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Dietary fiber from coconut flour: A functional food

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Abstract

To determine the effectiveness of dietary fiber present in coconut flour as a functional food, the following studies were conducted: (a) Dietary Fiber Composition and Fermentability of Coconut Flour; (b) The Effect of Coconut Flour on Mineral Availability from Coconut Flour Supplemented Foods; (c) Glycemic Index of Coconut Flour Supplemented Foods in Normal and Diabetic Subjects; and (d) The Cholesterol Lowering Effect of Coconut Flakes in Moderately Raised Cholesterol Levels of Humans. The dietary fiber content of coconut flour was 60.0±1.0 g/100 g sample, 56% insoluble and 4% soluble. Fermentation of coconut flour produced short chain fatty acids with butyrate (1.73±0.07 mmol/g fiber isolate)>acetate (1.40±0.12; ($P<0.05$)>propionate (0.47±0.01; $P<0.05$). Iron and zinc availability were highest for carrot cake (Fe, 33.3±0.7%; Zn, 12.6±0.1%) supplemented with 20% coconut flour while multigrain loaf supplemented with 10% and macaroons with 25% coconut flour were highest for calcium availability (63.4±8.0% and 38.7±1.1%, respectively). Increasing concentrations of dietary fiber from coconut flour did not affect mineral availability from all test foods. The significantly low glycemic index foods (<60 mmol×min/l) investigated were: macaroons (45.7±3.0), carrot cake (51.8±3.3) and brownies (60.1±5.4) with 20–25% coconut flour. The test foods containing 15% coconut flour has a glycemic index ranging from 61 to 77 mmol×min/l. Among the test foods, pan de sal (87.2±5.5) and multigrain loaf (85.2±6.8) gave significantly higher glycemic index with 5% and 10% coconut flour. On the other hand, granola bar and cinnamon which contained 5% and 10% coconut flour, respectively gave a glycemic index ranging from 62 to 76 mmol×min/l and did not differ significantly from the test foods containing 15% coconut flour ($P<0.05$). A very strong negative correlation ($r=-85$, $n=11$, $P<0.005$) was observed between the glycemic index and dietary fiber content of the test foods supplemented with coconut. There was a significant reduction (%) in serum total and LDL cholesterol for: oat bran flakes, 8.4±1.4 and 8.8±6.7, respectively; 15% coconut flakes, 6.9±1.1 and 11.0±4.0, respectively; and 25% coconut flakes, 10.8±1.3 and 9.2±5.4, respectively ($P<0.05$). Serum triglycerides were significantly reduced for all test foods: corn flakes, 14.5±6.3%; oat bran flakes, 22.7±2.9%; 15% coconut flakes, 19.3±5.7%; and 25% coconut flakes, 21.8±6.0% ($P<0.05$). Results from the above study can be a basis in the development of coconut flour as a functional food.

Keywords: Dietary fiber; Coconut flour; Functional food

Industrial relevance: The functionality of coconut flour in terms of prevention for risk of chronic diseases, e.g. diabetes mellitus, cardiovascular diseases (CVD) and colon cancer, revealed increase production of coconut and coconut flour. The production of coconut flour is very economical because it can be produced in a small or large scale. The raw material is obtained from the by-product (waste) of the coconut milk industry and the process and equipment used in its production is simple and cheap. Coconut flour as a good source of dietary fiber can be added to bakery products, recipes and other food products for good health.

1. Introduction

The Philippines is the second largest coconut producer in the world and the largest exporter of coconut products. About 85% is processed into copra, 5% into desiccated coconut and 10% is

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for home use and other manufacturing coconut products. One by-product of the coconut milk industry is the coconut residue taken after extraction of the coconut milk. The coconut residue is made into coconut flour and believed to contain dietary fiber. Dietary fiber has been shown to have important health implications in the prevention for risk of chronic diseases such as cancer, cardiovascular diseases and diabetes mellitus. It comes from the family of carbohydrates, a non-starch polysaccharide, not digested in the small intestine but may be fermented in the colon into short chain fatty acids (SCFA) such as acetate, propionate and butyrate. SCFA contributes 1.5–2.0 kcal/g dietary fiber (Roberfroid, 1997). It enhances water absorption in the colon, thus prevent constipation. Propionate has been shown to inhibit the activity of the enzyme HMG CoA reductase, the limiting enzyme for cholesterol synthesis. Dietary fiber has the ability to bind with bile acids and prevents its reabsorption in the liver thus, inhibit cholesterol synthesis (Dietary Fiber, 1994). Butyrate enhances cell differentiation thus preventing tumor formation in the colon (Jenkins et al., 1982).

Dietary fiber's viscose and fibrous structure can control the release of glucose with time in the blood, thus helping in the proper control and management of diabetes mellitus and obesity (Dietary Fiber, 1994). Glycemic index, a classification of food based on their blood glucose response relative to a starchy food e.g. white bread, or standard glucose solution, has been proposed as a therapeutic principle for diabetes mellitus by slowing carbohydrate absorption (Creutzfeldt, 1983; Jenkins, Cuff, &Wolever, 1987). Low glycemic index food e.g. high dietary fiber food, has been shown to reduce post-prandial blood glucose and insulin responses and improve the overall blood glucose and lipid concentrations in normal subjects (Collier et al., 1988), and patients with diabetes mellitus (Brand et al., 1991; Fontvieille et al., 1988; Wolever, Jenkins, Vuksan, Jenkins, Buckly et al., 1992; Wolever, Jenkins, Vuksan, Jenkins, Wong et al., 1992).

The general objective of this study is to determine the effectiveness of the dietary fiber component of coconut flour, as a functional food, and the specific objectives are as follows: (a) to determine the dietary fiber composition and fermentability characteristics of coconut flour; (b) to determine the effect of coconut flour on mineral availability from coconut flour supplemented products; (c) to determine the glycemic index of coconut flour supplemented products from normal and diabetic subjects; and (d) to determine the cholesterol lowering effect of coconut flakes in moderately raised serum cholesterol levels of humans. The utilization of coconut flour as a functional food will not only solve the problem of chronic diseases now prevailing in almost all countries but also encourage the industry and farmers to produce value-added or healthful products from coconut flour. This will increase the production and promotion of the coconut industry.

2. Materials and methods

2.1. Production of coconut flakes, coconut flour, and coconut flour supplemented products

The coconut flour used in this study is produced from coconut residue, a by-product of the coconut milk industry. The coconut residue is blanched in boiling water for 1.5 min to remove microbial contaminants and dried using a tray type mechanical drier. The dried residue is passed through a special type of screw press under a specific expeller setting to reduce the oil content to a minimum level without too much change in color. The dried coconut flakes are produced and grinded to reduce particle size to a fine mesh to produce the coconut flour. The coconut flour was used in objectives (a) to (c) while coconut flakes was used in the study on the cholesterol-lowering effect.

The test foods supplemented with coconut flour were prepared as follows: pan de sal (5%), granola bar (5%), cinnamon bread (10%), multigrain loaf (10%), choco chip cookies (15%), hotcake (15%), choco crinkles (20%), carrot cake (20%), macaroons (25%), brownies (25%). The control food used was white bread prepared in a household bread maker following the formulation of Wolever et al. (1992) as follows: 33 g wheat flour, 4 g salt, 5 g yeast, 7 g sucrose and 330 ml water per 250 g carbohydrate loaf. Crust ends were not used. The coconut flour supplemented foods were used in the study on mineral availability and glycemic index.

2.2. Analytical methods

The proximate analysis, total, soluble and insoluble dietary fiber of coconut flour and all test foods/control food were determined using AOAC methods (Official Methods of Analysis, 1984a,b; Official Methods of Analysis, 1995; Sullivan and Carpenter, 1993). The phytic acid and tannic acid content of the test foods were also determined (Asoociation of Official Analytical Chemist, 1986; Earp, Ring, & Rooney, 1981).

2.3. In vitro fermentation of fiber isolates

Dietary fiber isolates from coconut flour was fermented in vitro using human fecal inoculum (McBurney & Thomson, 1987) against a standard wheat flour (NBS Standard Reference Material 1567A, Gaithersburg, MD, USA).

2.4. In vitro determination of mineral availability

Iron, zinc and calcium availability were determined in vitro simulating conditions in the small intestine and colon (Thompson et al., 1991; Trinidad, Wolever, & Thompson, 1996). Dialyzable minerals were used as a measure of mineral availability.

2.5. Protocol for the determination of glycemic index of test foods

Ten (10) normal and 10 diabetic subjects (Type II, diabetes mellitus) were evaluated by an endocrinologist on the basis of the following criteria: Normal subjects: Body Mass Index (BMI) 24 ± 1.2 kg/m^2, Fasting Blood Sugar (FBS) 4–7 mol/l, age 35–60 years, no physical defect and non-smokers; Diabetic Subjects: FBS 7.5–11.0 mol/l, age 35–60, no intake of drugs, no complications and non-smokers. Each subject was interviewed for physical activity and was asked to fill up a three-day food intake recall form. Subjects with common food intake

(pattern) and physical activity were included in the study. The diabetic subjects were managed through dietary consultations and advice.

Using the randomized cross over design, the control and test foods were fed in random order on separate occasions after an overnight fast. The control and test foods contained 50 g available carbohydrates. The subjects were told to fast overnight (10–12 h) prior to the start of the study. Feeding of white bread was repeated thrice while test foods were repeated twice. A standard glucose (Medic Orange 50 Glucose Tolerance Test Beverage Product No. 089, 50 g glucose/240 ml; Medic Diagnostic Laboratory, Pasig City, Philippines) was given once to determine the glycemic index of white bread.

Blood samples approximately 0.3–0.4 ml, were collected through finger prick before and after feeding in a 4-mm diameter and 10 cm long capillary tubing (PYREX, Corning, New York, USA) and sealed (Jockel Seal Sticks Cement, AH Thomas Catalogue No. 2454 W15, USA). For normal subjects, samples were collected at 0 h and every 15 min after feeding for one hour and every 30 min for the next hour while for diabetic subjects, samples were collected at 0 h and at 30 min interval after feeding for a period of 3 h. The serum was separated from the blood using a refrigerated centrifuge after all the blood was collected (Eppendorf Centrifuge, Eppendorf, Germany) and analyzed for glucose levels on the same day using a clinical chemistry analyzer (ARTAX Menarini Diagnostics, Firenze, Italy) after calibration with the glucose standard (Glucofix Reagent 1-Menarini Diagnostics, Firenze, Italy). The glycemic index was calculated from the following formula (Wolver, Jenkins, Jenkins, & Josse, 1991):

$$\text{Glycemic index} = \frac{\text{IAUC}^{*}\text{of the test food}}{\text{IAUC of the standard food}} \times 100$$

*Incremental area under the glucose response curve

2.6. Protocol for the cholesterol-lowering effect of coconut flakes

The subjects were selected based on the following criteria: moderately raised cholesterol level (250–300 mg cholesterol/100 g serum); 30–55 years old, no drug intake for cholesterol-lowering and no complications. They were interviewed to obtain data on their usual three-day food intake, physical activity and smoking habits. The total number of subjects in the study was 21. One of the subjects was not able to do one test food (15% coconut flakes).

The study was conducted in a double-blind randomized cross-over design on a 14-week period (3.5 months), consisting of four 2-week experimental periods, each experimental period separated by a 2-week washout period for a total of three washout periods. The subjects were made to fast overnight (10–12 h of fasting) prior to the study. They were weighed, their blood pressure measured and a sample of blood from their forearm vein was taken. The subjects were given the test foods to consume everyday to ensure compliance of the subjects, except on Fridays when 3 test foods were given to include Saturday and Sunday intakes. The subjects recorded their respective food intakes for the duration of the experimental study. On the 15th day, blood was drawn from the subjects after an overnight fast. Blood samples were taken into plain glass tubes from the forearm vein, left to clot at room temperature, centrifuged, and the serum separated. Total cholesterol, HDL cholesterol and triglycerides were measured in a clinical chemistry analyzer (ARTAX, Menarini Diagnostic, Florence, Italy) against standards (Cholesterol, Cholesterol Standard, 200 mg/dl, Sentinel CH, Milan, Italy; HDL Cholesterol, Cholesterol Standard, 50 mg/dl, Sentinel CH, Milan, Italy; Triglycerides, Glycerol Standard, 200 mg/dl, Sentinel CH, Milan, Italy). The amount of LDL was estimated from the formula used by Wolever, Jenkins et al. (1994) as follows:

$$\text{LDL} = (\text{total cholesterol} - \text{HDL}) - \text{triglyceride}/2.2$$

Subjects served as their own control.

2.7. Statistical analysis

The sample size was chosen to achieve 80% power at 5% level of significance. Differences between test foods and biomarkers were determined by two-way repeated measures analysis of variance and Duncan's Multiple Range Test, and correlation coefficients were determined to relate glycemic index and the different nutrients present in the test foods using the Statistical Analysis System Program (SAS Institute Inc., Cary, NC, USA).

3. Results and discussion

3.1. Dietary fiber composition and fermentability characteristics of coconut flour

The proximate analysis of coconut flour per 100 g sample is as follows: moisture, 3.6%; ash, 3.1%; fat, 10.9%, protein, 12.1%; and carbohydrates 70.3%. Coconut flour contained 60.9% total dietary fiber, 56.8% insoluble and 3.8% soluble. Table 1 shows the short chain fatty acids produced from dietary fiber fermentation of fiber isolates of coconut flour. The dietary fiber from coconut flour was fermentable and produced short chain fatty acids with butyrate > acetate > propionate. The standard wheat flour has a different short chain fatty acid pattern with acetate > butyrate > propionate. The total dietary fiber content of coconut flour was greater than the dietary fiber sources from North America such as oat bran (8.3 g/100 g) and flaxseed (28.0 g/100 g). Oat bran and flaxseed have been shown to have some protective and preventive effects on cardiovascular diseases (Anderson, 1990; Kirby, Anderson,

Table 1
Short chain fatty acids from fermentation of coconut flour fiber isolate, (mmol/g; $n=3$; mean ± SEM)

	Acetate	Propionate	Butyrate
Coconut flour	$1.40 \pm 0.^{12b,y}$	$0.47 \pm 0.01^{b,z}$	$1.73 \pm 0.07^{b,x}$
Standard Wheat Flour	$3.55 \pm 0.40^{a,x}$	$0.86 \pm 0.09^{a,z}$	$2.25 \pm 0.05^{a,y}$

[a,b] Denote significant differences between test foods.
[x,y] Denote significant differences between short chain fatty acid produced.

Table 2
Mineral content of test foods, mg/100 g S (mean±SEM, $n=6$)

Food sample	Iron	Zinc	Calcium
White bread	$1.7\pm0.0^{f,y}$	$4.4\pm0.3^{b,x}$	$4.3\pm0.2^{g,x}$
Pan de sal (5%)	$2.1\pm0.1^{d,e,z}$	$5.2\pm0.2^{a,y}$	$8.5\pm1.3^{e,x}$
Granola bar (5%)	$3.2\pm0.1^{c,y}$	$3.1\pm0.1^{d,y}$	$46.4\pm1.3^{c,x}$
Cinnamon (10%)	$3.2\pm0.5^{c,z}$	$4.7\pm0.1^{b,y}$	$9.2\pm1.2^{e,x}$
Multigrain loaf (10%)	$4.7\pm0.5^{a,y}$	$5.3\pm0.1^{a,y}$	$53.4\pm1.0^{b,x}$
Choco chip (15%)	$3.0\pm0.4^{c,z}$	$3.9\pm0.1^{b,c,y}$	$5.1\pm0.5^{f,x}$
Hotcake (15%)	$2.4\pm0.1^{d,z}$	$5.5\pm0.1^{a,y}$	$24.1\pm1.2^{d,x}$
Choco crinkles (20%)	$2.5\pm0.2^{c,d,z}$	$3.6\pm0.1^{c,y}$	$5.8\pm0.2^{f,x}$
Carrot cake (20%)	$2.0\pm0.0^{e,y}$	$4.5\pm0.1^{b,x}$	$4.0\pm0.4^{g,x}$
Macaroons (25%)	$4.7\pm0.1^{a,y}$	$3.4\pm0.2^{c,d,z}$	$104.8\pm0.7^{a,x}$
Brownies (25%)	$3.6\pm0.4^{b,y}$	$4.3\pm0.1^{b,x}$	$4.8\pm0.6^{f,g,x}$

^{a,b,c,d,e,f,g} Denote significant differences between test foods at $P<0.05$.
^{x,y,z} Denote significant differences between minerals at $P<0.05$.

Sieling, Rees et al., 1981), and colon and breast cancer (Jenab & Thomson, 1996; Serraino & Thompson, 1992; Thompson, Seidl, Orcheson, & Rickard, 1994), respectively.

3.2. Mineral availability of coconut flour supplemented products

Table 2 shows the mineral content of the test foods in mg/100 g S. Multigrain loaf and macaroons were the best source of iron while hotcake, multigrain loaf and pan de sal were the best source of zinc among the test foods (Table 2). The best source of calcium were macaroons, multigrain loaf and granola bar.

Table 3 shows the total dietary fiber, phytic acid and tannic acid content of the test foods. As expected, macaroons and brownies supplemented with 25% coconut flour have significantly higher dietary fiber content in comparison to the other test foods (Table 3; $P<0.05$). The phytic acid content of the test foods was significantly greater in hotcake followed by choco crinkles and macaroons in comparison to the other test foods (Table 3; $P<0.05$). Tannic acid was significantly greater for cinnamon, choco crinkles and brownies than the other test foods (Table 3; $P<0.05$).

Table 4 shows the mineral availability of the test foods. Iron availability from carrot cake (20%) was significantly greater than the rest of the test foods followed by choco chips (15%), choco crinkles (20%) and granola bar (5%) (Table 7; $P<0.05$). The multigrain loaf (10%) has significantly lower iron availability than the other test meals (Table 4; $P<0.05$). Carrot cake (20%), choco chips (15%) and granola bar (5%) have significantly higher zinc availability in comparison to the other test meals while cinnamon has significantly lower zinc availability (Table 4; $P<0.05$). Multigrain loaf (10%) has significantly greater calcium availability than macaroons (25%) and granola bar (5%). Cinnamon (10%) and white bread (0) have significantly lower calcium availability (Table 4; $P<0.05$).

Increasing the amount of dietary fiber from coconut flour present in the test foods did not affect mineral availability. However, differences in percent mineral availability of the test foods with the same amount of added dietary fiber from coconut flour were observed. Multigrain loaf and cinnamon both contained 10% dietary fiber from coconut flour. Multigrain loaf has the highest iron (4.7±0.5 mg/100 g), zinc (5.3±0.1 mg/100 g) and calcium (53.4±1.0 mg/100 g) content among the test foods but has the lowest iron (3.7±0.4%) and zinc (5.7±2.0%) availability and the highest calcium availability (63.4±8.0%). Cinnamon bread has an iron (3.2±0.5 mg/100 g) and zinc (4.7±0.1 mg/100 g) content close to multigrain loaf and has lower calcium (9.2±1.2 mg/100 g) content. A significantly higher iron availability (6.2±1.8%) and lower zinc (1.8±0.6%) and calcium (3.2±0.5%) availability was observed in cinnamon bread ($P<0.05$). This suggested that calcium inhibited iron and zinc availability from multigrain loaf and iron inhibited zinc and calcium availability from cinnamon bread. Studies have shown that absorption of minerals is affected by the presence of other minerals present in foods/meals (Cook, Dassenko, & Whittaker, 1991; Davidsson, Almgren, Sandstrom, & Hurrell, 1995; Davidsson, Kastemayer, & Hurrell, 1994; Dawson-Huges, Seligson, & Huges, 1986; Deehr, Dallal, Smith, Tualbee, & Dawson-Huges, 1990; Gleerup, Rossander-Hulthen, Gramatkovski, & Hallberg, 1995; Gleerup, Rossander-Hulthen, & Hallberg, 1993; Hallberg, Brune, Erlandson, Sandberg, & Rossander-Hulthen, 1991; Hallberg, Brune, Rossander-Hulthen, & Gleerup, 1992; Hunt, Gallagher, Johnson, & Lykken, 1995; Forbes, Erdman,

Table 3
Total dietary fiber, phytic acid and tannic acid content of test foods, mean±SEM; $n=4$

Food samples	Total dietary fiber g/100 g S	Phytic acid mg/100 g S	Tannic acid mg/100 g S
White bread	3.1 ± 0.1^{f}	204.8 ± 10.9^{I}	113.8 ± 4.8^{e}
Pan de sal (5%)	7.6 ± 0.4^{e}	248.8 ± 0.7^{f}	176.8 ± 4.2^{c}
Granola bar (5%)	$9.8\pm0.2^{c,d}$	289.6 ± 0.3^{d}	177.0 ± 1.0^{c}
Cinnamon (10%)	9.5 ± 0.2^{d}	227.1 ± 1.0^{h}	265.8 ± 3.5^{a}
Multigrain loaf (10%)	10.8 ± 0.2^{b}	223.3 ± 3.2^{h}	184.7 ± 6.5^{c}
Choco chip (15%)	$10.1\pm0.1^{b,c}$	196.7 ± 1.2^{I}	213.8 ± 2.7^{b}
Hotcake (15%)	10.3 ± 0.9^{b}	422.2 ± 0.9^{a}	106.2 ± 0.8^{f}
Choco crinkles (20%)	11.9 ± 1.1^{b}	341.7 ± 8.6^{b}	271.8 ± 3.6^{a}
Carrot cake (20%)	12.6 ± 1.2^{b}	232.4 ± 1.0^{g}	132.2 ± 5.9^{d}
Macaroons (25%)	14.8 ± 0.2^{a}	307.8 ± 0.2^{c}	126.1 ± 2.0^{d}
Brownies (25%)	14.0 ± 0.3^{a}	266.4 ± 1.1^{e}	267.1 ± 0.0^{a}

^{a,b,c,d,e,f,g,h,i} Denote significant differences between test foods at $P<0.05$.

Table 4
Total dialyzable mineral (%)*, in vitro (small intestinal and colonic conditions, mean±SEM; $n=6$)

Food sample	Iron	Zinc	Calcium
White bread	$10.7\pm1.4^{c,x}$	$7.5\pm1.1^{c,y}$	$3.3\pm0.7^{e,f,z}$
Pan de sal (5%)	$12.3\pm0.9^{c,x}$	$8.4\pm1.0^{b,c,y}$	$2.3\pm0.4^{f,z}$
Granola bar (5%)	$19.5\pm1.5^{b,y}$	$11.3\pm1.4^{a,b,z}$	$28.8\pm0.0^{c,x}$
Cinnamon (10%)	$6.2\pm1.8^{d,x}$	$1.8\pm0.6^{e,z}$	$3.2\pm0.5^{e,f,y}$
Multigrain loaf (10%)	$3.7\pm0.4^{e,z}$	$5.7\pm2.0^{c,d,y}$	$63.4\pm8.0^{a,x}$
Choco chip (15%)	$18.6\pm3.2^{b,x}$	$12.3\pm1.4^{a,y}$	$5.1\pm1.1^{d,z}$
Hotcake (15%)	$11.2\pm2.2^{c,x}$	$7.9\pm0.3^{c,y}$	$3.3\pm0.1^{e,z}$
Choco crinkles (20%)	$17.5\pm2.8^{b,x}$	$6.6\pm0.3^{d,y}$	$2.5\pm0.1^{f,z}$
Carrot cake (20%)	$33.3\pm0.7^{a,x}$	$12.6\pm0.1^{a,y}$	$5.0\pm0.3^{d,z}$
Macaroons (25%)	$6.4\pm1.3^{d,z}$	$8.0\pm0.6^{c,y}$	$38.7\pm1.1^{b,x}$
Brownies (25%)	$6.1\pm3.2^{d,e,x}$	$9.6\pm0.5^{b,x}$	$5.0\pm0.4^{d,y}$

^{a,b,c,d,e,f} Denote significant differences between test foods at $P<0.05$.
^{x,y,z} Denote significant differences between mineral release at $P<0.05$.
*Expressed as a percent of total mineral content.

Parker, Kondo, & Keteisen, 1983). Several investigators have observed the inhibitory effect of calcium on iron (Cook et al., 1991; Deehr et al., 1990; Gleerup et al., 1995, 1993; Hallberg et al., 1991, 1992) and zinc absorption (Dawson-Huges et al., 1986; Forbes et al., 1983). Calcium may have competed for iron and zinc binding sites on the intestinal lumen that interfere with intestinal iron and zinc uptake and intracellular transport (Dawson-Huges et al., 1986). On the other hand, the phytic acid content of both multigrain loaf (227.1±1.0 mg/100 g) and cinnamon bread (223.3±3.2 mg/100 g) did not differ significantly, while multigrain loaf (184.7±6.5 mg/100 g) has a significantly lower tannic acid content than cinnamon bread (265.8±3.5 mg/100 g; Table 2, $P<0.05$). Tannic acid has been shown to inhibit mineral absorption (Brune, Rossander, & Hallberg, 1989; Brune, Rossander-Hulthen, Hallberg, Gleerup, & Sandberg, 1992; Gillooly, Bothwell, & Trrance, 1983; Kelsay, 1987; Turitawiroon, Sritongkul, & Brune, 1991). The interaction between minerals and tannic acid may have played a role that resulted in differences in mineral availability between the two test foods containing 10% coconut fiber.

While mineral–mineral interaction, phytic acid or tannic acid may cause the decrease in mineral availability observed among the test foods, the interaction between these factors may have strongly contributed to the differences in mineral availability of the test foods supplemented with similar amounts of coconut flour. In general, increasing amounts of dietary fiber from coconut flour has little or no effect on mineral release from the test foods for potential absorption in the gastrointestinal tract.

3.3. Glycemic index of coconut flour supplemented products in normal and diabetic subjects

Table 5 shows the characteristics of the subjects. The body mass index (BMI) of the normal subjects were found to be on the upper limit and above of the criteria for normal subjects (24±1.2). Half of the normal subjects were within the BMI limit. There were no significant differences between the normal and diabetic subjects for age and BMI. There were significant differences observed between subjects for the fasting blood sugar; diabetic subjects were significantly greater than the normal subjects ($P<0.05$). Normal readings of the standard glucose used in the clinical chemistry analyzer ranged from 4.0 to 6.4 mmol/l glucose. The initial blood glucose obtained from the normal subjects for all test foods did not exceed 6.2 mmol/l glucose. All of the subjects were able to consume all test foods (white bread 3×, test foods 2× and standard glucose, once) in 24 occasions. All test foods with and without coconut flour were analyzed for fat, protein, and dietary fiber (Table 6). There was an increasing trend in dietary fiber content of the test foods fed at increasing level of dietary fiber from coconut flour supplemented foods with macaroons having a significantly greater dietary fiber content (14.3±0.2 g; $P<0.05$) than the other test foods. On the other hand, macaroons have a significantly higher fat content (33.5±0.8 g; $P<0.05$) among the test foods while white bread was significantly lower (0.3±0.1 g; $P<0.05$). Pan de sal has a significantly higher protein content (12.1±0.1 g; $P<0.05$) while granola bar (4.4±0.1 g; $P<0.05$) and choco chip cookies (4.4±0.4 g; $P<0.05$) have significantly lower protein content.

Table 5
Characteristics of the subjects for glycemic index study, mean±SEM

Subjects	No. of subjects	Age	SEM	BMI*	SEM	FBS**	SEM
		(Years)		(kg/m^2)		(mmol/l)	
Normal	10	46.0	2.3^{a}	26.0	0.8^{a}	6.1	0.1^{b}
Diabetic	10	44.0	2.4^{a}	25.6	1.6^{a}	8.9	0.6^{a}

*Body Mass Index = Weight/(Height)^2.
**Fasting Blood Sugar.
Different letters denote significant differences between subjects at $P<0.05$.

Table 6
Nutrient content of test foods fed to subjects, mean±SEM*

Test foods	CHO (g)	Dietary fiber		Fat		Protein	
		(g)	SEM	(g)	SEM	(g)	SEM
White bread	50	2.3	0.1^{f}	0.3	0.1^{h}	7.3	0.1^{d}
Pan de sal (5%)	50	4.5	0.4^{e}	2.8	0.1^{f}	12.1	0.1^{a}
Granola bar (5%)	50	5.8	0.2^{d}	9.9	0.1^{d}	4.4	0.1^{g}
Cinnamon (10%)	50	7.3	0.2^{c}	14.2	0.3^{c}	8.5	0.4^{c}
Multigrain loaf (10%)	50	7.4	0.2^{c}	4.0	0.1^{e}	9.8	0.2^{b}
Choco chip cookies (15%)	50	7.5	0.1^{c}	9.9	0.7^{d}	4.4	0.4^{g}
Hotcake (15%)	50	7.4	0.9^{c}	1.5	0.3^{g}	9.5	0.1^{b}
Choco crinkles (20%)	50	8.0	1.1^{bc}	9.4	0.8^{d}	4.7	0.3^{g}
Carrot cake (20%)	50	10.2	1.2^{b}	19.3	0.8^{b}	5.9	0.1^{f}
Macaroons (25%)	50	14.3	0.2^{a}	33.5	0.8^{a}	7.6	0.3^{d}
Brownies (25%)	50	10.5	0.3^{b}	15.0	0.8^{c}	6.3	0.1^{e}

*Freeze-dried basis.
Different letters denote significant differences between test foods at $P<0.05$.

Table 7 shows the glycemic index of the test foods. The glycemic index of all test foods did not differ significantly between normal and diabetic subjects except for choco crinkles, 61.2±5.4 and 77.0±4.4, respectively. The significantly low glycemic index foods (<60) investigated were: macaroons (45.7±3.0) and carrot cake (51.8±3.3) (Table 3) contained 20–25% coconut flour ($P<0.05$). The test foods with 15% coconut flour have glycemic index ranging from 61 to 71.

Among the test foods, pan de sal (87.2±5.5) and multigrain loaf (85.2±6.8) have significantly higher glycemic index with

Table 7
Glycemic Index (GI) of test foods in normal and diabetic subjects, mean±SEM

Test foods	Normal		Diabetic	
	GI*	SEM	GI*	SEM
Pan de sal (5%)	61.9	5.5^{b,x}	68.6	6.1^{b,x}
Granola bar (5%)	46.2	4.9^{c,x}	50.8	4.7^{c,x}
Cinnamon (10%)	44.5	4.2^{c,x}	50.7	4.9^{c,x}
Multigrain loaf (10%)	60.5	6.8^{b,x}	65.7	5.9^{b,x}
Choco chip cookies (15%)	43.4	4.6^{c,x}	50.7	7.3^{c,x}
Hotcake (15%)	46.2	3.3^{c,x}	51.3	5.8^{c,x}
Choco crinkles (20%)	43.4	5.4^{c,x}	54.7	4.4^{c,y}
Carrot cake (20%)	36.8	3.3^{d,x}	39.0	3.7^{d,x}
Macaroons (25%)	32.4	3.0^{d,x}	46.6	3.7^{e,x}
Brownies (25%)	42.7	5.4^{c,d,x}	43.5	5.6^{c,d,x}

^{a,b,c,d,e} Denote significant differences between test foods at $P<0.05$.
^{x,y} Denote significant differences between subjects at $P<0.05$.
*Glucose based GI: the GI of the test foods with white bread used as the standard food was multiplied by 0.71.

5% and 10% coconut flour ($P<0.05$). On the other hand, granola bar and cinnamon with 5% and 10% coconut flour, respectively gave a glycemic index ranging from 62 to 72 and did not differ significantly from the test foods with 15% coconut flour ($P<0.05$).

No significant correlation was found between the glycemic index and the protein content of test foods fed to the subjects. We found a negative correlation between the glycemic index and fat content of the test foods, $r=-0.66$, $n=11$, $P<0.05$. A very strong negative correlation ($r=-0.85$, $n=11$, $P<0.005$) was observed between the glycemic index and dietary fiber content of the test foods supplemented with coconut flour.

Results of the study showed that even at constant amount of available carbohydrates in the test foods (50 g available carbohydrates), there was a significant variation in the glycemic index confirming that equal carbohydrates portions of different foods may not necessarily have the same glycemic effect in humans (Wolever, Katzman-Relle et al., 1994). The blood glucose response may be influenced by insulin responses in the presence of protein (Gannon, Nuttall, Neil, & Westphal, 1988; Nuttall, Mooradian, Gannon, Billington, & Krezowski, 1984; Simpson, McDonald, Wahlqvist, Atley, & Outch, 1985), and differences in the rates of digestion and absorption influenced by the presence of dietary fiber, fat, cooking, anti-nutrients, particle size, food form and starch structure (Wolever, 1990; Wolever et al., 1986; Wursch, 1989). The protein content of the test foods fed to the subjects ranged from 4.4–12.1 g (Table 6). According to several investigators (Gannon et al., 1988; Nuttall et al., 1984), 20–30 g dietary protein is needed to increase insulin responses sufficient to reduce glycemic responses especially in subjects with non-insulin-dependent diabetes mellitus (NIDDM). Therefore, the protein content of the test foods may not have any effect on the variability of glycemic index in the test foods investigated.

A wide variability in fat content of the test foods ranging from 0.28 to 33.5 g was observed (Table 6). We do not believe that fat strongly affected the glycemic index of the test foods investigated in this study. There was only one test food that contained greater than 20 g of fat in the study, macaroons with 33.5 g fat (Table 2). To further support the non-significant effect of fat on the GI of the test foods investigated in this study, a multi-regression stepwise analysis using the SPSS Statistical Program was done to look at the interaction between GI and dietary fiber while controlling for fat content. A significant contribution of dietary fiber (87.4%) in the variability of the glycemic index from all test foods for both normal and diabetic subjects ($P<0.001$) and a non-significant contribution from fat were obtained. This result also supported the corresponding low glycemic index of the test foods at higher concentration of dietary fiber from coconut flour. Dietary fiber contributed in delaying the glycemic responses of the coconut flour supplemented food similar to previous work on dietary fiber and glycemic index of foods (Jenkins et al., 1978, 1982, 1989). Moreover, purified soluble fibers reduce glycemic responses to a greater extent than purified insoluble fiber (Jenkins et al., 1978). Considering the dietary fiber present in whole foods, insoluble fiber relates better to the glycemic index than soluble fiber content (Jenkins et al., 1982). The significant differences between the GI of normal and diabetic subjects from choco crinkles are difficult to explain. The differences in glucose responses between the two groups may be due to rates of digestion and absorption in relation to the food ingested.

3.4. The cholesterol-lowering effect of coconut flakes in moderately raised serum cholesterol levels of humans

Table 8 shows the characteristics of the subjects. There were 4 males and 17 females for a total of 21 subjects. The initial serum total cholesterol for all subjects ranged from 259 to 283 mg/dl. The serum LDL cholesterol were significantly higher in females than in males ($P<0.05$) while serum triglycerides was significantly higher in males than in females ($P<0.05$; Table 8). All other parameters were similar in both males and females. All subjects did not have alcohol intake.

Table 9 shows the composition of the test foods. The 25% coconut flakes has the highest dietary fiber, fat, protein, and ash content. Oat bran flakes has the highest moisture content. The mean energy intake of the subjects for the duration of the experimental study as estimated from the food record collected for fourteen days for each test food fed was 1413.0±38.5 kcal per day. Protein, fat and carbohydrate intake, estimated as percent of total calories were 12.1±0.2%, 18.4±1.7% and 70.5±1.4%, respectively. Protein and fat sources were beef, pork and chicken. The type of fat consumed by the subjects was mostly saturated fat. Only one subject ate fish frequently while the others had very low intake of fish. Carbohydrate sources came mainly from rice, bread and noodles. Vegetables and fruits were only eaten once or not even once a day.

Table 10 shows the serum total, LDL and HDL cholesterol, and triglycerides of subjects before and after feeding of the different test foods. Serum total cholesterol were significantly lower after consumption of oat bran, 15% coconut flakes and 25% coconut flakes for fourteen days ($P<0.05$; Table 10). Similar results were also observed for LDL cholesterol. For all test foods there was a significant reduction in serum triglycerides ($P<0.05$; Table 10). There was no increase in HDL cholesterol observed in the study (Table 10).

Table 8
Characteristsics of subjects for cholesterol study, mean±SEM

Subject	No.	Age	BMI	Total cholesterol	LDL cholesterol	HDL cholesterol	Triglyceride
Male	4	50±3	25±2	271±12	120±7[b]	45± 6	277±24[a]
Female	17	48±1	25±1	270±4	156±6[a]	48±5	174±16[b]

[a,b]Signify significant differences between males and females at $P<0.05$.

Table 9
Composition of test foods (g)*, mean±SEM

Component	Corn flakes	Oat bran flakes	Corn flakes+15% DF from coco flakes	Corn flakes+25% DF from coco flakes
Total amount fed to subjects/day	51.0	59.5	65.8	75.7
Carbohydrates	50	50	50	50
Dietary fiber	1.0**	8.5**	16.0 ± 1.0^{b}	26.0 ± 0.9^{a}
Fat	0.04 ± 0.03^{d}	0.86 ± 0.06^{c}	2.50 ± 0.02^{b}	4.16 ± 0.02^{a}
Protein	3.1**	5.4**	4.8 ± 0.1^{b}	6.0 ± 0.1^{a}
Ash	2.03 ± 0.00^{c}	1.35 ± 0.04^{d}	2.42 ± 0.00^{b}	2.67 ± 0.01^{a}
Moisture	1.68 ± 0.00^{d}	3.11 ± 0.02^{a}	2.38 ± 0.02^{c}	2.84 ± 0.02^{b}

*As analyzed.
**From food label.
DF, dietary fiber.
[a,b,c,d]Denote significant differences between test foods at $P<0.05$.

Table 11
Percent reduction in serum total cholesterol, LDL cholesterol and triglycerides levels of subjects fed with different test foods, mean ±SEM

Test foods	Total cholesterol	LDL cholesterol	Triglycerides*
Corn flakes	$-1.3\pm1.8^{c,y}$	$-0.9\pm6.3^{b,y}$	$14.5\pm6.3^{a,x}$
Oat bran flakes	$8.4\pm1.4^{a,b,y}$	$8.8\pm6.7^{a,y}$	$22.7\pm2.9^{a,x}$
15% coco flakes	$6.9\pm1.1^{b,y}$	$11.0\pm4.0^{a,x,y}$	$19.3\pm5.7^{a,x}$
25% coco flakes	$10.8\pm1.3^{a,y}$	$9.2\pm5.4^{a,x,y}$	$21.8\pm6.0^{a,x}$

*Only 60% of subjects were considered for % reduction (serum triglycerides >170 mg/dl).
[a,b,c]Denote significant differences between test foods at $P<0.05$.
[x,y,z]Denote significant differences between serum total cholesterol, LDL cholesterol and triglycerides at $P<0.05$.

Table 11 shows the percent reduction in serum total cholesterol, LDL cholesterol and triglycerides of subjects fed with the different test foods. After feeding the subjects with 15% and 25% dietary fiber from coconut flakes for fourteen consecutive days, a 6.9% and 10.8% reduction respectively were observed in serum total cholesterol (Table 11; $P<0.05$). These were comparable with that of oat bran flakes with an 8.4% reduction in serum total cholesterol. The percent reduction of serum total cholesterol for 25% dietary fiber coconut flakes was significantly greater than that of the 15% dietary fiber coconut flakes (Table 11; $P<0.05$). However, both 15% and 25% coconut flakes did not differ significantly from that of oat bran flakes (Table 11). Similar results were also observed in the percent reduction of LDL cholesterol from all foods, except for corn flakes (Table 11). Although corn flakes did not lower serum total and LDL cholesterol, it caused a 14.5% reduction in serum triglycerides and is comparable to oat bran, and 15% and 25% coconut flakes (Table 11). Only 60% of the subjects had a serum triglyceride greater than 170 mg/dl (normal is 60–170 mg/dl) and was included in the analysis. Epidemiological data suggested that high intakes of dietary fiber reduced the risk of coronary heart disease (CHD) (Despres et al., 1996). The Lipid Research Clinics Coronary Primary Prevention Trial predicted that for every 1% decrease in serum cholesterol concentration, there is a decreased risk of CHD of 2% (Lipid Research Clinic Program, 1984). In a previous meta-analysis of 20 trials, the daily intake of 3 g β-glucan from oats caused a clinical reduction of 0.13–0.16 mmol serum cholesterol/l (Ripsin et al., 1992).

Results of the study revealed that daily consumption of 15% and 25% dietary fiber from coconut flakes with the usual meal reduced serum total and LDL cholesterol, and triglycerides in humans (Table 4). Interestingly, the greatest reduction in serum total and LDL cholesterol as well as triglycerides was observed from subjects fed with 25% dietary fiber from coconut flakes but did not differ significantly from that of oat bran flakes (Table 4; $P<0.05$). A study revealed that coconut kernel contained water-soluble galactomannans (Monro, Harding, & Russell, 1985). The galactomannans from coconut have been shown to be the leguminous type (Monro et al., 1985) with a mannose:galactose ratio of 2:1 similar to guar gum (Jensen, Spiller, Gates, Miller, & Whittam, 1993). Galactomannans are not digested in the small intestine but are metabolized by the microflora in the large intestine and produce short chain fatty acids. One interesting component of coconut that may have also contributed to lowering serum cholesterol levels is its uronic acid content also present in pectin (Jenkins, Leeds, Newton, & Cummings, 1975). Uronic acid increases as coconut matures (Monro et al., 1985). It is also fermentable in the large intestine and produces short chain fatty acids (Monro et al., 1985). The hypocholesterolemic property of dietary fiber is associated with the water-soluble fractions of fiber, e.g. galactomannans, uronic acid, glucomannans. However, various water-soluble fibers may differ in their ability to reduce serum cholesterol (Bell, Hectorn, Reynolds, & Hunninghake, 1990; Jenkins et al., 1975). In this study, oat bran flakes was given at 8.5 g dietary fiber, while 15% and 25% dietary fiber coconut flakes were given at 15.0 and 25.0 g dietary fiber, respectively, with a percent serum cholesterol reduction of 8.4, 6.9 and 10.8%, respectively. There were no significant differences between the three dietary fiber sources (Table 9; $P<0.05$). The amount of dietary fiber present in the 25% coconut flakes (25 g) was more than twice that of oat bran flakes (8.5 g). Results of the study revealed that for every gram of dietary fiber from oat bran, 2–3 g of dietary fiber from coconut flakes is needed to obtain a serum total cholesterol reduction of 6–12%. The present study also confirmed

Table 10
Serum total, LDL and HDL cholesterol, and triglycerides levels of subjects before and after feeding of the different test foods, mean±SEM

Test food	Total cholesterol		LDL cholesterol		HDL cholesterol		Triglyceride	
	Before	After	Before	After	Before	After	Before	After
Corn flakes	276±7	280±10	144.3±7.0	145.6±6.8	47.4±4	45.3±5	277±18	236±15*
Oat bran	296±10	271±9*	154.0±3.7	140.4±4.9*	50.2±5	45.2±4	233±16	180±13*
15% coco flakes	288±7	268±7*	152.6±5.0	135.8±5.0*	53.3±4	44.3±4	327±24	264±23*
25% coco flakes	296±10	264±10*	168.7±4.8	153.1±3.1*	41.7±3	38.1±2	243±19	190±16*

*Significantly different at $P<0.05$.

the United States Food and Drug Administration health claim for oat bran's role in reducing serum cholesterol level in humans. Oat bran has been shown to decrease serum total cholesterol in humans in many studies and is preventive of cardiovascular disease (Anderson, 1987; Anderson and Gustafson, 1988; Anderson, Story, Sieling, and Chen, 1984; Anderson, Stery, Sieling, Chen, Petro, et al., 1984; Anderson et al., 1991; Kirby, Anderson, & Sieling, 1981; Poulter et al., 1993; Ripsin et al., 1992; Whyte, McArthur, Topping, & Nestel, 1992).

There was no significant increase or decrease in HDL cholesterol levels of all subjects. The concentration of serum HDL cholesterol is affected by alcohol intake and body mass index (BMI) (Bolton-Smith, Woodward, Smith, & Tunstall-Pedoe, 1991). However, all subjects do not drink alcohol and the BMIs were not significantly different between subjects in the duration of the experimental period.

4. Conclusion

In conclusion: (a) coconut flour is a rich source of dietary fiber, it is fermentable and produce short chain fatty acids with butyrate > acetate > propionate; (b) increasing amounts of dietary fiber present in coconut flour added to the different test foods has little or no effect on mineral availability. Differences in mineral availability from coconut flour supplemented foods may be attributed to mineral content, mineral–mineral interaction, and the presence of phytic acid and tannic acid; (c) the glycemic index of coconut flour supplemented foods decreased with increasing levels of dietary fiber from coconut flour; and (d) fifteen and 25% dietary fiber from coconut flakes reduced serum total cholesterol, LDL cholesterol and triglycerides of humans with moderately raised serum cholesterol levels. The results of this study serve as a basis in the development of coconut flakes/flour as a functional food justifying increased production of coconut and coconut by-products.

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