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Functional Properties and Characterization of Dietary Fiber from *Mangifera pajang* Kort. Fruit Pulp

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ABSTRACT: A dried high fiber product from bambangan (*Mangifera pajang* Kort.) fruit pulp was prepared and evaluated for proximate composition, functional properties, and soluble and insoluble dietary fiber composition. *Mangifera pajang* fibrous (MPF) consisted of 4.7% moisture, 0.8% fat, 4% protein, and 30 mg total polyphenol per g of dry sample, and 9, 79 and 88% soluble, insoluble and total dietary fiber, respectively. Water holding capacity, oil holding capacity, swelling, and solubility were found to be 9 g/g dry sample, 4 g/g dry sample, 16 mL/g dry sample, and 11%, respectively. The glucose dialysis retardation index of MPF was approximately double that of cellulose fiber. Soluble dietary fiber contained mannose, arabinose, glucose, rhamnose, erythrose, galactose, xylose, and fucose at 1.51, 0.72, 0.39, 0.16, 0.14, 0.05, 0.04, and 0.01%, respectively, with 5.8% uronic acid, while insoluble dietary fiber was composed of arabinose (18.47%), glucose (4.46%), mannose (3.15%), rhamnose (1.65%), galactose (1.20%), xylose (0.99%), and fucose (0.26%) with 15.5% uronic acid and 33.1% klason lignin. These characteristics indicate that MPF is a rich source of dietary fiber and has physicochemical properties which make it suitable as an added ingredient in various food products and/or dietetic, low-calorie high-fiber foods to enhance their nutraceutical properties.

KEYWORDS: *Mangifera pajang*, physicochemical properties, composition, characterization

INTRODUCTION

Developing countries have a very low occurrence of a number of gastrointestinal diseases among communities which consume high amounts of fiber. Consumption of dietary fiber (DF) has many benefits to the gut[1] and overall human health and body function because DF is associated with decreased occurrence of disorders and diseases such as chronic bowel disorders, obesity, diabetes, cardiovascular disease, and cancer.[2,3] The usual sources of DF added to foods are cereals. Presently, the demand for byproduct from fruits and vegetables as sources of DF continues to rise because these sources have a higher nutritional quality, larger quantities of DF, lower caloric content, more potent antioxidant activity, and higher levels of fermentability and water retention.[4] Therefore, the food industry seeks to increase product fiber levels in an effort to support human health.

Dietary guidelines recommend a minimum daily intake of 25 g of DF, equivalent to 12.5 g of DF per 1000 calories consumed,[17,18] which is considerably higher than the estimated intake in Western countries 18 g/day.[19] In these countries, there is a need to increase fiber intake, which has prompted the consumption of dietary supplements or fiber-enriched food products. DF components such as pectins, gums, cellulose, and others have been used as functional ingredients by the food industry, and there is an extensive market for food byproducts as DF sources.

In general, soluble dietary fiber (SDF) has a high hydration capacity and swells to form viscous solutions. It also adsorbs and retains other substances like minerals, nonpolar molecules, and glucose, etc. Insoluble fibers can also adsorb and retain water within their fibrous matrix and adsorb other components such as SDF but without forming viscous solutions. Technologically, this results in the use of soluble fiber components (pectins, gums, carrageenans, and alginates) as thickening and gelling agents, foam and emulsion stabilizers, and film-forming and fat-mimetic agents, and they may also have a potential use in encapsulation. In contrast, insoluble fibers stabilize food systems, improve product density, and minimize shrinkage, and may also be used as agents that enhance food texture and appeal. In addition, commercial fibers are used as anticaking and antisticking agents due to their hydration properties; as a result, fibers are used to retard staling, control moisture, and ice crystal formation, reduce syneresis, and increase food stability.[1,31]

Many commercial DF sources, usually obtained as byproducts of the food industry (e.g., cereal brans and wine byproducts), provide more IDF than SDF, which, because of its functional properties, is of lesser nutritional and technological interest. The designation of Klason lignin (KL) as a DF constituent is controversial. According to some researchers and in some countries, KL is excluded as a DF when DF is defined as all indigestible nonstarch polysaccharides of plant origin.[42] However, KL is an integral component of DF as officially defined by the AOAC[9] and is an indigestible constituent of plant foods.[43,29] KL encompasses not only lignin but also other polyphenols including condensed tannins, resistant protein, and Maillard reaction products.[10]

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Mango is one of the most vital fruits, and its juice is a major industrial product, while its industrial byproducts represent 35 to 60% of the total fruit weight.[25] *Mangifera pajang* Kort. is one of the indigenous *Mangifera* trees found on Borneo Island. Its fruit is known as *bambangan* or *embawang* in Sabah and Sarawak, Malaysia. The fruit of *Mangifera pajang* Kort. is larger and has a thicker peel and larger seed than that of the commercial mango (*Mangifera indica* L). Furthermore, *M. pajang* fruit has highly fibrous pulp generated as a byproduct of juice preparation which is reported to contain high DF.[6] Also, the *M. Pajang* peel is considered a rich source of DF and antioxidants compounds; therefore, it can be incorporated with food products to improve their properties.[5] Huge amounts of byproduct fibrous pulp can be exploited from *M. pajang* with a better source of DF and physicochemical properties which make it a suitable byproduct to be used in the preparation of a low calorie and high fiber diet; thus, the aim of the present study was to prepare a high fiber product from *Mangifera pajang* pulp and to determine its proximate composition, functional properties, and soluble and insoluble dietary fiber composition in order to assess its potential usefulness as a source of DF in food industry products.

MATERIALS AND METHODS

Materials. *Mangifera pajang* Kort. fruits belonging to the family Anacardiaceae were purchased at their commercial ripening stage from several locations (Kampung Segong, Kampung Duyoh, Kampung Ketupong, and Kampung Bawang) in Sarawak, Malaysia. The fruits were harvested on 28/10/2008 then immediately wrapped with papers, placed in boxes, and rapidly air-freighted and delivered to Nutrition Laboratory, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, Malaysia. Upon arrival, the fruits were cleaned with tap water and left at room temperature for two hours.

Chemicals. Gallic acid, D-galacturonic acid, glucose assay kit, cellulose and monosaccharide standards (glucose, rhamnose, erythrose, D-mannose, L-arabinose, D-galactose, and fucose), α-amylase, protease, and amyloglucosidase were purchased from Sigma Aldrich Co. (St. Louis, MO, USA), while D-xylose and trifluoroacetic acid were purchased from Fisher Scientific (Loughborough, United Kingdom). Folin−Ciocalteu reagent was obtained from Merck (Darmstadt, Germany). All other chemicals and solvents used were either of analytical or HPLC grade.

Preparation of *Mangifera pajang* Fiber. The fibrous portion of 150 kg of *M. pajang* fruit was obtained by removing its peel and separating the seed from the pulp. The pulp (90 kg) was wet-milled, and the juice was separated to yield 12 kg of pomace. The pomace was washed with water, pressed in a fruit press, and dried at 50 °C using a conventional air oven for 18 h.[7] The pressed, dried pomace was then ground and passed through a 250-μm mesh sieve using a centrifuge ball mill (ZN 100, Retsch, Germany) to produce 4.7 kg of fibrous powder designated as *M. pajang* fiber (MPF).

Proximate Composition of MPF. The moisture, ash, protein, and fat contents were determined according to methods established by the AOAC.[8] Total insoluble and soluble dietary fiber in the MPF was determined according to the enzymatic-gravimetric method using Fibertec 1023 (Tecator Tech., Sweden).[9]

Total Polyphenol. Total polyphenols were extracted by adding 40 mL of methanol (50%, v/v) to 1 g of MPF with constant shaking in an orbital shaker (Unimax 1010, Heidolph Instruments GmbH & Co. KG, Germany) at 200 rpm for 1 h at room temperature. Extracts were centrifuged at 1500*g* for 10 min at 23 °C in a Hettichi centrifuge (Zentrifugen, Germany); 40 mL of acetone (70% v/v) was then added to the residue with constant shaking for 1 h at room temperature and centrifuged at 1500*g* for 10 min at 23 °C. Supernatant extracts were combined and adjusted to 100 mL with distilled water. Polyphenols were determined spectrophotometrically, at 725 nm using a UV/VIS 1601 spectrophotometer (Shimadzu, Kyoto, Japan) and the Folin−Ciocalteau reagent with gallic acid as a standard.[10,11]

Estimation of Available Carbohydrate. The amount of MPF carbohydrate was measured spectrophotometrically using anthrone reagent and glucose as a standard, on the basis of the method described by Mañas et al.[12]

Physico-Chemical Properties of MPF. *Water Holding Capacity (WHC) and Solubility.* WHC and solubility were determined by the method of Jimenez et al.[13] MPF (250 mg) and 250 mg of cellulose were weighed into separate 50 mL centrifuge tubes. Twenty-five milliliters of distilled water, containing 0.02% sodium azide to inhibit microbial growth, was added to each tube; contents were mixed carefully and allowed to stand at room temperature for 60 min. Mixtures were centrifuged at 3000*g* for 15 min; supernatants were carefully discarded; and the final weights were recorded. WHC was expressed as the amount of water retained per gram of dry sample (g/g dry matter). The residue was dried and weighed; solubility was defined as the difference in weight of sample before and after WHC processing.

Oil Holding Capacity (OHC). MPF (250 mg) and 250 mg of cellulose were weighed in separate 50 mL centrifuge tubes. To each tube, 25 mL of olive oil was added; contents were mixed carefully and allowed to stand at room temperature for 60 min. Mixtures were centrifuged at 3000*g* for 15 min at room temperature; supernatants were carefully discarded, and the final weights were recorded. OHC was expressed as the amount of oil retained per gram of dry sample (g/g dry matter).[14]

Swelling Capacity. MPF (200 mg) and 200 mg of cellulose were weighed precisely and transferred into separate calibrated cylinders (1.5 cm diameter), to which 10 mL of distilled water containing 0.02% sodium azide was added. After careful mixing, samples were allowed to stand for 18 h at room temperature. Bed volume was recorded and the swelling index was calculated as mL per g of dry sample.[14]

Glucose Dialysis Retardation Index (GDRI). GDRI was determined as described by Lecumberri et al.[1] MPF (400 mg) and 400 mg of cellulose were extracted twice with 80% ethanol to ensure the total removal of soluble sugar and then stirred continuously with 15 mL of distilled water for 1 h at room temperature. An equal amount of glucose (2 mg/mL) was added to both samples before transfer to 15 cm portions of previously hydrated dialysis bags (12,000 MWCO, Sigma Chemical Co.); an equal volume glucose solution alone was placed in a dialysis bag as a control. Samples were dialyzed against 400 mL of distilled water in separate beakers and incubated in a thermostatic water bath at 37 °C for a total of 1 h. After 20, 40, and 60 min, 0.5 mL of dialysate was collected from each sample; glucose concentration was determined spectrophotometrically at 540 nm using a glucose oxidase peroxidase.[1] The retardation of glucose diffusion from the dialysis bag into the dialysate was calculated as follows:

$$\mathrm{GDRI} = 100 - \left(\frac{\text{total glucose diffusion from sample}}{\text{total glucose diffusion from control}} \times 100 \right)$$

Composition of Soluble and Insoluble Dietary Fiber. MPF was digested successively with heat-stable α-amylase at 100 °C for 1 h and then protease and amyloglucosidase at 60 °C for 1 h. The digest was centrifuged at 3000*g* for 15 min to separate soluble and insoluble fractions obtained after enzymatic hydrolysis. The supernatant was collected, and the precipitate (pellet) was washed twice with 10 mL of distilled water.[9]

The soluble dietary fiber (SDF) was dialyzed against water for 48 h at 25 °C (water flow 7 L/h) and hydrolyzed with 1 M sulfuric acid at 100 °C for 90 min, hydrolysates were filtered using a polytetrafluoroethylene

Table 1. Chemical Composition of *Mangifera pajang* Fiber[a]

component	percentage (%)
moisture	4.65 ± 0.01
ash	0.84 ± 0.01
fat	0.79 ± 0.02
protein	3.73 ± 0.10
total dietary fiber	87.57 ± 1.65
soluble dietary fiber	9.05 ± 0.39
insoluble dietary fiber	78.52 ± 1.48
available carbohydrate	4.02 ± 0.10
total extractable polyphenol	30.17 ± 0.27

[a] Results were expressed as % dry matter, except for moisture and total extractable polyphenols (mg GAE/g MPF) contents. All results are presented as the means of three independent experiments with each analyses performed in triplicate.

disposable filter (diameter 13 mm, pore size 0.22 μm; Alltech, Deerfield, IL), then the acid was removed by evaporation under a gentle stream of nitrogen. The resulting sample was diluted to determine uronic acid and neutral sugar. To estimate insoluble dietary fiber (IDF), the residue (obtained after enzymatic hydrolysis) was dried an overnight at room temperature, hydrolyzed with 12 M H_2SO_4 for 1 h at 30 °C, diluted to 1 M H_2SO_4, and then hydrolyzed at 100 °C for 90 min with shaking. The IDF was centrifuged at 3000*g* for 15 min, then residues were washed twice with distilled water, dried at 105 °C overnight, and gravimetrically quantified as Klason lignin (KL). The supernatants were combined to determine uronic acid and neutral sugar. Uronic acid levels (UA) in hydrolysates from both SDF and IDF were determined using a galacturonic acid assay.[15]

Neutral sugars (NS) were analyzed by HPLC-RI using a Purospher star NH_2 column (250 mm ×4.6 mm, 5 μm) (Merck, Germany) using acetonitrile/water (75:25, v/v) as eluent at a flow rate of 1 mL/min. Carbohydrate standards (erythrose, rhamnose, arabinose, xylose, fucose, glucose, and galactose) at concentrations ranging from 2 mg/mL to 10 mg/mL were used for *M. pajang fiber* monosaccharide identification.[16] NSP, equivalent to SDF and IDF, was calculated as the sum of UA + NS; IDF was calculated as NSP of IDF + KL, SDF as NSP of SDF; and total dietary fiber (TDF) was calculated as IDF + SDF.

Statistical Analysis. The results were expressed as the mean values ± standard deviations. Statistical analyses were performed using SPSS Version 16.0 software (Chicago, IL, USA). Data were analyzed using one-way ANOVA followed by Duncan's test. The confidence interval was 95% ($p < 0.05$).

RESULTS AND DISCUSSION

Proximate Composition of MPF. In the present work, we reported the composition and physicochemical properties of MPF, a promising high fiber ingredient for various food products and/or dietetic, low-calorie high-fiber foods.

Table 1 shows the proximate composition of MPF. We found the moisture content to be lower than previously reported; the moisture content of mango varieties ranges from 74.1% to 90%,[20] and 86.84% for *M. pajang*,[6] whereas MPF contained less than 5% moisture. Protein content of MPF was well below compared with the protein in grape skin fiber (11.6−14.4 g/100 g dry sample)[10] and red grape peels (14.4 g/100 g dry sample).[21]

MPF lipid content of 0.79 g/100 g dry sample was much lower than that of grape skin lipid (6.87−7.78 g/100 g dry sample)[10] and *Citrus sinensis* peel (22.2 g/100 g dry sample).[22] Fruits are also characterized by their content of certain mineral components; MPF ash content was 0.84 g/100 dry sample, lower than that of *Mangifera indica* L. fiber (2.8 g/100 g dry sample),[23] *Citrus sinensis* peel (3.3 g/100 g dry sample),[22] and red grape skin (between 5.7 and 9.2 g/100 g dry sample).[10,21]

Table 2. Physico-Chemical Properties of *Mangifera pajang* Fiber Relative to Cellulose[a]

	MPF	cellulose
WHO (g/g)	8.81 ± 0.15	12.42 ± 0.45
OHC (g/g)	4.65 ± 0.26	0.98 ± 0.09
swelling (mL/g)	16.08 ± 0.16	19.16 ± 1.40
solubility (%)	11.61 ± 0.12	61.48 ± 1.53

[a] MPF: *Mangifera pajang* fiber; cellulose as standard. WHC: water holding capacity. OHC: oil holding capacity. All results are presented as the means of three independent experiments with each analyses performed in triplicate.

However, the TDF content in MPF (87.57%) exceeded those of *Mangifera indica* L. (28.1%),[23] guava (48−49%),[24] grape skins (54.1−64.6%),[10,21] citrus peel (57%),[22] and *Mangifera indica* L. peel (65−71%).[25] The relatively high TDF content in MPF concentrate corresponds to its low starch content. The majority of the fiber in MPF is insoluble, as is the case with Mexican lime peel[26] and citrus peel (47.6 g/100 g dry sample of IDF and 9.4 g/100 g dry sample of SDF).[22] We measured 4.02 g/100 g dry sample of available carbohydrates in MPF. Available carbohydrates in MPF are lower than those reported in the fibers of *Mangifera indica* L. (32.6 g/100 g dry sample),[23] guava (28 g/100 g dry sample), citrus peel (27.3 g/100 g dry sample),[22] and mango peel (26.7 g/100 g dry sample).[25]

Polyphenols, especially highly polymerized compounds such as condensed tannins and phenols bound to protein and polysaccharides from cell walls, are some of the substances associated with dietary fiber (DF) and can by partially quantified as Klason lignin residues. Some polyphenolic compounds behave as DF constituents, resisting hydrolysis by digestive enzymes, increasing fecal bulk, and promoting protein and fat excretion.[27−29] However, polyphenols are also bioactive compounds that have shown to be protective against diseases such as coronary heart disease, cancer, and neurodegenerative disorders, mostly through their antioxidant properties.[27,30] Total polyphenol content in MPF was higher than those reported in some fiber sources such as apple (3 mg/g),[25] commercial mango (*Mangifera indica* L.) (16.1 mg/g),[23] and Mexican lime (10.55 and 19.9 mg/g),[26] but lower than fiber from guava (58.7 mg/g),[24] grape skins (between 37.6 and 52.2 mg/g),[10] and mango peels (between 44 and 70 mg/g).[25]

Physico-Chemical Properties. The technological functionality and nutritional effects of DF are determined by its physicochemical properties, especially the composition of its soluble and insoluble fractions.[1] Our fiber rich MPF powder, with a high IDF content, showed physicochemical properties common to insoluble fiber materials, as shown in Table 2, where the hydration properties (swelling and water holding capacities) and glucose retardation index of the MPF product were comparable to cellulose, another source of DF. As a pure source of IDF, cellulose showed lower swelling and water retention capacities than MPF, indicating that noncellulosic components markedly contribute to its hydration properties.

Table 2 shows the water holding capacity (WHC), oil holding capacity (OHC), swelling, and solubility of MPF. WHC is an important function of DF from both a physiological and

Table 3. Glucose Dialysate Retardation Index of *Mangifera pajang* Fiber[a]

time (min)	MPF	cellulose
20	53.67 ± 0.21 a	21.60 ± 0.19 b
40	57.16 ± 0.22 a	23.71 ± 0.24 b
60	60.04 ± 0.61 a	31.17 ± 0.21 b

[a] MPF: *Mangifera pajang* fiber; cellulose as standard. All results are presented as the means of three independent experiments with each analyses performed in triplicate.

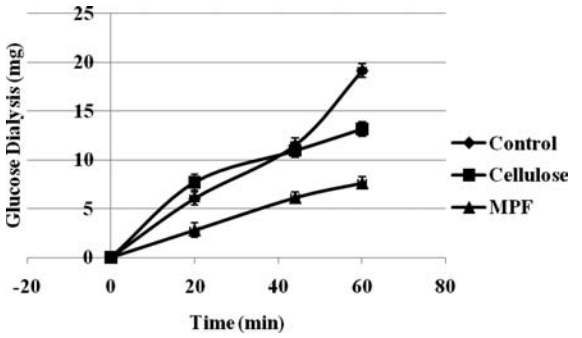

Figure 1. Glucose dialysis in the presence of cellulose vs *Mangifera pajang* fiber.

technological perspective because of the ability of DF to retain water within its matrix; the solubility of MPF was 12%.

MPF held 9 g of water per g of dry matter, whereas cellulose can hold 12 g water/g of sample. WHO of MPF was lower than peach pulp[32] and lemon fiber,[33] but higher than rice bran[34] and cocoa husks.[1] Together, these results suggest MPF could be used to improve the viscosity and texture of some food products as well as reduce their caloric content.

The OHC of MPF was much higher than that of apple pomace, citrus peel,[35] unripe banana flour,[36] and our cellulose control (Table 2), but similar to that found in dried orange pulp.[37] Because MPF has high OHC, it will be useful in promoting the emulsification of some products.

The swelling capacity of MPF was lower than that of cauliflower (16.9−17.5 mL/g dry matter)[38] and may be related to its high content of IDF. It is known that the structural characteristics and the chemical composition of fiber (including the water affinity of its components) play an important role in the kinetics of water uptake.[35] According to López et al.,[39] water may be held in capillary structures within the fiber because of its high surface tension; in addition, water is capable of interacting with various molecular components of fiber through hydrogen bonding or dipole formation.

Glucose Dialysis Retardation Index (GDRI). The retardation of glucose diffusion was measured for MPF and cellulose at different time points (Table 3). GDRI is a useful in vitro index to predict the effect of a fiber on delaying glucose absorption in the gastrointestinal tract.[39] GDRI of MPF was significantly ($P < 0.05$) higher than that of cellulose for all three time points (20, 40, and 60 min) (Table 3).

The GDRI of MPF was higher than values reported for wheat bran,[40] guar gum, apple pectin, mango peel, and lemon peel and carambola pomace.[41] This may be a function of the high content of IDF in MPF compared to SDF.[39] Because MPF effectively delayed glucose diffusion, it may help to control postprandial blood glucose as a low calorie ingredient for fiber enrichment and dietetic snacks.

Figure 1 shows the GDRI for the addition of glucose to MPF relative to cellulose. As the time increased (from 20 to 60 min), the glucose content in the MPF dialysate increased from 2.8 mg at 20 min to 7.6 mg at 60 min, whereas the glucose (control) dialysate ranged from 6.1 mg at 20 min to 19.1 mg at 60 min. Thus, MPF significantly ($P < 0.05$) decreased the levels of diffusible glucose from dialysis tubing throughout the time course of the experiment.

Table 4. Monosaccharide Composition of Soluble and Insoluble Dietary Fibers of *Mangifera pajang* Fiber (% Dry Weight)[a]

	MPF (% dry weight)	
monosaccharide	soluble dietary fiber	insoluble dietary fiber
erythrose	0.14 ± 0.01	n.d.
glucose	0.39 ± 0.01	4.46 ± 0.11
galactose	0.05 ± 0.01	1.20 ± 0.06
rhamnose	0.16 ± 0.01	1.65 ± 0.04
arabinose	0.72 ± 0.02	18.47 ± 0.19
mannose	1.51 ± 0.03	3.15 ± 0.12
xylose	0.04 ± 0.01	0.99 ± 0.02
fucose	0.01 ± 0.01	0.26 ± 0.02
neutral sugars	3.02 ± 0.11	30.18 ± 0.56
uronic acids	5.83 ± 0.13	15.51 ± 0.17
Klason lignin	n.d.	33.11 ± 0.72
total	8.85 ± 0.24	78.80 ± 0.96

[a] n.d.: not detected. All results are presented as the means of three independent experiments, and each analysis was determined in triplicate.

Composition of MPF Soluble and Insoluble Dietary Fiber. TDF and the content of the major constituents of the soluble and insoluble dietary fiber fractions (neutral sugars, uronic acids, and Klason lignin) are shown in Table 4. TDF content of MPF was extremely high, over 85% of the dry matter; this indicated that this product may be used as a food supplement, including potential applications as a functional ingredient in confectioneries and in the preparation of low-fat, high-fiber dietetic products. As for the constituent subfractions, SDF accounted for 9% of MPF, higher than that reported in powdered coffee beans.[44] Uronic acids (6% of the SDF dry matter) were the major components from neutral sugar, followed by mannose, arabinose, and glucose; the other monosaccharides detected were erythrose, rhamnose, xylose, fucose, and galactose (Table 4).

Quantitatively, IDF was the main component of MPF. Close to two-thirds of this IDF fraction corresponded to nonstarch polysaccharides (made up of neutral sugars and uronic acids), the remaining IDF portion was composed of Klason lignin (KL). As for the constituent sugars, the IDF fraction was richest in arabinose followed by glucose and mannose (Table 4). The high amount of mannose content in SDF and IDF of the studied fruit might be from a storage polysaccharide.[45,46] Minor amounts of monosaccharides such as rhamnose, xylose, and galactose, together with a significant quantity of uronic acids, were indicative of the presence of hemicelluloses (xyloglucans, arabinoxylans, and glucuronoxylans) and pectic substances associated with the cell wall matrix in *Mangifera pajang* fiber (Table 4).

These properties of MPF are of interest to the food industry because of their beneficial physiological effects. It has been shown

that high consumption of DF is associated with reduced incidence of disorders and diseases that are common in developed nations such as chronic bowel disorders, obesity, diabetes, cardiovascular disease, and cancer.[2,3,19]

In conclusion, DF is a quantitatively important constituent of *Mangifera pajang* pulp. MPF also contains appreciable amounts of beneficial chemical and physiochemical compounds. The extractable polyphenol content was comparable to that of other reported fruit fibers. Water and oil-holding capacities of MPF are also important characteristics to take into account during the processing of food products which might contain this preparation. With its high TDF and indigestible fraction composition, MPF appears to be a promising ingredient for functional foods. Further research is needed to investigate the biological properties of its DF.

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