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In Vitro Interactions on Glucose by Different Fiber Materials Prepared from Mung Bean Hulls, Rice Bran and Lemon Pomace

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ABSTRACT

Fiber was prepared from mung bean hulls, rice bran and lemon pomace by the chemical precipitation method and then characterized. The characteristics investigated included bulk density, water-holding capacity, oil-holding capacity, swelling properties, water solubility and glucose adsorption and diffusion *in vitro* experiments. The results showed that the smaller the fiber particles were, the higher the bulk density was and the lower the ability of the fiber was to absorb water and oil. Mung bean hull fiber had a significantly higher bulk density and water-holding capacity than cellulose. The swelling property of mung bean hull fiber was also significantly higher than that of cellulose. The water-holding capacity, oil-holding capacity and swelling property of rice bran fiber were all significantly higher than those values for cellulose. The water-holding capacity, oil-holding capacity, swelling property and water solubility of lemon pomace fibers were also significantly higher than those for the other experimental groups. The glucose effects in the *in vitro* experiments indicated that mung bean hull fiber had a higher level of adsorption when the glucose level was low. Fiber made from rice bran and lemon pomace had much better adsorption when exposed to high levels of glucose. In a mixed system including fiber, amylase and substrate, the level of glucose produced in the mixture containing lemon pomace fiber with a size <50 mesh was the lowest, and it was the best inhibitor of amylase activity. After 180 min of glucose adsorption, mung bean hull fiber with a size of 30-50 mesh was able to lower glucose diffusion. All of these mechanisms might contribute the rate reduction of glucose adsorption in the intestines, as a result, decrease the postprandial serum glucose concentration.

Key words: fiber, glucose, *in vitro*

INTRODUCTION

Mung bean hulls, rice bran and lemon pomace are commonly mass-produced wastes in Taiwan. Mung bean hulls are often used for pillow fillings, especially in agricultural areas. However, mung bean hulls contain a high percentage of fiber and can be further processed to create added value(1). Rice bran is the byproduct of rice processing. Research confirms that rice bran is composed of 50% cellulose along with some other physiologically active ingredients, such as unsaturated fatty acids and soluble polysaccharides, that can improve brain vessel function and prevent high blood fat, high blood pressure, high blood sugar and constipation(2). The many past studies indicated that citrus peels contain water-soluble dietary fiber and are excellent raw materials for the production of dietary fiber(3). These three agricultural wastes-mung bean hulls, rice bran and lemon pomace can be processed to yield fiber by physicochemical characteristics modification and can thus be developed to be physiologically functional products.

Some types of fiber have been reported to exhibit special bio-functional effects. For example, fiber has been shown to induce a number of physiological effects, such as increased fecal bulk, reduced levels of plasma cholesterol and reduced glycemic response to meals(4). Additionally, fiber has been shown to promote glucose attenuation and laxation, and can reduce the risk of coronary heart disease, colon cancer and obesity(5-7).

In this study, we used mung bean hulls, rice bran and lemon pomace to produce fiber by the chemical precipitation method, analyzed the physicochemical characteristics of the prepared fiber and then determined the effect

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of each type of fiber on glucose adsorption *in vitro*. All of these results may help in the evaluation of the physiologically relevant functions of fiber products made from mung bean hulls, rice bran and lemon pomace.

MATERIALS AND METHODS

I. *Plant Samples*

Mung bean hulls were purchased from Flavor Full Foods Inc. (Hsinchu, Taiwan). Rice bran was produced by Liu-Hsin Rice Mills Co., Ltd. (Hsinchu, Taiwan). Lemon pomace was made in the laboratory by squeezing lemons from a general fruit shop to remove the liquid.

II. *Separation of the Fiber*

Fiber was prepared from the mung bean hulls, rice bran and lemon pomace according to the method described by Chau *et al.*[8-10] with slight modifications. The mung bean hulls, rice bran and lemon pomace were homogenized in ethyl ether (sample:ethyl ether = 1:4, w/v) using an Osterizer at the "Hi" speed for 2 min twice. Then the samples were added to 10 volumes of cold distilled water (sample:water = 1:10, w/v) and homogenized again using the Osterizer at the "Hi" speed for 2 min three times. After filtration, three fiber samples of each one of mung bean hull, rice bran and lemon pomace fiber were washed with 85% ethanol three times, and the residue was dried at 50°C. The particle size of the fiber was determined by sieving a 50 g sample using a Ro-Tap testing sieve shaker with > 35, 35-50, and < 50 mesh sieves, respectively.

III. *Chemical Analysis*

Based on the methods described by Chau *et al.*[9] and the AOAC official methods[11,12], the moisture and total ash contents of the fiber samples were estimated. The crude protein content was determined by multiplying the nitrogen content of the fiber by a factor of 6.25 according to the AOAC official method. The lipids in the fiber samples (about 2 g) were extracted using 25 mL petroleum ether in a water-bath (55°C) for 16 hr. The ether was then evaporated on steam bath, and the extracted lipids were dried at 100°C for 30 min. The dried residue was cooled in a desiccator and weighed. The fiber content was determined by the AOAC official method.

IV. *Physicochemical Properties*

According to the methods described by Chau *et al.*[10,13,14], the bulk density (g/mL), the swelling property (mL/g), the oil-holding capacity (mL/g) and the water-holding capacity (mL/g) of the three types of fiber (mung bean hull, rice bran and lemon pomace) were determined and compared with the corresponding values for cellulose (microgranular, Sigma, MO, USA). The swelling property (mL/g) was determined by the bed volume technique. The oil-holding capacity (mL/g) and water-holding capacity (mL/g) were measured by mixing the fiber samples with vegetable oil (1:10, w/v) for 30 min and with distilled water (0.88 g/mL) for 24 hr, respectively.

The determination of water solubility was based on the method described by Ralet *et al.*[15] with modifications. The fiber sample (1 g) was mixed with distilled water (10 mL) for 1 hr at room temperature. The mixture was then centrifuged at 1,000 × *g* for 10 min, and the soluble fiber was recovered from the supernatant by evaporation overnight at 105°C. The resulting sludge was collected, weighed and washed twice with distilled water. On the other side, insoluble pellet from centrifugation was washed successively with ethanol and acetone, dried overnight at 40°C and weighed.

V. *Ability of Fiber to Adsorb Glucose*

The ability of the three kinds of fiber to adsorb glucose was determined according to the methods of Ou *et al.*[16] and Chau *et al.*[9] with modifications. A small amount of fiber, 0.1 g, was added to 10 mL of glucose solution of 10, 50, 100 or 200 mM. The mixture was stirred, incubated in a water bath at 37°C for 6 hr and then centrifuged at 2,000 × *g* for 2 min. The glucose content in the supernatant was determined using a glucose assay kit (Randox, London, United Kingdom).

VI. *Effect of Fiber on α-Amylase Activity*

According to the methods of Ou *et al.*[16] and Chau *et al.*[9] with modifications, the effect of the three types of fiber on α-amylase activity was determined. Briefly, 40 g of potato starch was added to approximately 900 mL of 0.05 M phosphate buffer (pH 6.0). After stirring at 65°C for 30 min, the total volume of the solution was brought up to 1,000 mL to give a 4% (w/v) starch solution. The effect of various fibers on starch digestibility was determined as a function of time in a fiber-enzyme-starch mixture system. The system was composed of 0.2% α-amylase (ICN Biomedical Inc, CA, USA) and 1% of one of each type of fiber in a 4% starch solution. The mixture was prepared by combining 0.25 g of fiber and 0.05 g of α-amylase in 25 mL of 4% potato starch solution. The solution was stirred at 37°C for 1 hr. Twenty milliliter of 0.1 M NaOH was then added and the solution was centrifuged at 2,000 × *g* for 5 min. The glucose content of the supernatant was determined using a glucose assay kit. A control experiment was carried out without adding fiber to the reaction mixture.

VII. *Effect of Fiber on the Diffusion of Glucose in a Glucose-Fiber System*

According to the methods of Ou *et al.*[16] and Chau *et al.*[9], with modifications, the effect of the three types of fiber on glucose diffusion was determined. A glucose-fiber system composed of 100 mM of glucose and 2.0% (v/v) fiber (mung bean hull, rice bran or lemon pomace) was dialyzed in a dialysis bag (14,000 Da cut-off) against 100 mL deionized water at 37°C. After 10, 30, 60, 120 and 180 min, the glucose content of solution from deionized water was measured using a glucose assay kit. A control solution with fiber excluded was also analyzed. The maximum diffusion rate of glucose (Vmax) was calculated as follows: the experimental data were fitted to a parabolic function with the formula $Y = ax^2 + bx + c$, where Y is the glucose content (μmol); x is time (min); and a, b, and c are coefficients. The equation used to calculate the diffusion rate (Y') at any time is $Y' = 2ax + b$. When x is 0, $Y' = V\text{max} = b$.

VIII. *Statistical Analysis*

Data collected from this study were analyzed by the Duncan test using the Statistical Analysis System (SAS). Values of $P < 0.05$ were considered statistically significant.

RESULTS

I. *Chemical Composition of Fiber Prepared from Mung Bean Hulls, Rice Bran and Lemon Pomace*

Table 1 shows the chemical compositions of the fiber samples prepared from mung bean hulls, rice bran and lemon pomace. The levels of total dietary fiber in mung bean hull fiber, rice bran fiber and lemon pomace fiber were 63.83, 72.41 and 44.88%, respectively indicating that mung bean hulls, rice bran and lemon pomace are rich in dietary fiber. The protein level in mung bean hull fiber was the highest (16.50%), followed by lemon pomace fiber (8.02%) and rice bran fiber (3.45%). The levels of crude fat, moisture and carbohydrate were the highest in the lemon pomace fiber, and the levels of ash were the highest in the rice bran fiber. Total dietary fiber existed in rice bran fiber at the highest level, followed by in the mung bean hull fiber and lemon pomace fiber. Among these three types of fiber, rice bran fiber contained the lowest levels of crude protein (3.45%), crude fat (0.98%), moisture (5.87%) and carbohydrate (33.05%), but contained the highest levels

Table 1. Chemical compositions (%) of fiber prepared from mung bean hulls, rice bran and lemon pomace

Fiber from	Crude Protein	Crude fat	Ash	Moisture	Carbohydrate*	Crude fiber	Total dietary fiber
Mung bean hulls	16.50 ± 0.04^{a}**	0.99 ± 0.12^{b}	1.97 ± 0.04^{c}	8.77 ± 0.97^{b}	42.20 ± 5.30^{bc}	29.57 ± 0.89^{b}	63.83 ± 5.15^{b}
Rice bran	3.45 ± 0.09^{c}	0.98 ± 0.15^{b}	10.75 ± 0.02^{a}	5.87 ± 0.04^{c}	33.05 ± 0.04^{c}	45.90 ± 0.97^{a}	72.41 ± 0.08^{a}
Lemon pomace	8.02 ± 0.01^{b}	5.55 ± 1.57^{a}	4.80 ± 0.03^{b}	13.74 ± 1.19^{a}	54.89 ± 0.38^{a}	13.00 ± 0.04^{c}	44.88 ± 1.23^{c}

* Carbohydrate was defined as the residue e125xcluding protein, fat, ash, moisture and crude fiber, and calculated by following formula (100% - protein% - fat% - ash% - moisture% - crude fiber%)

** Data are mean ± SD (n = 3). Values in the same column with different letters are significantly different ($P < 0.05$).

Table 2. Effect of particle size on the physicochemical properties of fiber prepared from mung bean hulls, rice bran and lemon pomace

Fiber from	Particle size (mesh)	n	Bulk density (g/mL)	Water-holding capacity (mL/g)	Oil-holding capacity mL/g)	Swelling property (mL/g)	Solubility (%)	
							Water-soluble	Water-insoluble
Cellulose	< 50	9	0.40 ± 0.01^{d}*	1.67 ± 0.48^{g}	1.86 ± 0.30^{d}	5.14 ± 0.31^{f}	0.42 ± 0.08^{f}	97.42 ± 3.10^{a}
Mung bean hulls	> 35	9	0.45 ± 0.05^{c}	4.44 ± 0.79^{b}	1.83 ± 0.39^{de}	9.20 ± 0.30^{b}	0.78 ± 0.10^{ef}	89.50 ± 3.30^{b}
Mung bean hulls	35-50	9	0.52 ± 0.06^{b}	3.52 ± 0.40^{cd}	1.50 ± 0.13^{e}	6.10 ± 0.54^{de}	0.99 ± 0.16^{de}	89.38 ± 3.70^{b}
Mung bean hulls	< 50	9	0.64 ± 0.05^{a}	3.13 ± 0.21^{de}	1.49 ± 0.56^{e}	5.51 ± 0.35^{e}	0.97 ± 0.15^{de}	91.35 ± 2.78^{b}
Rice bran	> 35	6	0.23 ± 0.03^{f}	3.69 ± 0.71^{c}	2.81 ± 0.29^{a}	7.95 ± 0.30^{c}	0.93 ± 0.11^{ef}	91.74 ± 0.18^{b}
Rice bran	35-50	6	0.32 ± 0.02^{e}	2.95 ± 0.31^{ef}	2.47 ± 0.19^{b}	7.73 ± 0.98^{c}	1.03 ± 0.09^{de}	91.58 ± 0.47^{b}
Rice bran	< 50	6	0.38 ± 0.02^{d}	2.48 ± 0.30^{f}	2.09 ± 0.15^{cd}	6.47 ± 0.33^{d}	1.48 ± 0.06^{d}	90.85 ± 0.36^{b}
Lemon pomace	> 35	6	0.24 ± 0.01^{f}	6.02 ± 0.27^{a}	3.04 ± 0.23^{a}	10.27 ± 0.43^{a}	16.61 ± 0.84^{c}	87.00 ± 2.14^{b}
Lemon pomace	35-50	6	0.32 ± 0.02^{e}	5.57 ± 0.48^{a}	2.31 ± 0.13^{bc}	9.34 ± 0.36^{ab}	17.12 ± 1.00^{b}	68.33 ± 4.22^{c}
Lemon pomace	< 50	6	0.34 ± 0.01^{e}	4.79 ± 0.25^{b}	2.25 ± 0.20^{bc}	8.95 ± 0.11^{b}	23.86 ± 0.22^{a}	35.80 ± 2.93^{d}

* Data are mean ± SD from separate experiments. Values in the same column with different letters are significantly different ($P < 0.05$).

of crude fiber (45.90%), total dietary fiber (72.41%) and ash (10.75%). These results indicate that rice bran is rich in dietary fiber and may be an ideal source of plant-based dietary fiber.

II. *Effect of Particle Size on the Physicochemical Characteristics of Fiber*

Table 2 shows the effect of particle size on the physicochemical properties, including bulk density, water-holding capacity, oil-holding capacity, swelling property and water solubility, of the fiber samples prepared from mung bean hulls, rice bran and lemon pomace. When the particle size was decreased, the bulk density increased, but the water-holding capacity, oil-holding capacity and swelling property all decreased. Although the water solubility of each type of fiber was not high, the effect of particle size on water solubility depended on the type of fiber. The highest values for bulk density, water-holding capacity, oil-holding capacity and swelling property among these three types of fiber were as follows: bulk density - 0.64 g/mL for mung bean hull fiber with a size < 50 mesh; water-holding capacity - 6.02 mL/g for lemon pomace fiber with a size > 35 mesh; oil-holding capacity - 3.04 mL/g for lemon pomace fiber with a size > 35 mesh; and swelling property - 10.27 mL/g for lemon pomace fiber with a size > 35 mesh. As to the water solubility, the lemon pomace fiber showed higher when compared with mung bean hull fiber, rice bran fiber and cellulose. When comparing three kinds of fiber to cellulose with the same particle size (< 50 mesh), all types of fiber exhibited higher water-holding capacities, swelling properties and water solubility than cellulose. The oil-holding capacities of mung bean hull fiber were lower than that of cellulose. The bulk density of lemon pomace fiber was lower than that of cellulose; however, mung bean hull fiber had a higher value than cellulose did.

In summary, lemon pomace fiber with a size > 35 mesh had the highest water-holding capacity, oil-holding capacity, swelling property and water solubility. Each fiber had its own unique physicochemical characteristics, which were indeed affected by particle size.

III. *Effects of Fiber Particle Size on Glucose Adsorption*

Table 3 shows the glucose-*adsorption* capacity of the various types of fiber in glucose solutions with concentrations of 10, 50, 100 and 200 mM. The results indicated that the glucose *adsorption* capacity of each type of fiber increased gradually when the glucose concentration increased. The particle size had no significant effect on glucose *adsorption*. The glucose *adsorption* capacities of the different types of fiber in a low concentration of glucose (10 mM) were as follows : rice bran > mung bean hull > cellulose > lemon pomace. However, the glucose *adsorption* values for rice bran fiber and lemon pomace fiber were significantly higher than those for cellulose and mung bean hull fibers in glucose solutions of high concentrations (100 and 200 mM).

Table 4 shows the effects of the fiber samples prepared from mung bean hulls, rice bran and lemon pomace on the activity of α-amylase in a system made up of fiber, enzyme and substrate. The results indicated that cellulose could inhibit amylase activity. There was no

Table 3. Glucose-adsorption capacities of fiber prepared from mung bean hulls, rice bran and lemon pomace in different concentrations of glucose

Fiber from	Particle size (mesh)	n	Glucose adsorbed (mmol/g)*			
			10 mM	50 mM	100 mM	200 mM
Cellulose	< 50	6	0.43 ± 0.01^{c}**	1.85 ± 0.05^{a}	4.76 ± 0.19^{d}	13.49 ± 0.34^{d}
Mung bean hulls	> 35	6	0.45 ± 0.01^{b}	1.75 ± 0.09^{b}	4.91 ± 0.05^{cd}	13.69 ± 0.15^{d}
Mung bean hulls	35-50	6	0.45 ± 0.01^{b}	1.76 ± 0.07^{b}	4.90 ± 0.07^{cd}	13.65 ± 0.19^{d}
Mung bean hulls	< 50	6	0.45 ± 0.01^{b}	1.75 ± 0.04^{b}	4.82 ± 0.08^{d}	13.63 ± 0.19^{d}
Rice bran	> 35	4	0.49 ± 0.02^{a}	1.81 ± 0.04^{ab}	5.04 ± 0.08^{bc}	14.24 ± 0.15^{abc}
Rice bran	35-50	4	0.46 ± 0.01^{b}	1.84 ± 0.02^{a}	5.07 ± 0.13^{ab}	14.22 ± 0.13^{bc}
Rice bran	< 50	4	0.46 ± 0.01^{b}	1.84 ± 0.02^{a}	5.16 ± 0.07^{ab}	14.01 ± 0.19^{c}
Lemon pomace	> 35	4	0.32 ± 0.01^{d}	1.89 ± 0.02^{a}	5.13 ± 0.10^{ab}	14.49 ± 0.15^{ab}
Lemon pomace	35-50	4	0.32 ± 0.01^{d}	1.86 ± 0.03^{a}	5.23 ± 0.14^{a}	14.53 ± 0.22^{a}
Lemon pomace	< 50	4	0.31 ± 0.01^{d}	1.88 ± 0.02^{a}	5.22 ± 0.10^{a}	14.41 ± 0.20^{ab}

* Glucose adsorbed = (glucose concentration of original solution - glucose concentration when the adsorption reached equilibrium) × volume of solution ÷ weight of fiber.

** Data are mean ± SD from separate experiments. Values in the same column with different letters are significantly different ($P < 0.05$).

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Table 4. Effect of fiber prepared from mung bean hulls, rice bran and lemon pomace on the activity of α-amylase

Fiber from	Particle size (mesh)	n	Glucose produced (μmol/hr)
Control*		9	507.4 ± 9.5^{ab}**
Cellulose	< 50	9	487.9 ± 8.7^{de}
Mung bean hulls	> 35	9	496.5 ± 7.1^{bcd}
Mung bean hulls	35-50	9	498.7 ± 6.4^{bcd}
Mung bean hulls	< 50	9	507.1 ± 6.9^{ab}
Rice bran	> 35	6	518.0 ± 5.9^{a}
Rice bran	35-50	6	510.9 ± 8.4^{ab}
Rice bran	< 50	6	508.0 ± 8.5^{ab}
Lemon pomace	> 35	6	500.9 ± 28.2^{bc}
Lemon pomace	35-50	6	510.7 ± 6.2^{ab}
Lemon pomace	< 50	6	481.7 ± 10.5^{e}

* Control is without fiber addition.

** Data are mean ± SD from separate experiments. Values in the same column with different letters are significantly different (P < 0.05).

significant inhibition of amylase activity by the various sizes of mung bean hull and rice bran fibers. However, lemon pomace fiber with a size < 50 mesh was able to inhibit amylase activity more than cellulose did, resulting in a lower amount of glucose in the mixed system.

Figure 1 shows the effects of various types of fiber on glucose diffusion in a glucose-fiber system. The results indicated that glucose diffusion was the lowest for all experimental groups when fiber was added by dialysis for 10-60 min. Meanwhile, the particle size of each fiber had no significant effect on glucose diffusion except for mung bean hull fiber with a size of 35-50 mesh. The mixture with lemon pomace fiber showed the highest level of glucose diffusion after dialysis for 180 min, suggesting that lemon pomace fiber is least able to retard glucose diffusion in the intestine. On the other hand, mung bean hull fiber with a size of 35-50 mesh is expected to inhibit glucose diffusion in the intestine the most of all types of fiber tested.

Table 5 shows the maximum glucose diffusion rates for the different fibers. The results indicated that the maximum glucose diffusion rates of each fiber group were between 9.33 and 10.06 μmol/min. There were no significant difference among different types of fiber.

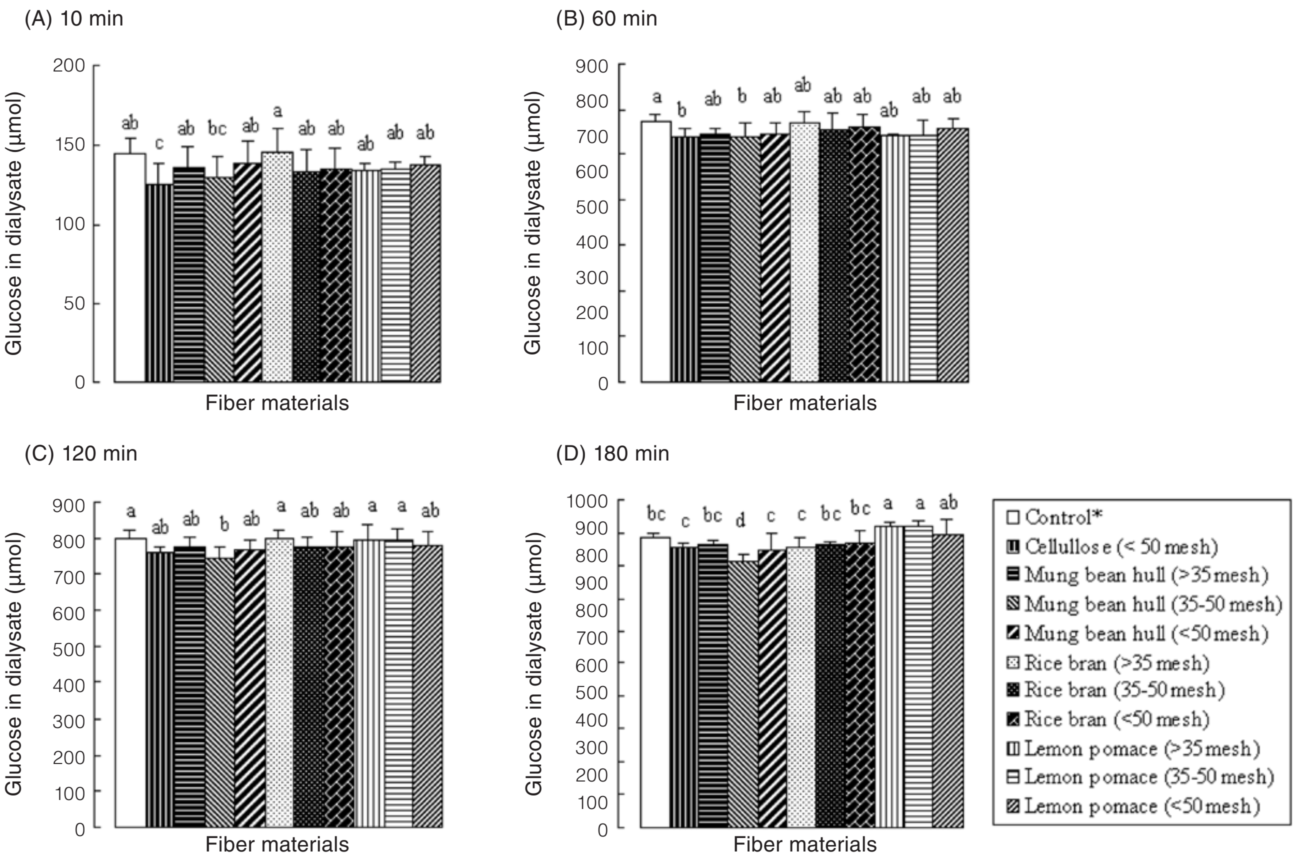

Figure 1. Effect of various fibers prepared from mung bean hull, rice bran and lemon pomace on glucose diffusion.
Dialysis time:(A) 10 min (B) 60 min (C) 120 min (D) 180 min.*Control is without fiber addition. Data are mean ± SD from separate experiments , n = 6. Means (bar value) with different letters are significantly different (P < 0.05).

Table 5. Maximum velocity of glucose diffusion in suspensions of fiber from mung bean hulls, rice bran and lemon pomace

Fiber from	Particle size (mesh)	n	V_{max} (μmol/min)*
Control**		6	9.87 ± 0.38[a]***
Cellulose	< 50	6	9.47 ± 0.28[a]
Mung bean hulls	> 35	6	9.50 ± 0.75[a]
Mung bean hulls	35-50	6	9.54 ± 0.26[a]
Mung bean hulls	< 50	6	9.50 ± 0.88[a]
Rice bran	> 35	6	10.06 ± 0.70[a]
Rice bran	35-50	6	9.66 ± 0.65[a]
Rice bran	< 50	6	9.70 ± 0.78[a]
Lemon pomace	> 35	6	9.33 ± 0.82[a]
Lemon pomace	35-50	6	9.33 ± 0.78[a]
Lemon pomace	< 50	6	9.42 ± 0.46[a]

* Maximum diffusion velocity of glucose (V_{max}) was calculated as follows: the experimental data were fitted to a parabolic function with the form $Y = ax^2 + bx + c$, as described in method.

** Control is without fiber.

*** Data are mean ± SD from separate experiments. Values in the same column with different letters are significantly different ($P < 0.05$).

DISCUSSION

The fiber samples prepared from mung bean hulls, rice bran and lemon pomace exhibited different physicochemical characteristics. The particle size of the fiber is usually important because it can influence many events in the intestines, such as delivery time, fermentation and excrement. The particle sizes of the different types of fiber are dependent on botanical cell wall types and the processing level. Delivery duration of fiber in the intestines is multiple, such as the effects of chewing, stomach grinding and cellular decomposition in the large intestine. Drying and humidity exert important effects on fiber structures because some types of fiber can swell in aqueous solution. Fiber's swelling property can be used to deduce the range of particle sizes present in the sample. In addition to the overall bulk density, the fiber particle size can have a large effect on digestion[17]. The fiber of mung bean hull, rice bran and lemon pomace was mesh larger, meaning that the particle size was smaller and the bulk density of the fiber was larger. When the particle size of the fiber decreased, the water-holding and oil-holding capacities were lower. When the size of the fiber particles made of mung bean hulls and lemon pomace decreased, their swelling capacities became lower. This indicated that particle size has a large influence on the physicochemical characteristics of fiber. The physical structures of some types of dietary fiber have been reported to affect their hydration[18]. Ground fiber has been found to have an enlarged surface area, resulting in gaps or structural collapses by the fiber. The gaps or structural collapses leads to a reduction in the water-holding capacity[19]. In this study, we found that refining the fiber can lead not only to an increase in the bulk density but also to a decrease in the water-holding capacity, the oil-holding capacity and the swelling property. One possible explanation for this result is that the grinding or the preparatory process might destroy the substrate structure of the fiber.

The water-holding capacity is an indicator of the physicochemical characteristics of a fiber sample. Usually, water molecules infiltrate into gaps in the fiber structure until the fiber reaches its water-holding capacity. The number of bonds between the fiber surface and the water will affect the water-holding capacity of the fiber[20,21]. It has been reported that there is a relationship between the bulk density and the water-holding capacity of fiber[22]. From the overall results, mung bean hull fiber had a higher bulk density and a much higher water-holding capacity than cellulose, and those fibers with a size > 35 mesh had a much higher swelling property than that of cellulose or rice bran fiber. This indicates that mung bean hull fiber may be able to increase chyme bulk after hydration in the intestines, stimulate intestine peristalsis and shorten the intestinal evacuation duration. Zhen and Lee[23] have suggested that dietary fiber with a high water-holding capacity can prevent dehydration and shrinkage of product structures and can be used by the baking industry to reduce product water loss and lengthen products' shelf lifespan.

The swelling property refers to the swelling bulk caused by the weight of the fiber due to gravity. The water-holding capacity is the amount of water retained by a known weight of fiber under the condition of centrifugation. Normally, the fiber water hydration refers to the swelling property and the water-holding capacity and is beneficial information when providing fiber-supplemented foods[17]. A high fiber swelling property can cause chyme to have a larger bulk in the intestines and can increase satiety. Additionally, a high fiber swelling property can increase the viscosity of the stomach contents, resulting in increased difficulty in the absorption of nutrients[24]. In this study, the water-holding capacity and the swelling property of rice bran fiber were significantly higher than those of cellulose. Although rice bran fiber had the highest level of total dietary fiber, there was no prominent difference in the physicochemical characteristics among the different types of fiber that could have been due to the higher level of crude fiber. In this study, the water-holding capacity, the swelling property and the water solubility of lemon pomace fiber were significantly higher than those of other types of fiber. The water solubility of fiber is very important for hydration, especially for the swelling property. It was found that the more the fiber was refined, the higher the water solubility of the lemon pomace fiber was. One explanation for this result is that the surface enlargement of the fiber accelerated water absorption. This could increase the viscosity, improve the adsorption rate and decrease the absorption of nutrients.

The oil-holding capacity is influenced by the preparation method used and is highly relative to the full charge density and hydrophobic bonding ability of the fiber molecules[25,26]. In this study, there was no significant difference in the oil-holding capacities of the three different types of fiber, but the water-holding capacities and the oil-holding capacities were lower when the particle size was smaller. Lemon pomace fiber had the highest oil-holding capacity (2.25-3.04 mL/g), followed by rice bran fiber (2.09-2.81 mL/g) and cellulose (1.86 mL/g). The oil-holding capacity of mung bean hull fiber was significantly lower than those of the other types of fiber. Although the different types of fiber could possibly have different hydrophobic bonding abilities that could lead to differences in the oil-holding capacities, the particle size did not affect the oil-holding capacity.

Fiber is able to absorb glucose and can effectively reduce the amount of absorbable glucose in the intestine[16]. In this study, the glucose-adsorption of cellulose was significantly lower in low concentrations of glucose. Among the different types of fiber that we characterized, mung bean hull and rice bran fiber exhibited a higher level of glucose-adsorption at low concentrations of glucose than cellulose did. Lemon pomace fiber had higher glucose adsorption when glucose concentrations were higher than 100 mM.

Amylase activity was significantly inhibited by cellulose. The lemon pomace fiber with a size smaller than 50 mesh showed reduced amylase activity compared to the control group without fiber and also inhibited amylase activity more than the other lemon pomace fiber groups. When compared with the control group, the solution including mung bean hull fiber with a size > 35 mesh also showed a lower level of glucose production, meaning that it was also an effective inhibitor of amylase activity. In the mixed system of fiber, enzyme and substrate, the glucose production was the lowest for lemon pomace fiber with a size < 50 mesh, indicating that it was the most effective inhibitor of amylase activity. The ability of fiber to inhibit amylase activity may be due to the adsorption of the starch and the enzyme, but the actual mechanism remains unknown[27]. Ou *et al.*[16] showed that fiber can inhibit amylase activity and that starch and enzyme can be encapsulated by fiber. The reduced accessibility of the starch to the enzyme and the direct adsorption of the enzyme onto the fiber lead to the decrease in amylase activity. Moron *et al.*[28] showed that carrots have a stronger inhibitory effect, followed in intensity by green beans and black beans. Although all of the residues assayed inhibited α-amylase activity on soluble starch, effect of black bean fiber seemed to be due to its tannin content.

Ou *et al.*[16] suggested that dietary fiber has at least three pathways for lowering glucose production after a meal: 1) increasing the viscosity of the contents in the small intestine, thereby suppressing glucose diffusion; 2) preventing glucose diffusion by absorbing glucose; and 3) suppressing amylase activity and delaying glucose release from amylum. In this study, there was no difference among the maximum velocity of glucose diffusion rates for all types of fiber. This result suggested that these three types of fiber have a similar effect on glucose diffusion.

CONCLUSIONS

This study demonstrated that fiber prepared from mung bean hulls, rice bran and lemon pomace could effectively adsorb glucose, postpone the release of glucose from starch and inhibit α-amylase activity. All of these mechanisms might function in concert to lower the rate of glucose adsorption and, as a result, decrease the postprandial serum glucose concentration. Further investigations are needed to analyze the *in vivo* hypoglycemic effects and other physiological functions of these types of fiber.

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