Soy inclusion in the diet improves features of the metabolic syndrome: a randomized crossover study in postmenopausal women

Leila Azadbakht, Masoud Kimiagar, Yadollah Mehrabi, Ahmad Esmaillzadeh, Mojgan Padyab, Frank B Hu, and Walter C Willett

ABSTRACT

Background: Little evidence exists regarding the effects of soy consumption on the metabolic syndrome in humans.

Objective: We aimed to determine the effects of soy consumption on components of the metabolic syndrome, plasma lipids, lipoproteins, insulin resistance, and glycemic control in postmenopausal women with the metabolic syndrome.

Design: This randomized crossover clinical trial was undertaken in 42 postmenopausal women with the metabolic syndrome. Participants were randomly assigned to consume a control diet (Dietary Approaches to Stop Hypertension, DASH), a soy-protein diet, or a soy-nut diet, each for 8 wk. Red meat in the DASH period was replaced by soy-protein in the soy-protein period and by soy-nut in the soy-nut period.

Results: The soy-nut regimen decreased the homeostasis model of assessment-insulin resistance score significantly compared with the soy-protein (difference in percentage change: −7.4 ± 0.8; P < 0.01) or control (−12.9 ± 0.9; P < 0.01) diets. Consumption of soy-nut also reduced fasting plasma glucose more significantly than did the soy-protein (−5.3 ± 0.5%; P < 0.01) or control (−5.1 ± 0.6%; P < 0.01) diet. The soy-nut regimen decreased LDL cholesterol more than did the soy-protein period (−5.0 ± 0.6%; P < 0.01) and the control (−9.5 ± 0.6%; P < 0.01) diet. Soy-nut consumption significantly reduced serum C-peptide concentrations compared with control diet (−8.0 ± 2.1; P < 0.01), but consumption of soy-protein did not.

Conclusion: Short-term soy-nut consumption improved glycemic control and lipid profiles in postmenopausal women with the metabolic syndrome.


KEY WORDS Metabolic syndrome, insulin resistance, soy, glycemic control, lipid profiles

INTRODUCTION

The metabolic syndrome is a clustering of metabolic abnormalities that occurs in individuals with impaired insulin sensitivity (1, 2). Existing data suggest that the incidence of the metabolic syndrome is rising at an alarming rate (3, 4). In Tehran, Iran, it has been estimated to affect >30% of adults (5), a prevalence significantly higher than that of most developed countries (6). The etiology of this syndrome is largely unknown: genetic, metabolic, and environmental factors, including diet, are thought to play a major role (7). In previous investigations, intakes of unsaturated fatty acids (8), n–3 fatty acids (9), dairy products (10), and whole grains (11) appeared to influence the prevalence of this syndrome, either positively or negatively, but little emphasis has been placed on the specific therapeutic diets that control the metabolic syndrome. In choosing a therapeutic diet, high amounts of vegetables, fruits, legumes, whole grains, low-fat dairy foods, and low amounts of saturated fat and salt have been used in previous studies (12–15). Foods that improve insulin sensitivity might also modulate the metabolic abnormalities linked with insulin resistance (16).

Many studies have reported beneficial effects of soy consumption on human health, but most of these investigations have been conducted among type 2 diabetic or hypercholesterolemic patients (16–19), or healthy subjects (20). Although some studies have reported effects of soy consumption on the metabolic syndrome in animals (21, 22), to our knowledge no reports are available regarding the effects of soy intake on features of the metabolic syndrome in humans. Soy consumption could reduce the risk of the metabolic syndrome through its beneficial components, including complex carbohydrates, unsaturated fatty acids, vegetable protein, soluble fiber, oligosaccharides, vitamins, minerals, inositol-derived substances such as lipintol and pinitol, and phytoestrogens, particularly the isoflavones genistein, diadzein, and glycitein (23–28). However, the amount and kind of these components may vary in different kinds of soy products; ie, textured soy-protein or soy-nut. We evaluated the effects of soy consumption (in the form of soy-protein and unsalted soy-nut) on features of the metabolic syndrome, including plasma lipids, lipoproteins, insulin resistance, and glycemic control, in postmenopausal women with the metabolic syndrome.

1 From the Department of Human Nutrition, School of Nutrition and Food Science (LA, MK, and AE), and the School of Public Health (YM and MP), Shaheed Beheshti University of Medical Sciences, Tehran, Iran; and the Departments of Nutrition and Epidemiology, Harvard School of Public Health, Boston, MA (FBH and WCW).

2 Supported by the National Nutrition and Food Technology Research Institute, Shaheed Beheshti University of Medical Sciences.

3 Reprints not available. Address correspondence to L Azadbakht, Department of Human Nutrition, School of Nutrition and Food Science, Shaheed Beheshti University of Medical Sciences, Tehran, PO Box 19816-19573, Iran. E-mail: lazadbakht@hotmail.com.

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SUBJECTS AND METHODS

Participants

A total of 120 postmenopausal women were screened for inclusion in the study. The study was conducted in Tehran in 2005. Women were considered postmenopausal if menstrual periods had been absent for >1 y and follicle-stimulating hormone, serum luteinizing hormone, testosterone, and estradiol concentrations confirmed their status (29). The metabolic syndrome was defined according to Adult Treatment Panel (ATP) III guidelines (30): 1) abdominal adiposity (waist circumference >88 cm); 2) low concentrations of serum HDL cholesterol (<50 mg/dL); 3) hypertriglyceridemia (≥150 mg/dL); 4) elevated blood pressure (≥130 mm Hg systolic blood pressure and ≥85 mm Hg diastolic blood pressure); and 5) impaired glucose homeostasis (≥110 mg/dL). To be enrolled in the study, patients had to have ≥3 of the above-mentioned criteria to be classified as having metabolic syndrome. Exclusion criteria were any secondary cause of hyperglycemia, current or previous (in the preceding 6 mo) use of estrogen therapy, treatment with insulin or oral hypoglycemic agents, untreated hypothyroidism, smoking, kidney or liver diseases, and breast malignancy or breast cancer. Finally, a total of 42 postmenopausal women who had 5 components of the metabolic syndrome and met the inclusion criteria were included in the present study. All participants provided informed written consent. The present study was approved by the research council and ethical committee of the National Nutrition and Food Technology Research Institute of Shaheed Beheshti University of Medical Sciences.

Study procedures

We used a randomized crossover design. After 3 wk of run-in on a usual diet (55% of energy from carbohydrate, 15% of energy from protein, and 30% of energy from fat), we randomly assigned women to consume the control diet (Diet A = red meat-DASH diet), DASH diet with soy-nut (Diet B = soy-nut period), or DASH diet with soy-protein (Diet C = soy-protein period) each one for 8 wk. Each patient received all 3 diets and had 2 washout periods (each washout for 4 wk) between the 3 diets. We set 6 different sequence of diet intakes (ABC, ACB, BCA, BAC, CBA, and CAB) with 2 washouts in each model; patients randomly followed one of these sequences. The randomization was conducted at the end of the run-in.

Measurements were obtained before run-in, after run-in, after each diet, and after each washout. Baseline measurements were performed at the beginning of each dietary period. The participants were free-living during the study period and they prepared their own meals. Only soy products were given to them during the different phases of the study. The participants were asked not to change their habitual physical activity level for the duration of the study. The patients recorded their physical activities for 3 days each month.

Diets

We used 3 diets. 1) Control diet: this diet was a DASH diet. The general recommendation for macronutrient composition of the DASH diet was the following: 50–60% of energy as carbohydrate, 15–20% of energy as protein, and <30% of energy as total fat. This diet had one serving of red meat (red meat-DASH) and was rich in fruit, vegetables, whole grains, and low-fat dairy products and was low in saturated fat, total fat, cholesterol, refined grains, and sweets. The sodium intake was 2400 mg/d (31). Sodium intake was determined according to the Iranian Food Composition Table. We prescribed little added salt during cooking (only 1 tsp) and no table salt. 2) Diet with soy-nut: this diet was the same as the control diet, but we replaced red meat with soy-nut. Every 30 g soy-nut was considered 1 serving of red meat (32). 3) Diet with soy-protein: this diet was the same as the control diet, but we replaced red meat with soy-protein. Every 30 g soy-protein was considered 1 serving of red meat (32). Soy-nut was produced by Toos manufacturer in Mashhad, Iran, and soy-protein has produced by Sobhan manufacturer in Behshahr, Iran. The nutrient compositions of the soy-nut and soy-protein consumed by the study participants, based on our analysis, are shown in Table 1. Soy-composition data was determined by biochemical analysis. No significant differences were found between the results of the analysis and those that were calculated with the food-composition tables. The amount of soy isoflavones consumed was 84 mg/d (8 mg glycitein, 43 mg genistein, and 33 mg diadzein) during the soy-protein period and 102 mg/d (9 mg glycitein, 53 mg genistein, and 40 mg diadzein) during the soy-nut period. The patients received education in how they could prepare their meals with soy-protein. A nutritionist explained to the participants how to wash the soy-protein products, soak them for 30 min, and then cook them in boiling water with turmeric, lemon juice, and tomato paste for 10 min.

The calorie requirements of each participant were calculated individually on the basis of equations suggested by the Institute of Medicine, Food and Nutrition Board (33). Weight loss was not a goal, and patients were not on a weight-reducing diet.

The participants were visited every 2 wk for 45–60 min per patient. They were in touch with the study nutritionist daily by phone. For measuring food intake, 3-d diet records were used at baseline and during the intervention for each month. Every participant had to bring her 3-d diet record and physical activity records every month when they were reviewed by the study staff; these records were used for checking diet compliance. Each food and beverage in the diet records was then coded according to the prescribed protocol and analyzed for content of energy and the other nutrients by using NUTRITIONIST III software (version 7.0; N-Squared Computing, Salem, OR), which was designed for Iranian foods. Physical activity records were activities in MET-h/d.

The study nutritionist explained the benefits of each diet for patients. Patients also received education in using an exchange list of foods and in writing food diaries. The diets were individually prescribed by using a calorie count system, and an exchange...
list was given to each patient for exchanging the food items and calculating calories. A 7-d menu cycle at 6-calorie levels (1800, 1900, 2000, 2100, 2200, and 2300 calories) was developed for each diet. Subjects were free-living and they provided their own meals.

To maximize treatment fidelity, group discussions, in which the food items that should be eaten were emphasized, were performed monthly. Patients also received education on the methods of preparing soy-protein according to their menu and were encouraged to follow their diets. The investigators randomly took part in the counseling sessions and controlled the messages that nutritionist was giving to each group. Patient adherence was assessed by analyzing the 3-d food record diaries monthly and by the attendance at the meetings and monthly visits.

**Measurements**

Body weight was measured while the subjects were minimally clothed without shoes by using digital scales and recorded to the nearest 0.1 kg. Height was measured in a standing position, without shoes, by using a tape meter while the shoulders were in a normal state. Waist circumference (WC) was measured to the nearest 0.1 cm at the narrowest level over light clothing, with the use of an unstretched tape measure, without any pressure to body surface. Blood pressure was measured twice after the participants sat for 15 min.

Twelve-hour fasting blood samples were collected into tubes containing 0.1% EDTA and were centrifuged at 4°C and 500 x g for 10 min to separate the plasma. Blood glucose was measured on the day of blood collection by an enzymatic colorimetric method by using glucose oxidase. Serum total cholesterol and triacylglycerol concentration were measured with commercially available enzymatic reagents (Pars Azmoon, Tehran, Iran) adapted to a Selectra autoanalyzer (Vital Scientific, Spankeren, Netherlands). HDL cholesterol was measured after precipitation of the apolipoprotein B-containing lipoproteins with phosphotungstic acids (34). Inter-and intraassay CVs were both <5% for all measurements. Serum insulin concentrations were measured by using an enzyme-linked immunosorbent assay (ELISA; Diagnostic Biochem Canada Inc, Montreal, Canada). The CV, which was calculated by using duplicate study samples, was <10%; the analytic sensitivity was 2 μU/mL. Insulin resistance was calculated by using the homeostasis model of assessment-insulin resistance (HOMA-IR) (35). Serum luteinizing hormone and follicle-stimulating hormone were measured by radioimmunoassay; testosterone and estradiol were measured by ELISA. C-peptide was also measured by ELISA (Diagnostic Biochem Canada Inc) (36). Plasma phytoestrogens were measured by HPLC according to Franke et al (37, 38). Serum concentrations of apolipoprotein B 100 (apoB-100) and apoA-I were determined by ELISA (Diagnostic Biochem Canada Inc). We used standard and control solutions for all measurements, all laboratory measurements were standardized, and standard curves were plotted for all of them. Soy-derived phytoestrogens were measured by HPLC to determine the patients’ adherence (38).

**Statistical analysis**

We used 3 methods of analyses to be confident that the results were similar. First, we used general linear models to compare the means of the metabolic variables at the end of the soy-nut, soy-protein, and control phases. Then, we used Tukey’s test as a post-hoc test for comparing the end of treatment values of each group with each other group. The percentage change for each variable was also calculated by the formula (\( \frac{E - B}{B} \) × 100), where \( E \) is the end of treatment value and \( B \) is the baseline value. We compared groups using the percentage change in both repeated-measures analysis of variance and paired t test analyses. We also determined the mean percentage change differences, which were derived by calculating the differences in percentage change for each variable in pair-wise group comparisons. This parameter gives the most direct estimate of the difference in response in comparing groups. Interactions between soy intake and weight were not significant for any of the metabolic features. Period and treatment order effects were tested by using the appropriate general linear models.

For skewed variables (apoA-I and fasting insulin concentration), we used log-transformed values in all analyses and reported the geometric means. Pearson correlation coefficients were used to evaluate the relation between soy-derived phytoestrogens intake (calculated from self reported soy intake in 3-d diet records) and plasma phytoestrogen concentrations. All results were considered significant if the two-tailed \( P \) value was < 0.05. Statistical analysis was performed by using SPSS for WINDOWS version 13.0 (SPSS, Chicago, IL) and SAS version 8.2 (SAS Institute Inc, Cary, NC).

**RESULTS**

All participants (42 postmenopausal women with the metabolic syndrome) completed the entire crossover study. Calculated nutrient content and food group servings of 3-d diet records according to the patients’ report is shown in Table 2. Both the soy-nut and soy-protein diets were well tolerated. Only one person complained of feeling bloated during the soy-protein period. The activity level of the subjects remained the same across all study periods [\( x \pm SE \) physical activity in control period: 2.38 ± 0.19 MET-h/d; in soy-protein period: 2.50 ± 0.26 MET-h/d; and in soy-nut period: 2.44 ± 0.26; \( P = 0.10 \)].

The baseline characteristics of the study participants and the effects of the 3 diets on components of the metabolic syndrome, lipid profiles, and glycemic control are shown in Table 3. No significant differences in the baseline characteristics of the study participants were seen. Significant differences between the end values of control diet, soy-protein regimen, and soy-nut consumption for glycemic control indexes were seen. A post-hoc comparison of the diets showed a significant difference between the control and soy-protein diets with regard to LDL cholesterol, total cholesterol, fasting insulin, HOMA-IR, and apoB-100. Similar results were seen for fasting plasma glucose (FPG), LDL cholesterol, total cholesterol, fasting insulin, HOMA-IR, C-peptide, and apoB-100 in a comparison of the soy-nut and control diets. No significant effects of period or treatment order were observed. Compared with the control diet, plasma phytoestrogen increased significantly after the soy-nut regimen (percentage change: 64%; \( P < 0.01 \)) and after the soy-protein diet (percentage change: 48%; \( P < 0.01 \)).

**DISCUSSION**

We found that soy as a replacement for red meat in a DASH eating plan had beneficial effects on features of the metabolic syndrome, soy-nut being more effective than soy-protein. We
also found that soy consumption improved glycemic control and cardiovascular disease risk factors, at least in the short term, in postmenopausal women with the metabolic syndrome. Although some studies have assessed the effects of soy intake on the metabolic syndrome in animals (21, 22), to our knowledge this is the first study in which such an effect has been evaluated in humans. Both soy-nut and soy-protein had beneficial effects on serum lipids. (11%) with the consumption, on average, of 47 g soy- erol, and apoB-100. Such results have also been seen among subjects with different types of diseases (39, 40). Beneficial effects of soy consumption on blood lipids were the most consistently reported findings. In a meta-analysis of 38 controlled clinical trials, Anderson et al (18) showed significant reductions in total cholesterol (9%), LDL cholesterol (13%), and triacylglycerols (11%) with the consumption, on average, of 47 g soy- protein/d. Two recent meta-analyses concluded that the isoflavone content of soy may be responsible for its lipid-lowering effect (41, 42). Controversy still exists in the field regarding the relative contribution of potential mechanisms of action of soy- protein, isoflavones, and other soy components on blood lipids and lipoproteins.

Besides abnormalities in lipid metabolism, elevated blood pressure is another feature of the metabolic syndrome. Most studies showed no effect on blood pressure with consumption of soy-protein containing isoflavones (25, 43, 44). In the current study, neither soy-protein nor soy-nut consumption had significant effects on systolic or diastolic blood pressures compared with the control diet. It seems that the blood pressure-lowering effect of the overall DASH diet in the 3 periods of the study may be responsible for the changes in blood pressure during the soy- nut or soy-protein periods.

We also observed that soy consumption improved glycemic control. HOMA-IR decreased significantly at the end of the soy- nut diet compared with the soy-protein and control diets. This finding may support a direct pharmacologic effect of soy constitu- tients. The hypothesis that soy isoflavones modulate glycemic control is not proven yet. We assumed that a higher level of isoflavones in combination with polyunsaturated fatty acids, pinitol, and protein might have beneficial effects on glycemic control.

In most studies, the phytoestrogens, amino acids, and fatty acid content of soy-nuts were suggested to be responsible for its favorable effects (16, 45–47). In the present study, soy-nut intake had more beneficial effects on metabolic risks than did soy- protein intake. The combination of higher amounts of unsaturat- ed fat and isoflavones in soy-nut (48) may synergistically pro- vide an optimum benefit. Polyunsaturated fatty acids and lecithin, which are the most common fats in soy-nut, have well- documented favorable effects on the metabolic syndrome risks (8, 9, 49). A 20% difference in protein content from soy-nut and

<table>
<thead>
<tr>
<th>Daily dietary intakes</th>
<th>Control(^{1}) ((n = 42))</th>
<th>Soy-protein(^{1}) ((n = 42))</th>
<th>Soy nut(^{1}) ((n = 42))</th>
<th>(p^{5})</th>
<th>Washout(^{6}) ((n = 42))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soy protein (g)</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>—</td>
<td>0</td>
</tr>
<tr>
<td>Soy nut (g)</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>—</td>
<td>0</td>
</tr>
<tr>
<td>Nutrients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>2055 ± 24(^{7})</td>
<td>2039 ± 23</td>
<td>2049 ± 21</td>
<td>0.62</td>
<td>2078 ± 20</td>
</tr>
<tr>
<td>Protein (% of energy)</td>
<td>17 ± 0.4</td>
<td>17 ± 0.3</td>
<td>17 ± 0.4</td>
<td>0.71</td>
<td>15 ± 0.4</td>
</tr>
<tr>
<td>Total fat (% of energy)</td>
<td>28 ± 0.6(^{a})</td>
<td>25 ± 0.7(^{b})</td>
<td>29 ± 0.5(^{a})</td>
<td>&lt;0.05</td>
<td>31 ± 0.5</td>
</tr>
<tr>
<td>Saturated fat (% of energy)</td>
<td>7 ± 0.6</td>
<td>5 ± 0.6</td>
<td>5 ± 0.5</td>
<td>0.61</td>
<td>14 ± 0.5</td>
</tr>
<tr>
<td>Polyunsaturated fat (% of energy)</td>
<td>8 ± 0.6(^{a})</td>
<td>8 ± 0.5(^{a})</td>
<td>11 ± 0.6(^{b})</td>
<td>&lt;0.05</td>
<td>7 ± 0.6</td>
</tr>
<tr>
<td>Monounsaturated fat (% of energy)</td>
<td>10 ± 0.5</td>
<td>10 ± 0.6</td>
<td>10 ± 0.6</td>
<td>0.73</td>
<td>9 ± 0.5</td>
</tr>
<tr>
<td>Cholesterol (mg)</td>
<td>189 ± 10</td>
<td>173 ± 8</td>
<td>175 ± 8</td>
<td>0.51</td>
<td>300 ± 7</td>
</tr>
<tr>
<td>Carbohydrate (% of energy)</td>
<td>55 ± 1</td>
<td>58 ± 2</td>
<td>57 ± 1</td>
<td>0.79</td>
<td>54 ± 2</td>
</tr>
<tr>
<td>Fiber (g)</td>
<td>25 ± 1(^{a})</td>
<td>32 ± 2(^{b})</td>
<td>33 ± 2(^{b})</td>
<td>&lt;0.05</td>
<td>11 ± 2</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>4395 ± 143</td>
<td>4416 ± 176</td>
<td>4426 ± 144</td>
<td>0.31</td>
<td>1546 ± 133</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>1209 ± 71</td>
<td>1219 ± 77</td>
<td>1227 ± 88</td>
<td>0.49</td>
<td>750 ± 85</td>
</tr>
</tbody>
</table>

\(^{1}\) Means with different superscript letters are significantly different, \(P < 0.05\) (Tukey’s test).

\(^{2}\) This diet provided one serving of red meat and was rich in fruit, vegetables, whole grains, and low-fat dairy products and was low in saturated fat, total fat, cholesterol, refined grains, and sweets. The sodium intake was 2400 mg/d [Dietary Approach to Stop Hypertension (DASH) pattern].

\(^{3}\) This diet was the same as the control diet (DASH diet), but we replaced red meat with soy-protein. Every 30 g soy-protein was considered 1 serving of red meat.

\(^{4}\) This diet was the same as the control diet (DASH diet), but we replaced red meat with soy-nut. Every 30 g soy-nut was considered 1 serving of red meat.

\(^{5}\) Differences between the 3 trial periods (repeated-measures ANOVA).

\(^{6}\) In this period, patients consumed the same diet they consumed before the study.

\(^{7}\) \(\bar{x} \pm \text{SEM} \) (all such values).
Apolipoprotein A1 (g/L)
Baseline 70.0 ± 0.9 70.0 ± 0.8 70.1 ± 0.8 0.98
End of trial 70.1 ± 0.9 70.7 ± 0.9 70.4 ± 0.8 0.57

Waist (cm) 9
Baseline 91.5 ± 0.7 91.4 ± 0.7 91.2 ± 0.8 0.60
End of trial 91.9 ± 0.8 91.5 ± 0.9 91.0 ± 1.0 0.19

SBP (mm Hg) 6
Baseline 136 ± 0.7 136 ± 0.7 136 ± 0.7 0.97
End of trial 131 ± 1.2 132 ± 0.7 131 ± 1.0 0.26

DBP (mm Hg) 6
Baseline 87 ± 0.1 87 ± 0.2 87 ± 0.2 0.16
End of trial 84.0 ± 0.5 85.0 ± 0.5 85.0 ± 0.5 0.85

FPG (mg/dL) 6
Baseline 120 ± 0.6 119 ± 0.6 118 ± 0.5 0.25
End of trial 112 ± 1.0a 111 ± 0.9a 103 ± 0.5b 0.01

Triacylglycerols (mg/dL) 6
Baseline 219 ± 1.3 220 ± 1.1 218 ± 1.2 0.79
End of trial 213 ± 1.2 210 ± 1.7 212 ± 1.7 0.30

HDL cholesterol (mg/dL) 6
Baseline 31.0 ± 0.4 32.0 ± 0.4 32.0 ± 0.4 0.91
End of trial 33.3 ± 0.7 34.0 ± 0.7 33.3 ± 0.4 0.51

LDL cholesterol (mg/dL) 6
Baseline 143 ± 0.8 142 ± 0.6 137 ± 3.2 0.08
End of trial 134 ± 3.3a 127 ± 2.4a 118 ± 3.0b <0.01

Total cholesterol (mg/dL) 6
Baseline 238 ± 1.0 239 ± 0.9 238 ± 0.9 0.37
End of trial 228 ± 0.9a 217 ± 0.5b 209 ± 0.6c <0.01

Fasting insulin (μIU/mL) 7
Baseline 14.3 ± 0.09 14.2 ± 0.09 14.1 ± 0.09 0.73
End of trial 14.2 ± 0.09 13.3 ± 0.04b 12.8 ± 0.09c <0.01

HOMA-IR 8
Baseline 4.19 ± 0.03 4.20 ± 0.04 4.16 ± 0.06 0.65
End of trial 3.9 ± 0.04a 3.6 ± 0.03b 3.3 ± 0.03c <0.01

C-peptide (ng/mL) 8
Baseline 2.09 ± 0.04 2.1 ± 0.03 2.1 ± 0.02 0.79
End of trial 1.92 ± 0.04a 1.86 ± 0.03a 1.77 ± 0.04b <0.05

Apolipoprotein AI (g/L) 7
Baseline 1.33 ± 0.02 1.30 ± 0.02 1.32 ± 0.01 0.51
End of trial 1.32 ± 0.01 1.30 ± 0.01 1.31 ± 0.01 0.35

Apolipoprotein B100 (g/L) 6
Baseline 1.33 ± 0.02 1.28 ± 0.01 1.25 ± 0.01 0.61
End of trial 1.08 ± 0.03a 0.98 ± 0.03b 0.92 ± 0.04b <0.01

Values are x ± SE.

1 n = 42. SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting blood glucose; HOMA-IR, homeostasis model of assessment-insulin resistance. Means with different superscript letters are significantly different, P < 0.05 (Tukey’s test). No significant period effect or interaction of period effect and treatment effect were observed for any of the variables.

2 This diet provided one serving of red meat and was rich in fruit, vegetables, whole grains, and low-fat dairy products and was low in saturated fat, total fat, cholesterol, refined grains, and sweets. The sodium intake was 2400 mg/d [Dietary Approach to Stop Hypertension (DASH) pattern].

3 This diet was the same as the control diet (DASH diet), but we replaced red meat with soy-nut. Every 30 g soy-nut was considered 1 serving of red meat.

4 This diet was the same as the control diet (DASH diet), but we replaced red meat with soy-protein. Every 30 g soy-protein was considered 1 serving of red meat.

5 Comparison of the 3 diet periods (repeated-measures ANOVA).

6 Values are x ± SE.

7 Values are geometric x ± SE.
The washout period of 4 wk between 2 treatment phases in our study seemed adequate, because the values of metabolic risk factors returned to baseline levels before the start of the next trial. A strength of the present study was the good compliance of our subjects, which was confirmed by the phytoestrogen concentrations in each period of the study. We did not evaluate the effects of soy-protein or soy-nut according to estrogen receptor genotype in our participants; in some studies, responses to isoflavone consumption have varied according to estrogen receptor genotype (51–53). Also, further studies may be warranted to assess the effect of soy consumption on features of the metabolic syndrome while taking the “equol producer” or “equol nonproducer” status into account (51–53). In conclusion, our findings suggest that short-term soy-nut consumption may reduce insulin resistance and improve glycemic control and lipid concentrations in postmenopausal women with the metabolic syndrome.

We thank the participants of this study for their enthusiastic support. We would also like to thank Amy Cohen from Harvard School of Public Health for her valuable help.

LA and AE designed the study, collected and analyzed the data, and wrote the manuscript. MK served as a supervisor and YM as advisor for this research. MP helped with the statistical analysis. FBH and WCW commented on this work and helped in the manuscript preparation. None of the authors have any personal or financial conflicts of interest.

REFERENCES