diseases along with space for policy development to address the social and commercial determinants of food choices. Most dietary interventions to reduce risk for chronic disease are focused on decreased carbohydrate intake, reduced calorie intake, and increased physical activity via individual and group counseling. The focus of this study was an intervention to increase the variety of plant foods consumed through education and grocery reimbursement and to determine whether it was associated with reduced intake of ultra-processed foods and reduced risk for chronic disease.

2. Methods

2.1. Participants

The study was approved by the Institutional Review Board of St. Catherine University. Informed consent was obtained from each subject. University students were recruited as a convenience sample to participate in the study using flyers posted in designated university spaces and by emails to students. Prospective subjects completed a screening tool to determine their eligibility. Inclusion criteria included university student status with a BMI equal to or greater than 25 kg/m^2. Prospective subjects were excluded if they had a BMI below 25 kg/m^2 and/or a self-reported history of disordered eating behaviors or eating disorder diagnosis. Of the 22 subjects that started the study, 19 completed. Of the 19 subjects that completed the intervention (completed the ASA24 recalls and records and turned in their plant foods list), 2 did not come to their time point 3 check-in and 5 did not come to their follow-up (time point 4) check-in. Of the three that started and did not complete the study, one dropped out early in the intervention, one left after the initial meeting when they realized the time requirement to stay in the study was too much for them, and one completed about half of the study before they indicated they were too busy to continue. The 2 that missed the time point 3 check-in and the 5 that missed their follow-up (time point 4) check in had left because it was the end of the semester, indicated they were too busy to come in, or were lost to follow-up.

2.2. Study design

An eighteen-week quasi-experimental dietary intervention trial was conducted to analyze the impact of an intervention to increase intake of a variety of plant foods on ultra-processed food consumption and chronic disease risk factors. A four-week control period was followed by an eight-week dietary intervention in which participants were asked to increase their non-ultra-processed plant food intake to 30 varieties per week. Participants completed a follow-up appointment six weeks after the end of the intervention.

The research team consisted of two faculty members from the Department of Nutrition and Dietetics (both registered dietitians), a faculty member from the Department of Psychology, and three undergraduate students (two from nutrition and one from psychology). Major outcomes were plant food intake, ultra-processed food intake and chronic disease risk factors. Dietary assessment was conducted during the control and intervention periods. Risk factors for chronic disease were assessed at four time points: baseline (before the control period), before the intervention, after the intervention, and six weeks after the end of the intervention period.

2.3. Dietary intervention

At the start of the four-week control period, each subject met with one of the registered dietitians on the research team for approximately 30 min to review and sign the informed consent and have anthropometric measurements taken. Subjects were instructed not to change any of their eating or lifestyle behaviors during the control period.

At the start of the eight-week intervention period, subjects again met individually with a research team member for approximately 45 min to have anthropometric measurements taken, complete the pre-education assessment, and receive dietary instruction. Dietary instruction consisted of a member of the research team explaining to subjects that the goal of the intervention was to consume more than 30 non-ultra-processed plant food varieties each week. Education on the four categories of processed foods based on the NOVA system was provided [5]. Subjects were informed that they were eligible to receive up to $50 in grocery reimbursement each week for non-ultra-processed plant food purchases (subjects submitted receipts for review of purchases). Subjects were also informed that they needed to create an account in EdPuzzle and would be assigned a weekly module (for each of eight weeks) to watch.

The eight weekly education modules consisted of original narrated videos that varied from seven to 18 min. Some of the videos included practical demonstrations, such as how to get arils out of a pomegranate. These modules were created by the study staff and distributed on the EdPuzzle platform. The eight modules were focused on positive messaging and topics were as follows: 1. Introduction to Plant Food

Intake: what is it, why is it important, and what does it look like?; 2. Increasing Plant Food Intake: ideas, recipes, grocery shopping, meal planning; 3. Plant Food Intake: flavors, methods of preparation, and satiety; 4. Fiber, Phytochemicals, Antioxidants, and Micronutrients: what are they, how do we get enough of them, and how do they reduce our risk for chronic disease?; 5. Introduction to Ultra-Processed Foods: what are they, why are they enticing, why is it important to minimize intake?; 6. Nutrition and Chronic Disease: how are they related?; 7. Plant Foods on a Budget; and 8. Plant Food Intake for Long-Term Sustainable Health.

Throughout the eight-week intervention period, participants were emailed sample meal plans that included a wide variety of plant foods and limited processed foods as well as grocery lists and recipes corresponding to the meal plans. Participants were emailed weekly to announce the new weekly educational module, provide motivation to continue with the effort to increase dietary diversity, and remind them to submit their weekly plant food checklist and grocery receipts for reimbursement.

Subjects submitted grocery receipts to study staff, who evaluated the receipts for non-ultra- processed plant foods. Subjects received financial compensation with gift cards to their preferred store (Target, Trader Joe's, Amazon, etc.) of up to $50 each week for the 8-week intervention period. Food purchases categorized into the NOVA classification groups one through three were eligible for reimbursement, while NOVA category four foods (ultra-processed foods) were not.

At the end of the eight-week intervention, subjects met with a research team member to have anthropometric measurements taken and to complete the post-education assessment.

2.4. Education assessment and ultra-processed food intake assessment

The efficacy of the educational modules was measured using a ten-question assessment tool that was distributed to participants before and after the intervention period (Supplemental Fig. S1). The assessment tool included one multiple choice question (1 point for the correct answer), two short answer questions (3 points each), two true/false/don't know questions (1 point for correct answer), and five scaled questions (higher points for the more correct answers). The highest possible score on the education assessment was 28.

Prior to the start of the study, subjects also completed a survey administered by Qualtrics to determine whether they consumed ultra-processed foods and if so, why. The survey was organized into four blocks of questions: consumption, determinants, predictions, and demographics base/universal questions. The consumption questions asked if participants ate specific ultra-processed food in the last six months. Determinant questions were constructed similar to the Eating Motivation Survey (TEMS), which investigated fifteen psychological factors underlying eating behavior [13]. These fifteen factors were used to create questions about specific reasons why people choose ultra-processed foods. At the end of this block, participants were given the opportunity to address any factors in their ultra-processed food choices that the survey had not included. The predictions block asked participants to use the Likert scale to predict if they would choose fewer ultra-processed foods under hypothetical conditions. Finally, participants were asked to identify their height, weight, living arrangement (on or off-campus), and age.

2.5. Dietary assessment

Dietary intake was assessed during the control and intervention periods by 24-h recalls and 3-day diet records using the Automated Self-Administered 24-Hour Dietary Assessment Tool (ASA24). Subjects completed 24-h recalls in which they recorded everything they consumed in 24 h, once during the control period and once during the intervention. The 24-h recalls were announced at random. Subjects were also asked to complete three-day food records once during the control period and once during the intervention. Subjects received an email instructing them when they needed to complete the recalls and records. Subjects set up an account in ASA24 and were given login and passwords to complete the 24-h recalls and three-day food records. The research team monitored the completion of the recalls and records, prompting subjects to complete them if they hadn't. Dietary assessment data was not used If reported energy intake was less than 1000 calories. Ultra-processed food intake was assessed from the ASA24 data by tabulating the number of ultra-processed foods consumed in each 24-h period and averaged for each subject.

Participants were asked to keep weekly records of the number of non-ultra-processed (NOVA groups one through three) plant food varieties they consumed using a chart created by the research team that consisted of a comprehensive list of fruits, vegetables, legumes, and seeds in which they placed a check by the items they consumed at least once in the seven-day period (Supplemental Fig. S2). The average number of non-ultra-processed plant foods consumed by each participant each week was calculated.

The Health Eating Index (HEI)-2015 score was calculated for each participant using the simple HEI scoring algorithm method and the recall and record data from ASA 24 ([14] HEI scoring algorithm). The HEI-2015 is an estimate of the alignment of the intake with the 2015 Dietary Guidelines for Americans (DGA). The HEI-2015 score is the sum of 13 component scores, 9 of which are adequacy components for which higher intake leads to a higher score, and 4 of which are moderation components for which higher intake leads to a lower score [15]. Intake of most components (for example, whole grains) is normalized to calorie intake. The fatty acid component is calculated a little bit differently in that it is a ratio of polyunsaturated fatty acids and monounsaturated fatty acids to saturated fatty acids. The total score (0–100) is used to assess diet quality based on the alignment with the DGA. The closer the score is to 100, the more in alignment the intake is with the DGA. HEI scores for each subject were an average from the days they recorded intake.

2.6. Chronic disease risk assessment

Risk for chronic disease was assessed by anthropometric and laboratory data. Blood pressure was measured while subjects were comfortably seated with both feet flat on the floor, using an automatic blood pressure cuff (Omron Healthcare, Inc., Bannockbum, Illinois). Height and weight were measured using a balance beam column scale with a height rod (Health o meter Professional). Body composition was measured using a bioelectrical impedance analysis (Omron Healthcare, Inc., Bannockbum, Illinois). Waist and hip circumference were measured by study staff according to NIH guidelines using a standard tape measure. Waist circumferences were obtained at the mid-point between the lowest rib and the iliac crest to the nearest 0.1 cm. Hip circumferences were rounded to the nearest 0.1 cm at the widest part between the waist and knees.

Blood samples were collected and processed by M Health Fairview laboratories. Subjects were asked to fast for 12 h prior to their blood draw. Routine chemistry samples were drawn in either Lithium Heparinized gel tubes (green gel) and centrifuged at approximately 5000 rpm for 4 min and held capped at room temperature prior to analysis (typically <1hr). Analysis was performed on the Siemens Vista platform. Methodologies are as follows: for C-reactive protein- Nephelometry; for fasting glucose-bichromatic endpoint; for lipids- HDL and triglycerides - bichromatic endpoint; cholesterol-polychromatic endpoint; LDL - calculated (=[CHOL-HDL-(TRIG/5)]) Cholesterol, HDL and Triglyceride in mg/dL]).

2.7. Statistical analysis

Paired t-tests were conducted to examine for differences in the average number of plant foods participants reported consuming

Table 1
Demographic data.

Variable	Subjects
Sex, F % (n)	100% (n = 19)
Age, y (Mean ± SD)	28 ± 11.79
Race/ethnicity % (n)	
White	13
Asian	3
Black or African American	2
Hispanic	None reported
American Indian or Alaskan Native	None reported
Native Hawaiian or other pacific Islander	None reported
Unknown	1
Health Conditions	
PCOS	1
Diabetes	1
Hypertension	1
Crohn's Disease	1
Thyroid Disease	1

between the control and intervention periods, and to determine differences in scores on the educational assessment tool before and after the intervention. Differences between overall and individual item HEI scores were assessed by T-tests. Laboratory data were analyzed using repeated measure ANOVA and Bonferroni post-hoc tests. Due to participant attrition across the 4 time points, the ANOVA analyses were conducted on the 12 participants for whom we had data across all 4 time points. The laboratory measurements for C-reactive protein only provided exact values when the values were greater than 2.9 mg/dl. Values lower than this were reported as <2.9 mg/dl. For this reason, for our ANOVA analyses, we used the value of 2.9 mg/dl for participants whose c-reactive protein values fell below that level. All data analyses were conducted using Microsoft Excel, and significance levels were set at an alpha of 0.05.

3. Results

3.1. Participants

The 19 subjects in the study identified as female (Table 1). The average age of participants was 28 years (± 11.8). One subject had lactose intolerance and one had a peanut allergy. Five of the participants (26.3%) reported having a chronic disease: hypertension (n = 1), polycystic ovarian syndrome (n = 1), diabetes (n = 1), Crohn's Disease (n = 1), and thyroid disease (n = 1).

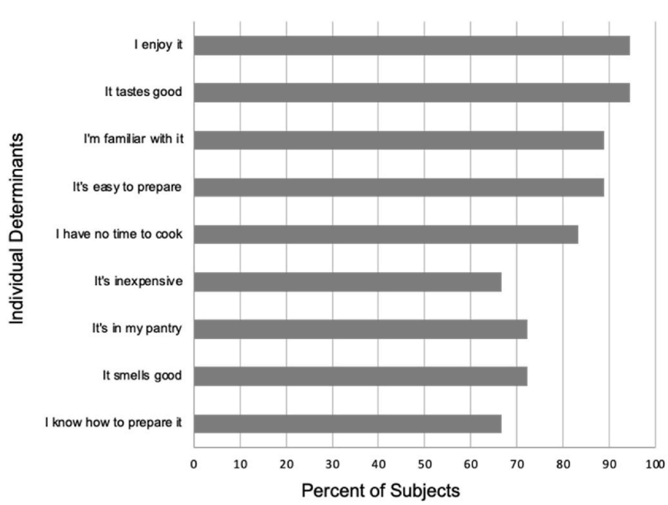


Fig. 1A. Individual Determinants of Ultra-Processed Food Intake (% of respondents).

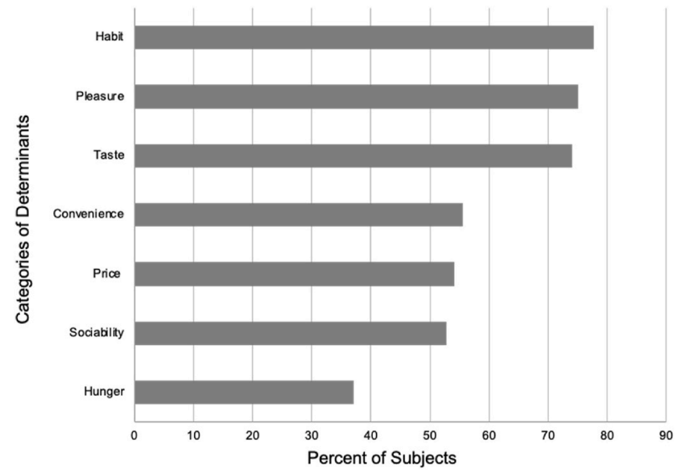


Fig. 1B. Categories of Determinants of Ultra-Processed Food Intake (# of respondents/# of items within a category multiplied by # of respondents).

3.2. Determinants of ultra-processed food intake

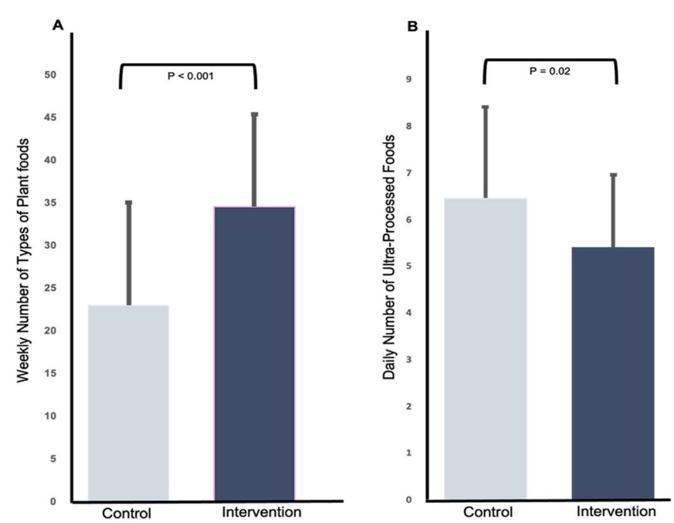
All subjects that completed the determinants of UPF intake survey (n = 18) indicated that they consumed ultra-processed foods. The three most common individual determinants of UPF intake were "I enjoy it", "It tastes good", "I'm familiar with it", and "It's easy to prepare" (Fig. 1A). The most common categories of determinants of UPF intake that subjects selected were habit, pleasure, and taste (Fig. 1B).

3.3. Plant food and UPF intake

The average weekly number of plant food varieties was higher in the intervention compared to the control period (34.7 ± 10.8 vs 23.1 ± 12.1; $p < 0.001$). The average number of ultra-processed foods consumed per day was significantly lower during the intervention compared to the control period (5.32 ± 1.65 vs 6.54 ± 2.04; $p < 0.05$) (Fig. 2).

3.4. Healthy eating index

There was no difference in average HEI score between the control



Data are means and error bars are standard deviation. Statistical significance is denoted by brackets and P-values.

Fig. 2. Weekly intake of plant foods and UPF during the control and intervention periods.

Table 2
Differences in HEI-2015 scores between the Intervention and Control periods.

HEI-2015	Control	Intervention
Total HEI-2015 (0–100)	57.34 ± 14.61	60.51 ± 14.90
Total Fruits (0–5)	2.03 ± 1.96	3.28 ± 1.76*
Whole Fruits (0–5)	1.39 ± 2.25	1.75 ± 2.08
Total Vegetables (0–5)	6.68 ± 3.4	7.08 ± 2.86
Greens and Beans (0–5)	2.66 ± 2.32	3.16 ± 2.21
Whole Grains (0-10)	2.46 ± 3.23	2.91 ± 3.59
Dairy (0-10)	5.07 ± 3.26	5.41 ± 3.07
Total Protein Foods (0–5)	4.14 ± 1.29	4.22 ± 1.21
Seafood and Plant Proteins (0–5)	3.21 ± 2.16	3.48 + 1.99
Fatty Acids (0-10)	6.43 ± 3.27	5.64 ± 3.69
Refined Grains (0-10)	6.04 ± 3.72	6.43 ± 3.41
Sodium (0-10)	4.42 ± 3.51	4.03 ± 3.16
Added Sugars (0-10)	7.66 ± 2.55	8.35 ± 2.03
Saturated Fats (0-10)	5.08 ± 3.29	4.95 ± 3.41

Data are means ± standard deviations. *$p < 0.001$.

and intervention periods (Table 2). There was a statistically significant increase in the score for total fruits.

3.5. Education assessment

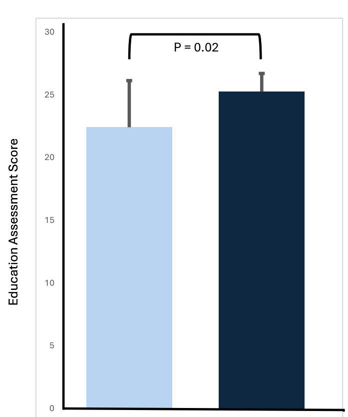
For the subjects that completed both the pre- and post-education assessments, the average score on the post-education assessment was significantly higher than the pre-education assessment (25.31 ± 1.45 vs 22.47 ± 3.71; $p < 0.05$) (Fig. 3).

3.6. Anthropometric assessment

Anthropometric measurements remained largely unchanged across the four time points except for diastolic blood pressure. There was a significant difference in diastolic blood pressure across the 4 different time points; $F(3,14) = 3.70$, $p < 00.05$) (Table 3). Post-hoc analysis indicated that there was a significant difference in the diastolic blood pressure between baseline (time point 1) and the start of the intervention (time point 2). Diastolic blood pressure was significantly lower at time point 2 compared with time point 1 ($t = 3.95$, $df = 14$, $p < 00.01$).

A greater percentage of blood pressure measurements were in the normal category after the intervention compared to before, however this was not statistically significant (Table 4).

There were no significant differences in any of the biochemical assessment measures across the 4 time points of the study (Table 5). The majority of participants had values within the normal range at the beginning and the end of the study (Table 6).



Data are means and error bars are standard deviation. Statistical significance is denoted by brackets and P-values.

Fig. 3. Education assessment score before and after the intervention.

Table 3
Anthropometric measurements across the four time points.

	Time Point 1	Time Point 2	Time Point 3	Time Point 4
BMI kg/m²	30.23 ± 4.07	30.35 ± 4.12	30.25 ± 4.27	30.47 ± 3.38
% Body Fat	34.92 ± 5.02	34.92 ± 4.83	34.9 ± 4.73	34.53 ± 5.05
WHR	0.82 ± 0.06	0.83 ± 0.07	0.81 ± 0.06	0.81 ± 0.07
Systolic BP mmHg	118.87 ± 11.39	116.4 ± 6.25	115.4 ± 9.17	113.7 ± 11.3
Diastolic BP mmHg	85.4 ± 7.05[a]	77.6 ± 6.23[b]	80.67 ± 9.76[a,b]	78.6 ± 7.91[a,b]

Data are means ± standard deviation. Superscript a's and b's denote statistical groups. n = 16 for all measures except diastolic and systolic BP. For diastolic and systolic BP, n = 15.

4. Discussion

Ultra-processed foods are attractive, palatable, and abundantly available, however increased consumption of ultra-processed foods and the associated reduction in the intake of a variety of plant foods may lead to increased risk for chronic disease. The present study tested an intervention designed to increase the number of varieties of non-ultra-processed plant foods consumed each week through education and grocery reimbursement. While there was a significant increase in the average number of varieties of plant foods that were consumed each week and a decrease in UPF intake during the intervention, this did not translate to a clinically meaningful reduction in risk for chronic disease within the study period.

Ultra-processed food intake is associated with increased calorie intake. A study examining the impact of ultra-processed foods on calorie intake found that consuming a diet largely based on ultra-processed foods was associated with an average of 500 more calories per day compared to a diet largely based on whole foods [3]. In the present study, there wasn't a change in BMI or body composition over the course of the 18-week study suggesting that calorie intake did not change appreciably despite the increased dietary diversity and reduced intake of ultra-processed foods. This is likely due to the nature of the intervention which was designed to increase the number of varieties of plant foods consumed, but not eliminate ultra-processed foods. While the subjects had a small but significant reduction in the average number of ultra-processed foods consumed, they still consumed an average of 5 ultra-processed foods each day on the days that dietary intake was recorded. The approach for the dietary intervention followed the evidence that gradual dietary changes are more likely to be sustained, however a longer study duration may be needed to demonstrate clinically significant changes in disease risk with modest dietary changes [16].

The intervention was designed specifically to focus on the positive messaging of increasing the number of varieties of plant foods consumed. National nutrition guidelines have mainly focused on promoting intake from all food groups which is distinct from diversity within food groups. The intervention of the current study focused on increasing variety across plant foods based on research demonstrating a beneficial impact on health. Effective campaigns to promote intentional consumption of a wide variety of fruits, vegetables and other plant foods are lacking. The Dietary Guidelines for Americans 2020–2025 emphasizes getting foods from all food groups but only briefly mentions diversity within each food group [17]. Dietary diversity within food groups is just as important as across the food groups. For example, someone may eat 1–2 servings of fruits per day, however the fruits may always consist of an apple and a banana. An apple and a banana every day is much better than no fruit, however individuals can increase the nutritional quality of their diet by consuming a variety of fruits daily to get a variety of vitamins, minerals, and phytochemicals and to promote

Table 4
Percentage of normal and elevated blood pressures.

Timepoint	Systolic Blood Pressure (mmHg)				Diastolic Blood Pressure (mmHg)			
	1	2	3	4	1	2	3	4
Normal	53.3%	80.0%	73.3%	80.0%	20.0%	66.7%	53.3%	60.0%
Elevated	46.7%	20.0%	26.7%	20.0%	80.0%	33.3%	46.7%	40.0%

n = 15.

Table 5
Biochemical measurements across the four time points.

	Time point 1	Time point 2	Time point 3	Time point 4
LDL mg/dL	94.59 ± 25.94	96.71 ± 29.08	93.76 ± 33.24	97.00 ± 27.48
Triglycerides mg/dL	85.06 ± 35.97	81.53 ± 31.45	96.06 ± 41.82	88.83 ± 32.72
C-Reactive Protein mg/L	3.38 ± 1.22	4.29 ± 3.45	3.44 ± 0.95	3.99 ± 2.45
Glucose mg/dL	89.53 ± 6.87	91.94 ± 6.29	91.65 ± 5.58	91.5 ± 4.74

Data are means ± standard deviations. n = 17 for time points 1–3. n = 12 for time point 4.

Table 6
Percentage of normal and elevated biochemical markers across the four timepoints.

		Time point 1	Time point 2	Time point 3	Time point 4
LDL mg/dL	*Normal*	70.6%	64.7%	64.7%	50.0%
	Elevated	29.4%	35.3%	35.3%	50.0%
Triglycerides mg/dL	*Normal*	94.1%	100.0%	88.2%	100.0%
	Elevated	5.9%	0.0%	11.8%	0.0%
C-Reactive Protein mg/L	*Normal*	100.0%	88.2%	100.0%	81.8%
	Elevated	0.0%	11.8%	0.0%	18.2%
Glucose mg/dL	*Normal*	88.2%	88.2%	94.1%	100.0%
	Elevated	11.8%	11.8%	5.9%	0.0%

n = 17 for time points 1–3. n = 12 for time point 4.

diversity of gut bacteria.

McDonald et al. found that those who consume, on average, more than 30 plant foods per week as measured by FFQs tend to have a greater variety of gut bacteria than those whose diets do not include this much diversity [9]. Dietary diversity as measured in two prospective cohorts, also by FFQ, was positively associated with diversity of gut bacteria and serum bile acids, however the focus was on diversity across food groups, not within food groups [18]. Conklin et al. used an FFQ to measure diversity of intake across food groups and within food groups in a prospective cohort study and found that diversity across the food groups and within the dairy and vegetable groups was associated with a significant reduction in risk for type 2 diabetes [19]. While the mechanism underlying the health benefits from increased variety of foods within food groups is unclear, it may in part be through modulation of the gut microbiome [20]. A diverse gut microbiome may help to regulate hunger and satiety signals, which may promote weight maintenance and reduce the associated comorbidities [21]. Diets with more plant food varieties tend to be higher in fiber, which, when fermented by bacteria in the gut, produces short-chain fatty acids (SCFA) (Skoglund, 2016). SCFAs are necessary for regulating satiety signals, subsequently helping manage a person's energy intake [22].

The average HEI-2015 score of participants in the present study was 57 before the intervention, which is close to the average HEI-2015 score in the US for 19–30 year-olds of 53 (USDA). The increase in the HEI-2015 score to 60 during the intervention was not statistically significant. However, the individual component of whole fruit intake was statistically significantly increased in the self-reported dietary intake during the intervention compared to the control period. This is in alignment with the statistically significant increase in the number of non-ultra-processed plant foods consumed per week as assessed by the plant foods tool and the decrease in ultra-processed foods consumed per day based on the ASA 24 data. It is not surprising that the HEI-2015 score did not change, because it includes protein and dairy food intake which was not addressed by the dietary intervention. The tool to assess the variety of plant foods intake was built specifically to capture non-ultra-processed plant foods (fruits, vegetables, whole grains, nuts, seeds, and legumes) which was addressed by the dietary intervention, while the HEI-2015 is a broader assessment of more food groups including animal products.

Because the intervention included education and grocery reimbursement, it is difficult to tell the relative contribution of each to the significant increase in number of varieties of plant foods per week and reduction in number of ultra-processed foods per day. Both aspects of the intervention were necessary to complement each other and both education and affordability should be addressed in future strategies to improve dietary patterns of individuals and populations.

The present study has several limitations. Dietary intake was self-reported which may be inaccurate. Intake of non-ultra-processed plant foods and of ultra-processed foods was assessed by number of items, not by percent of total calories. The short duration of the intervention was a limitation in that it was likely inadequate to see meaningful changes in laboratory and anthropometric changes with the amount of dietary change that occurred. The small pool of subjects was limited to college students, who were in a life stage associated with consumption of convenience foods and prioritization of school and socializing over health. The significant increase in number of varieties of plant foods consumed may not have been great enough to have an impact given the continued albeit lower consumption of ultra-processed foods. The tool that was used to assess the variety of plant foods consumed was newly developed by the research team and is not validated. However, the significant increase in the HEI-2015 whole fruit score corroborated in part the increase in the number of plant food varieties consumed each week that was demonstrated by the tool.

The limitations of the study do not undermine the strengths of the study which include a novel dietary intervention that builds upon previous research suggesting that a variety of intake within food groups, particularly of plant foods, is associated with health benefits. Another strength is the development of an easy-to-use tool to assess the variety of plant foods consumed. Future studies to further our understanding of the contribution of the variety of plant foods consumed to human health that the underlying biological mechanisms will be helpful.

In conclusion, a dietary intervention promoting an increase in the variety of non-ultra-processed plant foods that are consumed through education and financial reimbursement may be an effective way to reduce reliance on ultra-processed foods. More research is needed to determine whether an increase in dietary diversity and a reduction in ultra-processed food intake impacts risk for chronic disease.

Funding

This work was funded by an innovative scholarship award from St. Catherine University to MB and AM.

CRediT authorship contribution statement

Anaya Mitra: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft. **Kathy Thames:** Conceptualization, Data curation, Methodology, Supervision, Writing – review & editing. **Anna Brown:** Investigation, Methodology. **Isabelle Shuster:** Data curation, Methodology. **Molly Rosenfield:** Methodology, Writing – review & editing. **Megan D. Baumler:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.hnm.2024.200258.

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