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# The effects of a new soluble dietary fiber on weight gain and selected blood parameters in rats

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**Abstract**

This study was designed to investigate a new dietary fiber, α-cyclodextrin, marketed under the trade name FBCx (Wacker Biochem, Adrian, MI), for beneficial effects on weight reduction and the improvement of certain blood parameters in rats. Male Wistar rats were divided into 4 groups and fed ad libitum for a period of 6 weeks: (1) a normal low-fat diet (LF; 4% fat wt/wt); (2) an LF diet with FBCx added; (3) a high-fat diet (HF, 40% fat wt/wt); and (4) an HF diet with FBCx. The FBCx was added at the rate of 10% (wt/wt) of the fat in the diet. Body weight and food intake were recorded 3 times per week. Plasma constituent levels and liver and fecal lipid contents, as well as body composition were determined at sacrifice. Adding FBCx to the diet significantly reduced weight gain in rats fed with an HF diet relative to rats fed with the HF control diet ($P < .05$). FBCx also elicited a reduction in plasma triglyceride levels of 30%, total cholesterol of 9%, and increased the fat content of the feces in the rats fed with the HF diet with FBCx. In addition, the serum leptin levels were normalized, and the calculated insulin sensitivity was improved. No adverse effects were observed in the rats consuming FBCx. It would appear that FBCx might be effective in reducing body weight gain and improving metabolic syndrome.


## 1. Introduction

The prevalence of obesity and diabetes has increased dramatically over the past decade. It is reported that in the year 2000, more than 64% of the US population was either overweight or obese [1]. This represents an increase of more than 15% relative to the 1988 to 1994 levels of 55.9%. The prevalence of type 2 diabetes mellitus in 2001 was 7.9%, a 61% increase over the 1990 figures of 4.9% [2]. The total health care cost associated with diabetes reached $98 billion in 1997, whereas the cost associated with obesity was predicted to be $117 billion in 2000 [3]. It would appear obvious that the incidence of diabetes and obesity has reached epidemic proportions [4]. It might be assumed that if nothing is done to control these epidemics, the health consequences and the burden to the health care system will be staggering.

Pharmaceutical treatments for obesity have been developed. At present, there are only 2 Food and Drug Administration (FDA)–approved long-term–use antiobesity drugs, orlistat and sibutramine. The mode of action for orlistat is to inhibit pancreatic lipase activity in the small intestine. When taken in conjunction with a hypoenergetic diet, this drug can induce modest weight loss and better weight maintenance than diet alone [5]. However, in the absence of major dietary changes, the adverse effects of gastrointestinal discomfort, flatulence, and diarrhea have limited its use [5]. In addition, its long-term efficacy and safety have not been established [6]. Sibutramine, a serotonin and norepinephrine reuptake inhibitor, reduces body weight by suppressing appetite [7]. The FDA has approved it for the treatment of obesity for up to 2 years. Because it inhibits the reuptake of norepinephrine, it may

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increase blood pressure. Therefore, it is contraindicated for use in some obese patients [7,8]. Other side effects of sibutramine include increased heart rate, insomnia, constipation, headache, abdominal pain, and so on. For normotensive obese patients, sibutramine, in combination with diet and behavioral modifications, has been demonstrated to have beneficial effects [9].

Although type 2 diabetes mellitus is associated with excess body weight, there are other metabolic abnormalities observed in obesity that may contribute to the onset of type 2 diabetes mellitus. Obese individuals tend to be hyperlipidemic, hyperinsulinemic, hyperleptinemic, and insulin-resistant, all of which have been shown to increase the risk of developing type 2 diabetes mellitus [10,11]. Therefore, a reduction in the severity of any of these abnormalities should also reduce the risk of developing type 2 diabetes mellitus.

The effects on human weight reduction by various dietary supplements, including several of the commonly consumed fibers, have been the subject of several reviews [12,13]. Although Howarth et al [12] report that the addition of 14 g/d of either soluble or insoluble fiber increases postmeal satiety and causes a modest decrease in body weight, both Pittler and Ernst [13] and Egger et al [14] suggest that there is little evidence that the commonly available fiber supplements, such as chitosan, have any beneficial effects on human health.

Given that we are in the midst of an obesity epidemic, high-fat (HF) diets promote obesity in humans and animals [15,16], and obese people tend to prefer HF foods [17]; any substance, for example, a fiber, that can reduce the absorption of dietary fat without the unwanted side effects of the current medications should have significant health benefits. FBCx (generically known as α-cyclodextrin; Wacker Biochem, Adrian, MI) is a soluble fiber derived from corn. The World Health Organization has given it an acceptable daily intake of "not specified." Furthermore, based on the safety data presented [18-21], this material was recently granted Generally Recognized As Safe status by the FDA. FBCx has been shown to bind with free fatty acids in aqueous solution [22]. Based on this property of FBCx, this study was designed to test the hypothesis that by feeding rats with an HF diet with FBCx, dietary fat absorption would be reduced. As a result, body weight gain would be reduced in growing animals.

It is worth mentioning that more than 20 years ago, Suzuki and Sato [23] described the use of what they referred to as α-cyclodextrin as an indigestible carbohydrate substitute for weight loss. At levels significantly higher than what are proposed here, they found small beneficial effects to this substitution. It is of note that what Suzuki and Sato [23] used in their studies was actually a mixture of *n*-dextrin/α-cyclodextrin/β-cyclodextrin/γ-cyclodextrin (50:30:15:5); thus, it is impossible to establish what effects individual dextrins or their mixtures contributed to their study. Moreover, they meal-fed this mostly indigestible fiber to rats for only 2 h/d. Undernutrition/malnutrition may account for the effects they reported.

## 2. Methods

### 2.1. Animals

Forty-two 10-week-old male Wistar rats were purchased from Harlan (Indianapolis, IN). They were housed in polycarbonate cages with wood shaving bedding within a climate-controlled colony room. They had access to the designated diet and water ad libitum.

### 2.2. Diets

Four diets were used in this study. The control or low-fat (LF) diet was formulated according to AIN-93M diet and contains 4% (wt/wt) soybean oil as the fat source [24]. The HF diet, a modification of the LF, was prepared to contain 40% (wt/wt) soybean oil. In anticipation that the rats on the HF diet might not consume as much food as those on the LF diet because of its higher energy content [25], the protein, vitamin, and mineral content of the HF diet were increased to avoid deficiencies. α-Cyclodextrin (FBCx; Wacker Biochem) was added to these diets in the amount of 10% (wt/wt) of the fat content of the food. All diets were prepared by Dyets (Bethlehem, PA) and stored in a cold room until use. The composition of these 4 diets is shown in Table 1.

### 2.3. Procedures

After a 1-week adaptation period, during which time the animals were fed the control LF diet, all of the rats were divided equally into LF-diet and HF-diet groups. These 2 groups were further divided into 2 subgroups based upon the presence or absence of FBCx in their diets. Thus, 4 groups were formed: HF control (HF; n = 10), HF diet with FBCx (HF-FBCx; n = 11), LF control (LF; n = 10),

Table 1
Diet composition of the 4 diets used in this study (g/kg)

| | LF | LF-FBCx | HF | HF-FBCx |
|---|---|---|---|---|
| Casein | 140 | 140 | 210 | 210 |
| Cornstarch | 410.692 | 406.692 | 55.530 | 15.530 |
| Dextrinized cornstarch | 135 | 135 | 10 | 10 |
| Maltose dextrin | 175 | 175 | 175 | 175 |
| Cellulose | 50 | 50 | 75 | 75 |
| FBCx | – | 4 | – | 40 |
| Mineral mix | 35 | 35 | 52.5 | 52.5 |
| Vitamin mix | 10 | 10 | 15 | 15 |
| Vitamin E acetate (500 IU/g) | 0.00 | 0.00 | 0.39 | 0.39 |
| Soybean oil | 40 | 40 | 400 | 400 |
| TBHQ | 0.008 | 0.008 | 0.08 | 0.08 |
| L-Cystine | 1.8 | 1.8 | 2.7 | 2.7 |
| Choline bitartrate | 2.5 | 2.5 | 3.8 | 3.8 |
| Energy (kJ/g) | 16.57 | 15.31 | 23.85 | 23.39 |
| % Energy from fat | 9.5 | 9.5 | 66.5 | 68.6 |

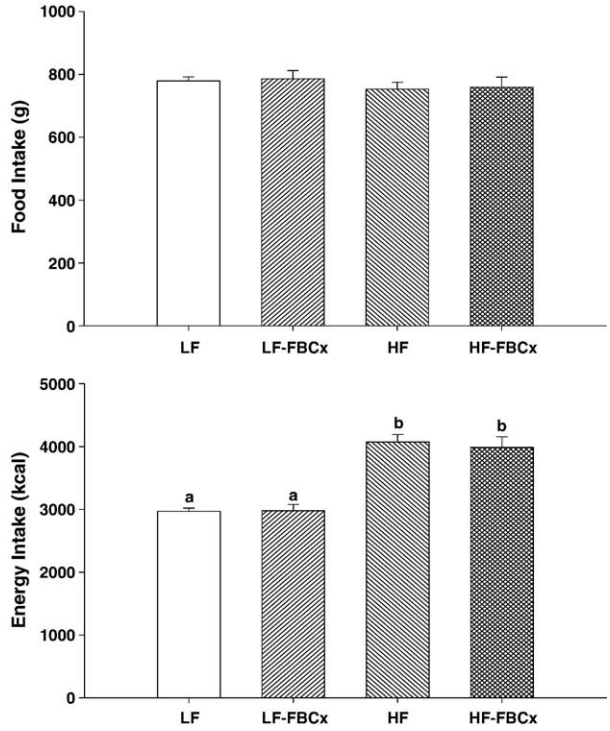


Fig. 1. Top, Total amount of food consumed by the 4 groups of rats over the 6-week period of the study. The 4 groups are identified by their respective diets as LF, LF-FBCx, HF, and HF-FBCx. Bottom, Total energy consumed by the 4 groups of rats over the 6-week period of the study. The 4 groups are identified by their respective diets as LF, LF-FBCx, HF, and HF-FBCx. There is a significant difference among those groups with different superscripts.

and LF diet with FBCx (LF-FBCx; n = 11). The study proceeded for 6 more weeks. Food intake and body weight were measured twice weekly. In the last week of the study (week 6), they were housed individually in metabolic cages to facilitate urine and feces collection for the last 3 days of the study. At the end of the sixth week, all rats were fasted overnight. The next morning, they were killed by decapitation after a brief exposure to carbon dioxide. Trunk blood and the livers were collected from each animal. The bodies were eviscerated, and all visible fat from the abdominal cavity was collected and weighed. This fat was considered as internal fat. The carcass was frozen for body composition analysis at a later date. This protocol was approved by the Animal Investigation Committee of Wayne State University.

### 2.4. Measurement of collected samples

#### 2.4.1. Blood plasma parameters

Glucose concentrations were measured with a glucose oxidase–based method from Pointe Scientific (Lincoln Park, MI). High-density-lipoprotein cholesterol (HDL-C) levels were determined with the AUTOHDL-C reagent available from Pointe Scientific. Insulin levels were determined using a radioimmunoassay kit purchased from ICN Pharmaceuticals (Costa Mesa, CA). Leptin levels were assayed using a rat-specific radioimmunoassay kit purchased from Linco Research (St. Charles, MO).

#### 2.4.2. Liver and fecal triglyceride determinations

Frozen liver samples were homogenized, and lipid was extracted using a chloroform/methanol mixture. Total lipid in feces was extracted from dried and ground fecal samples. Both liver and fecal lipid content was determined using the method described by Folch et al [26].

#### 2.4.3. Body composition analysis

Body composition was measured on the eviscerated carcasses according to the method described by Jen [27]. In brief, each carcass was shaved, autoclaved, and homogenized with a Polytron homogenizer (Brinkmann, Westbury, NY). Aliquots of the homogenates were taken in triplicate, and total lipid content was determined by the method described by Folch et al [26]. As this fat was from the eviscerated carcasses, it was considered to be subcutaneous fat. Total body fat mass was considered to be the sum of the internal and subcutaneous fat masses, as we have previously reported [28].

The in vitro study was performed by dissolving various amounts of FBCx into 6 mL of water containing a small amount of food coloring for ease of visualization, the addition of 4 mL of olive oil (this experiment has subsequently been repeated with soy, canola, peanut, sesame, and vegetable oils with identical results), and vigorous shaking or vortex mixing for a few seconds. Mixing was followed by a light centrifugation to separate the phases.

### 2.5. Statistical analysis

The means and SEs were calculated for all of the collected parameters. Analyses of variance with repeated measures were used to analyze body weight data. Analyses of variance were conducted to compare the effects of dietary

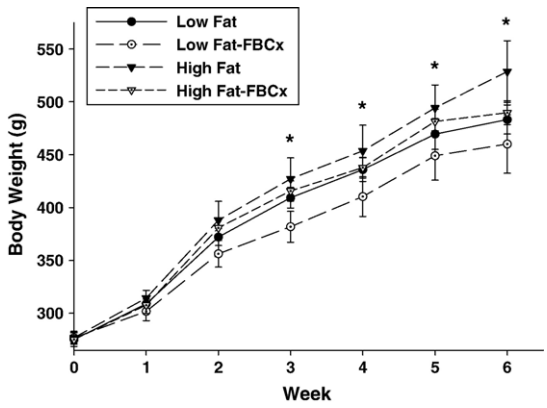


Fig. 2. The weight gain by the 4 groups is illustrated. The 4 groups are identified by their respective diets as LF, LF-FBCx, HF, and HF-FBCx. Asterisk indicates significant fat effect and FBCx effect on body weight of the 4 groups beginning at week 3.

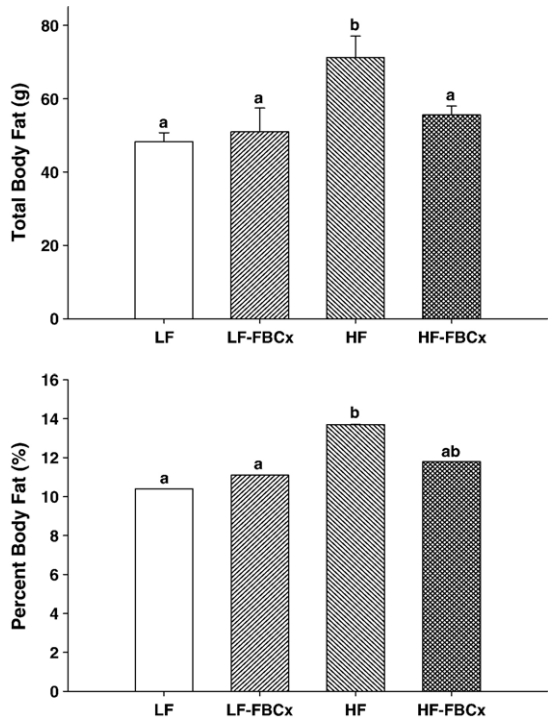


Fig. 3. Top, Total body fat of the 4 groups of rats at sacrifice. The 4 groups are identified by their respective diets as LF, LF-FBCx, HF, and HF-FBCx. There is a significant difference among those groups with different superscripts. Bottom, Amount of body fat of the rats at sacrifice relative to their total body weight. The 4 groups are identified by their respective diets as LF, LF-FBCx, HF, and HF-FBCx. There is a significant difference among those groups with different superscripts.

fat and FBCx as well as their interaction on the metabolic parameters. All of the statistical analyses were performed by computer using the appropriate SPSS software (SPSS, Chicago, IL). The significance level was set at $P < .05$.

## 3. Results

### 3.1. Food intake

The HF-fed rats did not compensate for the higher energy content in food, and all 4 groups consumed similar amounts of food during the 6-week study period. As a result, rats in the 2 HF groups consumed significantly more energy than rats in the LF groups. Adding FBCx to the diet had no apparent effect on either the quantity of food or the energy intake (Fig. 1) relative to their respective control groups.

### 3.2. Body weight

There was no significant difference in body weight among the 4 groups at the beginning of the study. By the end of the second week of feeding, the rats on the HF diet weighed significantly more than the LF-fed rats ($P < .05$ or .01, Fig. 2). The addition of fat and FBCx to the diets had significant effects on the rats' body weight. Rats fed with the HF-FBCx diet gained weight at a significantly slower rate relative to their HF control rats. A 7.4% reduction in body weight was observed in the HF-FBCx group compared with the HF group ($P < .05$) at the end of the study. The difference in body weight between LF- and LF-FBCx–fed rats failed to reach statistical significance (4.6%, NS). It should be noted that rats fed with the HF-FBCx diet gained weight at a rate similar to the rats consuming the LF diet, as indicated in Fig. 2. As a result, at the end of the study, the HF-FBCx, LF, and LF-FBCx groups all had similar body weights.

### 3.3. Body composition

The HF diet–fed rats had a significantly higher total adipose tissue mass than did the LF diet–fed rats ($P < .01$; Fig. 3, top). The percentage of the total body fat was also elevated by the HF feeding ($P < .05$; Fig. 3, bottom). FBCx feeding reduced body fat mass in HF-fed rats by 22% ($P < .05$). HF-FBCx rats showed a 14% reduction in the percentage of body fat (from 13.7% to 11.8%) as compared with rats in the HF group. However, this reduction in the percentage of body fat by FBCx feeding failed to reach significance ($P = .11$). The LF, LF-FBCx, and HF-FBCx groups had similar percentages of body fat. The LF and LF-FBCx groups had significantly lower body fat percentage than that of the HF group.

### 3.4. Blood plasma parameters

Table 2 presents the data for a number of blood parameters. Rats in the 2 HF groups had significantly lower triglyceride levels than did the rats in the 2 LF groups ($P < .002$). Adding FBCx to the diet further lowered triglyceride

Table 2
Plasma parameters of 4 groups of rats at sacrifice (mean ± SEM)

| | LF | LF-FBCx | HF | HF-FBCx | $P$ (diet effect) | $P$ (FBCx effect) | $P$ (diet × FBCx) |
|---|---|---|---|---|---|---|---|
| Triglyceride (mmol/L) | $1.43 \pm 0.14^{a}$ | $1.02 \pm 0.17^{b}$ | $0.76 \pm 0.08^{bd}$ | $0.53 \pm 0.03^{cd}$ | <.002 | <.05 | NS |
| Total cholesterol (mmol/L) | $1.52 \pm 0.1^{a}$ | $1.35 \pm 0.05^{ac}$ | $1.18 \pm 0.04^{bc}$ | $1.08 \pm 0.07^{b}$ | NS | <.09 | NS |
| HDL-C (mmol/L) | $0.92 \pm 0.05$ | $0.84 \pm 0.03$ | $0.84 \pm 0.02$ | $0.79 \pm 0.05$ | NS | NS | NS |
| Glucose (mmol/L) | $8.43 \pm 0.61$ | $10.1 \pm 0.55$ | $8.6 \pm 0.55$ | $8.7 \pm 0.44$ | NS | NS | NS |
| Insulin (pmol/L) | $305 \pm 42$ | $277 \pm 33$ | $361 \pm 54$ | $265 \pm 18$ | NS | <.09 | NS |
| Insulin/glucose | $36.2 \pm 3.9^{ab}$ | $28.4 \pm 2.6^{a}$ | $42.8 \pm 6.5^{b}$ | $35.9 \pm 1.3^{ab}$ | NS | <.05 | NS |
| Leptin (ng/mL) | $7.5 \pm 1.9^{ac}$ | $3.8 \pm 0.8^{a}$ | $18.1 \pm 3.2^{b}$ | $9.6 \pm 1.8^{c}$ | <.001 | <.05 | <.08 |
| Leptin/g fat | $0.11 \pm 0.02^{ac}$ | $0.075 \pm .001^{a}$ | $0.24 \pm 0.03^{b}$ | $0.17 \pm 0.03^{c}$ | <.001 | <.001 | <.07 |

NS indicates not significant.
Numbers with different superscripts are significantly different from each other at $P < .05$ or $P < .01$.

Table 3
Liver and feces fat content of 4 groups of rats at sacrifice (mean ± SEM)

| | LF | LF-FBCx | HF | HF-FBCx | *P* (diet effect) | *P* (FBCx effect) | *P* (diet × FBCx) |
|---|---|---|---|---|---|---|---|
| Liver lipid (g) | 0.85 ± 0.07[a] | 1.14 ± 0.2[a] | 2.0 ± 0.2[b] | 2.2 ± 0.1[b] | <.001 | NS | NS |
| Liver lipid (%) | 6.42 ± 0.4[a] | 8.32 ± 1.12[a] | 13.2 ± 0.9[b] | 15.2 ± 1.0[b] | <.001 | NS | NS |
| Fecal lipid (g) | 0.16 ± 0.02 | 0.16 ± 0.02 | 0.29 ± 0.04 | 0.29 ± 0.02 | NS | NS | NS |
| Fecal lipid (%) | 5.2 ± 0.36[a] | 4.7 ± 0.25[a] | 7.9 ± 0.34[b] | 9.5 ± 0.22[c] | <.01 | <.05 | <.001 |

Numbers with different superscripts are significantly different from each other at $P < .05$ or $P < .01$.

levels by about 30% compared with their respective controls ($P < .05$). There was no obvious difference in the total cholesterol levels of the 4 groups. FBCx appears to have reduced total cholesterol levels by 11% in LF-fed rats and 9% in HF-fed rats relative to their respective control groups, and these differences failed to reach significance ($P < .09$). There was no difference in HDL-C levels among the 4 groups. Fasting glucose and insulin levels were similar among all 4 groups. Insulin-glucose ratio, an indirect indicator of insulin sensitivity [29], was significantly reduced by FBCx ($P < .05$, Table 2), indicating an improved insulin sensitivity in the 2 FBCx-fed groups. Serum leptin levels were significantly elevated by the HF diet ($P < .001$), but significantly reduced in both FBCx groups ($P < .05$). The HF-FBCx and LF groups had similar leptin levels, whereas the HF-diet group had the highest levels among the 4 groups. Because leptin is secreted by the adipose tissue and the HF-fed rats had more body fat, leptin per gram of adipose tissue was calculated to normalize for differences in body fat mass. The leptin–fat tissue ratios were significantly higher in HF-fed rats ($P < .001$). Adding FBCx to the diet significantly reduced these ratios ($P < .001$) as the HF-FBCx group had a ratio that was very similar to the LF group.

### 3.5. Liver and fecal lipid content

The livers of the HF diet–fed rats weighed significantly more ($P < .05$) than those of the LF diet–fed rats; there was no effect of FBCx on liver weight (LF, 13.1 ± 0.5 g; LF-FBCx, 13.1 ± 0.6; HF, 14.8 ± 0.7; HF-FBCx, 14.1 ± 0.4, NS). Liver lipid content was significantly elevated in the HF-diet groups relative to the LF-diet groups (Table 3). FBCx had no effect on the mass of lipid content in the livers. Liver lipid expressed as a percentage of total liver weight was also increased in the HF-diet groups ($P < .001$); however, FBCx in the diet had no apparent effect relative to the respective control groups. There was no difference in fecal consistency upon visual inspection among the 4 groups. The HF diet increased fecal lipid expressed as a percentage of total dry weight of the feces ($P < .01$). Including FBCx in the diet further increased the fecal lipid percentage in the HF-FBCx–fed animals by 20%. Consequently, rats fed with the HF-FBCx diet had the highest fecal fat percentage relative to the other 3 groups.

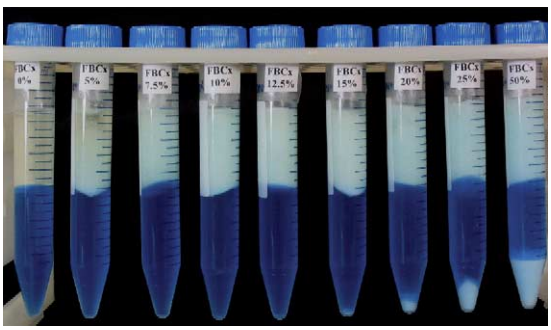


Fig. 4. The results of an in vitro study demonstrating the formation of the "wax-like" emulsion and the interdependencies of the amounts of oil, water, and FBCx. Each test tube contains 6 mL water, 4 mL olive oil, and various amounts of FBCx. After mixing by vortex mixer, each tube was centrifuged at 2000 rpm for 2 minutes to separate the layers. Water-soluble blue dye was added for easy visualization.

### 3.6. In vitro study

Fig. 4 illustrates the results of the in vitro study into the effects of various amounts of FBCx on an oil/water mixture. The tubes are labeled as percentage by weight of FBCx to oil, for example, the tube labeled "10%" contains 4 g of oil and 400 mg of FBCx. All of the tubes, except 0%, contain at least some stable emulsion. As the concentration of FBCx decreased, the amount of free oil seen on top of the tubes increased. At levels of 10% and higher, there is no free oil visible until the FBCx reached more than 25% when small amount of oil was not complexed. At 50%, significantly more FBCx was found in the bottom of the tube. However, even at lower levels, there was some free FBCx found in the bottom of the tubes.

## 4. Discussion

In this study, we examined the effects that FBCx had on rats when it was included in diets of 2 different fat contents. By adding FBCx at a rate of 10% of the fat content, we observed that FBCx reduced body weight gain in the HF-diet group. Hence, the HF-FBCx rats gained weight at the same rate as that of the LF rats. The weight reduction function of FBCx was not as effective in LF rats. FBCx also induced reductions in serum levels of triglyceride, leptin, leptin–fat tissue ratios, and insulin-glucose ratios in HF-fed rats. These data demonstrate that although rats were fed with a diet high in fat content, by adding FBCx to the diet, the added dietary fat had no obvious effects on body weight and blood hormone and substrate levels. In effect, these rats, with the exception of liver lipid content, were no different from LF-fed rats. On the other hand, FBCx increased fecal lipid percentage of the HF-fed rats. This may partially explain why HF-FBCx rats did not gain weight as rapidly as

rats in the HF group. However, it is worth mentioning that not all the calculated unabsorbed dietary fat can be accounted for by the fecal fat. Similar findings have been observed by Jackson et al [30]. It is also of note that the ratios of FBCx to fat to water are critical for complex formation (Fig. 4). As water is reabsorbed in the large intestine, the complex may slowly break apart, thus allowing the microflora to (partially) metabolize the previously complexed triglyceride. Further study using more sensitive measuring techniques to detect the fate of the dietary fat in FBCx-fed rats may be warranted.

Based upon the amount of weight gained and the amount of fat consumed by the HF-FBCx– and LF-fed rats, we are able to calculate that 1 g of FBCx prevented the absorption of the equivalent of 9 g of dietary fat. We are proposing that FBCx complexes with dietary fat to form a gel or stable emulsion, as is illustrated in Fig. 4. We have been able to confirm the formation of a gel/emulsion in an in vitro study that also confirmed the 1:9 ratio of FBCx fat. This emulsion has proven to be very stable as it has sat at room temperature for over 24 months without any obvious bacterial growth or changes in appearance or consistency. As it is understood, lipolytic activity requires the reduction of large droplets of fat into much smaller micelles; the formation of this stable gel or emulsion would reduce the ability of pancreatic lipase to catalyze the hydrolysis of dietary triglycerides and thus prevent absorption of these fats. The significant increase in the percentage of fecal fat in the HF-FBCx rats as compared with the HF-fed rats further suggests that at least some portion of the dietary fat thus complexed passes through the large intestine without being metabolized by the intestinal flora. However, FBCx did not alter the percentage of fat in the feces of the LF-fed rats. Thus, FBCx would appear to be more effective in inducing fat excretion when fat consumption is high. Unlike the unwanted gastrointestinal side effects of orlistat [31], no steatorrhea was observed in the FBCx-fed rats. The precipitated FBCx evident in the bottom of most of the tubes (Fig. 4) may be because of the displacement phenomenon caused by either the oil or, more likely, the emulsion. It appears that 10% FBCx/oil (wt/wt) is the optimum ratio.

Chitosan, a fiber extracted from crustaceans, has been promoted to bind dietary fat, thus reducing fat absorption and body weight. However, meta-analysis has revealed that without a hypoenergetic diet, chitosan does not induce weight loss in overweight/obese patients [13]. In addition, the amount of fat "trapped" by chitosan and therefore excreted in the feces in normal/overweight males was negligible [32]. Thus, chitosan's efficacy in treating overweight/obese patients is questionable.

Soluble fibers are reported to exert their health benefits through 1 of 3 major mechanisms: nutrient binding, fermentation, and gel formation. Soluble fibers have been shown to reduce blood cholesterol levels in humans and animals by binding bile acids, cholesterol, and free fatty acids, thereby increasing bile excretion and bile synthesis [33,34]. A meta-analysis has revealed that soluble fibers such as psyllium reduce human blood cholesterol levels by 5% and low-density lipoprotein cholesterol concentration by 9% [35]. In the current study, we observed a 9% reduction in total cholesterol by adding FBCx to the diet of the HF-fed rats and an 11% reduction in LF-fed rats. Possibly because of the brevity of this study, these reductions did not reach statistical significance; however, they are larger than the decreases observed in humans consuming relatively large amounts of other soluble fibers. It is of note that the amount of FBCx that was added to the diets was relatively small in comparison to the amounts of fiber used in previous studies [12]. Thus, FBCx may be considered to be more effective at lower levels than previously studied fibers for reducing blood cholesterol levels.

Soluble fibers also reduce blood cholesterol levels by the production of short-chain fatty acids (SCFAs) through fermentation of the undigested fiber by colonic microflora [36]. We did not measure SCFA production in this study; thus, we cannot discount the possibility that SCFA production in the FBCx-fed rats did not contribute to the hypocholesterolemic effect observed in the present study.

Rats fed with the HF diet had significantly lower blood triglyceride levels than that of the LF-fed rats. These data are consistent with our earlier observations [37], as well as by others [38], which indicated a lowering of plasma triglyceride levels despite increased dietary fat intake. The formation of a stable emulsion by FBCx may further contribute to the reduction in blood triglyceride and cholesterol levels because pancreatic lipase may only be able to interact with the oil on the surface of the emulsion. In addition, a decrease in hydrolysis of dietary triglycerides may decrease the absorption of cholesterol, as has been reported by Young and Hui [39], due to a reduced release of free fatty acids in the small intestine.

We did not observe any difference in serum glucose and insulin levels among the 4 groups. However, insulin-glucose ratios, an indirect indicator of insulin sensitivity [29], were lowered in the FBCx-fed rats. Thus, it would appear that FBCx improves insulin sensitivity as do some other soluble fibers [40].

Serum leptin levels were elevated in the HF groups, as has been previously demonstrated [41,42]. After adjusting for the body fat mass, both the HF and FBCx groups still showed significant changes in the serum leptin levels: increased levels were observed in the HF groups, whereas decreased levels were seen in the 2 FBCx groups. The observed decreases in serum leptin levels were more than that which could be accounted for by the reduction in body fat. Improved insulin sensitivity observed in this study might have contributed to this reduction because high leptin levels have been correlated with insulin resistance [43]. With reduction in leptin levels, leptin sensitivity and its desired function may be restored. This may explain why the rats consuming the FBCx diets did not eat more than the

animals that presumably were absorbing more fat. It is likely that the animals that consumed less bioavailable energy had greater sensitivity toward leptin and therefore were just as satiated as those animals that had more bioavailable fat. This phenomenon may, in the future, make weight loss and maintenance easier to accomplish.

Soluble fibers have been reported to reduce liver weight and lipid levels [36,44] as well as to have no effects on these 2 parameters [45]. In the current study, total liver weight, liver lipid weight, and percentage of liver lipid were elevated by HF feeding but not by FBCx feeding. Thus, the lowered blood triglyceride levels in FBCx-fed rats cannot be attributed to impaired hepatic lipid secretion. With the increased fecal fat percentage, it may be concluded that the body weight– and blood lipid–lowering effects of FBCx are more likely the result of FBCx binding with dietary fat, thus reducing the action of pancreatic lipase and increasing the excretion of dietary fat.

In conclusion, this study demonstrates that a soluble fiber, FBCx, prevented body weight gain, reduced serum triglyceride and leptin levels, and increased (calculated) insulin sensitivity and fecal fat excretion in rats consuming an HF diet. No adverse effects from ingestion of FBCx were identified in this study. Thus, FBCx may be appropriate for inclusion during food preparation or, perhaps, taken alone as a soluble fiber with a fat-containing meal. Its effects are more pronounced with HF diets. Obesity and type 2 diabetes mellitus are reaching epidemic proportions in the United States; FBCx may prove to be a very effective aid in the curtailment of the spread of obesity and type 2 diabetes mellitus, thus reducing the prevalence of chronic disease in the US population.

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