Soybean and Soyfood Consumption Increase Oxalate Excretion

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Abstract
Eight healthy adults with no prior history of kidney stones participated in eight oxalate (Ox) load tests, seven foods, and an Ox solution control. After correction for endogenous Ox synthesis, increases in urinary Ox excretion during the 8 hours after eating one meal of the two soybean lines and five soyfoods tested ranged from 19.6 ± 23.3 to 124 ± 156 mmol (1.7 ± 2.1 to 10.9 ± 13.8 mg). Thus, frequent consumption of soybeans and soy products (TVP, soynuts, soy beverage, and tofu) may be a risk factor for CaOx kidney stone formation in susceptible individuals, such as those with a prior history of Ca stones, high normal urinary Ox concentrations, or intestinal disease.

Keywords
calcium, kidney stones, oxalate, soy

Disciplines
Agronomy and Crop Sciences | Botany | Nutrition

Comments

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Soybean and Soyfood Consumption Increase Oxalate Excretion

Eight healthy adults with no prior history of kidney stones participated in eight oxalate (Ox) load tests, seven foods, and an Ox solution control. After correction for endogenous Ox synthesis, increases in urinary Ox excretion during the 8 hours after eating one meal of the two soybean lines and five soyfoods tested ranged from 19.6 ± 23.3 to 124 ± 156 µmol (1.7 ± 2.1 to 10.9 ± 13.8 mg). Thus, frequent consumption of soybeans and soy products (TVP, soynuts, soy beverage, and tofu) may be a risk factor for CaOx kidney stone formation in susceptible individuals, such as those with a prior history of Ca stones, high normal urinary Ox concentrations, or intestinal disease. Key words: calcium, kidney stones, oxalate, soy

INTRODUCTION

Recent reports that a soy-enriched diet may reduce the risk of heart disease, osteoporosis, and many types of cancer has many Americans increasing their dietary soy consumption. Ilarslan et al1,2 identified the presence of many calcium (Ca) oxalate (Ox) crystals in soybean seeds (referred to hereafter as soybeans). CaOx is considered insoluble and once was thought to be a virtually unabsorbed Ca salt. However, Heaney and Weaver3 demonstrated that Ca absorption from a 5

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This is a joint contribution: Journal Paper No. J–19422 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3352, supported by Hatch Act and State of Iowa funds, the United States Department of Agriculture, Agriculture Research Service, Corn Insects and Crop Genetics Research Unit, Washington State University Agriculture Research Station Project 0246, and the Virginia Shafer Fund. The mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by Washington State University, Iowa State University, or the USDA and does not imply its approval to the exclusion of other products that also may be suitable.

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mmol (203 mg) load of $^{45}$Ca labeled CaOx was 10.0 ± 4.3%. This finding suggested that Ox also would be absorbed. This hypothesis was verified by Hanes et al. who showed doubly labeled $^{45}$Ca-$^{14}$C Ox was absorbed intact in rats. Hanes et al. concluded that dissociation and solubilization of CaOx is not necessary for absorption. After Ox is absorbed, it cannot be metabolized and is excreted by the kidney in urine. High urinary Ox excretion is a risk for CaOx precipitation, resulting in kidney stones.

Dietary restriction of Ox intake often is recommended to decrease urinary Ox concentration. However, the effectiveness of Ox-restricted diets is hindered by limited numbers of published food values of Ox content. In addition, Ox absorption is understood poorly and has been examined for only a few foods, mostly fruits and vegetables, with limited data on legumes. Based on absorption studies, individuals with a predisposition for kidney stone formation are advised to restrict dietary Ox intake of foods shown to increase urinary Ox excretion. Unfortunately, no study examining dietary Ox content and its absorption from soybeans and soyfoods has been published. Thus, it was the purpose of this study to examine Ox absorption by measuring changes in urinary Ox excretion after ingestion of Ox-containing soybeans and soyfoods to determine whether consumption of soybeans and soyfoods may be a risk factor for CaOx kidney stone formation.

METHODS AND PROCEDURES

Subjects

University faculty, staff, and students age 18 years and older were recruited through posted announcements on campus. Responders were screened through a self-reported health history questionnaire and were required to meet the following criteria for inclusion in the study: (1) no history of prior kidney stones; (2) no disorders of Ca or Ox metabolism; (3) no diseases involving the intestinal tract, liver, or kidneys; and (4) no use of chronic medications, vitamins, minerals, or other nutritional supplements that would interfere with Ca or Ox metabolism. Nine healthy people (four men and five women) with no prior history of kidney stones ranging from 23 to 59 years of age (37.9 ± 12.2) were invited to participate. All nine volunteers accepted and completed at least seven of the eight oxalate load (OL) tests.

The screening procedures and experimental protocol were approved by the Human Subjects Institutional Review Board of Washington State University (WSU). The purpose and potential risks of the study were explained fully to the subjects and informed written consent was obtained from all study participants. Participant characteristics are listed in Table 1.

Oxalate loads

Each subject participated in OL tests comprised of two soybean lines, five soyfoods,

Table 1. Participant characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD*</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>37.9 ± 12.2</td>
<td>23–59</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.6 ± 12.8</td>
<td>59.1–101.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.9 ± 9.2</td>
<td>154.9–185.4</td>
</tr>
<tr>
<td>BMI*</td>
<td>26.0 ± 4.2</td>
<td>19.5–31.8</td>
</tr>
</tbody>
</table>

*SD = standard deviation.

*BMI = body mass index (weight in kg/height in m$^2$).
and 8.3 mmol NaOx in solution. The NaOx load was included to verify that no participant was an Ox hyperabsorber, defined as 20% or more absorbed. One OL test a week was conducted for eight consecutive weeks. Soyfood selection for the feeding studies was based on product popularity and the different processed forms of soy in the food items. Table 2 illustrates the type, amount, and energy content of each OL consumed. Table 3 illustrates that the amount of soybeans and soyfoods fed during each OL test was in excess of a standard portion size; however, the portions fed are not considered an unreasonable amount when consumed during a typical day or several soyfoods at a single meal. All foods were purchased in batch lots sufficient for the entire study to ensure consistency of processing and nutrient composition.

Soybeans of the L95–1409 and L95–1116 lines were provided by Iowa State University (ISU) and by Dr. R. Benard of the University of Illinois, Urbana-Champaign. These soybean lines were selected for inclusion in this study because they contained the highest insoluble and total Ox contents and the highest Ca content from 11 lines of soybeans analyzed at ISU.11

**Procedures**

Subjects were provided a list of 10 Ox-rich foods and asked to avoid these foods (spinach, rhubarb, beets, beans, chocolate, tea, wheat bran, nuts, parsley, and strawberries) for 2 days immediately prior to each OL test to decrease urinary Ox excretion variability associated with the consumption of high Ox-

<table>
<thead>
<tr>
<th>Oxalate Load</th>
<th>Brand</th>
<th>Portion size</th>
<th>Total Kcal/portion</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOx (apple juice plus plain bagel)</td>
<td>Tree Top Orowheat</td>
<td>8.3 mmol NaOx dissolved in 180 mL juice + 95 g</td>
<td>350&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Soybean strain L95–1116, cooked</td>
<td>—</td>
<td>200 g&lt;sup&gt;b&lt;/sup&gt;</td>
<td>346&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Soybean strain L95–1409, cooked</td>
<td>—</td>
<td>200 g&lt;sup&gt;c&lt;/sup&gt;</td>
<td>346&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tofu, calcium precipitated, raw</td>
<td>Azumaya Tofu, extra firm</td>
<td>158 g</td>
<td>140&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tofu, magnesium precipitated, raw</td>
<td>Small Planet Organic Tofu, firm</td>
<td>170 g</td>
<td>135&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Textured vegetable protein</td>
<td>Bob’s Red Mill</td>
<td>355 g&lt;sup&gt;d&lt;/sup&gt;</td>
<td>320&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Soy beverage, vanilla</td>
<td>Soy Dream</td>
<td>480 mL</td>
<td>320&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Soynuts, unsalted</td>
<td>GeniSoy</td>
<td>70 g</td>
<td>325&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Table 2.** Estimated energy content of each soybean and soyfood oxalate load

OL = oxalate load; NaOx = sodium oxalate.
<sup>a</sup>Caloric value calculated from product label data.
<sup>b</sup>Rehydrated weight.
<sup>c</sup>Caloric value from 1999 U.S. Soyfoods Directory.
containing foods. In addition, Ca-rich foods were restricted to two servings of dairy products per day, 480 mL (2 cups) milk or equivalent, for two days prior to each OL test in order to establish normocalciuria. Other than the stated dietary stipulations, subjects were encouraged to consume their usual diet for the entire course of the study. Diet records were not used to assess compliance with the low Ox, Ca-restricted diet.

For each OL test, the subjects fasted for 12 hours from 8 p.m. on the day prior to each OL test to 8 a.m. the morning of the test. A fasting (pre-load) urine sample was obtained immediately upon arrival at the feeding lab. The subjects ingested the OL during a 10- to 20-minute period. The use of salt-free seasonings was permitted to enhance palatability of the OL. One subject regularly drank caffeinated beverages at breakfast and expressed a desire to continue consuming caffeine during the study. This subject received two caffeine pills (100 mg caffeine/tablet), equivalent to 360 mL (1½ cups) of coffee, with each OL. All urine (post-load) was collected for 8 hours and poured in a 2 L jug containing 10 mL 3N hydrochloric acid to maintain a pH < 2 to prevent conversion of ascorbate to Ox and precipitation of Ox from solution. During this 8-hour post-load, subjects worked their usual jobs or attended classes. Physical activities were not restricted, but the subjects were mostly sedentary because they either were working or in class. Each subject was provided a water bottle with distilled water and instructed to consume a minimum of 1 L during the 8-hour collection period to ensure adequate urine production. All food and beverages except for distilled water and a lunch provided by the investigators were withheld during the 8 hours following the OL. At noon, subjects were given a standardized liquid meal of 237 mL Boost Plus, containing 360 calories, 0.19 mmol (17 mg) Ox, 5 mmol (200 mg) Ca, and 3.3 mmol (80 mg) Mg, to avoid the effects of prolonged fasting on calcium excretion. At the end of the 8-hour urine collection period, the pooled post-load urine volume was recorded.

### Measurements

Weight measurements were obtained for each participant using a standing beam bal-

Table 3. Standard portion sizes of selected soybeans and soyfoods

<table>
<thead>
<tr>
<th>Soyfood item</th>
<th>Standard serving size</th>
<th>Amount fed</th>
<th>Number of standard servings ingested</th>
<th>μmol Ox per standard serving size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybeans, cooked and boiled</td>
<td>86 g (½ cup)</td>
<td>200 g (1½ cups)</td>
<td>2½</td>
<td>1678–1961</td>
</tr>
<tr>
<td>Tofu-calcium precipitated</td>
<td>79 g (2.8 oz)</td>
<td>158 g (5.6 oz)</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>Tofu-magnesium precipitated</td>
<td>113.5 g (4 oz)</td>
<td>170 g (6 oz)</td>
<td>1½</td>
<td>144</td>
</tr>
<tr>
<td>Textured vegetable protein</td>
<td>24 g&lt;sup&gt;a&lt;/sup&gt; (¼ cup)</td>
<td>96 g&lt;sup&gt;a&lt;/sup&gt; (1 cup)</td>
<td>4</td>
<td>764</td>
</tr>
<tr>
<td>Soynuts</td>
<td>28 g</td>
<td>70 g</td>
<td>2½</td>
<td>446</td>
</tr>
<tr>
<td>Soy beverage</td>
<td>240 mL (8 oz)</td>
<td>480 mL (16 oz)</td>
<td>2</td>
<td>387</td>
</tr>
</tbody>
</table>

<sup>a</sup> Data referenced from the 1999 U.S. Soyfoods Directory.

<sup>b</sup> Dry weight.
CHEMICAL ANALYSIS

Food items were prepared for analysis by blending 5 g of each food with 100 mL 3N hydrochloric acid until a smooth slurry was created. The slurries were centrifuged at 2,800 rpm for 10 to 15 minutes. The resultant clear supernatant was assayed for Ca concentration with an atomic absorption spectrophotometer (Perkin-Elmer model 2380, Norwalk, CT) and for Ox using an Ox oxidase commercial kit (Sigma Diagnostics, St. Louis, MO). An 9.5 mL aliquot of each pre-load fasting urine sample was pipetted into a 15 mL centrifuge tube and acidified with 0.5 mL 3N hydrochloric acid to a pH < 2 to prevent conversion of ascorbate to Ox and precipitation of Ox from the solution. The 10 mL aliquots of fasting urine were frozen for later analysis. Ten mL aliquots were filtered through Whatman no. 2 filter paper to remove insoluble particles and frozen for later analysis. Pre-load and post-load urine were analyzed for Ca and Ox using the same methods. Urinary creatinine was determined by colorimetric assay (Sigma Diagnostics, St. Louis, MO).

Because plant foods are free of creatinine, researchers assumed that the subjects’ urinary creatinine values were unaffected by consumption of the soybean and soyfood OL tests. Thus, excretions of Ox and Ca were expressed relative to creatinine to partially correct for differences in renal function and lean body mass among individuals as well as to correct for any uncleared Ox and Ca absorption from the diet because the subjects consumed a low-Ox diet, but not an Ox- and Ca-free diet, prior to each OL. The net increase in urinary Ox excretion was corrected for actual endogenous Ox excretion as follows. Pre-load urinary Ox excretion was expressed relative to urinary creatinine (Ox/Cr) and then multiplied by one third of the expected creatinine excretion per 24 hours for age based on age, gender, and height. The 8-hour calculated endogenous Ox excretion then was subtracted from the total post-load urinary Ox excretion to calculate the net rise in urinary Ox excretion that was due to eating the OL. The net increase in urinary Ox was assumed to be that absorbed from the food eaten. The 8-hour urinary Ca excretion was corrected similarly for endogenous Ca excretion.

Statistical analyses

One subject was dropped from data analysis because of hypercalciuria so the analysis was based on eight individuals. Paired t-test (Excel, 1997, Microsoft, Bellevue, WA) was used to test the level of significance for post-load values from pre-load values for urinary Ox and Ca excretion. A p < 0.05 was considered significant.

RESULTS

Oxalate

Table 4 shows that of the two soybean lines and five soyfoods tested, soybean line L95–1409 was the only food to produce a statistically significant increase in urinary Ox/creatinine excretion during the 8-hour post-load period. Post-load urinary Ox concentrations and percent Ox absorption are summarized in Table 5. Ingestion of the NaOx load produced a significant increase in net urinary Ox.
excretion of $770 \pm 493 \mu\text{mol} (67.8 \pm 43.4 \text{mg})$ in 8 hours, with $7.8 \pm 5.0\%$ Ox absorbed. Net urinary Ox excretion increased $103 \pm 59.0$ and $87.5 \pm 85.8 \mu\text{mol} (9.1 \pm 5.2$ and $7.7 \pm 7.5 \text{mg})$ per 8 hours, respectively, following ingestion of soybean lines L95-1116 and L95-1409. The percent absorption for the two high Ox soybean lines was similar at $2.2 \pm 1.2\%$ for L95-1116 and $2.1 \pm 2.1\%$ for L95-1409. The relative absorption of Ox from the soy beverage, soynuts, or textured vegetable protein (TVP) was higher, with an increment in urinary Ox excretion during 8 hours after ingestion of the OL of $42.7 \pm 60.5 \mu\text{mol} (3.8 \pm 5.3 \text{mg})$, $71.0 \pm 55.0 \mu\text{mol} (6.2 \pm 4.8 \text{mg})$, or $124 \pm 156 \mu\text{mol} (10.9 \pm 13.7 \text{mg})$, respectively. The 8-hour net urinary Ox excretion was higher for Ca-precipitated tofu ($28.6 \pm 40.0 \mu\text{mol} = 2.5 \pm 3.5 \text{mg}$) than Mg-precipitated tofu ($19.6 \pm 23.3 = 1.7 \pm 2.1 \text{mg}$); however, the percent Ox absorption was lower for Ca precipitated tofu ($4.1 \pm 5.8\%$) than Mg precipitated tofu ($4.8 \pm 5.7\%$). All confidence intervals for the increases in urinary oxalate after eating the soybeans and soyfoods tested were greater than zero (Table 5).

### Calcium

Table 4 shows soybean line L95-1116 and soy beverage were the only two foods that did not produce a significant increase in urinary Ca/creatinine excretion during the 8-hour, post-load period. Post-load urinary Ca concentrations and percent Ca absorption are summarized in Table 6. After correction for basal Ca excretion, the increase in 8-hour post-load urinary Ca excretion ranged from $0.34 \pm 0.29 \text{mmol} (13.6 \pm 11.8 \text{mg})$ from the NaOx solution and bagel feeding to $1.29 \pm 1.13 \text{mmol} (51.8 \pm 45.3 \text{mg})$ from the Ca-precipitated tofu load. Ca absorption from the soybean and soyfood items ranged from $7.6 \pm 4.3$ to $13.1 \pm 10.9\%$.

### DISCUSSION

Foods containing greater than $0.11 \text{mmol} (10 \text{mg})$ of Ox per serving are considered high-Ox foods. The Ox content of the seven soyfoods tested ranged from $0.14$ to $1.96 \text{mmol} (12$ to $172 \text{mg})$ Ox per serving (Table 3), indicating that all seven of these soy products are high-Ox foods. The primary

<table>
<thead>
<tr>
<th>Soyfood</th>
<th>Pre-load Ox/Cr</th>
<th>Post-load Ox/Cr</th>
<th>P value</th>
<th>Pre-load Ca/Cr</th>
<th>Post-load Ca/Cr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOx (AJ + bagel)</td>
<td>$0.035 \pm 0.008$</td>
<td>$0.176 \pm 0.072$</td>
<td>$&lt;.001$</td>
<td>$0.074 \pm 0.036$</td>
<td>$0.108 \pm 0.058$</td>
<td>.016</td>
</tr>
<tr>
<td>Soybean L95-1116</td>
<td>$0.039 \pm 0.015$</td>
<td>$0.054 \pm 0.032$</td>
<td>.064</td>
<td>$0.096 \pm 0.055$</td>
<td>$0.149 \pm 0.101$</td>
<td>.081</td>
</tr>
<tr>
<td>Soybean L95-1409</td>
<td>$0.033 \pm 0.008$</td>
<td>$0.044 \pm 0.017$</td>
<td>.440</td>
<td>$0.075 \pm 0.042$</td>
<td>$0.173 \pm 0.116$</td>
<td>.031</td>
</tr>
<tr>
<td>TVP</td>
<td>$0.046 \pm 0.023$</td>
<td>$0.062 \pm 0.054$</td>
<td>.270</td>
<td>$0.093 \pm 0.078$</td>
<td>$0.173 \pm 0.125$</td>
<td>.005</td>
</tr>
<tr>
<td>Soynuts</td>
<td>$0.035 \pm 0.014$</td>
<td>$0.042 \pm 0.016$</td>
<td>.292</td>
<td>$0.084 \pm 0.131$</td>
<td>$0.170 \pm 0.140$</td>
<td>.006</td>
</tr>
<tr>
<td>Soy Beverage</td>
<td>$0.045 \pm 0.026$</td>
<td>$0.045 \pm 0.018$</td>
<td>.990</td>
<td>$0.080 \pm 0.060$</td>
<td>$0.175 \pm 0.170$</td>
<td>.073</td>
</tr>
<tr>
<td>Tofu-Ca ppt</td>
<td>$0.044 \pm 0.011$</td>
<td>$0.039 \pm 0.012$</td>
<td>.515</td>
<td>$0.066 \pm 0.040$</td>
<td>$0.201 \pm 0.133$</td>
<td>.018</td>
</tr>
<tr>
<td>Tofu-Mg ppt</td>
<td>$0.043 \pm 0.027$</td>
<td>$0.033 \pm 0.011$</td>
<td>.254</td>
<td>$0.099 \pm 0.079$</td>
<td>$0.153 \pm 0.074$</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Ox/Cr = oxalate per creatinine; Ca/Cr = calcium per creatinine; NaOx = sodium oxalate; AJ = apple juice; TVP = textured vegetable protein; Ca ppt = calcium precipitated; Mg ppt = magnesium precipitated.
Table 5. Urinary oxalate excretion after eating soyfoods or oxalate load (mean ± standard deviation, range and 95% confidence interval)

<table>
<thead>
<tr>
<th>Ox source</th>
<th>Load size</th>
<th>Ox (µmol/g food)</th>
<th>Food Ox (µmol/load)</th>
<th>Total Ox* (µmol/load)</th>
<th>Gross avg. µmol Ox/8-h post-load</th>
<th>Net avg. µmol Ox/8-h* post-load</th>
<th>Calculated percent absorption*</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOx in AJ + bagel</td>
<td>8.3 mmol Ox in 180 mL AJ + 95 g bagel</td>
<td>8,300 ± 57</td>
<td>8,753 ± 398</td>
<td>8,948 ± 398</td>
<td>921 ± 500 (338–1,875)</td>
<td>770 ± 493 (181–1,696)</td>
<td>7.8 ± 5.0 (2–17)</td>
</tr>
<tr>
<td>Soybean L95–1116</td>
<td>93 g*</td>
<td>49 ± 4,568</td>
<td>4,761 ± 7.8</td>
<td>8,753 ± 770</td>
<td>103 ± 59 (0–184) (CI 69–142)</td>
<td>2.2 ± 1.2 (0–3.9)</td>
<td></td>
</tr>
<tr>
<td>Soybean L95–1409</td>
<td>93 g*</td>
<td>42 ± 3,909</td>
<td>4,102 ± 2.2</td>
<td>229 ± 93.9 (97–377)</td>
<td>88 ± 86 (0–223) (CI 30–146)</td>
<td>2.1 ± 2.1 (0–5.4)</td>
<td></td>
</tr>
<tr>
<td>TVP</td>
<td>96 g*</td>
<td>32 ± 3,057</td>
<td>3,250 ± 2.1</td>
<td>278 ± 173 (26–649)</td>
<td>124 ± 156 (0–481) (CI 20–228)</td>
<td>3.8 ± 4.8 (0–15)</td>
<td></td>
</tr>
<tr>
<td>Soynuts</td>
<td>70 g</td>
<td>16 ± 1,114</td>
<td>1,307 ± 5.4</td>
<td>218 ± 54.0 (130–290)</td>
<td>71 ± 55 (16–166) (CI 34–108)</td>
<td>5.4 ± 4.2 (0.7–13)</td>
<td></td>
</tr>
<tr>
<td>Soy Beverage</td>
<td>480 mL</td>
<td>1.6 ± 773</td>
<td>966 ± 4.4</td>
<td>201 ± 52.2 (155–293)</td>
<td>43 ± 61 (0–133) (CI 2–84)</td>
<td>4.4 ± 6.3 (0–14)</td>
<td></td>
</tr>
<tr>
<td>Tofu-Ca ppt</td>
<td>158 g</td>
<td>3.2 ± 500</td>
<td>693 ± 28</td>
<td>175 ± 39.3 (136–253)</td>
<td>28.6 ± 40.0 (0–90) (CI 2–56)</td>
<td>4.1 ± 5.8 (0–13)</td>
<td></td>
</tr>
<tr>
<td>Tofu-Mg ppt</td>
<td>170 g</td>
<td>1.3 ± 216</td>
<td>409 ± 17.6</td>
<td>176 ± 49.0 (98–240)</td>
<td>19.6 ± 23.3 (0–69) (CI 4–36)</td>
<td>4.8 ± 5.7 (0–17)</td>
<td></td>
</tr>
</tbody>
</table>

Ox = oxalate; Avg. = average; NaOx = sodium oxalate; AJ = apple juice; TVP = textured vegetable protein; Ca ppt = calcium precipitated, Mg ppt = magnesium precipitated.

* Boost Plus contained 193 µmol Ox/can.
* Corrected for endogenous Ox excretion.
* All net increases in post-load Ox significant with p < 0.05.
* Percent absorption = net avg. µmol Ox per 8 h/total Ox (µmol/load).
* Dry weight.
### Table 6. Urinary calcium excretion after eating soyfoods or oxalate load (mean, standard deviation, range, and 95% confidence interval)

<table>
<thead>
<tr>
<th>Ca source</th>
<th>Load size</th>
<th>Ca (mmol/g food)</th>
<th>Food Ca (mmol/load)</th>
<th>Total Ca&lt;sup&gt;a&lt;/sup&gt; (mmol/load)</th>
<th>Gross avg. mmol Ca/8-h post-load</th>
<th>Net avg. mmol Ca/8-h post-load&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Calcualted percent absorption&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOx in AJ + bagel</td>
<td>8.3 mmol Ox in 180 mL AJ + 95 g bagel</td>
<td>0.005 + 0.025</td>
<td>3.25</td>
<td>8.25</td>
<td>1.18 ± 0.61 (0.6–2.5)</td>
<td>0.34 ± 0.29 (0–0.8)</td>
<td>[CI 0.14–0.49]</td>
</tr>
<tr>
<td>Soybean L95–1116</td>
<td>93 g&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.07</td>
<td>6.50</td>
<td>11.5</td>
<td>1.47 ± 0.55 (0.6–2.4)</td>
<td>1.00 ± 0.49 (0.3–1.6)</td>
<td>[CI 0.66–1.34]</td>
</tr>
<tr>
<td>Soybean L95–1409</td>
<td>93 g&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.06</td>
<td>5.34</td>
<td>10.3</td>
<td>1.88 ± 1.04 (0.6–3.7)</td>
<td>1.07 ± 1.00 (0.3–3.2)</td>
<td>[CI 0.38–1.76]</td>
</tr>
<tr>
<td>TVP</td>
<td>96 g&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.06</td>
<td>5.99</td>
<td>10.9</td>
<td>1.71 ± 0.71 (0.7–3.0)</td>
<td>0.83 ± 0.47 (0.1–1.4)</td>
<td>[CI 0.51–1.08]</td>
</tr>
<tr>
<td>Soynuts</td>
<td>70 g</td>
<td>0.05</td>
<td>3.48</td>
<td>8.48</td>
<td>1.91 ± 1.34 (0.9–4.2)</td>
<td>1.11 ± 0.92 (0.4–3.1)</td>
<td>[CI 0.48–1.74]</td>
</tr>
<tr>
<td>Soy beverage</td>
<td>480 mL</td>
<td>0.008</td>
<td>3.58</td>
<td>8.58</td>
<td>1.47 ± 0.91 (0.6–3.0)</td>
<td>0.77 ± 0.68 (0–2.0)</td>
<td>[CI 0.30–1.24]</td>
</tr>
<tr>
<td>Tofu-Ca ppt</td>
<td>158 g</td>
<td>0.07</td>
<td>11.4</td>
<td>16.4</td>
<td>2.01 ± 1.26 (0.5–4.7)</td>
<td>1.29 ± 1.13 (0–3.4)</td>
<td>[CI 0.51–2.07]</td>
</tr>
<tr>
<td>Tofu-Mg ppt</td>
<td>170 g</td>
<td>0.02</td>
<td>2.96</td>
<td>7.96</td>
<td>1.76 ± 0.70 (0.9–3.3)</td>
<td>0.70 ± 0.40 (0.1–1.1)</td>
<td>[CI 0.42–0.98]</td>
</tr>
</tbody>
</table>

Ca = calcium; Avg. = average; NaOx = sodium oxalate; AJ = Apple juice; TVP = textured vegetable protein; Ca ppt = calcium precipitated; Mg ppt = magnesium precipitated.

<sup>a</sup> Boost Plus contained 5 mmol Ca/can.
<sup>b</sup> Corrected for basal Ca excretion.
<sup>c</sup> Dry weight.

Percent absorption = net avg. mmol Ca per 8-h/total Ca (mmol/load).
form of Ox in the soyfoods was CaOx, which is virtually insoluble (0.00067 g/100 g in a cold aqueous solution and 0.00140 in hot aqueous solution\(^\text{13}\)).

The form of soluble Ox that the subjects consumed was the NaOx solution. A review of current literature suggests that the mean intestinal absorption efficiency of Ox in healthy subjects ranges between 2–19% when Ox is given as a 2 to 20 mmol (176 to 1,760 mg) load of soluble Na salt during fasting. In this study, the Ox absorption from the NaOx solution ranged from 2–17%. The mean absorption was 7.8 ± 5.0% from an 8.3 mmol load, which is comparable with 6.5%, 6.9%, and 7.3% from 20 mmol, 5 mmol, and 2 mmol NaOx loads\(^8\), and 9% from a 5 mmol NaOx load.\(^{14}\) Ox absorption following ingestion of soybean line L95–1116 (2.2 ± 1.2%), soybean line L95–1409 (2.1 ± 2.1%), TVP (3.8 ± 4.8%), soynuts (5.4 ± 4.2%), soy beverage (4.4 ± 6.3%), Ca precipitated tofu (4.1 ± 5.8%), and Mg precipitated tofu (4.8 ± 5.7%) are consistent with Ox absorption values from foods previously studied by Finch et al\(^\text{10}\) and by Brinkley et al.\(^8,9\)

The net increase in urinary Ox excretion for the NaOx solution was 6- to 39-fold greater than the net increase in urinary Ox excretion for the soybeans and soyfoods. Because the total Ox (mmol/load) to total Ca (mmol/load) ratio is 1.2:1 for the NaOx load compared with 0.04:1 to 0.42:1 for the seven soybean and soyfood loads, this suggests that more free Ox was available for urinary excretion after ingestion of the NaOx load. There was an excess of 1.61 mmol of Ox over Ca (Table 5) and the 0.77 mmol increase in 8-hour Ox excretion after the OL accounted for 48% of the potentially unbound excess Ox.

Individual subject variability in Ox absorption ranged from 1.8–17% for the NaOx load and from a minimum of 0% to a maximum of 17% for the soybean and soyfood OLs. The percent Ox absorption for the two soybeans lines was about one half that of the five soyfoods. This suggests that processing of the soybean into soyfoods makes the CaOx more available. It is possible that CaOx crystals found in intact soybeans are reduced in size and perhaps altered by processing into soy foods.

The percent of Ca absorbed after ingestion of the NaOx load was approximately two- to threefold less than the percent of Ca absorbed from the soybean and soyfood loads. The decreased Ca absorption after consumption of the NaOx load can be explained by the Ox to Ca ratio for the NaOx solution of 1.2:1, indicating that most of the Ca is bound to Ox, leaving less free Ca available for absorption. All seven soybean and soyfood OLs exhibited an Ox to Ca ratio of > 1, suggesting that more free Ca is available for absorption and excretion. The Ca absorption following ingestion of soybeans and soyfoods ranged from 7.6 ± 4.3% to 13.1 ± 10.9%, comparable with 10.0 ± 4.3% after ingestion of a 5 mmol (203 mg) load of \(^{45}\)Ca labeled CaOx obtained by Heaney and Weaver.\(^3\)

The net increase in urinary Ca excretion following ingestion of the Ca precipitated tofu (1.29 ± 1.13 mmol/8 hours = 51.8 ± 45.3 mg/8 hours) is nearly double that of Mg precipitated tofu (0.70 ± 0.40 mmol/8 hours = 28.1 ± 15.9 mg/8 hours), yet the percent Ca absorption after ingestion of both types of tofu are very similar (7.9 ± 6.9% for Ca and 8.8 ± 5.0% for Mg precipitated tofu). Thus, the increase in urinary Ca excretion seems to be proportional to the total Ca content of the tofu because Ca precipitated tofu contained twice as much Ca/load as the Mg precipitated...
Tofu (16.4 mmol = 657 mg per load versus 7.96 mmol = 319 mg per load, respectively).

Both Ca and Mg are bivalent cations capable of binding Ox in the gut, thereby decreasing Ox absorption. A comparison of Ca- and Mg-precipitated tofu suggests that Mg-precipitated tofu exhibits a slightly higher Ox absorption than Ca-precipitated tofu (4.8 ± 5.7% and 4.1 ± 5.8%, respectively). This finding that Ca is more efficient than Mg in reducing urinary Ox absorption and excretion is consistent with Liebman and Costa. Even though Mg-precipitated tofu contains 69% less Ox than Ca-precipitated tofu, the net increase in urinary Ox excretion observed is similar (19.6 ± 23.3 and 28.6 ± 40.0 µmol/8 hours = 1.7 ± 2.1 and 2.5 ± 3.5 mg/8 hours, respectively). Thus, one form of tofu is no better than the other, as consumption of either Ca or Mg precipitated tofu may be a risk factor for recurrent CaOx kidney stone formation.

The authors know of no studies that have looked for an association of rate of kidney stone formation with consumption of soy products. In his review, Trinchieri stated that the recent increases in stone incidence in Asian countries were associated with dietary changes accompanying relative affluence; ie, increases in “Western” foods that are higher in protein and salt. Genetic predisposition to kidney stones is also a factor that has not been studied in Asian populations who traditionally consume larger quantities of soybeans and soyfoods.

In summary, Ox absorption from soyfoods in this study ranged from 2.1 ± 2.1% to 5.4 ± 4.2%. Urinary Ox excretion increased by 19.6 ± 23.3 to 124 ± 156 µmol (1.7 ± 2.1 to 10.9 ± 13.8 mg) during the 8 hours following ingestion of the OLs. Because normal urinary Ox excretion is 110 to 440 µmol (10 to 39 mg) per day, the inclusion of soybeans and soyfoods in the diet is capable of increasing urinary Ox excretion to 450 µmol (40 mg) or more per day, a concentration defined as hyperoxaluria. Thus, frequent consumption of soybeans and soy products (TVP, soynuts, soy beverage, and tofu) may be a risk factor for CaOx kidney stone formation in susceptible individuals, such as those with a prior history of Ca stones, high normal urinary Ox concentrations, or intestinal disease.

REFERENCES