DIETARY FIBER PRODUCTION FROM SWEET POTATO RESIDUE BY SOLID STATE FERMENTATION USING THE EDIBLE AND MEDICINAL FUNGUS *Schizophyllum commune*

Jianguo Wu,[a] Hongxun Wang,[b,#] Xialu Yang,[a] Jilin Wan,[a] Ping Liu,[a] Qiwu Xu,[a] Yong Tang,[a] and Xiaoyu Zhang [a,]*

Dietary fiber (DF) has attracted increasing interest from nutritionists. The yield of DF by traditional extraction methods, however, is very low. This paper aims to increase the yield of DF by solid state fermentation using the edible and medicinal fungus *Schizophyllum commune*. Sweet potato residue (SPR) was selected as raw material for producing DF. Results showed that SPR was a good feedstock for DF production by solid state fermentation. Optimized conditions of solid state fermentation of SPR for DF were obtained as follows: material particle size = 1.8 mm to 2.5 mm, water moisture at 65%, natural lighting radiation, and temperature at 27 °C. Under the optimal conditions, the yield and DF content in fermented SPR were more than 80% and 70%, respectively. The increased DF yield was mainly attributable to increased cellulose and hemicelluloses conversion. Swelling capacity, water-holding capacity, oil-holding capacity, and glucose absorption capacity of the fermented SPR were also determined, and the data indicated that the fermented SPR could be considered as a new good DF. Therefore, this work showed us a novel bioconversion method to produce high-quality DF, and the yield of DF increased 4-fold compared with traditional extraction methods.

Keywords: Dietary fiber; Sweet potato residue; Solid state fermentation; Schizophyllum commune; Lignocelluloses

*Contact information: a: Key Laboratory of Molecular Biophysics Ministry of Education, College of Life Science and Technology, Huazhong University of Science and Technology, Wuhan 430074, China; b: College of Food Science and Engineering, Wuhan Polytechnic University, Wuhan 430023, China; *Corresponding author: xyzhang.imer@gmail.com*

INTRODUCTION

Some diseases of western civilization, such as obesity, diabetes mellitus, cancer, neurodegenerative diseases, and acne are increasing along with improvements in the standard of living (Melnik 2011). Some researchers (Cordain *et al.* 2005; Russo *et al.* 2010) have reported that lack of dietary fiber (DF) is one of the key reasons for these trends. DF mainly consists of plant cell wall complex carbohydrates such as cellulose, hemicelluloses, pectin, and lignin, as well as intracellular polysaccharides, which are not hydrolysable by human digestive enzymes (Spiller 2000). DF is typically classified into two categories, which are soluble dietary fiber (SDF), such as pectin, gum, and β-glucan, and insoluble dietary fiber (IDF), which includes cellulose, hemicelluloses, and lignin (Happi Emaga *et al*. 2008; Vergara-Valencia *et al*. 2007). The function of DF has led to its widespread use as a food additive in biscuits (Verardo *et al*. 2011), confectioneries

(Sidorova *et al.* 2007), drinks (Lummela *et al*. 2009), sauces (Pollard *et al*. 2009), desserts, and moon-cakes.

Traditionally, the sources of DF are milling by-products of cereal grains, fruits, and vegetables, including wheat, corn, sorghum, apple, orange, grapefruit, peach, sugarcane, celery, coconut, *etc*. (McKee and Latner 2000; Raghavendra *et al*. 2004; Rupérez and Toledano 2003).

Normal DF-producing methods include crude separation, chemical separation, membrane separation, and enzyme-aided chemical separation. The last method is the most widely used by researchers among four methods above, but there still remains a puzzle in that the extraction rate of total DF (TDF) is limited by DF content of the feedstocks (Mallillin *et al*. 2008; Mei *et al.* 2010). However, there is no report about DF production by solid state fermentation.

Sweet potato ranks No.1 among all vegetables for anti-cancer properties. DF is one of the major functional components in sweet potato residue (SPR), but the extraction yield of DF from SPR is very low (no more than 16%) (Mei *et al*. 2010). Starch and protein in SPR are non-DF compositions and can be transformed to mycelium and polysaccharides which are good DFs by solid state fermentation. Now, some products such as poly gamma-glutamic acid (Bajaj *et al*. 2008), adlay angkak (Pattanagul *et al*. 2008), monacolin K (Chen and Hu 2005), solid fuel (Wu *et al*. 2011a), and fiberboard (Wu *et al*. 2011b) have been produced by solid state fermentation. *Schizophyllum commune* is an edible and medicinal fungus, which produces cellulase, xylanase, glucosidase, and other extra enzymes (Steiner *et al*. 1989). Therefore, *S. commune* should have potential to transform some non-DF compositions of SPR into some DF compositions. This study aims to increase the yield and the content of DF by solid state fermentation using the edible and medicinal fungi *S. commune*.

EXPERIMENTAL

Microorganism Maintenance and Inoculums Preparation

The strain *S. commune* (code no.: DS1) was isolated, identified, and preserved by the Institute of Micro-biotechnology and Environmental Resources in Huazhong University of Science and Technology. *S. commune* was preserved on potato-glucose agar slants at 4 °C. Three agar blocks (about 1 cm^2) with hypha were inoculated to SPR liquid seed medium which included 20 g SPR (presented by Sanyou Potato Industry CO, LTD) and 1000 mL water for 4 days at 28 °C in a shaker with 150 r/min.

Solid State Fermentation of SPR

Liquid inoculum (10 mL) was added to 50 g SPR in a 250 mL flask containing a certain amount water. The flasks were incubated with no shear for 20 days at various temperatures.

Measurement of DF and Lignocelluloses

The whole cultivated matrix was dried in the oven at 60 °C until the mass was stable (measurement interval 2 h), and was analyzed for its TDF, IDF, and SDF contents by enzymatic and gravimetric method developed by the Association of Official Analytical Chemists (AOAC) (Farhath *et al*. 2000). The contents of their lignocelluloses were measured by the Van Soest method (Goering and Soest 1970).

Physicochemical Properties of Fermented SPR

The functional properties of the fermented SPR were measured, including the swelling capacity (SWC), water-holding capacity (WHC), oil-holding capacity (OHC), and glucose absorption capacity (GAC) (Mei *et al*. 2010).

Statistical Data Expression

All data were expressed as mean ± standard deviation, and the statistics data were calculated from five repeated experiments.

RESULTS AND DISCUSSION

Chemical Composition Analysis of SPR

The chemical compositions of SPR are shown in Table 1. TDF content of SPR was 22.3 %, which indicated that SPR was a good source for DF. The contents of cellulose, lignin, and hemi-cellulose in SPR were 8.9 %, 2.2 %, and 11.7 %, respectively. It was found that the TDF content was approximately equal to the total content of lignocelluloses (22.3% compared to 22.8%), which indicated that the TDF was mainly composed of lignocelluloses, such as cellulose, hemicelluloses, and lignin (Spiller 2000). The content of starch in SPR (50.1 %) was very high. That starch could be easily metabolized by starch degrading microorganism. Furthermore, the remaining 27.8 % of SPR consisted of other materials, which perhaps were protein, fat, *etc*. *S. commune* is an edible and medicinal fungus that has effective amylase and lignocellulose oxidation enzymes. Therefore, *S. commune* could grow well in SPR and produce new DF to increase the TDF content of SPR. Based on the chemical compositions of SPR, it was indicated that SPR was a good material for solid state fermentation by *S. commune* to produce DF.

Table 1. Chemical Compositions of SPR (grams per 100 g of SPR)

Ingredients	TDF	Starch	Cellulose	Hemi-cellulose	Lignin	Water	Others
Content	22.3±0.4	50.1±0.9	8.9±0.1	11.7±0.2	2.2±0.1	10.5±0.8	27.8±2.9

Optimization of Solid State Fermentation Conditions for DF

The size of particles in biomaterial affects the growth and metabolism of microbes in solid-state fermentation. Small material size accelerates the utilization of substrate by microbes but is not conducive to mycelial growth. Large material size has the opposite effect. In this paper, the SPR was processed with a crusher at different bore diameter in the range of 0.5 mm to 3.6 mm. The effect of material size on DF production by solid state fermentation is shown in Fig. 1(a). The TDF content increased with the increasing material size, and the maximum TDF content was 68.1% when the material size was 1.8 mm to 2.5 mm. The content of TDF subsequently decreased when the size was further increased.

The moisture content had a great impact on the physical properties of the solid substrate in solid state fermentation. Higher than optimum moisture level decreased porosity, lowered the oxygen transfer, and altered the particle structure (Pandey *et al*. 1999). Likewise, lower than optimum moisture level decreased the solubility of the solid substrate, lowered the degree of swelling, and produced a high water tension (Mahadika *et al*. 2002). From Fig. 1(b), the optimal water moisture was 65 % and the TDF content was 69.2 %.

Kuforiji and Fasidi (2009) reported that light affects the yields of fruit bodies and sclerotia of *Pleurotus tuberregium*. Does light affect the growth and metabolism of the strain *S. commune*? From Fig. 1(c), the TDF content was slightly changed respectively under conditions of full light, gap light (natural lighting radiation), and no light. The results indicated that light had little effect on producing DF by *S. commune*.

The incubation temperature was also optimized, as shown in Fig. 1(d). The TDF content was increased when the temperature increased from 19 °C to 27 °C and then decreased slightly when the temperature further increased. Thus the optimal temperature was 27 °C. From the results above, the optimum fermentation conditions were as follows: material size = 1.8 mm to 2.5 mm, water moisture at 65%, natural lighting radiation, and temperature at 27 °C. Under the optimum conditions, the yield and DF content of fermented SPR were higher than 80% and 70% by five repeated experiments, respectively. The yield was much higher than that with methods that were not optimized (increased 4- to 5-fold), while the DF contents were almost the same.

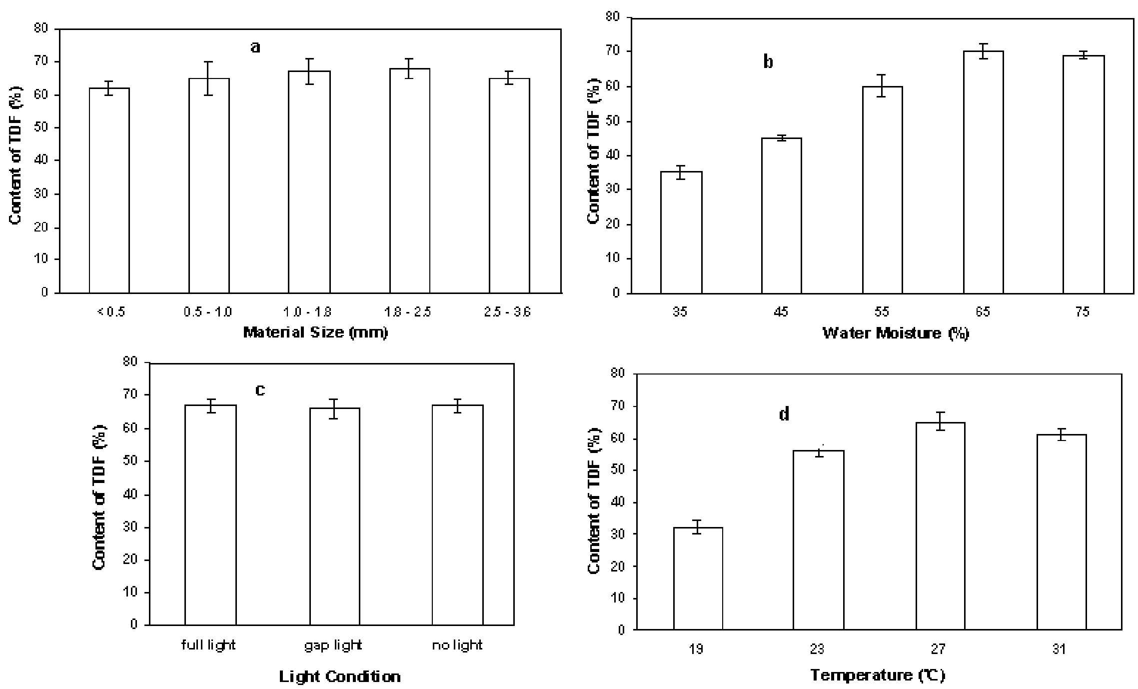

Fig. 1. The impact of fermentation conditions (material size (a), water moisture (b), light condition (c), and temperature (d)) on TDF by solid state fermentation using *S. commune*

Component Analysis of SPR in the Fermentation Process

From Fig. 2(a), the content of starch decreased rapidly to a lower level at the beginning of fermentation, and then it remained stable after 8 days.

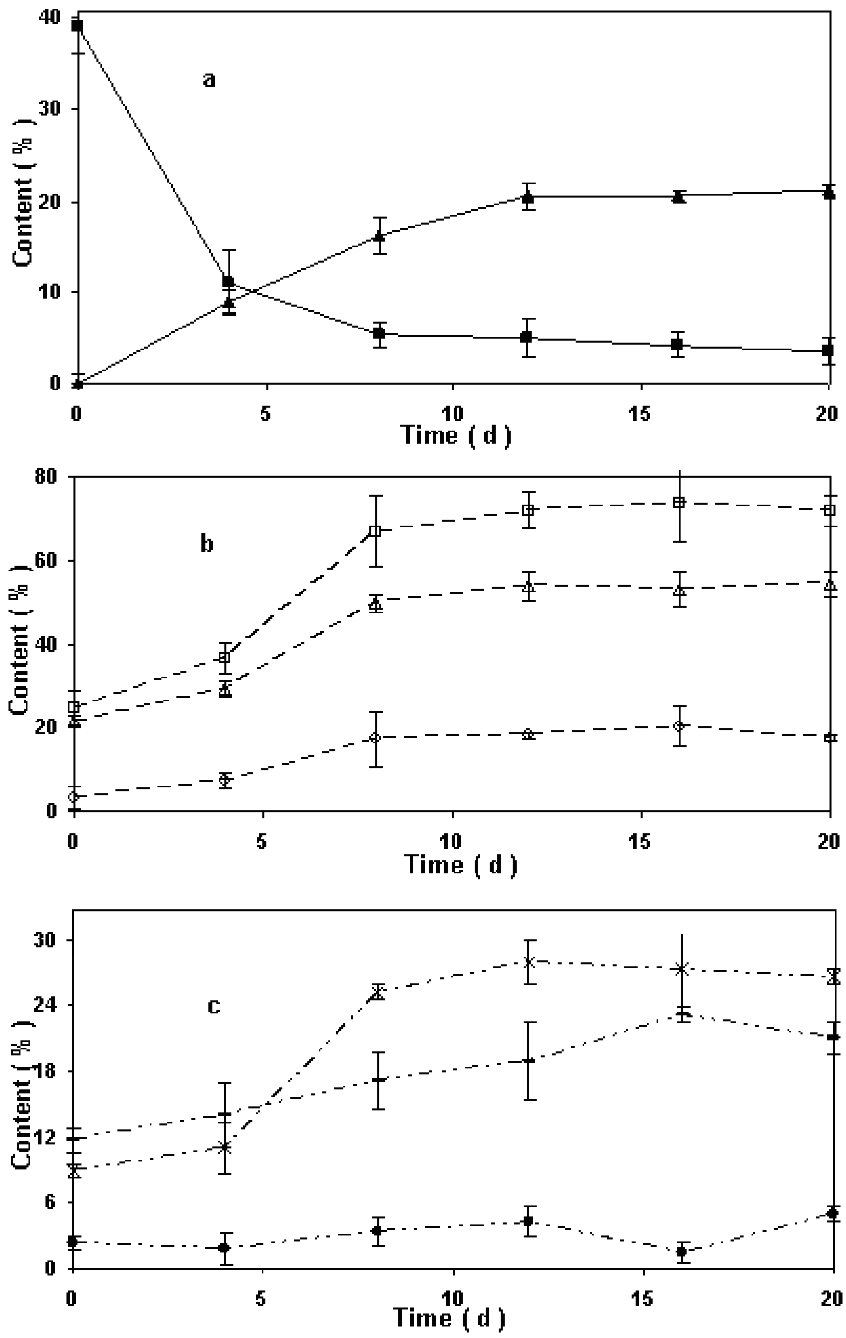

Fig. 2. Component analysis of SPR in the fermentation process.(—■—: starch, —▲—:Weight loss rate; – □ –: TDF, –△– :IDF; –◇– –: SDF; ✳·:cellulose; —·—: hemi-cellulose; —●··: lignin)

The weight of fermentation matrix decreased at a steady speed over the first 12 days, and then it remained stable thereafter. Comparing the decrement of starch and the weight loss of fermentation matrix, the former was greater, which indicated that the strain might have produced new ingredients after it metabolized the starch.

From Fig. 2(b), the DF content kept increasing until 8 days, which was in accordance with the decreasing result of the starch content (Fig. 2(a)). *S. commune* utilized the starch in SPR and transformed it to new DF. The DF consisted of 17.6% SDF and 54.2% IDF, and the ratio of IDF to SDF was about 3 to 1, which was the suggested proportion by nutritionists.

From Fig. 2(c), the content of cellulose was increasing during the first 8 days, and then it remained stable. The content of hemicelluloses was increasing until the 16th day. However, the content of lignin changed slightly during the entire fermentation. The results indicated that the DF increase was derived mainly from the cellulose and hemicelluloses by biotransformation of SPR by *S. commune*.

Physicochemical Properties of Fermented SPR

The physicochemical properties of fermented SPR are shown in Table 2. The SWC of the fermented SPR was 8.67 mL/g, which was higher than the SWC of fiber-rich cocoa product and apple pectin (6.51 and 7.42 mL/g, respectively) (Lecumberri *et al*. 2007). The WHC of the fermented SPR was 5.47 g/g. The WHC of some other DF products, such as guar gum, apple, and citrus pectin were 63.07, 16.51, and 28.07 g/g, respectively. The WHC of the fermented SPR was lower than guar gum, apple, and citrus pectin, but higher than cocoa DF with a value of 4.76 g/g (Lecumberri *et al*. 2007). The OHC of the fermented SPR was 1.64 g/g, which was higher than the OHC values in apple, pea, wheat, sugar beet, and carrot (1.3, 0.9, 1.3, 1.5, and 1.2 g/g, respectively) (Thebaudin *et al*. 1997). The GAC of the fermented SPR was 0.91 mmol/g, which was higher than the GAC value of alcohol-insoluble residue from pumpkin pressed-pulp (0.7 mmol/g) and pumpkin pressed-peel (0.3 mmol/g) (Pla *et al*. 2007).

Table 2. Physicochemical Properties of Fermented DF from SPR

Physicochemical properties	SWC (mL/g)	WHC (g/g)	OHC (g/g)	GAC (mmol/g)
Values	8.67±0.52	5.47±0.35	1.64±0.14	0.91±0.12

The SWC, WHC, OHC, and GAC results of fermented SPR were similar or higher than that of fiber-rich cocoa DF, which was an average DF. Therefore, the fermented SPR could be considered as a new good DF.

Historically, edible and medicinal fungi had been shown to have profound health-promoting benefits, and recent studies have been confirming their medical efficacy and identifying many of the bioactive molecules (Smith *et al.* 2002; Papaspyridi *et al.* 2012). Wu *et al*. (2012) found that the edible and medicinal fungi could bioconvert traditional Chinese medicine to produce some new bioactive compounds. From the above studies, we also find that the edible and medicinal fungi could produce DF from agro-processing residues (such as SPR). Compared with other traditional extraction methods (Mei *et al*.

2010), the yield of DF was increased 4-fold by this bioconversion method. Therefore, this work showed us a novel bioconversion method to produce high-quality and high-yield of DF, and extended the applied field of the edible and medicinal fungi.

CONCLUSIONS

1. Sweet potato residue (SPR) is a good raw material for solid state fermentation by the edible and medicinal fungi *S. commune*.
2. The yield and dietary fiber (DF) content of fermented SPR increased up to more than 80% and 70% by solid state fermentation employing the edible and medicinal fungi *S. commune*, and the ratio of insoluble dietary fiber (IDF) to SDF in fermented SPR was about 3 to 1.
3. The increase in dietary fiber yield was mainly because of increased conversion of cellulose and hemicelluloses by biotransformation of *S. commune*.
4. Swelling capacity, water-holding capacity, oil-holding capacity, and glucose absorption capacity of the fermented SPR indicated that the fermented SPR could be considered as a new good DF.

ACKNOWLEDGMENTS

The authors are grateful for the support of the National High Technology Research and Development Program of China (863 Program) (No. 2012AA101807).

REFERENCES CITED

Bajaj, I., Lele, S., and Singhal, R. (2008). "Enhanced production of poly (gamma-glutamic acid) from *Bacillus licheniformis* NCIM 2324 in solid state fermentation," *J. Ind. Microbiol. Biotech.* 35, 1581-1586.

Chen, F., and Hu, X. (2005). "Study on red fermented rice with high concentration of monacolin K and low concentration of citrinin," *Int. J. Food Microbiol.* 103, 331-337.

Cordain, L., Eaton, S., Sebastian, A., Mann, N., Lindeberg, S., Watkins, B., O'Keefe, J., and Brand-Miller, J. (2005). "Origins and evolution of the Western diet: health implications for the 21st century," *Am. J. Clin. Nutr.* 81, 341-354.

Farhath, K., Siddalinga, S., Krishna, K.S., Santhanam, K., and Viswanathan, K. (2000). "Dietary fiber content of commonly fresh and cooked vegetables consumed in India," *Plant Food. Hum. Nutr.* 55, 207-218.

Goering, H., and Soest, P.V. (1970). "Forage fiber analysis," *Agric. Handbook No. 379*, USDA-ARS,Washington, DC.

Happi Emaga, T., Robert, C., Ronkart, S.N., Wathelet, B., and Paquot, M. (2008). "Dietary fibre components and pectin chemical features of peels during ripening in banana and plantain varieties," *Bioresource Technol.* 99(10), 4346-4354.

Kuforiji, O., and Fasidi, I. (2009). "Influence of light and spawn quantity on the growth of Nigerian mushroom *Pleurotus tuberregium*," *J. Environ. Biol.* 30, 605-608.

Lecumberri, E., Mateos, R., Izquierdo-Pulido, M., Ruperez, P., Goya, L., and Bravo, L. (2007). "Dietary fibre composition, antioxidant capacity and physico-chemical properties of a fibre-rich product from cocoa (*Theobroma cacao* L.)," *Food Chem.* 104(3), 948-954.

Lummela, N., Kekkonen, R. A, Jauhiainen, T., Pilvi, T., Tuure, T., Järvenpää, S., Eriksson, J. G, and Korpela, R. (2009). "Effects of a fibre-enriched milk drink on insulin and glucose levels in healthy subjects," *Nutr. J.* 8, 45-51.

Mahadika, N., Puntambekara, U., Bastawdea, K., Khirea, J., and Gokhale, D. (2002). "Production of acidic lipase by *Aspergillus niger* in solid state fermentation," *Process Biochem.* 38, 715-721.

Mallillin, A., Trinidad, T., Raterta, R., Dagbay, K., and Loyola, A. (2008). "Dietary fibre and fermentability characteristics of root crops and legumes," *Brit. J. Nutr.* 100, 485-488.

McKee, L., and Latner, T. (2000). "Underutilized sources of dietary fiber: A review," *Plant Food. Hum. Nutr*. 55, 285-304.

Mei, X., Mu, T., and Han, J. (2010). "Composition and physicochemical properties of dietary fiber extracted from residues of 10 varieties of sweet potato by a sieving method," *J. Agri. Food Chem.* 58, 7305-7310.

Melnik, B. (2011). "Evidence for acne-promoting effects of milk and other insulinotropic dairy products," *Nestle Nutr. Workshop Ser Pediatr Program.* 67, 131-145.

Pandey, A., Soccol, C., Selvakumar, P., Soccol, V., Krieger, N., and Fontana, J. (1999). "Recent developments in microbial inulinases. Its production, properties, and industrial applications," *Appl. Biochem. Biotech.* 81, 35-52.

Papaspyridi, L.M., Aligiannis, N., Topakas, E., Christakopoulos, P., Skaltsounis, A.L., and Fokialakis, N. (2012). "Submerged fermentation of the edible mushroom *Pleurotus ostreatus* in a batch stirred tank bioreactor as a promising alternative for the effective production of bioactive metabolites," *Molecules* 17(3), 2714-2724

Pattanagul, P., Pinthong, R., Phianmongkhol, A., and Tharatha, S. (2008). "Mevinolin, citrinin and pigments of adlay angkak fermented by *Monascus* sp," *Int. J. Food Microbiol.* 126, 20-23.

Pla, M. F. D. E., Ponce, N. M., Stortz, C. A., Gerschenson, L. N., and Rojas, A. M. (2007). "Composition and functional properties of enriched fiber products obtained from pumpkin (*Cucurbita moschata* Duchesne ex Poiret) ," *Lwt-Food Sci. Technol.* 40(7), 1176-1185.

Pollard, C., Nicolson, C., Pulker, C., and Binns, C. (2009). "Translating government policy into recipes for success! Nutrition criteria promoting fruits and vegetables," *J. Nutr. Educ. Behav.* 41, 218-226.

Raghavendra, S. N., Rastogi, N. K., Raghavarao, K. S. M. S., and Tharanathan, R. N. (2004). "Dietary fiber from coconut residue: Effects of different treatments and particle size on the hydration properties," *Eur. Food Res. Technol.* 218, 563-567.

Rupérez, P., and Toledano, G. (2003). "Celery by-products as a source of mannitol," *Eur. Food Res. Technol.* 216, 224-226.

Russo, F., Riezzo, G., Chiloiro, M., Michele, G.D., Chimienti, G., Marconi, E., D'Attoma, B., Linsalata, M., and Clemente, C. (2010). "Metabolic effects of a diet with inulin-enriched pasta in healthy young volunteers," *Curr. Pharm. Design.* 16, 825-831.

Sidorova, L., Baĭkov, V., Bessonov, V., and Skobel'skaia, Z. (2007). "Effect of dietary fibers on preservation of lipid component in flour confectionery," *Voprosy Pitaniia* 76, 78-81.

Smith, J.E., Rowan, N.J., and Sullivan, R. (2002) . "Medicinal mushrooms: A rapidly developing area of biotechnology for cancer therapy and other bioactivities," *Biotechnol. Lett.* 24: 1839–1845

Spiller, G. (2000). *CRC Handbook of: Dietary Fiber in Human Nutrition*, New York: CRC Press, 9-10.

Steiner, W., Lafferty, R.M., Gomes, I., and Esterbauer, H. (1989). "Studies on a wild strain of *Schizophyllum commune*: cellulase and xylanase production and formation of the extracellular polysaccharide schizophyllan," *Biotechnol. Bioeng.* 30, 169-178.

Thebaudin, J. Y., Lefebvre, A. C., Harrington, M., and Bourgeois, C. M. (1997). "Dietary fibres: Nutritional and technological interest," *Trends Food Sci. Tech.* 8(2), 41-48.

Verardo, V., Riciputi, Y., Messia, M., Vallicelli, M., Falasca, L., Marconi, E., and Caboni, M. (2011). "Dietary fiber and flavan-3-ols in shortbread biscuits enriched with barley flours co-products," *Int. J. Food Sci. Nutr.* 62, 262-269.

Vergara-Valencia, N., Granados-Perez, E., Agama-Acevedo, E., Tovar, J., Ruales, J., and Bello-Perez, L.A. (2007). "Fibre concentrate from mango fruit: Characterization, associated antioxidant capacity and application as a bakery product ingredient," *Lwt-Food Sci. Technol.* 40(4), 722-729.

Wu, J., Gao, S., Wan, J., Zeng, Y., Ma, F., and Zhang, X. (2011a). "Thermogravimetric kinetics of corn stalk pretreated by oleaginous fungi *Cunninghamella echinulata*," *Bioresource Technol.* 102(8), 5255-5258.

Wu, J., Zhang, X., Wan, J., Ma, F., Tang, Y., and Zhang, X. (2011b). "Production of fiberboard using corn stalk pretreated with white-rot fungus *Trametes hirsute* by hot pressing without adhesive," *Bioresource Technol.* 102(24), 11258-11261.

Wu, J., Yang, X., Ge, J., Zhang, Y., Wu, L., Liu, J., and Zhang, X. (2012). "Biotransformation of sophoricoside in *Fructus sophorae* by the fungus *Schizophyllum commune*," *Bioresource Technol*. 111, 496-499

Article submitted: March 28, 2012; Peer review completed: July 3, 2012; Revised version received and accepted: July 9, 2012; Published: July 12, 2012.