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Using A Multi Omic Approach To Investigate A Diet Intervention In Young Adults At Risk Of Disease

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ABSTRACT

Purpose of the study: To examine the impact of an 8-week dietary intervention, based on USDA 2010 guidelines, on nutritional behaviors, metabolome, and microbiome of young adults at risk of disease.

Methodology: This study utilized an 8-week, free-living, randomized trial using Nutritionist Pro™ (Axxya Systems), ActiGraph GT3X accelerometers, and 16S rRNA sequencing for microbial profiling. Participants were counseled with weekly tailored interventions by a Registered Dietitian Nutritionist (RDN). Biochemical, anthropometric, dietary intake, and microbiome data were collected and analyzed using SAS and JMP software.

Main Findings: The intervention increased fruit, vegetable, and fiber intake while reducing saturated fat and empty calorie consumption. Significant improvements were observed in systolic blood pressure, waist circumference, and total cholesterol. Microbial analysis revealed decreased Firmicutes and increased Bacteroidetes post-intervention, along with improved inflammatory markers and serum ceramide levels.

Novelty/Originality of this study: This study uniquely integrates dietary intervention with a multi-omic approach including metabolomics and microbiome analysis in a young adult population. It provides foundational evidence for personalized nutrition and translational research, highlighting how targeted dietary changes can influence microbial composition and metabolic health.

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1. INTRODUCTION

The prevalence of chronic diseases such as obesity, cardiovascular disease, and type 2 diabetes continues to increase among young adults, especially during the transition into independent living and higher education[1]-[3]. This period often marks a decline in dietary quality, characterized by low fruit and vegetable intake and increased consumption of energy-dense, nutrient-poor foods. As poor dietary habits are linked to various metabolic dysfunctions, early intervention during young adulthood becomes crucial for long-term health improvement[4], [5].

Recent developments in nutrition science have moved beyond traditional dietary assessments and now integrate a multi-omic approach such as metabolomics and microbiome analysis to gain deeper insights into how dietary patterns influence health at the molecular and microbial levels[6]-[8]. These technologies enable researchers to examine interactions between diet, host metabolism, and gut microbiota composition in relation to disease risk.

Despite these advancements, limited studies have investigated the impact of personalized dietary interventions on young adults using such integrative approaches[9], [10]. Particularly, the application of dietary guidelines tailored through behavioral theories like the Social Cognitive Theory (SCT), in combination with next-generation sequencing and metabolite profiling, is still underexplored. Most existing interventions either focus on general health promotion or specific diet types, without considering the synergistic effects of comprehensive dietary change on multiple biological systems[11], [12].

This study introduces an innovative multi-omic approach to evaluate the effects of an 8-week dietary intervention based on the 2010 USDA Dietary Guidelines for Americans [13]-[15]. The intervention was designed with personalized counseling and behavior change techniques rooted in SCT. The FRUVEDomics project involved randomizing young adult participants into three dietary groups, increased fruit and vegetable consumption, a combination of fruit and vegetable with low refined carbohydrates, and fruit and vegetable with low-fat intake [16]-[18]. Using tools such as Nutritionist Pro™, ActiGraph GT3X, and 16S rRNA sequencing, the study assessed changes in metabolic parameters, dietary intake, and microbiota composition.

Previous research titled “Multi-omics Approaches for Precision Obesity Management” has made important contributions to the development of comprehensive biological data-driven obesity management strategies [19]-[21]. The study emphasized the importance of using multi-omics approaches including genomics, metabolomics, and proteomics to understand the biological mechanisms of obesity and design precision interventions. Although these approaches have great potential to improve the effectiveness of obesity management, the scope of these studies has been general and tends to focus on populations that are already obese or have associated chronic conditions. However, there is an important gap in the literature that has not been widely explored, namely the application of multi-omics approaches in the context of dietary interventions in populations that are not yet obese but at early risk for metabolic disease [22], [23]. Furthermore, previous studies have not specifically linked multi-omics data to the outcomes of specific dietary interventions in young age groups. In fact, the young adult phase is a crucial period for early prevention through lifestyle modifications, including diet, which can affect long-term health trajectories [24]-[26]. Thus, studies that integrate multi-omics approaches and preventive dietary strategies in this age group are still very limited. This study aims to fill this gap by combining specific dietary interventions and multi-omics analysis in a young adult population at early risk. The focus of this study is not only on treatment, but also on preventing disease progression through understanding the biological response to the diet applied. This approach provides an important contribution in developing personalized strategies for early nutritional interventions and expanding the scope of multi-omics applications in the field of preventive nutrition, which has not received enough attention in previous studies [27], [28].

Based on the background and research gap analysis, this study offers novelty in the integration of multi-omics approach with specific dietary intervention in a group of young adults who are at early risk of metabolic diseases [29]-[31]. Different from previous studies that have focused more on general obesity management and in individuals with chronic conditions, this study presents a preventive perspective by utilizing multi-omics data to understand individual biological responses to nutritional interventions before the onset of disease manifestations. The novelty of this study lies in its integrative methodology, which combines personalized nutrition, behavioral theory, and multi-omics technology to comprehensively evaluate the impact of diet. This study provides new insights into how targeted dietary changes affect gut microbiome structure, inflammatory markers, and overall metabolic health [32], [33]. With this approach, this study not only expands the scope of multi-omics applications in nutrition and health but also opens up opportunities for the development of more effective precision nutrition strategies in reducing disease risk in young adult populations [34]-[36].

This study has significant implications in both academic and practical domains. By combining personalized dietary interventions, behavioral theory, and multi-omics analysis, this study has the potential to drive the development of a more effective and evidence-based precision nutrition approach for the prevention of metabolic diseases from a young age [37], [38]. The findings of this study can provide a strong scientific basis for the formulation of more proactive and biologically data-driven public health policies, especially in designing nutritional intervention programs for at-risk populations. In addition, its practical implications can also be felt in the clinical world and the nutrition industry, where this integrative approach can be utilized to create functional food products, supplements, or diet services that are more targeted and have a long-term impact on health [39], [40]. Thus, the results of this study are expected to strengthen the foundation for the transition from a reactive medicine approach to personalized and precision prevention in the modern health era.

This research is important because the increasing prevalence of metabolic diseases in young people is a worrying global health issue, while personalized and biologically data-based prevention efforts are still very limited [41], [42]. The young adult period is a crucial phase in the life cycle, where lifestyle interventions, especially diet, can have a long-term impact on health quality. However, conventional approaches to dietary interventions often do not consider individual variability influenced by genetic factors, microbiomes, and other biological responses [43], [44]. Therefore, more precise and holistic methods are needed, such as multi-omics approaches, to deeply understand how the body responds to certain nutritional interventions. This research is here as an answer to this need by offering an innovative approach that not only focuses on improving diet, but also on mapping biological factors that play a role in disease risk. This urgency is even higher considering the great potential of preventive approaches in reducing the burden of chronic diseases in the future and building a healthier young generation in a sustainable manner.

The uniqueness of this study lies in its integrative and preventive approach, combining personalized dietary interventions, behavioral theory, and multi-omics technology to comprehensively evaluate the impact of nutrition in young adults at risk of metabolic disease. Rather than focusing solely on treating conditions that have already developed, this study emphasizes the importance of early prevention through understanding individual biological responses to dietary changes. By targeting the productive age group and using a comprehensive scientific approach, this study is expected to provide real contributions to the development of sustainable precision nutrition strategies that are relevant to modern health challenges.

2. RESEARCH METHOD

This study employed a randomized pre-post experimental design to evaluate the effects of a dietary intervention based on the USDA 2010 Dietary Guidelines for Americans [45], [46]. The study was conducted over an 8-week period using a free-living model among young adults at risk for metabolic disorders. The intervention was grounded in Social Cognitive Theory (SCT) and incorporated personalized nutrition counseling and multi-omic analyses, including metabolomics and microbiome profiling, to comprehensively assess dietary and physiological changes.

The study involved 36 young adults (ages 18–30) enrolled at West Virginia University (WVU). Inclusion criteria required participants to be free of chronic disease, not pregnant, not undergoing any special dietary regimen, and to have a BMI greater than 18.5. Exclusion criteria included engagement in other nutrition-related studies or having specific dietary restrictions. Participants were randomly assigned into one of three dietary groups, FRUVED (50% fruits and vegetables), FRUVED + LRC (low refined carbohydrates), and FRUVED + LF (low fat).

The study used a variety of instruments and tools for comprehensive data collection.

Table 1. Research Instruments

Instrument Type	Purpose
Nutritionist Pro™ software	Nutritional analysis and personalized dietary planning
Food logs, food photos, receipts	Dietary adherence tracking
Accelerometer (ActiGraph GT3X)	Objective physical activity measurement
Anthropometric tools (SECA scale, Stadiometer, tape measures, BodPod)	Body composition and circumference measurements
Questionnaires (PSQI, PSS)	Sleep quality and stress level assessment
Venous blood sampling tools	Biochemical marker analysis (lipids, glucose, insulin, CRP, etc.)
Fecal sample kits	Gut microbiome analysis using 16S rRNA sequencing

Data collection in this study was conducted at baseline and after the 8-week intervention period, encompassing comprehensive anthropometric, biochemical, microbiome, behavioral, physical activity, and dietary assessments. Anthropometric measurements included weight, height, waist and neck circumference, BMI, and body fat percentage, taken using standardized procedures and BodPod® for body composition. Biochemical data were obtained through fasting venous blood samples, which were analyzed for glucose, insulin, lipid profiles (total cholesterol, HDL, LDL, triglycerides), potassium, sodium, high-sensitivity C-reactive protein (hs-CRP), and ceramides providing a metabolic and inflammatory health profile. Stool samples were collected to analyze the gut microbiome via DNA extraction and 16S rRNA gene sequencing, offering insights into bacterial diversity and compositional changes associated with diet. Behavioral data were gathered using validated questionnaires, including the Pittsburgh Sleep Quality Index (PSQI) and Cohen's Perceived Stress Scale (PSS), to assess sleep quality and psychological stress. Physical activity levels were objectively monitored using ActiGraph GT3X accelerometers worn for one week before and after the intervention to record movement patterns and step counts. Dietary intake was evaluated through weekly 24-hour recalls conducted in one-on-one sessions with a Registered Dietitian Nutritionist (RDN), supported by participant-maintained food logs, photographs, and receipts, with intake data analyzed using Nutritionist Pro™ software to determine caloric, macronutrient, fiber, and empty calorie consumption.

All quantitative data in this study were analyzed using SAS® (version 9.3) and JMP® Pro 11, beginning with descriptive statistics (mean ± standard deviation) to summarize demographic characteristics and baseline measurements. Prior to hypothesis testing, normality of data distribution was evaluated for all continuous variables, and non-normally distributed variables were transformed using logarithmic or square root transformations to meet the assumptions of parametric tests. The primary statistical method applied was Repeated Measures Analysis of Variance (ANOVA) to assess both within-subject effects over time (pre- vs post-intervention) and between-group differences among the three dietary intervention groups (FRUVED, FRUVED+LRC, FRUVED+LF). The general linear model for the repeated measures ANOVA was specified as follows.

$$Y_{ijk}=\mu+\alpha_i+\beta_j+(\alpha\beta)_{ij}+\varepsilon_{ijk} \qquad (\ldots1)$$

where Y_{ijk} Yijk is the observed value for subject k in group i at time j ; μ represents the overall mean; αi is the main effect of the dietary group; βj is the main effect of time (pre/post); $(\alpha\beta)_{ij}$ represents the interaction between group and time; and ε_{ijk} is the residual error term. This model allowed the detection of main effects of time (indicating overall dietary changes across all participants), main effects of group (comparing differences among the three dietary interventions), and interaction effects (indicating whether the pattern of change over time differed by group). When significant main or interaction effects were identified, Tukey's Honest Significant Difference (HSD) test was conducted as a post hoc procedure to adjust for multiple comparisons and control for Type I error. A significance threshold of $p < 0.05$ was applied for all statistical tests. For the analysis of gut microbiome data, advanced bioinformatic methods were employed, including beta diversity analysis, inverted beta binomial modeling, and multiple regression analyses, to explore shifts in bacterial taxa relative abundance and their associations with dietary components and circulating serum amino acids, offering mechanistic insights into the diet–microbiome–host metabolism interface.

The research procedure for the FRUVEDomics study was implemented through a structured and sequential process to ensure the validity and reliability of the intervention outcomes. The study began with participant recruitment, conducted through university-wide flyers, digital news postings, and word-of-mouth. Interested individuals underwent an eligibility screening via phone interviews, during which inclusion and exclusion criteria were assessed. Eligible participants were then invited to complete informed consent procedures and baseline assessments (Week 0), which included anthropometric measurements, blood sampling, stool collection, and behavioral surveys. Following this, participants were randomly assigned to one of three dietary intervention groups: (1) FRUVED (fruit and vegetable-focused diet), (2) FRUVED + LRC (low refined carbohydrate), or (3) FRUVED + LF (low fat). Prior to the start of the intervention, all participants attended a nutrition education session led by a Registered Dietitian Nutritionist (RDN), where they received guidance on menu planning, portion control, grocery shopping tips, and were equipped with a culinary toolkit to support at-home food preparation. The intervention phase spanned eight weeks, during which participants received weekly individualized counseling sessions with the RDN, maintained food logs, provided 24-hour dietary recalls, and adhered to their assigned dietary protocol. Upon completion of the intervention, post-test assessments were conducted in Week 8, using the same measurement tools as at baseline, to evaluate the impact of the dietary treatments on metabolic health, dietary behaviors, microbiome composition, and related outcomes. This step-by-step process ensured a controlled yet realistic approach to evaluating diet-related health changes in a free-living college population.

3. RESULTS AND DISCUSSION

This section presents the findings of the study and provides a comprehensive discussion on the observed outcomes. The FRUVEDomics pilot study investigated dietary behavior, metabolic responses, and microbiome changes in young adults subjected to three different dietary interventions over an eight-week period. The discussion is divided into two sub-sections based on the main domains of the research findings.

3.1. Changes in Dietary Intake and Metabolic Parameters

The intervention successfully influenced participants' dietary behaviors across all groups. There was a significant increase in the intake of fruits and vegetables, dietary fiber, and total carbohydrate percentage ($p < 0.001$). Simultaneously, a reduction in saturated fat and empty calorie consumption was observed, supporting adherence to the USDA 2010 Dietary Guidelines. As shown in Table 1, improvements in several metabolic health indicators were also reported. These include significant reductions in waist circumference, systolic blood pressure, and total cholesterol among participants who adhered to the dietary prescriptions ($p < 0.05$).

Table 1. Changes in Selected Metabolic Indicators Before and After Intervention

Variable	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	*p*-value

Waist Circumference (cm)	91.2 ± 10.1	87.5 ± 9.4	< 0.01
Systolic BP (mmHg)	122.3 ± 8.6	115.6 ± 7.3	< 0.05
Total Cholesterol (mg/dL)	183.5 ± 21.4	174.2 ± 20.8	0.05

Although there were no significant changes in body weight and BMI, a trend toward improvement was noted. HDL cholesterol levels decreased, which might be attributed to reduced total fat intake. This paradoxical effect has been observed in other studies focusing on high-fiber, low-fat diets [1]. Nonetheless, the overall reductions in pro-inflammatory biomarkers and improved cardiometabolic markers suggest a beneficial impact of the dietary intervention.

3.2. Microbiome and Metabolomic Shifts

The microbial analysis using 16S rRNA sequencing revealed a significant shift in gut microbiota composition post-intervention. A notable decrease in Firmicutes and increase in Bacteroidetes were observed, which is indicative of improved microbial balance associated with leaner phenotypes [2]. At the family level, the abundance of Ruminococcaceae decreased while Bacteroidaceae and S24-7 increased, aligning with dietary patterns rich in fiber and plant-based foods.

Moreover, correlations were identified between dietary fiber intake, serum amino acid profiles, and specific microbial taxa. These findings support emerging evidence that gut bacteria mediate the host's metabolic response to diet via fermentation and metabolite signaling. The integration of metabolomic data showed that serum ceramides and pro-inflammatory markers decreased significantly after the intervention. These lipids are known to be involved in insulin resistance and cardiovascular risk, indicating a potentially protective mechanism induced by the dietary changes.

These findings provide a scientific foundation for the application of personalized nutrition strategies in young adults. They demonstrate how structured, theory-based dietary interventions can produce measurable changes not only in eating behavior but also in physiological and microbial markers of health. The combined use of dietary tracking, behavior counseling, and multi-omic data strengthens the validity of the outcomes and may contribute to future precision nutrition applications.

This study has demonstrated that a multi-omics approach encompassing microbiome, metabolome, and inflammation analyses provides a more comprehensive understanding of an individual's biological response to dietary interventions. Key findings suggest that personalized dietary changes can influence gut microbiome composition, reduce inflammatory markers, and improve metabolic profiles in young adults at risk for metabolic diseases. This strengthens the evidence that combining precision nutrition with multi-omics technologies may be an effective strategy for early prevention. However, there are a number of gaps that need to be addressed in future studies. One major limitation is the relatively short duration of the intervention, which does not fully represent the long-term impact on chronic disease risk. Furthermore, the inter-individual variability in response has not been fully explained by the available data, given that the multi-omics approach used still does not include epigenetic or transcriptomic dimensions that could broaden the understanding of the molecular mechanisms involved. This study is also limited in generalizing its results due to the relatively small number of participants and their demographically homogeneous backgrounds. Therefore, further studies are needed with a more diverse population coverage, longer intervention duration, and broader integration of omics data including epigenetics, proteomics, and long-term behavioral analysis. In addition, an interdisciplinary approach that combines social, psychological, and digital health monitoring aspects can enrich the understanding of how dietary interventions interact with external factors in an individual's daily life. By addressing these gaps, further research is expected to strengthen the effectiveness of multi-omics-based precision nutrition in preventing disease in a more comprehensive and sustainable manner.

Based on the results and discussions obtained, this study presents a novelty in the use of a multi-omic approach to simultaneously evaluate the impact of dietary interventions on multiple biological dimensions, such as the gut microbiome, metabolite profiles, and inflammatory biomarkers in young adults at risk for metabolic diseases [47], [48]. The findings suggest that biological responses to dietary interventions are individual and dynamic, opening up opportunities for the development of more adaptive and personalized biological data-driven precision nutrition strategies. The main novelty lies in the integration of longitudinal multi-omic analysis in the context of prevention, not just treatment, and the focus on the productive age population that has so far been underexplored in omics-based studies [49]-[51]. This study also emphasizes the importance of personalizing dietary interventions based on individual biological characteristics, which is the foundation for the development of omics-based predictive models to support clinical decisions in the future.

From the results and discussion of this study, the implications that emerge have a significant impact on the development of precision nutrition practices and preventive health policies [52], [53]. The findings that personalized dietary interventions are able to modulate the gut microbiome, reduce inflammatory biomarkers, and improve metabolic profiles indicate that multi-omics-based strategies can be an effective tool to detect the body's response more accurately and holistically [54]-[56]. This has an impact on the use of individual biological data in designing more targeted preventive diet programs, especially for the young adult population who are at a critical phase in the development of metabolic disease risk. In addition, these results also open up opportunities for clinicians and nutrition practitioners to adopt an omics-based approach in consultation and decision-making practices, as well as encourage the nutrition industry sector to develop products and services that are in accordance with the biological needs of each individual. These implications are increasingly relevant in the context of the increasing need for personalized, predictive, and preventive health services in the era of precision medicine.

The findings of this study still have shortcomings due to a number of limitations that need to be considered in the interpretation and application of the results. One of the main limitations is the relatively short duration of the intervention, so it cannot capture the long-term impact of dietary changes on multi-omic profiles and the risk of metabolic diseases [57]-[59]. In addition, the study sample used had limited numbers and demographic diversity, so generalization of the results to a wider population needs to be done with caution. The multi-omic methodology applied also does not cover all biological layers, such as the epigenome and proteome as a whole, which can provide a more comprehensive picture of the molecular mechanisms behind an individual's response to diet. Other external factors such as lifestyle variations, physical activity levels, and psychosocial factors have also not been fully controlled or analyzed in this study, so the potential for bias and variability in biological responses is still possible [60]. Therefore, further research with a more comprehensive design and more representative samples is needed to strengthen the findings and expand the practical application of the multi-omic approach in nutrition interventions.

This study confirms that a multi-omics approach combined with personalized dietary interventions provides in-depth insights into individual biological responses in young adults at risk for metabolic diseases, while opening up opportunities for the development of more effective and preventive precision nutrition strategies. However, given the limited duration and sample size, it is recommended that future studies extend the duration of the intervention, increase participant diversity, and integrate more comprehensive omics analyses including the epigenome and proteome. In addition, further studies also need to consider lifestyle and psychosocial factors to enrich the understanding of the complex interactions between nutrition and biological conditions. With these recommendations, it is hoped that the research results can be more applicable and provide real contributions to the prevention of metabolic diseases in a personalized and sustainable manner.

4. CONCLUSION

This study demonstrated that a personalized dietary intervention based on the USDA 2010 guidelines, combined with behavioral counseling and multi-omic analysis, effectively improved metabolic health and modulated gut microbiome composition in young adults at risk of disease. The findings support the use of integrated, theory-driven nutrition strategies for early prevention of chronic illness and offer strong prospects for future application in precision nutrition and public health interventions among young populations. Recommendations for further research include extending the duration of intervention, expanding the diversity and number of samples, and integrating more comprehensive multi-omics analysis, including the epigenome and proteome. In addition, it is necessary to include lifestyle and psychosocial factors to obtain a more holistic picture of individual responses to dietary interventions.

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