RESEARCH ARTICLE

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Effects of a Short-Term Vegan Challenge in Older Adults on Metabolic and Inflammatory Parameters—A Randomized Controlled Crossover Study

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Scope: A long-term vegan diet carries the risk of insufficient protein and micronutrient intake for older adults. However, even a short-term (48 h) vegan diet exerts positive metabolic effects in younger adults. In this study, we investigate the feasibility and effects of a short-term vegan challenge on metabolic and inflammatory markers in older adults.

Method and results: In this randomized controlled crossover-study, 30 healthy older adults (≥65 years) are assigned to either a 48 h ad libitum vegan or omnivorous diet. During the vegan diet, participants exhibit lower protein ($p = 0.001$) and fat intake as well as higher carbohydrate and dietary fiber intake, resulting in a lower caloric intake (all $p < 0.001$). Insulin concentrations ($p = 0.042$) and insulin resistance ($p = 0.036$) decline only after the vegan diet. The study observes reductions in serum glucose ($p < 0.001$), triglyceride ($p = 0.005$), and hsCRP ($p = 0.044$) concentrations and weight ($p < 0.001$), independent of the diet. Participants with low-grade inflammation exhibit notable metabolic improvements after the vegan diet.

Conclusion: Improvements in insulin homeostasis are observed after the vegan diet, but meeting protein requirements are not feasible during the short-term vegan challenge despite dietary counseling, which warrants concern.

1. Introduction

The aging process is often accompanied by inflammaging, a chronic low-grade state of inflammation, as well as an impaired glucose and lipid metabolism, which increases the risk of cardio-metabolic disease.[1,2] A vegan diet which omits all animal-based foods has been linked to many health benefits such as improved gut microbiome,[3–5] lowered blood glucose, and triglyceride concentrations,[6,7] lower risk of cardiovascular disease[8] as well as lower incidence of malignant tumors[9] and lower inflammation.[10,11]

In recent years, popularity for vegan diets has surged with a growing interest even among adults aged over 65 years.[12] Vegan diets are, however, usually associated with lower protein intake.[13] Furthermore, plant protein has a lower protein quality and anabolic potential compared to animal protein.[14] In older

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adults, a long-term vegan diet might therefore predispose to sarcopenia, the age-associated loss of muscle mass and strength.[15] Simply increasing portion sizes to compensate for the lower protein quality is not a feasible approach in older adults due to earlier and higher satiety after fiber-rich meals.[16] Moreover, older adults are more prone to develop vitamin B12 deficiency due to gastric atrophy or certain medications. Thus vegan diets might further promote vitamin B12 deficiency in higher age, as it is one of the micronutrient deficiencies associated with long-term vegan diets.[12,13] Taken together, a long-term vegan diet is not recommended for older adults.[14,17]

Nevertheless, a recent study[18] reported metabolic benefits of a short-term (48 h) vegan intervention, such as significantly lowered insulin, triglyceride, and cholesterol concentrations in healthy adults (18–55 years) following an otherwise omnivorous diet. Possibly, introducing repeated bouts of short-term vegan interventions on an, e.g., monthly basis in an otherwise well-balanced omnivorous diet, offers older adults the benefits of vegan diets while minimizing the risk of nutritional deficiencies.

However, feasibility and effects of a short-term vegan diet in older adults have not yet been studied. Generally, data on vegan diets in older adults are missing. We, therefore, studied feasibility and effects of a short-term vegan challenge on markers of glucose metabolism (glucose, insulin, homeostatic model assessment of insulin resistance [HOMA-IR], triglycerides) and inflammation (high-sensitive C-reactive protein [hsCRP], interleukin-6 [IL-6]) in adults aged 65 years and older.

2. Results

2.1. Cohort Characteristics

In total, 30 older adults were included in the study (Figure S1, Supporting Information). Participants were overall healthy with on average two self-reported medical conditions (e.g., high blood pressure). **Table 1** shows baseline characteristics of the study population. Grip strength and gait speed indicated a normal muscle functionality,[15] which also did not change in regard of the dietary intervention (data not shown).

Table 1. Baseline characteristics of study participants at their first visit.

Characteristics	
Age [years]	72.5 ± 4.72
Sex, *n* [%] of participants	
Female	25 (83.3%)
Male	5 (16.7%)
BMI [kg m^{-2}]	26.1 ± 2.52
Blood pressure	
Systolic [mmHg]	148 ± 21
Diastolic [mmHg]	92 ± 14
Appetite visual analogue scale [%]	56.1 ± 22.0
Functional parameters	
Grip strength [kg]	28.3 ± 7.04
Gait speed [m s^{-1}]	1.38 ± 0.19
Satiety hormones	
PPY [ng mL^{-1}]	0.526 ± 0.781
GLP-1 (ng mL^{-1}]	0.884 ± 0.296
Metabolic parameters	
Glucose [mmol L^{-1}]	5.76 ± 0.73
Insulin [mU L^{-1}]	8.53 ± 7.88
HOMA-IR	2.18 ± 2.05
Triglycerides [mmol L^{-1}]	1.19 ± 0.49
Inflammatory parameters	
hsCRP [µg mL^{-1}]	1.66 ± 1.77
IL-6 [pg mL^{-1}]	2.67 ± 3.79

Data given as number (%) or mean ± SD. GLP-1, glucagon-like peptide 1; HOMA-IR, homeostatic model assessment of insulin resistance; hsCRP, high sensitive C-reactive protein; IL-6, interleukin-6; PPY, peptide tyrosine tyrosine (Peptide YY).

2.2. Dietary Intake and Effects on Weight and Satiety

As shown in **Table 2**, dietary intake differed between diets. The most striking difference consisted of a lower fat as well as a higher carbohydrate and dietary fiber intake during the vegan diet, resulting in a lower caloric intake than during the omnivorous control diet. Furthermore, while protein percentage was similar for both diets, protein intake per kg body weight was significantly lower during the vegan intervention and the participants did not meet their protein requirements with the vegan diet. During both diets, however, participants lost weight (time $p < 0.001$) and there was a non-significant trend for higher weight loss in the vegan diet compared to the omnivorous control diet (time × group, $p = 0.057$, **Figure 1**). Sodium intake was markedly lower during the vegan diet (1267 ± 431 mg vs 2323 ± 983 mg, $p < 0.001$) and generally, sodium intake was correlated with absolute (rho = 0.380, $p = 0.003$) and percentage weight change (rho = 0.388, $p = 0.002$), thus low sodium intake was associated with higher weight loss.

Table 2. Dietary intake during each study phase respectively.

	Omnivorous diet	Vegan diet	*p*-value
Energy [kcal]	1824 ± 404	1486 ± 293	<0.001
Fat [*E*%]	41.9 ± 5.85	31.6 ± 5.18	<0.001
Carbohydrates [*E*%]	39.4 ± 6.65	49.7 ± 5.08	<0.001
Dietary fiber [g]	22.6 ± 8.11	34.0 ± 10.8	<0.001
Protein [*E*%]	17.8 ± 3.22	16.8 ± 2.23	0.238
Protein [g kg^{-1} BW^{-1}]	1.15 ± 0.35	0.89 ± 0.27	0.001
Plant protein [*E*%]	5.83 ± 1.56	16.8 ± 2.23	<0.001
Animal protein [*E*%]	12.0 ± 3.58	0.00 ± 0.00	<0.001

Data are shown as mean ± SD, $n = 30$. BW, body weight; *E*%, energy percentage.

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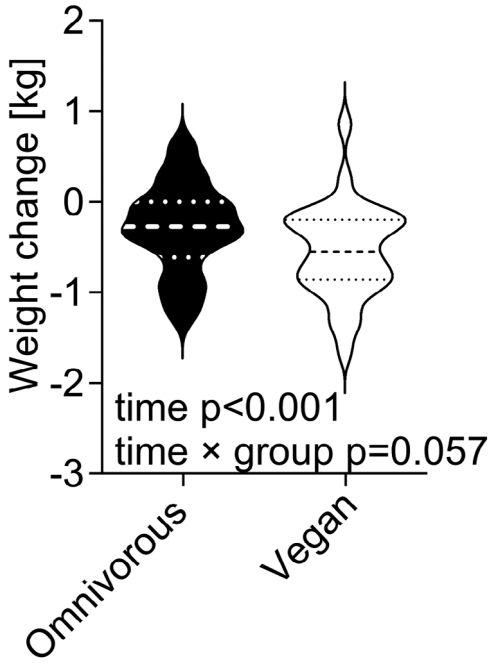

Figure 1. Changes in weight during each dietary phase. Data are shown as a violin plot, with lines indicating median, 25th and 75th percentile.

Notably, systolic blood pressure decreased over time ($p = 0.002$) and there was a trend for a higher decline after the vegan phase (time × group: $p = 0.059$). Reported appetite did not change over time (omnivorous diet: 56.3 ± 23.4% to 55.9±23.9%, vegan diet: 57.7±19.3% to 54.5±23.9%; time $p = 0.831$) and was not dependent on the diet (time × group, $p = 0.320$). This corresponds with plasma PYY (time $p = 0.725$, time × group, $p = 0.867$) and GLP-1 (time $p = 0.629$, time × group, $p = 0.320$) concentrations, which also did not change significantly.

2.3. Effect of Diet on Triglyceride Levels, Glucose Metabolism, and Inflammatory Markers

Both glucose and triglyceride concentrations declined significantly during the 48 h intervention (**Figure** 2A,B), but this effect was independent of the intervention diet. Insulin concentrations as well as HOMA-IR declined during the vegan intervention (Figure 2C,D). We observed a significant decrease in hsCRP concentration during both diets, without a significant difference between the vegan and the omnivorous diet (**Figure** 3A). There were no changes in IL-6 concentrations over time during either intervention diet (Figure 3B).

In a sub-analysis we analyzed the effect of a vegan intervention in participants with low-grade systemic inflammation, we

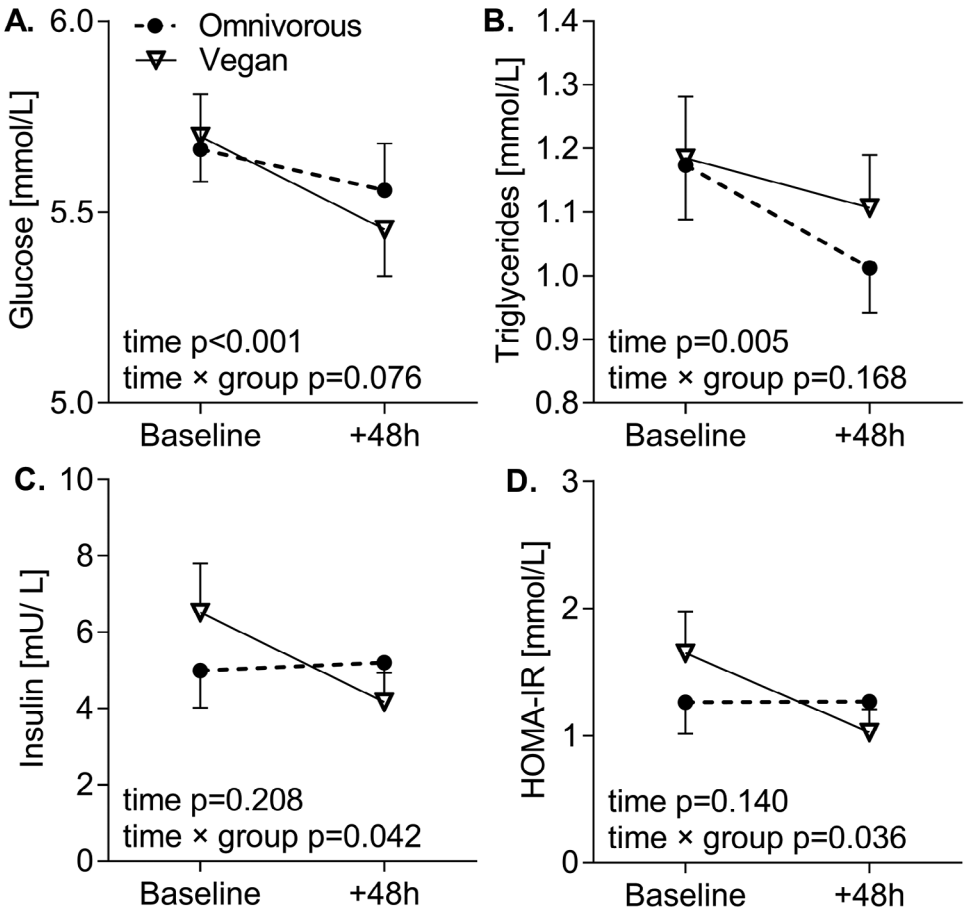

Figure 2. Changes of metabolic parameters during each dietary phase: A) glucose, B) triglycerides, C) insulin, D) HOMA-IR. Data are shown as mean ± SEM.

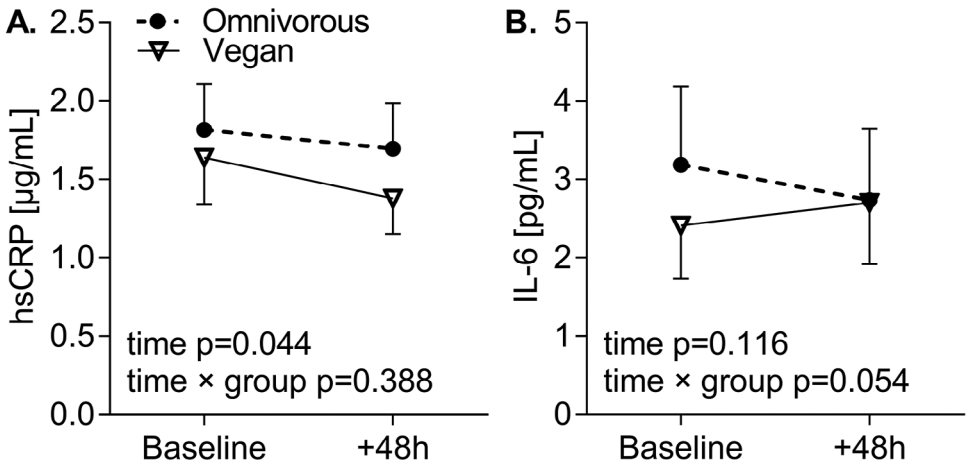

Figure 3. Changes of hsCRP (A) and IL-6 (B) during each dietary phase. Data are shown as mean ± SEM.

categorized them according to their baseline hsCRP concentration. In the group with lower inflammation, we see no differences between interventions (**Table 3**). In the group with higher inflammation, changes in weight, insulin, and HOMA-IR are significantly different between interventions, with the vegan phase resulting in greater changes.

A correlation analysis, to test which diet component might affect the inflammation status of the participants, revealed that higher fiber intake was associated with lower hsCRP concentrations (rho = −0.298, $p = 0.021$) and higher protein g kg^{-1} body weight with lower IL-6 concentrations (rho = −0.370, $p = 0.004$).

3. Discussion

This is the first study assessing feasibility and effects of a short-term vegan challenge in healthy older (≥65 years) adults. While insulin concentrations as well as HOMA-IR improved after the vegan intervention, there were no differences for fasting glucose, triglyceride, IL-6, or hsCRP concentrations compared to the control omnivorous diet. However, low-grade inflammation appeared to affect the results, as metabolic improvements were seen in particular in participants with low-grade inflammation. Interestingly, both higher fiber and higher protein intake were associated with lower hsCRP and IL-6 concentrations, irrespective of type of diet. However, we observed a small but significant weight loss after each 48 h diet phase, which is most likely due to a caloric deficit during both interventions. Caloric intake was also significantly lower during the vegan intervention compared to the control phase and there was a trend for a higher weight loss.

Lower caloric intake might in part be due to the significantly higher amount of dietary fiber intake in the vegan diet and the fact that plant-based meals are less dense in energy.[19] During the vegan challenge, participants were able to achieve recommended daily fiber intake (25–30 g). This results in a higher food volume that needs to be ingested in order to reach the same number of calories as comparable meals containing animal source products. The rise in volume and fiber content, together with a tendency of early onset satiation[20] and a delayed gastric emptying[21] in older age, may have led to reduced portion sizes, and thus explain the tendency towards a higher weight loss during the vegan intervention. During the control diet, recommended fiber intake was not achieved. The weight loss during the control diet, on the other hand, was less anticipated as the participants were instructed to stick to their habitual eating patterns, but might be attributable to the well-known Hawthorne effect, which describes study participants behaving differently as they are being observed.[22] We also found that lower sodium intake was associated with higher weight loss. At the same time, there was a more pronounced decline in systolic blood pressure during the vegan diet.

Table 3. Participants categorized according to inflammation status (median hsCRP concentration at baseline).

	No inflammation				Low-grade inflammation			
	Omnivorous	Vegan	Time	Time × group	Omnivorous	Vegan	Time	Time × group
Weight [kg]	−0.38 ± 0.60	−0.56 ± 0.61	<0.001	0.424	−0.22 ± 0.38	−0.53 ± 0.40	<0.001	0.035
Triglycerides [mmol L^{-1}]	−0.12 ± 0.30	−0.06 ± 0.40	0.214	0.302	−0.20 ± 0.33	−0.10 ± 0.39	0.007	0.431
Glucose [mmol L^{-1}]	−0.10 ± 0.35	−0.22 ± 0.32	0.018	0.270	−0.11 ± 0.27	−0.27 ± 0.38	0.004	0.164
Insulin [mU L^{-1}]	−0.65 ± 3.77	−0.12 ± 4.62	0.516	0.645	0.98 ± 4.30	−5.07 ± 7.21	0.112	0.001
HOMA-IR	−0.19 ± 0.98	−0.06 ± 1.22	0.475	0.724	0.16 ± 1.18	−1.34 ± 1.96	0.146	0.001
hsCRP [µg mL^{-1}]	0.05 ± 0.33	0.01 ± 0.32	0.243	0.218	−0.26 ± 1.23	−0.56 ± 1.24	0.028	0.607
IL-6 [pg mL^{-1}]	−0.98 ± 1.30	0.38 ± 1.26	0.060	0.010	0.01 ± 2.39	0.20 ± 1.11	0.580	0.770

Absolute change of parameter is shown as mean ± SD.

Weight loss in general is associated with beneficial effects on metabolic risk factors[23] and decreased pro-inflammatory markers,[23–25] hence possibly explaining, why we see significant reductions of glucose, triglycerides, and hsCRP after both diet phases. This is in contrast to studies showing superior effects of a vegan intervention compared to various omnivorous diets. For example, lower blood glucose, triglyceride, and insulin concentrations were found after a similarly short-term vegan diet in healthy young[18] or after long-term vegan interventions in obese adults.[26,27] A positive effect on markers of inflammation of a vegan diet has been shown before, particularly when compared to an omnivorous diet,[10] but also compared to the American Heart Association diet[11] which is a healthy plant-based diet with only limited animal source food. However, all of these studies examined vegan diets with a duration of at least 8 weeks to more than 4 years. To further explore whether low-grade inflammation would affect the response to the vegan challenge, we categorized the participants using the median hsCRP concentration into groups with and without low-grade inflammation. Here we saw that participants with low-grade inflammation in particular showed metabolic improvement after the vegan phase.

In spite of dietary counseling with emphasis on high protein intake, protein requirements were not met in the vegan challenge. A vegan diet is usually associated with a lower protein intake,[14] which is one of the reasons why most nutrition societies do not recommend a vegan diet in older adults.[12,14] In the study by Draper et al.,[18] the young participants also ate notably less protein during the vegan intervention, but still enough to fulfill dietary recommendations. For older adults, achieving sufficient macro- and micronutrient intake as well as preventing weight loss is crucial. Nevertheless, it remains a challenge for older adults who frequently fail to reach their protein requirements even with an omnivorous diet.

Interestingly, we found that a higher protein intake, irrespective of the diet, was associated with lower IL-6 concentrations. High protein intake has been suggested as a strategy to counteract inflammaging in the old by providing a greater availability of cysteine.[28] This may result in an increased glutathione synthesis, which acts as an antioxidant, downregulating pathways for immune cell mobilization.[28] Consequently, Nieman et al. showed in a meta-analysis that a rise in dairy protein intake reduces IL-6 and hsCRP plasma concentrations, particularly in overweight participants.[29] The cohort of the Framingham Heart Study Offspring showed an even greater association of reduced inflammation with plant protein compared to animal protein intake.[30] However, none of these studies investigated the short-term effect of protein intake on inflammatory parameters after 48 h.

This study is subject to limitations. First, it was not conducted under laboratory conditions, which would have allowed closer monitoring of dietary intake. Instead, it took place in a real-life setting, highly dependent on participant compliance. Second, despite dietary counseling, sufficient intake of energy and protein was not achieved in the vegan diet, which in turn led to a significant weight loss. Lastly, as the German food code does not contain all of the vegan products used in our study, which is why micronutrient intake is difficult to assess reliably and phytochemicals cannot be addressed. As this was the first trial in older adults, in which we only included participants absent of any chronic metabolic or inflammatory conditions and with stable weight, results cannot be extrapolated to other populations such as older adults with overweight. With our study, we, however, provide a basis for follow-up studies, where special focus needs to be set on achieving appropriate energy as well as protein intake. Vegan and plant-based diets are associated with effects that are suggested to be beneficial even for the older adults due to the, e.g., higher fiber intake.[31] Moreover, plant-based diets are promoted due to the lower environmental impact and supported by the EAT-Lancet commission.[32] Hence, studying the effects of vegan diets in older adults should not be dismissed.

4. Concluding Remarks

This is the first study to analyze the effect of a 48 h vegan challenge in older adults in which we observed significant reductions of insulin concentrations and HOMA-IR during the vegan diet and of glucose, triglyceride, and hsCRP concentrations, independent of the diet. Participants with low-grade inflammation appear to benefit the most form a short-term vegan diet. However, protein intake was low, which is concerning, since older adults are susceptible to loss of muscle mass. Even if the inadequate protein intake is short-term, repeated periods of a vegan diet would eventually contribute to sarcopenia. Whether a monthly repeated short-term vegan intervention which meets caloric and protein needs can be used as a therapeutic approach in older adults with metabolic or inflammatory conditions remains to be elucidated.

5. Experimental Section

Study Population and Design: In total, 56 older adults were prescreened, from which 30 healthy adults (25 women, 5 men) were included and completed the study (Figure S1, Supporting Information). Inclusion criteria were: age between 65 and 80 years, a stable body mass index (BMI) between 22.0 and 29.9 kg m^{-2} during the last 6 months, an omnivorous diet including regular consumption of animal source foods as well as the ability to prepare meals independently, following a recipe. Exclusion criteria were: type one or two diabetes, any severe chronic illness such as cancer, heart, or liver or kidney disease. This randomized controlled (1:1) crossover study was carried out with healthy older adults who were recruited via newsletters and flyers (Aug, 2021–Dec, 2021). This trial was approved by the ethics committee at Charité – University Medicine Berlin (EA1/028/21) and registered at the German study register (DRKS00025433). All participants gave written informed consent.

Randomization and Sample Size: Using the RAND() function in Microsoft Excel, participants were randomly assigned to start with either the omnivorous control or the vegan intervention diet for 2 consecutive days (48 h). Sample size calculation was based on expected changes in triglyceride concentrations, setting the probable reduction after a 48 h vegan versus omnivorous diet at 33%.[18] The required sample size was 22, based on an estimated power of 80% and an alpha error of 5%.

Study Protocol: The study included four visits in total (Figure S2, Supporting Information). Blood samples were drawn after an overnight fast (no meal after 10 pm) before and after the assigned 48 h diet. In between the two dietary phases, a washout period of 2 weeks was maintained. Parameters measured before the beginning of a dietary phase were set as the participants' respective baselines. Number and type of diseases and current prescribed medications were documented. Weight (kg) and height (m) were measured, and BMI calculated at every visit. A functional evaluation to better describe the participants included the assessment of maximum grip strength as well as gait speed. The best result out of three measures was recorded as maximum grip strength of the dominant hand

using a handheld dynamometer (JAMAR, Preston Bissell Health Care Co., Jackson, MI, USA). Gait speed was evaluated using a 4-m walking test, for which participants were instructed to walk at their usual, comfortable speed. Subjective rating of appetite before and after every diet phase was assessed on a 200 mm visual analogue scale (VAS). All participants were instructed to keep a detailed protocol of food and drink intake during each 48 h dietary phase. Dietary intake was calculated with the German software EBISpro version 2011, (Dr. J. Erhardt, Stuttgart, Germany) which was based on the German food code.

Diet Challenge: In both ad libitum diet phases, subjects were counseled to achieve protein requirements of 1.2–1.5 g protein per kg body weight. In addition, all participants were instructed to refrain from alcohol during the trial, regardless of the dietary intervention. They were also instructed to resume their habitual diet during the 2-week washout period in order to prevent carryover effects.

During the omnivorous control diet, participants were instructed to follow their regular eating habits including the consumption of animal source foods (ham, sausage, butter, cheese, egg, chicken, beef, and herring). They received a dietary counseling that resulted in a mapped-out meal plan for the 2 days of the control phase, based on dietary requirements and personal eating habits and preferences.

At the beginning of the vegan intervention of the study, the participants also received a dietary counseling and were moreover provided with vegan recipes as well as vegan food products, thus creating a customized meal plan based on dietary requirements. Participants were able to choose from three breakfast options (porridge with fruits, sandwich with vegetable spread, or with fruit jam). For lunch and dinner the options were eight warm cooked meals (soy fricassee, lentil stew with tofu, oven baked seitan and pumpkin, soy bolognese, soy goulash, seitan burger with potato wedges, soy chili sin carne, lentil pasta with vegetables) and two cold meals (vegetable salad with soy feta and chickpeas or a sandwich with vegetable spread and fresh vegetables). For snacks, participants were provided with vegan protein bars as well as dark chocolate.

Laboratory Assessments: Overnight fasting serum was obtained and stored at −80 °C until analyses. For laboratory assessments, glucose and triglyceride concentrations were measured using a calorimetric method (ABX Pentra 400, Horiba, Ltd. Japan). Enzyme-linked immunosorbent assay (ELISA) kits were used to measure blood concentrations of insulin (Mercodia, Uppsala, Sweden, inter-CV: 2.6–3.6%, intra-CV: 2.8–4.0%), hsCRP (BioVendor R&DR, Brno, Czech Republic; intra-CV: 5.1%, inter-CV: 6.1%), and IL-6 (BioVendor R&DR, Brno, Czech Republic; inter-CV: 4.9%, intra-CV: 4.7%) as well as plasma concentrations of GLP-1 (Biorbyt Ltd., St. Louis, USA, inter-CV: <10%, intra-CV: <8%) and PYY (Yanaihara Institute Inc., Shizuoka, Japan, intra-CV: 6.1–8.5%, inter-CV: 5.5–10.3%). Homeostasis model assessment index for insulin resistance (HOMA-IR) was calculated as HOMA-IR = (fasting insulin concentrations [mU L^{-1}] × fasting glucose concentrations [mmol L^{-1}])/22.5.

Statistical Analyses: SPSS Statistics (IBM version 27, SPSS Inc. Chicago, IL, USA) was used for statistical analysis, and graphs were created with GraphPad Prism (version 6.07 for Windows, GraphPad Software, La Jolla, CA, USA). Repeated-measures analysis of variance (rmANOVA) was used to examine the changes of metabolic and inflammatory parameters as well as parameters of satiety and physical function over time and the effect of the dietary intervention. Not normally distributed parameters were logarithmized before statistical analysis. Differences in dietary intakes during the two interventions were assessed by paired *t*-test. Spearman-rho was used to assess correlation on metabolic and inflammation markers with macronutrient and fiber intake. In a sub-analysis and to differentiate between low-grade inflammation and no inflammation, the study used median baseline hsCRP concentrations. The median of hsCRP of 1.26 μg mL^{-1} in women and 1.05 μg mL^{-1} in men fall in the range of 1–2 μg mL^{-1} which were associated with a higher risk for cardiovascular disease.[33] All data were shown as mean and standard deviation (SD) or standard error of mean (SEM) in tables and graphs. Statistical significance was assumed at $p < 0.05$. Possible carryover and thus study phase effects for body weight and every blood parameter were controlled using three different methods: a rmANOVA to assess the effect of the interaction of the dietary intervention and sequence of intervention; comparing differences between baseline values at the start of each diet phase as well as the differences between the values after 48 h after each diet phase. No statistically significant carryover effects were observed for any of the blood parameters.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

C.H. and K.N. contributed equally to this work. The authors' contributions were as follows: K.N. and C.H. designed the research; L.D., K.F., and K.S. contributed to study preparation; C.H., L.D., K.S., and L.G. conducted the study; K.N., C.H., L.D., and N.K. analyzed the data; K.N., C.H., and L.D. wrote the paper and had primary responsibility for final content; A.B.W. and U.M.W. provided critical review; all authors have read and approved the final version.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

aging, inflammaging, protein source, vegan challenge

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[1] C. Franceschi, M. Bonafè, S. Valensin, F. Olivieri, M. De Luca, E. Ottaviani, G. De Benedictis, *Ann. N. Y. Acad. Sci.* **2000**, *908*, 244.
[2] H. Nishikawa, A. Asai, S. Fukunishi, S. Nishiguchi, K. Higuchi, *Nutrients* **2021**, *13*, 3519.
[3] H. Sakkas, P. Bozidis, C. Touzios, D. Kolios, G. Athanasiou, E. Athanasopoulou, I. Gerou, C. Gartzonika, *Medicina (Kaunas, Lithuania)* **2020**, *56*, 88.
[4] H. Kahleova, E. Rembert, J. Alwarith, W. N. Yonas, A. Tura, R. Holubkov, M. Agnello, R. Chutkan, N. D. Barnard, *Nutrients* **2020**, *12*, 2917.
[5] V. DeClercq, J. T. Nearing, E. Sweeney, *Curr. Nutr. Rep.* **2022**, *11*, 354.
[6] G. Marrone, C. Guerriero, D. Palazzetti, P. Lido, A. Marolla, F. Di Daniele, A. Noce, *Nutrients* **2021**, *13*, 817.
[7] H. Kahleova, R. Fleeman, A. Hlozkova, R. Holubkov, N. D. Barnard, *Nutr. Diab.* **2018**, *8*, 58.

[8] M. Koutentakis, S. Surma, S. Rogula, K. J. Filipiak, A. Gasecka, *J. Cardiovasc. Dev. Dis.* **2023**, *10*, 94.
[9] Y. Zhao, J. Zhan, Y. Wang, D. Wang, *Front. Public Health* **2022**, *10*, 892153.
[10] J. Menzel, A. Jabakhanji, R. Biemann, K. Mai, K. Abraham, C. Weikert, *Sci. Rep.* **2020**, *10*, 21736.
[11] B. Shah, J. D. Newman, K. Woolf, L. Ganguzza, Y. Guo, N. Allen, J. Zhong, E. A. Fisher, J. Slater, *J. Am. Heart Assoc.* **2018**, *7*, e011367.
[12] K. Norman, S. Klaus, *Curr. Opin. Clin. Nutr. Metab. Care* **2020**, *23*, 145.
[13] D. R. Bakaloudi, A. Halloran, H. L. Rippin, A. C. Oikonomidou, T. I. Dardavesis, J. Williams, K. Wickramasinghe, J. Breda, M. Chourdakis, *Clin. Nutr.* **2021**, *40*, 3503.
[14] J. Domić, P. Grootswagers, L. J. C. van Loon, L. de Groot, *Adv. Nutr. (Bethesda, Md)* **2022**, *13*, 712.
[15] A. J. Cruz-Jentoft, G. Bahat, J. Bauer, Y. Boirie, O. Bruyere, T. Cederholm, C. Cooper, F. Landi, Y. Rolland, A. A. Sayer, S. M. Schneider, C. C. Sieber, E. Topinkova, M. Vandewoude, M. Visser, M. Zamboni, P. Writing Group for the European Working Group on Sarcopenia in Older, E. the Extended Group for, *Age Ageing* **2019**, *48*, 16.
[16] J. Slavin, H. Green, *Nutr. Bull.* **2007**, *32*, 32.
[17] J. Bauer, S. Walrand, *Curr. Opin. Clin. Nutr. Metab. Care* **2023**, *26*, 1.
[18] C. F. Draper, I. Vassallo, A. Di Cara, C. Milone, O. Comminetti, I. Monnard, J. P. Godin, M. Scherer, M. Su, W. Jia, S. P. Guiraud, F. Praplan, L. Guignard, C. Ammon Zufferey, M. Shevlyakova, N. Emami, S. Moco, M. Beaumont, J. Kaput, F. P. Martin, *Mol. Nutr. Food Res.* **2018**, *62*, https://doi.org/10.1002/mnfr.201700703
[19] S. Ivanova, C. Delattre, D. Karcheva-Bahchevanska, N. Benbasat, V. Nalbantova, K. Ivanov, *Foods* **2021**, 3052, https://doi.org/10.3390/foods10123052
[20] J. M. Bauer, A. Haack, K. Winning, R. Wirth, B. Fischer, W. Uter, J. Erdmann, V. Schusdziarra, C. C. Sieber, *J. Gerontol. A Biol. Sci. Med. Sci.* **2010**, *65*, 307.
[21] D. Rémond, D. R. Shahar, D. Gille, P. Pinto, J. Kachal, M. A. Peyron, C. N. Dos Santos, B. Walther, A. Bordoni, D. Dupont, L. Tomás-Cobos, G. Vergères, *Oncotarget* **2015**, *6*, 13858.
[22] P. Sedgwick, N. Greenwood, *BMJ* **2015**, *351*, h4672.
[23] W. E. Kraus, M. Bhapkar, K. M. Huffman, C. F. Pieper, S. Krupa Das, L. M. Redman, D. T. Villareal, J. Rochon, S. B. Roberts, E. Ravussin, J. O. Holloszy, L. Fontana, *Lancet Diabetes Endocrinol.* **2019**, *7*, 673.
[24] F. Magkos, G. Fraterrigo, J. Yoshino, C. Luecking, K. Kirbach, S. C. Kelly, L. de Las Fuentes, S. He, A. L. Okunade, B. W. Patterson, S. Klein, *Cell Metab.* **2016**, *23*, 591.
[25] M. J. Sharman, J. S. Volek, *Clin. Sci. (Lond.)* **2004**, *107*, 365.
[26] S. Argyridou, M. J. Davies, G. J. H. Biddle, D. Bernieh, T. Suzuki, N. P. Dawkins, A. V. Rowlands, K. Khunti, A. C. Smith, T. Yates, *J. Nutr.* **2021**, *151*, 1844.
[27] H. Kahleova, K. F. Petersen, G. I. Shulman, J. Alwarith, E. Rembert, A. Tura, M. Hill, R. Holubkov, N. D. Barnard, *JAMA Netw. Open* **2020**, *3*, e2025454.
[28] D. Draganidis, L. G. Karagounis, I. Athanailidis, A. Chatzinikolaou, A. Z. Jamurtas, I. G. Fatouros, *J. Nutr.* **2016**, *146*, 1940.
[29] K. M. Nieman, B. D. Anderson, C. J. Cifelli, *J. Am. Coll. Nutr.* **2021**, *40*, 571.
[30] A. Hruby, P. F. Jacques, *Curr. Dev. Nutr.* **2019**, *3*, nzz019.
[31] C. Herpich, U. Müller-Werdan, K. Norman, *Maturitas* **2022**, *165*, 47.
[32] W. Willett, J. Rockström, B. Loken, M. Springmann, T. Lang, S. Vermeulen, T. Garnett, D. Tilman, F. DeClerck, A. Wood, M. Jonell, M. Clark, L. J. Gordon, J. Fanzo, C. Hawkes, R. Zurayk, J. A. Rivera, W. De Vries, L. Majele Sibanda, A. Afshin, A. Chaudhary, M. Herrero, R. Agustina, F. Branca, A. Lartey, S. Fan, B. Crona, E. Fox, V. Bignet, M. Troell, *Lancet* **2019**, *393*, 447.
[33] T. Banait, A. Wanjari, V. Danade, S. Banait, J. Jain, *Cureus* **2022**, *14*, e30225.