Soy foods have low glycemic and insulin response indices in normal weight subjects

Robert M. Blair, Ph.D.*, E.C. Henley, Ph.D., Aaron Tabor, M.D.

Physicians Pharmaceuticals, Inc., 1031 E. Mountain St., Building 302, Kernersville, NC 27284

*Corresponding author

Email addresses:

RMB: drblair@revivalsoy.com

ECH: henleyec@aol.com

AT: drtabor@revivalsoy.com

Corresponding Author:

Robert M. Blair, Ph.D.

Research Manager

Physicians Pharmaceuticals, Inc.

1031 E. Mountain St., Building 302

Kernersville, NC 27284

Telephone: 336-722-2337, x1734

Fax: 336-722-7712

Abstract

Background

Foods with a low glycemic index (GI) may provide a variety of health benefits. The objective of the present study was to measure the GI and insulin index (II) of select soy foods.

Methods

The study was conducted in two parts with low-carbohydrate products being tested separately. In Experiment 1, subjects averaged 23.2 years of age with BMI = 22.0, while subjects in Experiment 2 averaged 23.9 years of age with BMI = 21.6. The reference (glucose) and test foods were served in portions containing 10 g of carbohydrates in Experiment 1 and 25 g of carbohydrates in Experiment 2. Subjects consumed the reference food twice and each test food once. For each test, subjects were instructed to consume a fixed portion of the reference food or test food together with 250 g of water within 12 min. Blood samples were collected before each test and at 15, 30, 45, 60, 90, and 120 min after consumption of reference or test foods to quantify glucose and insulin. Two-hour blood glucose and plasma insulin curves were constructed and areas under the curves were calculated. GI and II values for each subject and test food were calculated. Analysis of variance and the Fisher PLSD test for multiple comparisons were used to test for significant differences between the test foods' mean GI and II values.

Results

In Experiment 1, both low-carbohydrate soy foods were shown to have significantly ($P < 0.05$) lower GI and II values than the reference food. In Experiment 2, three of

the four test foods had significantly ($P < 0.05$) lower GI and II values than the reference food.

Conclusions

All but one of the soy foods tested had a low GI, suggesting that soy foods may be an appropriate part of diets intended to improve control of blood glucose and insulin levels.

Background

The glycemic index (GI) was first developed by Jenkins and colleagues (1) as a new method of classifying foods based on the blood glucose response after food consumption. The GI value of a food is a percentage of the 2-hour area under the blood glucose response curve of a reference food, typically glucose (2). Since the GI is determined for a particular quantity of carbohydrates in the food being tested and since the actual amount of carbohydrates consumed in a meal or snack varies greatly, the GI concept was expanded to include the concept of glycemic load (GL). The GL is determined by multiplying the GI of a food by the grams of carbohydrates in a serving. The GL value incorporates the amount of digestible carbohydrates in a serving in order to better gauge the impact of a meal or snack on postprandial glucose response (3, 4).

It has been reported that a high GI diet has adverse health consequences (5-7). Recent evidence suggests that high GI/GL diets may increase the risk for cardiovascular disease (CVD) (8-11), type 2 diabetes (3, 4, 12, 13), and cancer (14-22). A high GI diet may increase the risk for chronic disease through the stimulation of hyperglycemia and hyperinsulinemia (6).

In contrast, a low GI diet has been reported to have health benefits (5, 6, 23-25). A low GI diet has been shown to improve glycemic control (26-33), aid in weight loss (34, 35), and reduce some CVD risk factors (10, 26-28, 36-40).

To date, only about 30 – 40 soy foods have been assessed for their GI/GL values (1, 41-44). The objective of the current study was to determine the GI and II values of select soy food products (bars, drinks, pasta, and chips) currently available on the market.

Methods

The current study was conducted using internationally recognized GI methodology (45), which has been validated by results obtained from small experimental studies and large multi-centre research trials (46). The experimental procedures used in this study were in accordance with international standards for conducting ethical research with humans and were approved by the Human Research Ethics Committee of Sydney University where the study was conducted by contract.

Study Subjects

For both Experiments, 10 healthy, non-smoking subjects, 18-45 years old, were recruited from the staff and student population of the University of Sydney. Exclusion criteria included being overweight, dieting, impaired glucose tolerance, illness or food allergy, or regular use of prescription medication (other than contraceptive medication).

In Experiment 1 the 10 subjects (two females, eight males) had a mean age of 23.2 years (19.9–25.7 years) and a mean body mass index (BMI) score of 22.0 kg/m^2

(19.4–25.0 kg/m^2). In Experiment 2 the 10 subjects (four females, six males) had a mean age of 23.9 years (20.3–26.9 years) and a mean BMI score of 21.6 kg/m^2 (19.5–25.0 kg/m^2). Four subjects participated in both experiments.

Composition of Test Foods

In Experiment 1, the reference and two low-carbohydrate test foods (products with ≤6 g net carbohydrates; net carbohydrates = total carbohydrates – other carbohydrates – fiber) were served to subjects in portions containing 10 g of digestible carbohydrate. In Experiment 2, the reference and four test foods were served to subjects in portions containing 25 g of carbohydrate. Glucose (Glucodin® powder, Boots Health Care Company, North Ryde, NSW) dissolved in water was the reference food. Weights and nutrient contents of the reference and test foods (Revival Soy® from Physicians Pharmaceuticals, Inc., Kernersville, NC, USA) are listed in **Tables 1** and **2**.

Each portion of the reference food was prepared the day before required by dissolving the glucose in 250 g of water and storing overnight at 4 ^{o}C. The individual portions of the test foods were prepared the day before required, except for the soy spaghetti. The individual portions of the uncooked soy spaghetti were weighed the day before required. On the testing day, each portion of dry spaghetti was cooked for 4 minutes in boiling water and drained. The reference and test foods were served with 250 g of plain water. The subjects consumed all the food and fluid served to them at a comfortable pace within 12 minutes.

Experimental Procedures

The experimental methods used in the current study have been previously described (47) and are briefly outlined here. In both experiments, study subjects consumed the reference food on two separate occasions and each of the test foods on one occasion only after a 10-hour overnight fast. The reference food was consumed on the first and last test sessions, and test foods were consumed in random order in between. Each test session was completed on a separate morning with at least a day between subsequent sessions.

On each test day a baseline, finger-prick blood sample was obtained for blood glucose and plasma insulin determinations using an automatic, non-reusable lancet device (Safe-T-Pro®, Boehringer Mannheim Gmbh, Mannheim, Germany). Following consumption of the reference or test food, additional blood samples were collected at 15, 30, 45, 60, 90 and 120 minutes. Blood glucose concentrations were measured immediately after the blood samples were collected. Blood samples collected for plasma insulin determination were centrifuged for 30 seconds immediately after collection and the plasma layer from each sample was transferred into a labeled, uncoated microcentrifuge tube and stored at -20 ^{o}C until analyzed.

Blood Glucose and Glycemic Index Determinations

The glucose concentration in each sample was analyzed in duplicate using a HemoCue® B-glucose photometric analyzer employing a glucose dehydrogenase/mutarotase enzymatic assay (HemoCue AB, Ängelholm, Sweden). A two-hour blood glucose response curve was constructed and the area under the glucose response curve (AUC) was calculated. The GI value for each test food was calculated for each subject by dividing the two-hour blood glucose AUC value for the test foods by their average two-hour blood glucose AUC value for the reference food and multiplying by 100 to obtain a percentage score. The final reported GI value for each test food is the mean GI value for that food in the group of 10 subjects.

Plasma Insulin and Insulin Index Determinations

The concentration of insulin in each plasma sample was analyzed using a solid-phase antibody-coated tube radioimmunoassay kit (Diagnostic Products Corporation, Los Angeles, CA, USA). A two-hour plasma insulin response curve was constructed from the data and the area under the plasma insulin response curve (AUC) was calculated. An insulin index (II) value for each test food was calculated for each subject by dividing their plasma insulin AUC value for the test foods by their mean plasma insulin AUC value for the reference food and multiplying by 100 to obtain a percentage score.

Statistical Analyses

Sample size calculations (90% power, level of significance = 0.05) using data from published GI studies indicated that a minimum of eight study subjects would be needed to detect significant differences among the GI values of the reference and test foods. Analysis of variance (ANOVA) and the Fisher PLSD test for multiple comparisons were used to determine significant differences between the test foods' mean GI and II values. Statistical analyses were conducted using Statview Student™

Software (version 4, Abacus Concepts Inc., Berkley, CA, USA). Significance was assumed at $P < 0.05$.

Results

Experiment 1: Low-Carbohydrate Foods

The mean blood glucose response curves for the reference and two test foods are shown in **Figure 1**. The reference food produced a much larger rise in blood glucose during the first 30 minutes and a greater overall glycemic response than the two test foods. The two test foods produced slightly different glucose response curves with the Chocolate Raspberry Zing™ bar producing a higher glycemic response than the Chocolate Daydream™ sucralose shake. However, both foods produced very low glycemic response curves.

The mean plasma insulin response curves for the reference and two test foods are shown in **Figure 2**. The plasma insulin responses observed for the reference food and the test foods are directly proportional to their concurrent blood glucose responses. The reference food produced the highest peak plasma insulin concentration and the largest overall plasma insulin response, followed by the Chocolate Raspberry Zing™ bar and the Chocolate Daydream™ sucralose shake, respectively.

Experiment 2: Non-Low-Carbohydrate Foods

The mean blood glucose response curves for the reference and the four test foods are shown in **Figure 3**. Similar to the results observed in Experiment 1, the reference food produced a large rise in blood glucose during the first 30 minutes and the greatest overall glycemic response. The four test foods varied in their peak blood glucose concentrations and their overall glycemic responses. Among the test foods, the soy pasta chips produced the largest glycemic response followed by the Peanut Butter Chocolate Pal^{TM} bar, the soy spaghetti, and the Chocolate Daydream^{TM} fructose shake.

The mean plasma insulin response curves for the reference and the four test products are shown in **Figure 4**. The foods' average plasma insulin responses were similar to their respective mean plasma glucose responses. The reference food produced the largest plasma insulin response, followed by the four test foods in the same order as their glycemic responses.

Glycemic and Insulin Indices

The mean GI value of the glucose reference was significantly greater ($P < 0.001$) than the mean GI values of each of the test foods with the exception of the baked soy pasta chips (**Figure 5**). The mean GI value of the soy pasta chips was not different from the glucose reference, but was significantly greater ($P < 0.001$) than the mean GI values for the other five test foods. Despite a high GI value, the soy pasta chips had only a medium GL value due to the small serving size and relatively low carbohydrate level (**Table 3**).

The mean II value of the glucose reference was significantly greater ($P < 0.001$) than the mean II values of each of the six test foods (**Figure 5**). The mean II of the soy pasta chips was significantly higher ($P < 0.001$) than the mean II values for the soy spaghetti, Chocolate Daydream™ fructose shake, Chocolate Raspberry Zing™ bar, and the Chocolate Daydream™ sucralose shake. The mean II values for the Peanut Butter Chocolate Pal™ bar and the Chocolate Raspberry Zing™ bar were both significantly greater ($P < 0.001$) than the mean II values for the Chocolate Daydream™ fructose and Chocolate Daydream™ sucralose shakes.

Discussion

The results of this study demonstrate that 5 of the 6 soy food products tested have a low GI value (GI < 55). Of the 6 products tested, only the baked soy pasta chips had a high GI value (GI > 70). However, when the amount of available carbohydrates in one serving of the soy pasta chips was used to calculate a GL value, the soy pasta chips had a medium GL value. The other products tested also were either low or medium GL foods.

An increasing body of evidence suggests that the GI and/or GL values of foods impact human health (see 5-7, 23, 25, 48, and 49 for reviews). Recent evidence suggests that high GI diets may increase the risk for CVD (8-11), type 2 diabetes (11, 12), and a variety of cancers (14-22). In contrast, low-GI diets have been reported to have a variety of health benefits. Low-GI diets have been shown to improve glycemic control in diabetic (26-30) and non-diabetic (31-33) subjects, aid in weight loss (34, 35) and reduce some CVD risk factors (10, 26-28, 36-40).

Diet impacts the incidence of type 2 diabetes and the regulation of dietary carbohydrate has taken on a prominent role in dietary control of this chronic disease. Recent studies have reported that a high dietary GI is significantly associated with increased risk of type 2 diabetes in men and women (12, 13). It has also been demonstrated that high GL diets are positively associated with diabetes risk (3, 4). In contrast, two recent meta-analyses (24, 50) reported that consumption of low-GI foods rather than high-GI foods appears to modestly improve glycemic control by reducing plasma cholesterol, fructosamine, and hemoglobin A_{1C} (Hb_{A1c}) levels. These benefits may be mediated via improved glucose profiles (6, 51) and increased plasma adiponectin levels (52).

A number of studies suggest that high GI/GL diets may increase CVD risk (8-11), while several others indicate that low GI diets may reduce some CVD risk factors (10, 26-30, 36-40). A recent cross-sectional study demonstrated that Japanese women in the highest tertile of dietary GI had reduced high-density lipoprotein cholesterol (HDL-C) and higher triglycerides and insulin compared to those in the lowest dietary GI tertile (10). However, no associations were found for other CVD risk factors including total cholesterol, low-density lipoprotein cholesterol (LDL-C), fasting glucose, and BMI. In a separate study, a low-GI *ad libitum* diet stimulated a reduction in plasma triacylglycerols and plasminogen activator inhibitor – 1 compared to the energy-restricted control diet (53). The results of a meta-analysis indicated that low GI diets significantly reduced total cholesterol (average reduction = 0.17 mmol/L;

P = 0.03) and HbA_{1c} (average reduction after 12 weeks = 0.45%; P = 0.02) compared to high GI diets (54). However, no differences were observed for HDL-C, LDL-C, triglycerides, fasting glucose, or fasting insulin levels. These data suggest that dietary GI may improve some, but not all markers of cardiovascular disease risk.

Few studies have examined the effect of low GI diets on weight loss; however, there is some evidence that low GI diets may be beneficial (25, 49). In obese women, an energy-restricted, low GI diet significantly increased weight loss compared to an energy-restricted, high GI diet (34). Spieth and co-workers (35) demonstrated that an *ad libitum* low GI diet significantly ($P < 0.05$) reduced BMI to a greater extent than did an energy-restricted, low fat diet. A recent study demonstrated that dietary GI was inversely associated with thigh intramuscular fat while GL was inversely associated with visceral abdominal fat in men (55). It has been suggested that weight loss benefits may be due to increased satiety of low GI diets (56-57). An interim meta-analysis suggests that weight loss benefits of low GI diets in relation to high GI diets may only be present under conditions of *ad libitum* consumption (25). Despite the potential benefits of low-GI diets on weight loss, a number of studies report no effect on weight loss (53, 58, 59) or satiety (60).

A number of epidemiological studies have reported that an increased dietary GI and/or GL increased the risk for colorectal cancer (14, 15, 21, 22). In these studies, the relative risk (RR) in the highest GI groups ranged from 1.32-2.85 for colorectal cancer. Similarly, women with a high dietary GL had a 53% increase in pancreatic cancer risk with this risk being even greater in sedentary, overweight women (RR = 2.67). However, other studies have reported a lack of association between dietary

GI/GL and these cancers (61-63). Other cancers that may be associated with high dietary GI include breast, stomach, endometrial, and ovarian cancers (16-19). This potential increase in cancer risk may be due to dietary modulation of the insulin-like growth factor system (5, 64)

Dietary soy consumption has been shown to have beneficial effects on several aspects of human health, including the diseases potentially influenced by dietary GI levels (65-67). The health benefits of dietary soy have been attributed to its isoflavones as well as to the biological actions of its constituent proteins. However, an additional means of providing health benefits may be through the low GI of soy and soy foods.

The international table of GI and GL values (43) reports the GI/GL values of a number of soy foods. These values range from a low GI of 14 for soybeans canned in brine to a high GI of 115 for a tofu-based frozen dessert (41). The Revival Soy® products tested in this study fell within this range and with the exception of the baked soy pasta chips were all within the low GI category. Only a few other studies have reported on the GI of soy-based foods. Packer et al. (42) indicated that gluten-free, soy-based, bread had a high GI value. In contrast, the addition of soy foods has been shown to lower the GI value of mixed meals (44). Similarly, the replacement of unrefined wheat flour with soy flour lowers the GI value of parantha, an Indian snack food (68). Similar to the Revival Soy® bars tested in the current study, other snack bars containing soy have been shown to have low to medium GI values (69). Previous data report that the GI values of spaghetti ranges from 27 – 68. The Revival Soy® thin spaghetti had a GI value = 47, similar to other spaghetti products. Overall, these studies indicate that soy-based foods generally have a low to medium GI value and would be suitable for individuals concerned with regulating blood glucose and insulin levels.

The ingredients and form of a food product affect its GI value. For example, while soybeans have a low GI value, the use of high GI ingredients in soy foods can increase the GI value of the final product. This was likely the case with the baked soy pasta chips. The baked soy pasta chips contain potato starch and potatoes have a high GI value (43). Additionally, the baked soy pasta chips have a puffed physical form, which may lead to high GI values. Similar to planning diets with types of fat and protein in mind, types of carbohydrates should also be considered since carbohydrate types influence the GI. The substitution of high GI ingredients with low GI ingredients in food products like the baked soy pasta chips may help keep the final GI value down.

In addition to the effects of form and content of foods on the GI value, consumption of other foods with low GI foods can affect the overall GI value of meal. Sugiyama et al. (44) demonstrated that adding soybean products (miso, natto, and ground soybean) lowered the GI of white rice by 20 – 40%. However, further studies are required before any conclusions can be drawn.

Conclusions

With the apparent resurgence of interest in low-GI diets for weight loss and health benefits, it is important that information on the GI value of foods is available.

Therefore, we conducted the current study to determine the GI value of a small variety of commercially available soy foods. The results of the current study demonstrate that soy food products generally have low GI values and low to medium GL values. Improvements in ingredient selection and usage may further improve glycemic responses to soy foods. The low GI of soy foods appears to be an additional benefit of soy for human health and suggests that soy foods are an appropriate part of diet plans intended to improve control over blood glucose and insulin levels.

Competing interests

Dr. Blair is the Research Manager of Physicians Pharmaceuticals, Inc. Dr. Henley is a consultant to Physicians Pharmaceuticals, Inc. Dr. Tabor is the CEO and Medical Research Director of Physicians Pharmaceuticals, Inc.

Authors' contributions

RMB prepared the manuscript. ECH and AT participated in the coordination and design of the study and assisted with manuscript preparation.

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Figures

Figure 1 - Blood glucose response curves of low-carbohydrate soy products in Experiment 1.

The mean blood glucose response curves for the equal-carbohydrate portions of the reference food (glucose) and the two soy-based, low-carbohydrate food products tested in Experiment 1. Data are expressed as the change in blood glucose concentration from the fasting baseline concentration. Bars for each data point represent standard error of the means (SEM).

Figure 2 - Plasma insulin response curves of low-carbohydrate soy products in Experiment 1.

The mean plasma insulin response curves for the equal-carbohydrate portions of the reference food (glucose) and the two soy-based, low-carbohydrate food products tested in Experiment 1. Data are expressed as the change in plasma insulin concentration from the fasting baseline concentration. Bars for each data point represent standard error of the means (SEM).

Figure 3 - Blood glucose response curves of soy products in Experiment 2.

The mean blood glucose response curves for the equal-carbohydrate portions of the reference food (glucose) and the four soy-based food products tested in Experiment 2. Data are expressed as the change in blood glucose concentration from the fasting baseline concentration. Bars for each data point represent standard error of the means (SEM).

Figure 4 - Plasma insulin response curves of soy products in Experiment 2.

The mean plasma insulin response curves for the equal-carbohydrate portions of the reference food (glucose) and the four soy-based food products tested in Experiment 2. Data are expressed as the change in plasma insulin concentration from the fasting baseline concentration. Bars for each data point represent standard error of the means (SEM).

Figure 5 - Glycemic and insulin index values of tested soy products

The mean (± SEM) glycemic index and insulin index for the reference food (glucose) and the six tested soy-based food products. The dark bars represent the glycemic index values and the light bars represent the insulin index values.

Tables

Table 1 - Weights and nutrient contents of the test portions of the glucose reference and the two test foods in Experiment 1.

Test Food	Portion Size (g)	Energy (kJ [Cal])	Protein (g)	Fat (g)	Available Carbohydrate (g)	Sugars (g)	Fiber (g)
Glucose (Reference Food)	10.0 g glucose 250 g water	160 [38.2]	0.0	0.0	10.0	10.0	0.0
Chocolate Raspberry Zing^{TM} bar	150.0	2205 [526.7]	45.0	12.5	10.0	0.0	< 2.0
Chocolate Daydream^{TM} shake - sucralose	70.0 g powder 500.0 g water	1092 [260.8]	40.0	5.0	10.0	2.0	4.0

Table 2 - Weights and nutrient contents of the test portions of the glucose reference and the four test foods in Experiment 2.

Test Food	Portion Size (g)	Energy (kJ [Cal])	Protein (g)	Fat (g)	Available Carbohydrate (g)	Sugars (g)	Fiber (g)
Glucose (Reference Food)	25.0 g glucose 250 g water	400 [95.5]	0.0	0.0	25.0	25.0	0.0
Peanut Butter Chocolate Pal™ bar	48.4	813 [194.2]	12.9	4.8	25.0	14.5	0.8
Chocolate Daydream™ shake – fructose	47.1 g powder 305.0 g water	742 [177.2]	14.7	1.8	25.0	23.6	1.5
Lightly Salted Sunshine™ soy pasta chips	48.1	808 [193/0]	13.5	3.8	25.0	0.0	0.0
Soy spaghetti	42.4 (dry)	636 [151.9]	10.6	1.1	25.0	1.5	0.8

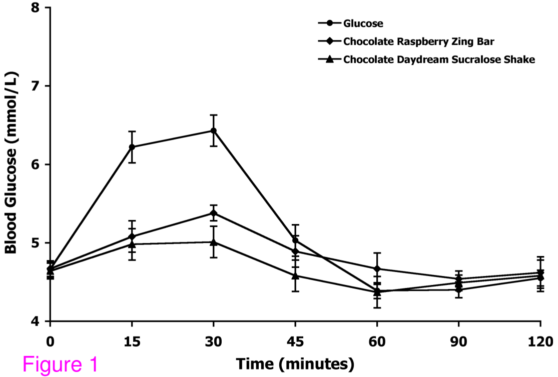
Table 3 - Glycemic index and glycemic load[1] values for the six tested soy food products.

	Glycemic Index			Glycemic Load	
Test Food	Value ± SEM	Category[2]	Carbohydrates /Serving (g)	Value	Category[3]
Chocolate Daydream™ shake – sucralose	25.00 ± 4.28	Low	5	1.25	Low
Chocolate Daydream™ shake – fructose	32.73 ± 4.41	Low	34	11.13	Medium
Soy spaghetti	47.03 ± 7.48	Low	33	15.52	Medium
Chocolate Raspberry Zing™ bar	47.42 ± 4.55	Low	6	2.85	Low
Peanut Butter Pal™ bar	51.82 ± 3.86	Low	31	16.06	Medium
Lightly Salted Sunshine™ soy pasta chips	86.79 ± 7.86	High	13	11.28	Medium

[1]Glycemic Load = (GI x net carbohydrates)/100

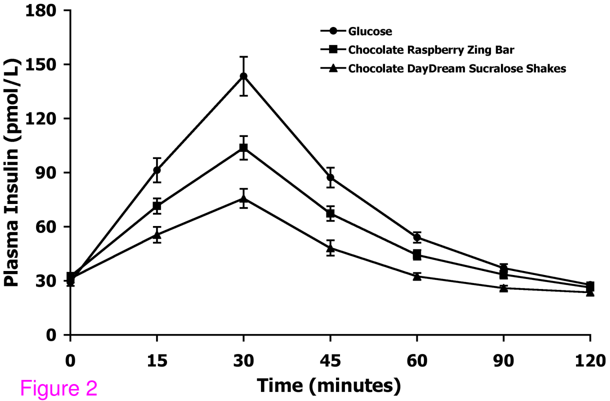
[2]Glycemic Index Category: Low = < 55; Medium = 56 – 69; High = > 70

[3]Glycemic Load Category: Low = < 10; Medium = 11 – 19; High = > 20



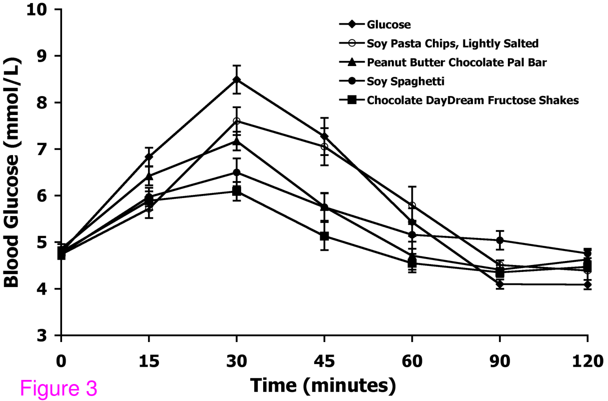
Glucose
Chocolate Raspberry Zing Bar
Chocolate Daydream Sucralose Shake
Blood Glucose (mmol/L)
8
7
6
5
4
0
15
30
45
60
90
120
Time (minutes)

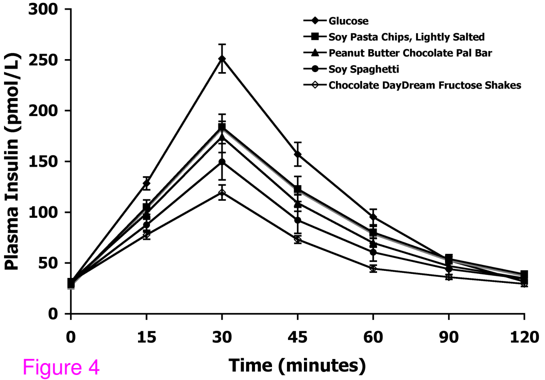
Figure 1



Glucose
Chocolate Raspberry Zing Bar
Chocolate DayDream Sucralose Shakes
Plasma Insulin (pmol/L)
180
150
120
90
60
30
0
0
15
30
45
60
90
120
Time (minutes)

Figure 2


Glucose
Soy Pasta Chips, Lightly Salted
Peanut Butter Chocolate Pal Bar
Soy Spaghetti
Chocolate DayDream Fructose Shakes
Blood Glucose (mmol/L)
10
9
8
7
6
5
4
3
0
15
30
45
60
90
120
Time (minutes)
Figure 3



Glucose
Soy Pasta Chips, Lightly Salted
Peanut Butter Chocolate Pal Bar
Soy Spaghetti
Chocolate DayDream Fructose Shakes
Plasma Insulin (pmol/L)
0
50
100
150
200
250
300
0
15
30
45
60
90
120
Time (minutes)

Figure 4

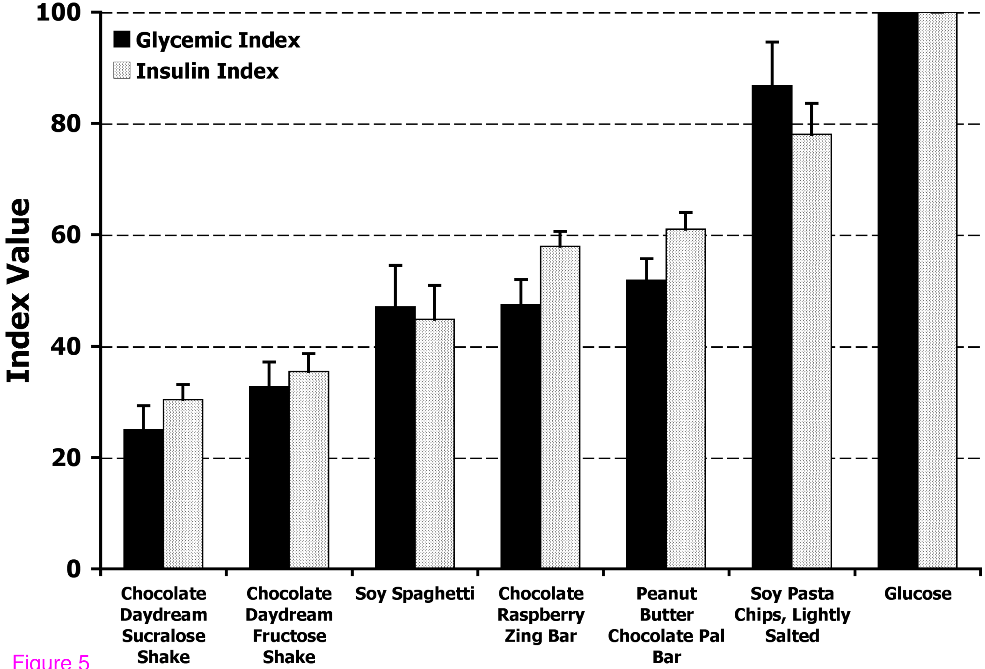

100
80
60
40
20
0
Index Value
Glycemic Index
Insulin Index
Chocolate Daydream Sucralose Shake
Chocolate Daydream Fructose Shake
Soy Spaghetti
Chocolate Raspberry Zing Bar
Peanut Butter Chocolate Pal Bar
Soy Pasta Chips, Lightly Salted
Glucose

Figure 5