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A High Legume Low Glycemic Index Diet Improves Serum Lipid Profiles in Men

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Abstract

All of the authors have read and approved the final submitted manuscript and there was no conflict of interest with the present paper. The authors' contributions were as follows: ZZ conducted research with participants, data analysis, and write up of manuscript; EL designed the research, contributed to data interpretation and manuscript preparation; PMKE and NHC contributed to data interpretation and manuscript preparation; DB conducted research with participants and and was involved with the write up of the manuscript; MJR contributed to data analysis and the write up of the manuscript; JSU, GB, and RSC contributed to data interpretation and the write up of the manuscript; and TJH designed research, contributed to data interpretation and manuscript preparation, and study oversight.

Clinical studies have shown that fiber consumption facilitates weight loss and improves lipid profiles; however, the beneficial effects of high fermentable fiber low glycemic index (GI) diets under conditions of weight maintenance are unclear. In the Legume Inflammation Feeding Experiment, a randomized controlled cross-over feeding study, 64 middle-aged men who had undergone colonoscopies within the previous 2 years received both a healthy American (HA) diet (no legume consumption, fiber consumption = 9 g/1,000 kcal, and GI = 69) and a legume enriched (1.5 servings/1,000 kcal), high fiber (21 g/1,000 kcal), low GI (GI = 38) diet (LG) in random order. Diets were isocaloric and controlled for macronutrients including saturated fat; they were consumed each for 4 weeks with a 2–4 week break separating dietary treatments. Compared to the HA diet, the LG diet led to greater declines in both fasting serum total cholesterol (TC) and low density lipoprotein cholesterol (LDL-C) (P <0.001 and P <0.01, respectively). Insulin-resistant (IR) subjects had greater reductions in high density lipoprotein cholesterol (HDL-C; P <0.01), and triglycerides (TAG)/HDL-C (P = 0.02) after the LG diet, compared to the HA diet. Insulin-sensitive (IS) subjects had greater reductions in TC (P <0.001), LDL-C (P <0.01), TC/HDL-C (P <0.01), and LDL-C/HDL-C (P = 0.02) after the LG diet, compared to the HA diet. In conclusion, a high legume, high fiber, low GI diet improves serum lipid profiles in men, compared to a healthy American diet. However, IR individuals do not achieve the full benefits of the same diet on cardiovascular disease (CVD) lipid risk factors.

Keywords

Legume intake; Lipids; Insulin resistance

Introduction

Numerous studies have shown an inverse association between intake of dietary fiber and risk for chronic diseases such as cardiovascular disease (CVD) [1, 2] and type 2 diabetes mellitus [3]. The beneficial effects may be partially due to fiber's hypocholesterolemic [4–6] and hypo-insulinemic effects [3]. On the basis of a number of epidemiological studies on coronary heart disease (CHD) [7–9], the Institute of Medicine (IOM) currently recommends a daily consumption of 14 g of fiber per 1,000 kcal for Americans (DGA 2005).

Legumes, such as pinto, navy, kidney, lima, and black beans, are a rich source of dietary fiber but the effects of these types of beans on blood lipid levels are limited. A meta-analysis of 67 controlled trials was conducted to quantify the hypocholesterolemic effects of major dietary fibers [10]. The results demonstrated that daily intake of 2–10 g of soluble fiber was associated with significant decreases in total cholesterol (TC, −1.7 mg/L per gram) and low density lipoprotein cholesterol (LDL-C, −2.2 mg/L per gram). A 12-week randomized dietary intervention with 40 men and women with metabolic syndrome and 40 healthy subjects [11] reported that daily intake of a bean entrée (130 g of cooked dry pinto beans) lowered serum TC by 8% in the healthy population and by 4% in the metabolic syndrome group. A limitation of legume-related studies is that most recent interventions have been conducted with a single test meal [12–15] or fiber supplement [16, 17] and some of these studies were designed to test short-term effects in hours or days [12, 14, 15].

The Legume Inflammation Feeding Experiment (LIFE Study, [18]) was a randomized controlled cross-over feeding study designed to test the effects of a legume-rich, high fermentable fiber, low glycemic index (GI) diet on bio-markers of inflammation and insulin resistance in middle-aged men at high risk for colorectal cancer. An important secondary objective of the LIFE Study was to evaluate the effects of diet on serum lipids. We hypothesized that the high legume low GI diet would significantly improve serum lipid profiles. To our knowledge, this was the first randomized controlled, cross-over feeding

study designed to assess the hypocholesterolemic effects of a mixture of the five types of beans under conditions of weight maintenance.

Subjects and Methods

Subjects and Recruitment

All aspects of this study were approved by the Institutional Review Boards of the Pennsylvania State University and the National Cancer Institute. Sixty six non-smoking male subjects age 35–75 who had undergone colonoscopies within the previous 2 years were recruited in Central Pennsylvania. The study was conducted from February 1st, 2006 to August 6th, 2008. History of colorectal adenomas (yes or no) was combined with insulin resistance (yes or no) for group classification. Insulin resistance was defined by a homeostasis model assessment (HOMA-IR) index level. The formula for calculation is as follows: fasting insulin (μU/mL) × fasting glucose (mmol/L)/22.5 [19]. Subjects with a HOMA-IR index level equal or higher than 2.6 were considered insulin resistant [20, 21].

Criteria and Restrictions

All participants were prescreened by telephone interview and a clinical screening test for study eligibility. In addition to the colonoscopy, subjects had to meet the following criteria: (1) weight maintenance or less than 10% body weight loss 6 months prior to the present study, (2) body mass index (BMI) within 20–37 kg/m^2, (3) no history of colorectal cancer, bowel resection or inflammatory bowel disease, (4) no serious medical conditions, e.g., heart disease, stroke, diabetes, renal or kidney disease, liver disease or cirrhosis, or cancer within the last 10 years, (5) not taking vitamin/mineral, herbal, or other nutritional supplements, and (6) not taking any cholesterol-lowering, glucose-controlling, or non-steroidal anti-inflammatory (e.g. aspirin) medications.

The subjects who met the eligibility criteria were invited to undergo clinical screening tests including a fasting blood draw at the General Clinical Research Center (GCRC) at Penn State University in University Park, PA, USA. Eligible subjects were asked to return to the GCRC to have resting metabolic rate measured and completed three 24-h telephone diet calls (two on weekdays and one on weekend) to estimate daily energy requirements.

Diet and Study Design

A detailed explanation of diet and study design was published previously [18]. In brief, the randomized controlled cross-over feeding study consisted of a first 4-week diet period, a 2–4 week compliance break, and a second 4-week diet period. The time period allowed for the test diet intervention was sufficient to assure that lipids had stabilized [22]. Subjects were first randomly assigned to either a healthy American diet (HA) or an isocaloric legume diet (LG; approximately 250 g of cooked pinto, navy, kidney, lima, and black beans per day), and then were switched to the other diet for the second feeding period. All foods for this study were prepared and distributed by the metabolic diet center at the GCRC. On weekdays, the participants ate breakfast or dinner at the GCRC and on Fridays, all the packed foods for weekends were taken home. The dietitians recorded body weight and food consumption at each visit. Uneaten foods were very little; they were returned to the GCRC and were measured and recorded by study dietitians daily as a measure of compliance. Seven-day cycle menus were created for each test diet and evaluated for percentages of energy contributed by each of the macronutrients using Nutrition Data System for Research (NDS-R, 2006, Minneapolis, MN, USA); GI and GL were calculated using Food Processor (2005). Total energy intake was adjusted by study dietitians in 200 kcal increments to maintain participants' body weights during the diet periods (e.g. 2,000, 2,200, 2,400, 2,600 kcal, etc.). Subjects were allowed up to two alcoholic beverages per week while consuming

the study diets. We used the same or similar foods to design our menus. For example, subjects had tuna pasta salad as lunch during the HA menu which was replaced by Italian bean and tuna salad during the LG menu. For dinner, the HA diet provided ginger chicken and rice, while the LG diet provided ginger chicken and beans. The ingredients of the two ginger chicken dishes were the same except that the substitution of beans for rice. The LG diet provided much of the protein from plant sources and the HA diet provided more protein from chicken (skinless) in order to meet the dietary recommendation for cholesterol. Daily compliance questionnaires indicated very good test diet adherence. Table 1 shows the composition of the participants' diets at entry (pre-study) and the two test diets.

Sample Collection and Measurements

Anthropometric measurements were completed using standardized methods by well-trained nurses at the GCRC on Penn State University Park campus. At the beginning and end of each test diet period, a 12-h overnight fasting blood sample was drawn and serum was collected for measurement of TC, LDL-C, HDL-C and TAG. All blood samples were centrifuged at 3,200×*g* for 15 min at 4°C, the supernatant was separated and aliquoted in cryovials, and stored at −80°C. Serum lipids were measured at Penn State Hershey Medical Center in the laboratory of Dr. Laurence Demers. All samples from each subject were grouped together for analysis in the same batch. Lipids were measured using enzymatic procedures on an automated chemistry analyzer (Roche); the intra- and inter-assay coefficients of variations (CV) for all biomarkers of interest were less than 5%. Fasting plasma insulin was measured using a human-specific insulin RIA (Linco-Millipore, MA, USA, HI-14 K; sensitivity, 2–200 μU/mL; inter-assay CV, 2.9–6.0%; intra-assay CV, 2.4–4.4%). Fasting plasma glucose was measured via an immobilized enzyme biosensor using the YSI 2300 STAT Plus Glucose and Lactate analyzer (Yellow Springs Instruments; inter- and intra-assay CV were less than 5%).

Statistical Analysis

The means for the pre-study diet were calculated by 3-day diet recalls and the means for the two test diets were based on the average of each 7-day menu for a 2,000 kcal diet (Table 1). The experimental diets and participants' pre-study diets were compared using one-way analysis of variance (ANOVA) with the Tukey test to adjust for the multiple comparisons. Baseline characteristics stratified by subjects' insulin resistance status were compared using one-way ANOVA. Log-transformation of HOMA-IR index, TAG, and TAG/HDL-C were performed for the analyses because of skewed distributions. General linear mixed models with repeated measurement (Proc mixed) were used to test for the effects of diet, period, and their interactions with change scores of all outcome variables. Subject was treated as a random and diet treatment as a fixed effect. Akaike Information Criteria (AIC) and Bayesian Information criteria (BIC) were evaluated to decide model correlation structure; we used unstructured based on these comparisons and because we believed the covariance between diet treatments might be different. Likelihood ratio tests were used to test for treatment effects. Analyses were also completed using paired *t* tests with similar results. Potential confounding by age, BMI, adenoma status (yes/no), insulin resistance status (yes/no) and initial biomarker status at study entry was assessed. We also evaluated potential diet period and diet order effects for their influence on end points of interest and no carry over effect was detected. The results indicated that initial insulin resistance status may be an important modifier for the interpretation of the changes of some biomarkers at study entry; therefore, we conducted analyses stratified by insulin resistance status. There was no evidence that adenoma status was an important effect modifier; therefore, stratified results were not presented. The change scores of outcomes were based on the differences between the beginning and the end of each dietary period for this variable. The percentage changes were calculated based on the change scores and respective biomarker value at study entry. In

addition, we evaluated and visualized the association between insulin resistance at study entry and the changes in lipids during dietary intervention using Pearson correlation and linear regression. Analyses were performed using SAS version 9.1 (SAS Institute, Inc, Cary, NC, USA). Significance was set at $P<0.05$.

Results

Sixty-four subjects finished all test diet periods. Two subjects dropped out in the first week of the first test diet period because of loss of interest (completion rate = 97%). Subjects who were insulin-resistant (IR) had higher BMIs, larger waist circumferences, and higher fasting serum glucose, insulin, and TAG levels than those who were insulin-sensitive (IS) (Table 2). Subjects with a previous history of adenomas were older than those who were adenoma-free; other descriptive variables did not vary significantly by adenoma status (data not shown).

Effects of Experimental Diets on Serum Lipids

Changes in lipids on the two test diets are presented in Table 3. Compared with the HA diet, the LG diet resulted in significantly greater reductions in TC (−11 ± 3 mg/dL, $P<0.001$) and LDL-C (−9 ± 3 mg/dL, $P<0.01$) levels. The LG diet reduced TC (10%, $P<0.001$), LDL-C (10.9%, $P<0.001$), and TAG (14.8%, $P<0.01$) over the 4 week feeding period. The HA diet also reduced TC (4%, $P<0.01$) and TAG (12.6%, $P<0.01$) but had less effect on LDL-C (3.1%, $P=0.09$). Both test diets slightly lowered HDL-C concentrations. We also analyzed three ratios (TC/HDL-C, LDL-C/HDL-C, and TAG/HDL-C) that are predictors of CVD risk. The changes between test diets did not differ. The LG diet was associated with significant reductions in TC/HDL-C (3%, $P=0.02$) and LDL-C/HDL-C (3.5%, $P=0.02$) over the 4 week feeding period. The HA diet was associated with a significant reduction in TAG/HDL-C (13.5%, $P=0.03$).

Effects of Experimental Diets on Serum Lipids Stratified by Insulin Resistance Status

We observed effect modification of the diet on biomarkers of interest by IR status (HDL-C, P-interaction = 0.03; TAG, P-interaction = 0.03; TC/HDL-C, P-interaction <0.001; TAG/HDL-C, P-interaction = 0.01); therefore, we present our results stratified by insulin resistance status (IR or IS, Table 4). Among IS subjects, the LG diet led to greater reductions in TC (−14 ± 4 mg/dL, $P<0.001$), LDL-C (−10 ± 4 mg/dL, $P<0.01$), TC/HDL-C (−0.30 ± 0.10, $P<0.01$), and LDL-C/HDL-C (−0.20 ± 0.08, $P=0.02$), compared with the HA diet. The 4-week LG diet favorably reduced almost all lipid profiles; however, the 4-week HA diet only improved TC concentrations. Both test diets reduced HDL-C concentrations (−2 ± 1 mg/dL, $P=0.02$, respectively) without between-diet difference.

Among IR subjects, the HA diet tended to have more favorable effects on the TAG/HDL-C ratio ($P=0.02$), compared with the LG diet. The LG diet significantly decreased fasting serum TC, HDL-C, and LDL-C concentrations ($P<0.001$ for each) but not in TAG or the HDL-related ratios. The HA diet significantly decreased TC, TAG, and TAG/HDL-C ($P=0.01$, $P<0.001$, and $P<0.01$, respectively).

Effects of Insulin Resistance Status at Study Entry on Lipid R esponses

We calculated the differences between the change scores during the LG diet and those during the HA diet (subtract the change scores over the HA diet from the change scores over the LG diet) and regressed on HOMA-IR values (at study entry). Figure 1 shows an inverse association; subjects with worse insulin resistance at study entry had smaller reductions in TC/HDL-C ratio ($\beta=0.27$, $R^2=0.11$, $P=0.03$).

Discussion

In the LIFE study under conditions of weight maintenance, the legume-rich, high fermentable fiber, low GI diet (LG) led to greater reductions in fasting serum TC and LDL-C concentrations. It is possible that the higher fiber and reduced cholesterol consumption acted to decrease fat absorption and lower hepatic synthesis of cholesterol contributing to lower circulating lipids. Another possibility is that the reduced GI and GL of the legume diet played a role in favorably altering lipid concentrations. Low GI and GL diets favor insulin sensitivity. Insulin inhibits the mobilization of free fatty acids from adipose tissue, thus lowering hepatic production of very low density lipoprotein (VLDL) and maintaining low levels of TC and LDL-C. Possibly, these changes accounted for greater reductions in TC and LDL-C concentrations on the LG diet.

Many but not all [23, 24] studies have shown hypo-cholesterolemic effects of dietary fiber [11, 13, 16, 17, 25–27]; however, studies specifically on legume consumption are still limited. Anderson et al. [4] reported that incorporating 100 g of dried beans into a Western diet for 28 days decreased TC (18.7%) and LDL-C (23.1%) in men ($n = 6$). In a feeding study of 24 hyperlipidemic men who consumed 120 or 162 g beans with tomato sauce for 21 days [28], both serum TC and LDL-C were significantly decreased (10.4 and 8.4%, respectively). Pittaway et al. [29] reported that an addition of 104 g of chickpeas into ad libitum diet for 12 weeks led to improvements in both TC (7.7 mg/dL) and LDL-C (7.3 mg/dL) among 13 pre-and 19 postmenopausal women and 13 men at high risk for CVD. Collectively, these studies demonstrate a hypocholesterolemic effect of legume consumption; yet, they were not designed as controlled feeding experiments. Among these clinical studies, weight changes either were not mentioned [14, 25, 30] or weight slightly decreased [26]. In our study, subject body weights were measured daily and their calorie intake adjusted for weight maintenance; therefore, changes in lipids were independent of weight loss.

The present study showed that both the LG diet and the HA diet significantly lowered fasting TAG concentrations. Our observations supported several [28, 31] but not all [13, 14] earlier feeding studies in terms of TAG-lowering influence. We observed that the HA diet lowered fasting TAG similarly to the LG diet. We compared the total and added sugars of the two experimental diets with that of the subjects' own diet; however, we did not find significant differences. It is possible that the TAG-lowering effects might not result from fiber consumption or GI. The LG diet provided increased plant protein in the diet. To match protein intake and maintain a lower cholesterol intake, we added more chicken, milk, and fish to the HA diet. Differences among both test diets compared to pre-study diets (e.g. protein consumption) may have contributed to the reductions in TAG observed with both diets [32].

Fruit and vegetables are good sources of many vitamins, minerals and bioactive compounds, which have been shown to possess cardioprotective effects. Antioxidants in fruit and vegetables such as vitamin C, carotenoids, vitamin E, and flavonoids may reduce CVD by reducing lipid oxidation and inflammation in the artery wall. The B-complex vitamins such as folate and B_6 may reduce CVD by lowering circulation homocysteine. A number of epidemiological studies demonstrate the inverse association between fruit and vegetable consumption and CVD risk [33–37]. In the National Heart, Lung, and Blood Institute Family Heart Study of 4,466 men and women aged 25 and older followed from 1993 to 1995 [38], persons in the higher range of fruit and vegetable consumption (mean of 5.4 servings/day for men and 5.5 servings/day for women) had lower fasting LDL-C concentrations (P for trend <0.0001 for each), compared to those in the lower range (mean of 1.4 servings for both). In the present study, we observed that both the LG and HA diets

provided higher amounts of fruit and vegetables compared with subjects' usual diets, although the differences were only significant between the LG diet and subjects' usual diets.

Several cross-sectional studies have reported that high dietary GI was inversely associated with HDL-C [39–43] and positively associated with LDL-C [43] and TAG concentrations [40, 43]. High dietary GL was inversely associated with HDL-C [39, 40, 43, 44] and was positively associated with TAG concentrations [40, 43, 44]. Ma et al. [41] reported an inverse associations between GL, TC and LDL-C concentrations; however, Du et al. [42] reported non-significant associations between GL and lipid and lipoprotein concentrations. Randomized intervention trials showed that low GL diets [45, 46] favorably improved HDL-C and/or TAG concentrations. In the present study, we observed that a high legume low GI/GL diet significantly reduced fasting serum TC and LDL-C concentrations; the results are consistent with the previous investigations. We also observed that fasting HDL-C concentrations decreased after the 4-week low GI/GL dietary intervention, which is not consistent with the aforementioned studies. The difference may be due to different study designs and target populations. In addition, unlike these studies, the present study controlled subjects' body weight and overall food intake.

The LIFE study was designed to evaluate the effects of fiber consumption on lipid profiles; however, other components such as phytosterols may also consider a mechanism for lipid reduction. Stanols and sterols, are primarily present in nuts, vegetable oils, seeds, cereals, and legumes [47]. Plant stanols and sterols have similar chemical structures to cholesterol; they may reduce cholesterol absorption by enterocytes [48] and the esterification rate of cholesterol in the enterocytes [49]. Decreased cholesterol absorption stimulates cholesterol synthesis [50] as well as the expression of LDL receptor mRNA [51] increasing LDL clearance and lowering LDL production resulting in lower circulating total cholesterol levels.

Metabolic syndrome causes dyslipidemia partially as the result of insulin resistance [52]. Our results demonstrate that insulin resistance may blunt response to a legume-enriched, high fiber diet. Among IS subjects, the LG diet led to significant reductions of all lipid profiles as well as the three ratios; however, among IR subjects, the same diet only had strong effects on the reductions of TC, LDL-C, and HDL-C. The HA diet led to significant reductions in TC and HDL-C among IS subjects; the same diet also had strong effects on TC, TAG, and TAG/HDL-C among IR subjects. Lefevre et al. [53] reported that subjects who had higher BMIs and waist circumferences, greater percentages of body fat and higher fasting insulin concentrations had smaller reductions in TC, LDL-C, TC/HDL-C after a Step II (low fat, low saturated fat) diet. Our results are consistent with this study. We observed that subjects who had higher HOMA-IR values at study entry had smaller reductions in TAG, TC/HDL-C, LDL-C/HDL-C, and TAG/HDL-C after the LG diet, though the reduction was only statistically significant for TC/HDL-C. Different from Lefevre's report, we found that subjects' BMIs at study entry did not predict changes in any lipid profiles or HDL-C related ratios.

Many human clinical studies have shown that a reduced intake of saturated fat may lower the risk for cardiovascular disease by decreasing TC and LDL-C concentrations [22, 32, 53, 54]. The effects of these types of diets on lowering TAG levels have been variable [22, 32, 54]. In the present study, we observed that moderate total (34%) and saturated fat (12%) with high fermentable fiber consumption also lowered TC and LDL-C concentrations, whereas the HA diet only lowered TC. The differences observed between test diets was significant for TC and LDL-C demonstrating an effect of total and soluble fiber, and possibly GL. Changes of this magnitude suggest that high fermentable fiber consumption may be another approach to lower risk for CVD [55].

There are several strengths of our study. First, we implemented a randomized, cross-over controlled feeding study design. In addition, we matched the two test diets so that they were isocaloric and provided similar percentages of energy from total fat, saturated fat, carbohydrate, and protein under conditions of weight maintenance. Second, though fiber consumption was higher than daily recommendations, the LG diet was well-tolerated.

There are some limitations in the present study. The present study defined insulin resistance by the HOMA-IR index, which has been widely used for clinical evaluation of insulin resistance. The cutoff value used in our study and others is somewhat subjective; however, the decision was based on two recent human clinical trials [20, 21]. Additionally, studies show that the classification of insulin resistance according to the HOMA-IR index is highly correlated to the ones based on the euglycemic insulin clamp technique, the gold standard for evaluation of insulin sensitivity/resistance [56, 57]. The LG diet included less dietary cholesterol than the HA diet; therefore, we are not able to rule out the possibility that dietary cholesterol consumption contributed to the observed effects on serum cholesterol levels. However, our analysis showed that the difference in dietary cholesterol between the LG and HA diet was not statistically significant. In addition, a 20 mg/day increment in dietary cholesterol intake only results in a very small change of serum cholesterol according to a meta-analysis of 27 studies [58]. Next, we only measured the changes in selected lipid/lipoprotein biomarkers. Recent studies indicate that small dense LDL-C particle (sd-LDL) level is a better predictor for CHD [59] than LDL-C. Apolipoprotein B (apoB) is the primary apolipo-protein in LDL-C; measurement of apo B may provide additional information on changes in LDL particle size. Similarly, apo A-I is the primary apolipoprotein in HDL-C; measuring the change in apo A-I may help to track the change in HDL particle size.

In conclusion, this study adds to the growing evidence that incorporating legumes in the moderate-fat diet improves lipid profiles, thus potentially lowering CVD risk. However, a cautionary note must be added since insulin resistance is highly prevalent and increasing, and individuals in this study with insulin resistance responded less favorably to the legume enriched, high fermentable fiber, low glycemic index diet than those without insulin resistance.

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Abbreviations

ANOVA	Analysis of variance apo
A-I	Apolipoprotein A-I
apo B	Apolipoprotein B
AIC	Akaike Information Criteria
BIC	Bayesian Information Criteria
BMI	Body mass index
CHD	Coronary heart disease
CVD	Cardiovascular disease

CV	Coefficients of variations
DGA	Dietary Guidelines for Americans
GCRC	General clinical research center
GI	Glycemic index
GL	Glycemic load
HA	Healthy American diet
HDL-C	High density lipoprotein cholesterol
HOMA-IR	Homeostasis model assessment index
IOM	Institute of Medicine
IR	Insulin-resistant
IS	Insulin-sensitive
LDL-C	Low density lipoprotein cholesterol
LDL-C/HDL-C	Low density lipoprotein cholesterol to high density lipoprotein cholesterol ratio
LG	Legume diet
LIFE	Legume inflammation feeding experiment
mRNA	Messenger ribonucleic acid
MUFA	Monounsaturated fatty acid
NDS-R	Nutrition data system for research
PUFA	Polyunsaturated fatty acid
RIA	Radioimmunoassay
SFA	Saturated fatty acid
sd-LDL	Small dense LDL-C particle
TC	Total cholesterol
TC/HDL-C	Total cholesterol to high density lipoprotein cholesterol ratio
TAG	Triglyceride
TAG/HDL-C	Triglyceride to high density lipoprotein cholesterol ratio
VLDL	Very low density lipoprotein

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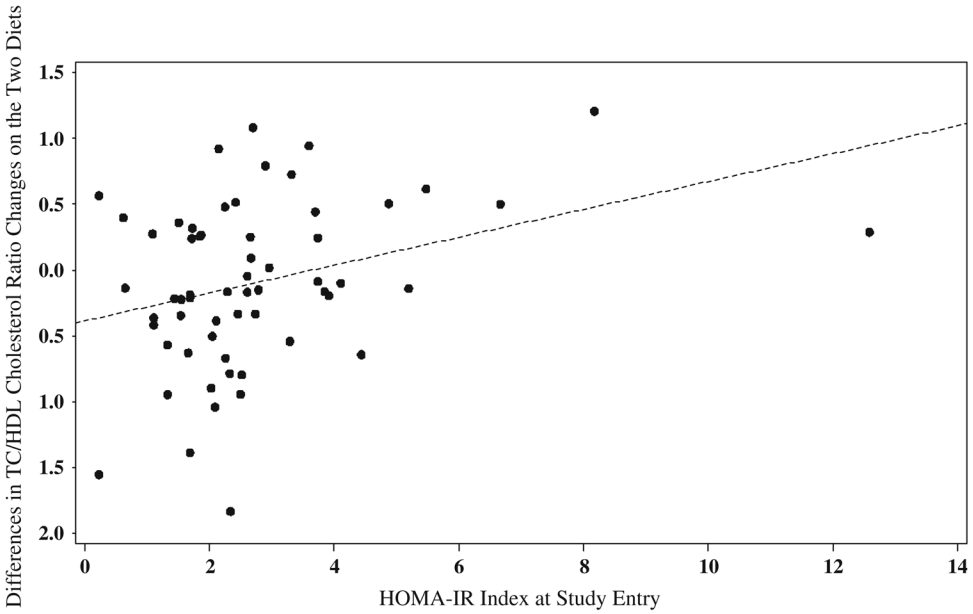

Fig. 1.

Relationship between HOMA-IR index at study entry and differences in TC/HDL cholesterol ratio changes (Delta TC/HDL-C ratio) on the two diets. Delta TC/HDL cholesterol was calculated by subtracting the change scores over the HA diet from the change score over the LG diet, thus $\text{change}_{LG} - \text{change}_{HA}$ ($n = 64$; $\beta = 0.266$, $R^2 = 0.11$, $P = 0.025$)

Table 1

Nutrient and food profile of the experimental diets (compared to pre-study diet)

Nutrient/food group	Pre-study diet	Healthy American (high GI) diet	Legume (low GI) diet	*P* value[a]
Glycemic index	60 ± 6	69 ± 3[b]	38 ± 2[b,c]	<0.001
Glycemic load	165 ± 77	152 ± 8	84 ± 4[b,c]	<0.001
Total Fat (% kcal)	35 ± 7	34 ± 1	34 ± 1	0.85
SFA (% kcal)	12 ± 3	11 ± 1	12 ± 1	0.71
MUFA (% kcal)	13 ± 3	13 ± 1	13 ± 2	0.87
PUFA (% kcal)	7 ± 2	8 ± 1	7 ± 2	0.41
Protein (% kcal)	16 ± 3	18 ± 1	18 ± 1	0.05
Carbohydrate (% kcal)	48 ± 8	50 ± 2	51 ± 1	0.60
Added sugar (g/1,000 kcal)	31 ± 15	25 ± 15	20 ± 7	0.14
Total fiber (g/1,000 kcal)[d]	9 ± 3	9 ± 1	21 ± 1[b,c]	<0.001
Soluble fiber (g/1,000 kcal)[d]	2 ± 1	2 ± 1	4 ± 1[b,c]	<0.001
Insoluble fiber (g/1,000 kcal)[d]	7 ± 2	7 ± 1	17 ± 1[b,c]	<0.001
Cholesterol (mg/1,000 kcal)[d]	125 ± 52	98 ± 9	70 ± 11[b]	0.001
Fruit (serving/1,000 kcal)[d]	0.7 ± 0.6	0.9 ± 0.4	1.3 ± 0.3[b]	0.02
Vegetable (serving/1,000 kcal)	1.4 ± 0.7	1.8 ± 0.5	2.2 ± 0.6[b]	0.01
Legume (serving/1,000 kcal)[d,e]	0.1 ± 0.2	0.0 ± 0.0	1.5 ± 0.0[b,c]	<0.001

Values are reported as means ± SD. The mean for 3-day diet recalls were used to assess participants' pre-study diets, the means of 7-day menus (on 2,000 kcal level) reflect the two test diets (HA and LG)

[a] *P* values reflect the overall difference across the three diets using one-way ANOVA with Tukey tests to adjust for the multiple comparisons

[b] Different from pre-study diet, $P<0.1$

[c] Different from Healthy American diet, $P<0.1$

[d] Data were log-transformed for analysis

[e] Legumes were excluded in the vegetables

Table 2

Baseline characteristics of study subjects by insulin resistance status

	Overall mean	Insulin sensitive (IS)	Insulin resistant (IR)	*P* value[a]
N	64	36	28	
Age (years)	54.5 ± 7.8	53.8 ± 7.6	55.5 ± 8.0	0.38
BMI (kg/m^2)	28.7 ± 3.5	27.4 ± 3.2[a]	30.3 ± 3.2[b]	<0.001
Waist circumference (cm)	97.2 ± 9.3	93.2 ± 8.7[a]	102.3 ± 7.5[b]	<0.001
Systolic blood pressure (mmHg)	123 ± 11	121 ± 10	126 ± 12	0.11
Diastolic blood pressure (mmHg)	81 ± 7	79 ± 6[a]	82 ± 7[b]	0.04
TC (mg/dL)	200 ± 37	195 ± 37	207 ± 37	0.19
HDL-C (mg/dL)	45 ± 11	47 ± 12	43 ± 10	0.15
LDL-C (mg/dL)	129 ± 32	127 ± 31	131 ± 35	0.60
TAG (mg/dL)[b]	135 ± 72	108 ± 48[a]	171 ± 83[b]	<0.001
Glucose (mg/dL)	97.3 ± 8.9	93.7 ± 7.9[a]	101.9 ± 7.9[b]	<0.001
Insulin (μU/mL)[b]	11.6 ± 7.6	7.4 ± 2.6[a]	17.0 ± 8.5[b]	<0.001

Values are reported as means ± SD

[a]Baseline characteristics stratified by subject's insulin resistant status were compared using one-way ANOVA. The different letters show statistical differences at $\alpha = 0.05$

[b]Data were log-transformed for the analysis

Table 3

Effects of diets on study endpoints

	Study entry	Δ LG	*P* value[a]	Δ HA	*P* value[b]	Δ LG − Δ HA[c]	*P* value[d]
TC (mg/dL)	200 ± 5	−20 ± 3 (10%)	<0.001	−8 ± 3 (4%)	<0.01	−11 ± 3	<0.001
HDL-C (mg/dL)	45 ± 1	−3 ± 1 (6.7%)	<0.001	−1 ± 1 (2.2%)	0.04	−2 ± 1	0.05
LDL-C (mg/dL)	129 ± 4	−14 ± 2 (10.9%)	<0.001	−4 ± 2 (3.1%)	0.09	−9 ± 3	<0.01
TAG (mg/dL)[e]	135 ± 9	−20 ± 6 (14.8%)	<0.01	−17 ± 5 (12.6%)	<0.01	−3 ± 8	0.93
TC/HDL-C	4.61 ± 0.15	−0.15 ± 0.06 (3%)	0.02	−0.08 ± 0.06 (1.7%)	0.17	−0.07 ± 0.08	0.39
LDL-C/HDL-C	2.97 ± 0.12	−0.12 ± 0.05 (3.5%)	0.02	−0.01 ± 0.05 (0.3%)	0.87	−0.11 ± 0.06	0.09
TAG/HDL-C[e]	3.40 ± 0.31	−0.28 ± 0.18 (9.4%)	0.27	−0.40 ± 0.17 (13.5%)	0.03	0.12 ± 0.27	0.52

Values are reported as means ± SEM (percentage change); $n = 64$. General linear mixed models with repeated measurement (Proc mixed) were used to test for the effects of diet, period, and their interactions with study outcomes

Δ*LG* = change over the 4-week enriched-legume diet, Δ*HA* = change over the four-week isocaloric healthy American diet

[a] Statistical significance over the enriched-legume diet

[b] Statistical significance over the healthy American diet

[c] ΔLG − ΔHA = difference in change between the two diets

[d] Statistical significance of the difference in change between the two diets

[e] Data were log-transformed for the analysis

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Table 4

Effects of diets on study endpoints among subjects stratified by insulin resistance status

	Changes during the LG diet			Changes during the HA diet			Difference between the two diets	
	Baseline	**ΔLG**	***P* value**	**Baseline**	**ΔHA**	***P* value**	**ΔLG − ΔHA[a]**	***P* value**
IS (*n* = 36)								
TC (mg/dL)	192 ± 6	−22 ± 3 (11.3%)	<0.001	188 ± 5	−7 ± 3 (3.7%)	0.04	−14 ± 4	<0.001
HDL-C (mg/dL)	46 ± 2	−2 ± 1 (4.3%)	0.02	47 ± 2	−2 ± 1 (4.3%)	0.02	0 ± 1	0.97
LDL-C (mg/dL)	124 ± 5	−15 ± 3 (12.1%)	<0.001	121 ± 4	−4 ± 3 (3.3%)	0.17	−10 ± 4	<0.01
TAG (mg/dL)[b]	123 ± 12	−27 ± 8 (22.0%)	<0.01	102 ± 7	−5 ± 6 (4.9%)	0.22	−23 ± 10	0.12
TC/HDL-C	4.34 ± 0.18	−0.30 ± 0.08 (6.9%)	<0.001	4.14 ± 0.15	−0.01 ± 0.07 (0.2%)	0.93	−0.30 ± 0.10	<0.01
LDL-C/HDL-C	2.79 ± 0.14	−0.19 ± 0.06 (6.8%)	<0.01	2.67 ± 0.13	0.001 ± 0.069 (0.04%)	0.98	−0.20 ± 0.08	0.02
TAG/HDL-C[b]	3.03 ± 0.41	−0.67 ± 0.23 (22.1%)	0.05	2.43 ± 0.25	−0.02 ± 0.22 (0.8%)	0.71	−0.65 ± 0.34	0.21
IR (*n* = 28)								
TC (mg/dL)	204 ± 7	−17 ± 3 (8.3%)	<0.001	206 ± 8	−10 ± 4 (4.9%)	0.01	−7 ± 5	0.13
HDL-C (mg/dL)	43 ± 2	−4 ± 1 (9.3%)	<0.001	42 ± 2	−0.4 ± 0.9 (1.0%)	0.69	− 4 ± 1	<0.01
LDL-C (mg/dL)	128 ± 6	−12 ± 3 (9.4%)	<0.001	129 ± 7	−4 ± 4 (3.1%)	0.33	−8 ± 4	0.05
TAG (mg/dL)[b]	164 ± 15	−10 ± 9 (6.1%)	0.30	180 ± 17	−33 ± 7 (18.3%)	<0.001	23 ± 12	0.11
TC/HDL-C	4.88 ± 0.24	0.05 ± 0.09 (1.0%)	0.60	5.05 ± 0.26	−0.17 ± 0.09 (3.4%)	0.05	0.22 ± 0.12	0.06
LDL-C/HDL-C	3.07 ± 0.18	−0.01 ± 0.07 (0.3%)	0.84	3.14 ± 0.20	−0.02 ± 0.08 (0.6%)	0.77	0.01 ± 0.09	0.93
TAG/HDL-C[b]	4.12 ± 0.47	0.21 ± 0.26 (5.1%)	0.57	4.79 ± 0.62	−0.90 ± 0.26 (18.8%)	<0.01	1.11 ± 0.39	0.02

Values are reported as means ± SEM (percentage change)

IS insulin-sensitive subjects, Δ*LG* = change over the enriched-legume diet, Δ*HA* = change over the isocaloric healthy American diet, *IR* insulin-resistant subjects

[a] ΔLG − ΔHA = change between the two diets

[b] Data were log-transformed for the analysis