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Composition and Physicochemical Properties of Dietary Fiber Extracted from Residues of 10 Varieties of Sweet Potato by a Sieving Method

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Dietary fiber (DF) was extracted from sweet potato residues after starch isolation of 10 varieties using a sieving method. The proximate composition of sweet potato residues, chemical composition, monosaccharide composition, and physicochemical properties of DF were investigated. The average yield and DF content of DF products from 10 sweet potato varieties were 9.97 and 75.19%, respectively. Average contents of cellulose, lignin, pectin, and hemicellulose were 31.19, 16.85, 15.65, and 11.38 g/100 g of dry matter in DF products, respectively. The relative monosaccharide contents of DF were in the order glucose > uronic acid > galactose > arabinose > xylose > rhamnose > mannose. Swelling capacity, water-holding capacity, oil-holding capacity, and glucose absorption capacity determinations of the DF of sweet potato varieties had respective ranges of 8.11−12.56 mL/g, 3.54−6.15 g/g, 1.43−2.48 g/g, and 0.54−1.27 mmol/g. DF of the 10 varieties had clear differences in characteristics and physicochemical properties.

KEYWORDS: Sweet potato; dietary fiber; chemical composition; monosaccharide composition; physicochemical properties

INTRODUCTION

Dietary fiber (DF) is a nonstarch polysaccharide complex that comes from the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine, but undergoes complete or partial fermentation in the large intestine (*1*). Dietary fiber can be classified into two major parts on the basis of solubility: soluble components, such as pectins, gums, and β-glucans; and insoluble components, which include cellulose, lignin, and hemicelluloses (*2*−*4*).

Dietary fiber plays an important role in human health. A good amount of research has revealed the relationship between DF intake and the incidence of constipation, obesity, cardiovascular diseases, colon cancer, and diabetes mellitus (*5*). Nowadays, the recommended DF intake is 25−30 g/day, with fiber addition to foods an alternative to compensate for deficiencies in the diet. Apart from nutritional purposes, fiber can also be used for technological purposes such as a bulking agent or fat substitute (*6*).

The physiological actions of DF are likely based on its physicochemical properties such as water- and oil-holding capacities, absorption of organic molecules, bacterial degradation, cation-exchange capacity, and antioxidant activity (*7*). Dietary fibers extracted from different materials or obtained using different methods differ in chemical composition, structure, and particle-size distribution, which obviously affect DF physicochemical properties, as a result of the influences on the physiological function and application of DF (*5*). However, functional properties of DF from different sources should be studied to show their individual characteristics.

Sweet potato has an annual production of approximately 85 million tonnes, with China the largest producer, accounting for 77.5% of worldwide production (FAO, 2008). The major commercial utilization of sweet potatoes in China includes starch and starchy food production, which generates a huge volume of residue. Traditionally, this residue is used as animal feed or discarded as waste, which in turn lowers the economic benefits of sweet potato processing and causes environmental pollution. A more environmentally friendly and profitable outlet is urgently needed for these byproducts.

Following starch, DF is the main component in sweet potato residue; however, there has been little research on sweet potato DF extraction and physicochemical properties, especially in China. Several Japanese researchers carried out experiments on sweet potato DF extraction by sieving and enzymatic methods (*8*, *9*), but there were no clear differences in DF content and properties among varieties, and thus no significant effects of varieties on utilization of residue and application of DF.

At present, hundreds of sweet potato varieties are used in China for different climates and purposes. Due to the differences in their chemical compositions, some varieties are used for starch processing and some for syrup, snack, or anthocyanin production. The objective of this work was to characterize DF of sweet potato from 10 varieties, as well as to determine differences in their composition and physicochemical properties, in order to analyze the feasibility of DF production from residues of the sweet potato starch processing industry and its use for nutritional and technological applications.

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MATERIALS AND METHODS

Sample Preparation. Ten cultivars (Weiduoli, Beijing553, Xinong431, Jishu98, Jishu21, Jishu82, Lvya18, Jishu99, Jishu71, and Xu55-2) of fresh sweet potato were used, and all were obtained from the Hebei Academy of Agricultural and Forestry Sciences, China. After starch extraction, residues were separated; fresh residues were washed several times using tap water and dried at 60 °C for 24 h, and then 30 g of dry sweet potato residue was ground into powder by a high-speed universal pulverizer (FW100, Tianjin, China) for 20 s. The resulting powder was passed through a 100-mesh sieve (aperture ≈ 150 μm) and stored at 4 °C prior to analysis.

Particle Size Distribution. Prior to the preparation of DF, the particle size distributions of the ground sweet potato residues and starch were measured using a Baite Particle Size Analyzer (BT-9300H; Dandong Bettersize Instruments Ltd., Dandong, China). The average particle size was characterized by the volume mean diameter $D[4,3]$, defined by $\Sigma_i n_i d_i^4 / \Sigma_i n_i d_i^3$, where n_i is the number of particles of diameter d_i. The theory used to calculate the size distribution assumes that the particles are isolated homogeneous spheres.

Extraction of Dietary Fiber. The method of DF extraction was according to Takamine et al. (*8*) with modifications. The powder of sweet potato residues was suspended in distilled water at a ratio of 1:60 (w/v), and the suspension pH was adjusted to 5.0 with 1.0 M HCl. The suspension was separated for 15 min on a horizontal-shaking unit, equipped with two sieves: 100-mesh on top and 400-mesh (aperture ≈ 35 μm) below, with a shaking frequency of 3.75 Hz. The portion of suspension passing through the 100-mesh but held back by the 400-mesh sieve was the DF, which was collected, dried, and ground. The powder was passed through a 100-mesh sieve and stored at 4 °C prior to analysis. Finally, the yield of DF was defined by the percentage of DF weight to sample weight.

Proximate Analyses. The ash, fat, protein, and starch contents were determined according to AOAC methods (*10*). Ash was produced by incinerating samples at 550 °C in a muffle furnace for 2 h (AOAC method 923.03). Fat was determined using AOAC method 960.39. Proteins were analyzed as total nitrogen content by Kjeldahl procedure; a factor of 6.25 was used for conversion of nitrogen to crude protein (method 955.04). Starch was hydrolyzed into glucose using thermo-stable α-amylase (A3306, Sigma) and amyloglucosidase (A9913, Sigma); the glucose was then determined according to the glucose oxidase-peroxidase method with a glucose assay kit (GAG020, Sigma) and starch content calculated as glucose × 0.9 (AOAC method 996.11).

Dietary Fiber Determination. Dietary fiber was determined according to AOAC method 991.43 (*10*). Briefly, the samples were treated with thermo-stable α-amylase and then digested with protease (P3910, Sigma), followed by incubation with amyloglucosidase to remove starch and protein components. Insoluble DF (IDF) was obtained by centrifugation (3000*g* for 15 min at 25 °C) after enzymatic digestion of starch and protein, and the soluble DF (SDF) was precipitated with 95% ethanol. Dietary fiber was calculated as the sum of IDF and SDF.

Pectin, Hemicellulose, Cellulose, and Lignin Contents. The DF samples of the 10 varieties were treated with 0.2 M phosphate buffer solution (pH 7.0) at the ratio of 1:10 (w/v) for 2 h at 20 °C and then centrifuged at 3000*g* for 15 min. The procedure was repeated three times and the supernatant collected. Residues were extracted with 0.01 M EDTA solution for 2 h to bind cations and solubilize pectic substances, the extracted mixtures were filtered by vacuum filtration with a microfiltration membrane (pores = 0.8 μm), filtrates were collected, and the extraction was repeated twice; the supernatants and filtrates were dialyzed and lyophilized to obtain soluble pectic substances.

After the extraction of the soluble pectic substances with EDTA, the residues were washed twice with 80% ethanol and three times with distilled deionized water to remove the alcohol; the washed residue was lyophilized for further analysis. The lyophilized sample was treated with thermo-stable α-amylase, amyloglucosidase, and protease, successively, to eliminate starch and protein. Finally, the mixture was filtered by vacuum filtration with a microfiltration membrane (pores = 0.8 μm); residues was washed three times with 80% ethanol, once with 95% ethanol, and three times with distilled deionized water and then freeze-dried. The residues obtained were extracted three times using 0.5% (w/v) ammonium oxalate solution at 85 °C for 2 h. The fiber residue was filtered and washed with ethanol and distilled water and then freeze-dried. Filtrates were collected, dialyzed, and lyophilized, and insoluble pectic substances were obtained. The sum of soluble and insoluble pectic substances amounted to the pectin content in the DF products.

The fiber residues resulting from insoluble pectic substances were used to fractionate hemicellulose, cellulose, and lignin according to the method of Claye et al. (*11*). Then the contents of hemicellulose, cellulose, and lignin in DF isolates were calculated.

Monosaccharide Composition of Dietary Fiber. According to the procedure of DF determination (AOAC 991.43) (*10*) to remove the starch and protein in DF samples of 10 varieties by enzymatic method, the residues after enzyme treatment were washed three times with 80 and 95% ethanol, respectively, and then lyophilized, and then purified DF was obtained.

The hydrolysis of DF was carried out as described by Salvador et al. with slight modifications (*12*). Neutral sugars and uronic acids contents were determined by high-performance anion-exchange chromatography with pulsed-amperometric detection (HPAEC-PAD) (*13*). Of DF, 5 mg was dispersed in 1 mL of 12 M H_2SO_4 for 1 h at 30 °C followed by dilution to 1 M and hydrolysis at 100 °C for 3 h. After cooling, the hydrolysates were neutralized with 6 M NaOH, and distilled water was added to a certain volume. Chromatography of the samples was carried out in a Dionex ICS-3000 Bio-LC system, using a CarboPac PA 10 column (250 mm × 4 mm) in combination with a CarboPac guard column (Dionex Corp., Sunnyvale, CA). A 20 μL sample was injected. All analyses were carried out at 30 °C and a flow rate of 1.0 mL/min. The neutral sugars were eluted isocratically using 4 mM NaOH for 35 min, whereas uronic acids were eluted using a gradient reaching 170 mM CH_3COONa and 100 mM NaOH for 10 min. The column was washed with 200 mM NaOH for 10 min and re-equilibrated with 4 mM NaOH for 10 min before the next injection. Detection was realized using a pulsed-amperometric detector with post-injection of 200 μL/min of 900 mM NaOH. Potentials of $E_1 = 0.1$ V, $E_2 = 0.1$ V, $E_3 = 0.1$ V, $E_4 = -2$ V, $E_5 = -2$ V, $E_6 = 0.6$ V, $E_7 = -0.1$ V, and $E_8 = -0.1$ V were applied for respective durations (i.e., $T_1 - T_8$) of 0, 0.20, 0.40, 0.41, 0.42, 0.43, 0.44, and 0.50 s, at a sensitivity of 1 μC.

Standard solutions containing neutral sugars (fucose, rhamnose, arabinose, xylose, mannose, glucose, and galactose) and uronic acids (galacturonic and glucuronic acids) with concentrations of 0.1−10 ppm were prepared to confirm the linearity of the detector response and to determine the relative response factors.

Physicochemical Properties of DF. The functional properties measured include the swelling capacity (SWC), water-holding capacity (WHC), oil-holding capacity (OHC), and glucose absorption capacity (GAC).

Samples were accurately weighed (0.5 g) and transferred into a calibrated cylinder (diameter = 1.5 cm); then 20 mL of distilled water was added and mixed thoroughly, and after equilibration for 16 h at room temperature, the bed volume was recorded and SWC expressed in milliliters per gram of sample (*14*, *15*). According to the method of Chau and Huang (*16*) with slight modifications, the WHC and OHC were determined by mixing 0.5 g of sweet potato DF with 20 mL of distilled water for 24 h and with 10 mL of corn oil (purchased from a supermarket) for 30 min, respectively. After centrifugation at 1500*g* for 5 min at 25 °C, the WHC and OHC were calculated as the amount of water and oil held by 1 g of DF, respectively.

Prior to the GAC assay, samples were washed successively with 75, 85, and 95% ethanol twice for thorough removal of soluble sugars. For the GAC assay, 1.0 g of sample was added to 100 mL of glucose solution (100 mmol/L), stirred, and incubated at room temperature for 6 h followed by centrifugation at 3500*g* for 15 min. The glucose content in the supernatant was measured using the glucose oxidase-peroxidase method described in AOAC method 996.11 (*10*) with a glucose assay kit (GAG020, Sigma). GAC was reported in millimoles of retained glucose per gram of sample (*6*, *15*, *17*).

Statistical Analysis. All analyses were carried out in triplicate, and data are presented as means and standard deviations (SD). The significant differences among samples were determined by analysis of variance and Duncan's multiple-range test ($P < 0.05$).

RESULTS AND DISCUSSION

Proximate Composition of Sweet Potato Residues. Starch is the predominant component of sweet potato residues followed by DF, protein, ash, and fat. The starch, DF, protein, ash, and fat

Table 1. Proximate Composition of Residues from 10 Sweet Potato Varieties (Grams per 100 g of DM)[a]

variety	ash	fat	protein	starch	DF
Beijing553	2.14 ± 0.01 d	0.45 ± 0.05 cd	5.97 ± 0.43 a	42.44 ± 0.04 k	23.81 ± 0.14 d
Jishu21	2.65 ± 0.08 b	0.52 ± 0.03 b	4.23 ± 0.05 cd	60.89 ± 0.11 a	17.15 ± 0.05 j
Jishu71	1.59 ± 0.02 g	0.37 ± 0.06 e	4.05 ± 0.10 cd	59.41 ± 0.12 b	17.83 ± 0.08 i
Jishu82	2.67 ± 0.03 b	0.38 ± 0.04 e	5.06 ± 0.05 b	49.73 ± 0.05 h	24.49 ± 0.07 c
Jishu98	2.09 ± 0.05 d	0.25 ± 0.03 f	4.37 ± 0.15 cd	53.76 ± 0.25 d	20.05 ± 0.06 g
Jishu99	1.88 ± 0.04 f	0.21 ± 0.03 f	4.20 ± 0.49 cd	59.10 ± 0.06 c	16.33 ± 0.11 k
Lvya18	1.99 ± 0.01 e	0.59 ± 0.02 a	3.38 ± 0.42 e	53.53 ± 0.06 e	18.75 ± 0.04 h
Weiduoli	3.02 ± 0.03 a	0.33 ± 0.02 e	6.11 ± 0.42 a	43.45 ± 0.09 j	26.55 ± 0.04 a
Xinong431	2.63 ± 0.15 b	0.37 ± 0.01 e	4.12 ± 0.16 cd	45.13 ± 0.11 i	23.35 ± 0.13 e
Xu55-2	1.95 ± 0.04 ef	0.48 ± 0.05 bc	3.97 ± 0.01 d	52.32 ± 0.06 f	25.82 ± 0.20 b
average	2.26 ± 0.03 c	0.40 ± 0.04 de	4.55 ± 0.04 c	51.98 ± 0.04 g	21.41 ± 0.05 f

[a] Mean ± SD values within the same column with different letters are significantly different from each other according to Duncan's multiple-range test ($P < 0.05$).

contents of the residues of 10 varieties had ranges of 42.44−60.89, 16.33−26.55, 3.38−6.11, 1.59−3.02, and 0.21−0.59 g/100 g of dry matter (DM), respectively, and averages of 51.98, 21.41, 4.55, 2.26, and 0.40 g/100 g of DM (**Table 1**). The average content of DF in sweet potato residues was lower than in residues from grapefruit, lemon, orange, apple (*18*), and pumpkin pulp (44.6 g/100 g of DM) (*6*) after juice extraction. If the starch, which accounts for almost 50% of sweet potato residues, could be recycled during DF extraction, this would save resources and also prevent environmental pollution caused by discarding starch. In addition, apart from the components mentioned above, there are other components in sweet potato residues that were not determined in this experiment, including soluble sugars, oligosaccharides, phenols, and pigments.

Statistical analysis revealed significant differences ($P < 0.05$) in content of the components of residues among the 10 varieties. The proximate composition of various types of yellow and green soybeans also varied significantly (*5*). In addition, Figuerola et al. also reported various DF contents in varieties of citrus and apple (*18*). The 10 varieties of sweet potato used in the present study were obtained from the same institute, and similar starch extraction technology was used for all, which suggests that the differences in proximate composition of sweet potato residues were of varietal origin.

The present study indicated that cv. Weiduoli would be an ideal source for extracting DF as it contained a high amount of DF and low starch (26.55 and 43.45 g/100 g of DM, respectively). However, cv. Jishu21, Jishu71, and Jishu99 may not be suitable for DF production as they were low in DF (16.33−17.83 g/100 g of DM) and contained high levels of starch.

Particle Size Distribution of Residues and Yield of Dietary Fiber. The sweet potato residues were mainly composed of particles with size < 150 μm (**Table 2**), which were > 95% of the particles from cv. Weiduoli, Beijing553, Jishu98, Jishu82, Lvya18, Jishu99, Jishu71, and Xu55-2. However, cv. Jishu21 and Xinong431 contained the highest amount of particles of size > 150 μm. The particle size of starch < 35 μm was predominant in residues of all varieties; however, there were few differences among varieties, the highest being 99.56% in cv. Weiduoli and the lowest being 93.37% in cv. Beijing553.

Dietary fiber was extracted from the 10 varieties of sweet potato residues by a sieving method, which was based on the principle of particle size variation, with the portion of particle size 35−150 μm being the DF. The particles of size < 35 μm (i.e., mainly starch) were eliminated and recycled. However, α-amylase was used to remove the starch in the fiber-rich powder preparation from banana flour described by Rodríguez-Ambriz et al. (*19*). Yoshimoto et al. (*9*) reported the use of the combination of α-amylase and glucoamylase to digest starch in sweet potato root and obtain DF. In the case of materials with low starch content, such as fruit pomace, DF extraction was simpler once samples were treated with hot water to remove soluble sugars (e.g., sucrose, glucose, and fructose), and DF or DF concentrate was obtained (*18*, *20*).

Table 2. Particle Size Distribution of Dried Sweet Potato Starch, Residue and Yield of Dietary Fiber

	particle size distribution[a] (%)						
	<35 μm		35−150 μm		>150 μm		
variety	starch	residue	starch	residue	starch	residue	DF yield[b] (%)
Beijing553	93.37	43.69	6.63	53.83	0	2.48	15.10 ± 0.02 a
Jishu21	98.83	38.44	1.17	41.41	0	20.15	8.59 ± 0.02 i
Jishu71	94.18	50.28	5.82	47.18	0	2.54	9.56 ± 0.01 f
Jishu82	95.42	49.16	4.58	46.77	0	4.07	8.69 ± 0.01 h
Jishu98	98.75	60.16	1.25	38.93	0	0.91	5.96 ± 0.07 j
Jishu99	94.51	50.36	5.49	48.28	0	2.64	10.38 ± 0.02 c
Lvya18	97.17	48.41	2.83	48.97	0	2.62	9.72 ± 0.03 e
Weiduoli	99.56	45.08	0.44	52.54	0	2.38	10.37 ± 0.01 c
Xinong431	99.13	42.73	0.87	45.95	0	11.35	9.20 ± 0.04 g
Xu55-2	98.54	46.19	1.66	49.59	0	4.22	12.12 ± 0.05 b
average							9.97 ± 0.01 d

[a] Values of particle size distribution are averages of triplicate, but the SD are not given as statistical analysis was not carried out (the average of 10 varieties is not shown). [b] Mean ± SD values within the same column with different letters are significantly different from each other according to Duncan's multiple-range test ($P < 0.05$).

Sieving is a physical method that does not involve use of chemical reagents. It is more suitable for DF preparation from sources rich in starch than enzymatic methods and has the virtues of simplicity, feasibility, and producing high-purity DF. The DF content of sweet potato extracted using the sieving method corresponded to DF products from nonstarch materials, which exhibited major characteristics of commercialized fiber products (total DF content > 50% and low lipid content) as described by Larrauri (*21*).

Statistical analysis showed that the level of particles with size of 30−150 μm in sweet potato residues was directly proportional to DF yield. The significant differences in DF yield among the 10 varieties were due to different particle size distributions. The highest DF yield was in cv. Beijing 553 (15.10%), the lowest was in cv. Jishu98 (5.96%), and the average was 9.97%; the particle size of starch had a clear effect on DF yield.

Proximate Composition of Dietary Fiber. The ash, fat, protein, starch, and DF contents of the products had respective ranges of 0.51−2.87, 0.23−0.78, 4.41−8.62, 8.77−23.41, and 66.67−83.51 g/100 g of DM (**Table 3**). In comparison to the proximate composition of residues, the average starch content in DF products decreased by 15.52 g/100 g of DM, DF content increased by 75.19 g/100 g of DM, the average fat and protein contents

Table 3. Proximate Composition of Crude Dietary Fiber Extracted from Sweet Potato Varieties (Grams per 100 g of DM)[a]

variety	ash	fat	protein	starch	DF
Beijing553	0.51 ± 0.03 k	0.35 ± 0.03 ef	8.62 ± 0.05 a	23.41 ± 0.05 a	66.67 ± 0.05 i
Jishu21	2.87 ± 0.02 a	0.55 ± 0.10 c	6.21 ± 0.04 f	8.77 ± 0.03 j	80.30 ± 0.06 c
Jishu71	0.65 ± 0.01 j	0.32 ± 0.02 f	5.14 ± 0.05 i	21.69 ± 0.05 b	70.80 ± 0.11 g
Jishu82	1.95 ± 0.01 c	0.67 ± 0.07 b	6.98 ± 0.07 d	16.08 ± 0.03 f	73.11 ± 0.31 f
Jishu98	1.27 ± 0.02 f	0.38 ± 0.01 ef	7.29 ± 0.05 c	16.92 ± 0.02 d	73.56 ± 0.19 e
Jishu99	0.81 ± 0.01 i	0.56 ± 0.01 c	7.57 ± 0.03 b	21.16 ± 0.05 c	68.61 ± 0.13 h
Lvya18	2.01 ± 0.03 b	0.78 ± 0.03 a	5.43 ± 0.03 g	10.90 ± 0.04 g	80.17 ± 0.41 c
Weiduoli	0.98 ± 0.02 g	0.46 ± 0.04 d	5.30 ± 0.02 h	9.03 ± 0.05 i	83.51 ± 0.03 a
Xinong431	1.59 ± 0.01 d	0.41 ± 0.03 de	7.32 ± 0.06 c	16.45 ± 0.04 e	73.52 ± 0.09 e
Xu55-2	0.85 ± 0.02 h	0.23 ± 0.04 g	4.41 ± 0.03 j	10.83 ± 0.06 h	81.64 ± 0.03 b
average	1.35 ± 0.01 e	0.47 ± 0.01 d	6.43 ± 0.04 e	15.52 ± 0.03 g	75.19 ± 0.09 d

[a] Mean ± SD values within the same column with different letters are significantly different from each other according to Duncan's multiple range test ($P < 0.05$).

increased a little, and ash content decreased. Dietary fiber content in sweet potato DF products was much higher than in other DF products, such as mango DF (28.05 g/100 g of DM) (*4*), fiber-rich powder from banana flour (31.8 g/100 g of DM) (*19*), and fiber-rich product from cocoa (60.51 g/100 g of DM) (*15*), but lower than date flesh DF concentrate (88.0 g/100 g of DM) (*20*) and a similar to grape DF (74.5 g/100 g of DM) (*22*).

There was a significant difference ($P < 0.05$) in the proximate composition of DF products among the sweet potato varieties. The DF products of cv. Weiduoli had the highest level of DF, followed by cv. Xu55-2 and Jishu21 (83.51, 81.64, and 80.30 g/100 g of DM, respectively).

Chemical Composition of Dietary Fiber. The chemical composition of DF from sweet potato residues extracted by sieving method is shown in **Table 4**; there were significant differences ($P < 0.05$) in the contents of cellulose, lignin, pectin, and hemicellulose in DF among the varieties. The highest pectin content was in cv. Xinong431, and the lowest in cv. Jishu99 (22.93 and 9.01 g/100 g of DM, respectively). For hemicellulose, the highest content was in cv. Xu55-2, and the lowest in cv. Xinong431 (15.98 and 8.70 g/100 g of DM, respectively). The highest lignin content was in cv. Jishu21, and the lowest in cv. Jishu82 (respectively, 22.61 and 8.96 g/100 g of DM). The highest cellulose content was in cv. Jishu71, and the lowest in cv. Xinong431 (36.54 and 25.92 g/100 g of DM, respectively). Yoshimoto et al. also found differences in the cellulose, pectin, and hemicellulose contents of DF extracted by enzymatic method from seven sweet potato varieties (*9*). This suggests that variety has a huge effect on the chemical composition of sweet potato DF.

The average content of these four components was in the order cellulose > lignin > pectin > hemicellulose, with values of 31.19, 16.85, 15.65, and 11.38 g/100 g of DM, respectively. In comparison, the average contents of cellulose, pectin, and hemicellulose reported by Yoshimoto et al. were higher than in the present study (*9*); this discrepancy could be due to differences in varieties and DF extraction methods used (sieving in the present study and enzymatic by Yoshimoto et al.). However, compared with six kinds of fruit pomace (apple, cherry, chokeberry, black currant, pear, and carrot) (*3*), the sweet potato DF in the present study had much higher pectin, lower hemicellulose, and similar cellulose contents.

Monosaccharide Composition of Dietary Fiber. The sugar compositions of DF from 10 varieties of sweet potato residues, determined by the HPAEC-PAD method after H_2SO_4 hydrolysis, are shown in **Table 5**. Dietary fiber of sweet potato residues was mainly composed of six neutral sugars (rhamnose, arabinose, galactose, glucose, xylose, and mannose) and two uronic acids (galacturonic and glucuronic acids), with no fucose detected.

Glucose was the predominant monosaccharide in sweet potato DF, with average relative content of 56.05%, and is mainly from

Table 4. Chemical Composition of Dietary Fiber Prepared from Sweet Potato Varieties (Grams per 100 g of DM)[a]

variety	pectin	hemicellulose	lignin	cellulose
Beijing553	10.56 ± 0.18 g	12.09 ± 0.11 c	16.57 ± 0.06 f	27.66 ± 0.08 i
Jishu21	15.36 ± 0.11ef	9.13 ± 0.04 g	22.61 ± 0.03 a	33.07 ± 0.30 b
Jishu71	9.31 ± 0.61 h	12.01 ± 0.03 c	14.83 ± 0.05 i	36.54 ± 0.03 a
Jishu82	21.02 ± 0.06 b	10.94 ± 0.10 e	8.96 ± 0.11 k	30.12 ± 0.13 f
Jishu98	15.67 ± 0.30 e	9.09 ± 0.02 g	21.12 ± 0.11 c	27.90 ± 0.05 h
Jishu99	9.01 ± 0.11 h	12.13 ± 0.05 c	17.41 ± 0.21 d	29.89 ± 0.11 g
Lvya18	19.25 ± 0.17 c	13.32 ± 0.30 b	15.20 ± 0.06 h	31.93 ± 0.08 d
Weiduoli	18.29 ± 0.16 d	10.45 ± 0.05 f	22.01 ± 0.02 b	32.49 ± 0.04 c
Xinong431	22.93 ± 0.16 a	8.70 ± 0.02 h	15.80 ± 0.07 g	25.92 ± 0.06 j
Xu55-2	15.13 ± 0.07 f	15.98 ± 0.07 a	13.94 ± 0.07 j	36.34 ± 0.21 a
average	15.65 ± 0.06 e	11.38 ± 0.05 d	16.85 ± 0.13 e	31.19 ± 0.08 e

[a] Mean ± SD values within the same column with different letters are significantly different from each other according to Duncan's multiple-range test ($P < 0.05$).

cellulose and hemicellulose (*12*, *23*); uronic acid was in second place, accounting for 22.95%, and is the main component of pectin (*12*, *23*), followed by galactose, arabinose, xylose, rhamnose, and mannose with values of 10.39, 3.68, 3.33, 2.05, and 1.27%, respectively, which are mostly found in pectin and hemicellulose, but seldom in cellulose (*12*, *23*). The average of relative contents of neutral sugars and uronic acids (**Table 5**) were similar to the results of Salvador et al. (*12*) and Noda et al. (*23*) obtained in sweet potato cell wall material (CWM, with the same chemical components as sweet potato DF), which were in the order glucose > uronic acid > galactose > arabinose > xylose > rhamnose > mannose. Compared to the average content of sugar composition (**Table 5**), the contents of glucose, rhamnose, and mannose found by Salvador et al. were lower at 38.3, 1.1, and 0.4%, respectively; however, the contents of uronic acids, galactose, arabinose, and xylose were higher at 31.1, 18.0, 7.0, and 4.1%, respectively. Apart from the varietal differences, the difference in sugar composition between the present study and that of Salvador et al. could be due to the isolation method of sweet potato DF or CWM (sieving in the former and enzymatic in the latter). Sieving could result in the loss of some soluble DF (pectin and hemicellulose) due to sample grinding and several flushings with distilled water. Sun et al. (*24*) found that onion CWM had much higher galactose content than the sweet potato DF in the present study; glucose, rhamnose, arabinose, and mannose contents were lower, whereas uronic acid and xylose contents were similar. Moreover, they also found differences between raw and cooked onion CWM. Garau et al. found differences in sugar composition between orange peel and pulp; air-drying temperature had little effect on these sugar compositions (*14*).

There was a significant difference ($P < 0.05$) in relative content of eight types of sugar among DF of 10 sweet potato varieties.

Table 5. Monosaccharide Composition of Dietary Fiber in Sweet Potato Residues (Percent)[a]

variety	fucose	rhamnose	arabinose	galactose	glucose	xylose	mannose	uronic acid[b]
Beijing553	0	1.86 ± 0.05 f	4.29 ± 0.03 a	13.86 ± 0.28 a	57.29 ± 0.78 cd	2.63 ± 0.07 e	1.21 ± 0.06 de	18.86 ± 0.32 d
Jishu21	0	2.39 ± 0.02 b	3.89 ± 0.09 bc	7.50 ± 0.09 f	58.95 ± 0.66 c	3.11 ± 0.04 cd	1.51 ± 0.05 c	22.65 ± 0.16 c
Jishu71	0	1.38 ± 0.01 g	3.96 ± 0.07 b	9.47 ± 0.22 d	65.73 ± 0.52 a	2.49 ± 0.06 e	2.14 ± 0.08 a	14.83 ± 0.23 e
Jishu82	0	2.24 ± 0.06 bc	3.79 ± 0.06 cd	8.52 ± 0.13 e	51.44 ± 0.41 f	2.92 ± 0.06 d	1.10 ± 0.08 e	26.35 ± 0.30 b
Jishu98	0	2.21 ± 0.05 cd	3.64 ± 0.05 e	8.75 ± 0.11 de	53.60 ± 0.37 ef	3.32 ± 0.08 c	2.08 ± 0.15 a	26.38 ± 0.11 b
Jishu99	0	1.51 ± 0.07 g	3.61 ± 0.05 e	12.11 ± 0.14 b	63.56 ± 0.43 b	3.17 ± 0.05 c	0.82 ± 0.03 f	15.22 ± 0.15 e
Lvya18	0	2.13 ± 0.04 de	3.88 ± 0.07 bc	10.91 ± 0.17 c	52.61 ± 0.29 f	3.68 ± 0.11 b	1.88 ± 0.07 b	25.91 ± 0.26 b
Weiduoli	0	2.30 ± 0.06 bc	2.90 ± 0.10 g	10.62 ± 0.18 c	54.47 ± 0.33 def	3.85 ± 0.09 ab	0.56 ± 0.04 g	25.31 ± 0.31 b
Xinong431	0	2.51 ± 0.08 a	3.19 ± 0.04 f	7.99 ± 0.17 ef	46.63 ± 0.51 g	4.07 ± 0.03 a	0.92 ± 0.05 f	34.69 ± 0.27 a
Xu55-2	0	2.01 ± 0.08 e	3.69 ± 0.11 de	14.21 ± 0.34 a	56.24 ± 0.62 cde	4.06 ± 0.08 a	0.47 ± 0.02 g	19.32 ± 0.19 d
average	0	2.05 ± 0.05 e	3.68 ± 0.06 de	10.39 ± 0.27 c	56.05 ± 0.49 cde	3.33 ± 0.10 c	1.27 ± 0.09 d	22.95 ± 0.28 c

[a] Mean ± SD values within the same column with different letters are significantly different from each other according to Duncan's multiple-range test ($P < 0.05$). [b] Uronic acid includes galacturonic and glucuronic acids.

The highest arabinose content (4.29%) was in cv. Beijing553, cv. Jishu71 contained the highest glucose (65.73%) and mannose contents (2.14%), cv. Xinong431 had the highest uronic acid (34.69%), rhamnose (2.51%), and xylose contents (4.07%), and the highest galactose content (14.21%) was in cv. Xu55-2. Walter et al. also found differences in sugar composition between two varieties of sweet potato CWM after the same storage time (*25*).

Physicochemical Properties of Dietary Fiber. The range of SWC of sweet potato DF was 8.11−12.56 mL/g in cv. Lvya18 and Xinong 431, respectively, with an average of 10.32 mL/g (**Table 6**). This was higher than the SWC of fiber-rich cocoa product and apple pectin and similar to citrus pectin (6.51, 7.42, and 10.45 mL/g, respectively) (*15*). Figuerola et al. (*18*) determined the SWC of fiber concentrates from one orange, two grape, two lemon, and three apple varieties using their byproducts after juice extraction, and SWC range was 6.11−9.19 mL/g. Among eight commercially available DFs (i.e., oat bran, fruits and fiber, wheat bran, pea, pea hull, apple, citrus, and coconut), coconut had the highest SWC and oat bran the lowest (20 and 5.3 mL/g, respectively) (*26*).

The WHC of sweet potato DF was between 3.54 g/g in cv. Jishu98 and 6.15 g/g in cv. Xu55-2, with an average of 4.82 g/g (**Table 6**). There have been series of WHC determinations for other DF products: the WHC of guar gum reached 63.07 g/g; apple and citrus pectins were 16.51 and 28.07 g/g, respectively, whereas cellulose was 0.71 g/g, and fiber-rich cocoa product and carob pod fiber were similar to sweet potato DF with values of 4.76 and 5.53 g/g, respectively (*15*). Enriched fiber products from pumpkin pulp, peel, or mesocarp obtained using different methods revealed excellent WHC of >24 g/g, with the highest 43 g/g from alcohol-insoluble residue in pumpkin pressed-pulp (*6*). Raghavendra et al. (*26*) showed that WHCs of DF products from different sources were significantly different; the values of citrus and coconut DF (7.0 g/g) were highest, and the lowest was wheat bran (1.9 g/g).

Among the 10 sweet potato varieties, the highest OHC was in cv. Xu55-2 and the lowest in cv. Jishu82 (2.48 and 1.43 g/g, respectively); the average was 1.95 g/g (**Table 6**), which was lower than the OHC of date flesh DF concentrate (9.6 g/g) (*20*). The OHC values in apple, pea, wheat, sugar beet, and carrot were 1.3, 0.9, 1.3, 1.5, and 1.2 g/g, respectively (*27*), similar to that of sweet potato DF. The OHC of DF from different grape, lemon, and apple varieties (*18*) showed similar results (range = 0.60−1.81 g/g) to sweet potato DF.

The range of GAC of the sweet potato DF was 0.54−1.27 mmol/g at the glucose concentration of 100 mmol/L (**Table 6**); cv. Xu55-2 and Jishu82 had excellent GAC, cv. Beijing553 had the least, and the average was 0.87 mmol/g. The GAC of sweet potato DF was significantly lower than the GAC value of insoluble DF (11.3 mmol/g), water-insoluble solids (9.95 mmol/g), alcohol-insoluble solids (9.36 mmol/g) from orange, and the value of cellulose (8.75 mmol/g) reported by Chau et al. (*17*); however, it 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) (*6*).

Table 6. Physicochemical Properties of Dietary Fiber Extracted from Sweet Potato Varieties[a]

variety	SWC (mL/g)	WHC (g/g)	OHC (g/g)	GAC (mmol/g)
Beijing553	10.12 ± 0.65 cd	4.21 ± 0.38 de	1.67 ± 0.01 g	0.54 ± 0.09 e
Jishu21	9.09 ± 0.38 f	4.55 ± 0.12 cde	2.06 ± 0.06 d	0.97 ± 0.08 b
Jishu71	9.81 ± 0.27 de	4.58 ± 0.12 cde	1.65 ± 0.11 g	0.84 ± 0.10 bcd
Jishu82	10.51 ± 0.16 bc	5.09 ± 0.01 bc	1.43 ± 0.03 i	1.18 ± 0.03 a
Jishu98	9.34 ± 0.05 ef	3.54 ± 0.34 f	1.56 ± 0.04 h	0.74 ± 0.16 cd
Jishu99	10.92 ± 0.24 b	4.78 ± 0.56 cde	2.38 ± 0.01 b	0.81 ± 0.14 bcd
Lvya18	8.11 ± 0.10 g	4.82 ± 0.33 cd	1.76 ± 0.01 f	0.92 ± 0.05 bc
Weiduoli	12.26 ± 0.55 a	4.96 ± 0.43 c	2.19 ± 0.01 c	0.78 ± 0.15 bcd
Xinong431	12.56 ± 0.31 a	5.56 ± 0.50 b	2.35 ± 0.07 b	0.68 ± 0.09 d
Xu55-2	10.51 ± 0.20 bc	6.15 ± 0.13 a	2.48 ± 0.05 a	1.27 ± 0.14 a
average	10.32 ± 0.20 c	4.82 ± 0.07 cd	1.95 ± 0.03 e	0.87 ± 0.06 bcd

[a] Mean ± SD values within the same column with different letters are significantly different from each other according to Duncan's multiple-range test ($P < 0.05$). SWC, swelling capacity; WHC, water-holding capacity; OHC, oil-holding capacity; GAC, glucose absorption capacity.

The SWC, WHC, OHC, and GAC results revealed significant differences ($P < 0.05$) in DF of the 10 sweet potato varieties. In previous studies, many factors affecting the physicochemical properties of DF were reported, including the temperature used when determining properties (*4*, *19*), DF sample particle-size distribution (*26*, *28*), and method and temperature of drying the DF sample (*14*, *29*). In this research, the same DF extraction method and property determination conditions were used throughout, so the factors mentioned above were excluded. This suggests that the differences in sweet potato DF properties were due to variety, and on this basis the relationships between chemical composition and properties of DF were evaluated.

Although there were no significant correlations between chemical composition and properties of DF, there were some relationships. Dietary fiber products with high pectin content had high WHC, and those with high cellulose content had high GAC. However, there were some exceptions, such as cv. Jishu98 and Jishu21, which had high pectin content and low WHC, and cv. Jishu71, with high cellulose content but low GAC. Earlier research found some relationships between properties and composition of DF. Marín et al. (*30*) found a positive correlation ($r^2 = 0.998$) between WHC and soluble DF from different citrus fibers. de Escalada Pla et al. (*6*) suggested that hydration properties (i.e., WHC and SWC) of DF depended on the presence of

rhamnogalacturonan-I and other hydrophilic pectins with side chains. In contrast, Figuerola et al. (*18*) and Thebaudin et al. (*27*) suggested that SWC could be related to the amount of insoluble fiber. In addition, some research suggested that components had a synergistic effect on DF properties, not a simple influence of one component. Chau and Huang (*16*) showed that the WHC and SWC of DF products from citrus were higher than from cellulose alone, indicating that other components (e.g., pectin, lignin, and hemicellulose) affected the hydration properties of citrus DF products; however, the component with the predominant role in hydration properties of DF was not identified. Different ratios of cellulose, pectin, hemicellulose, and lignin lead to different cross-linked structural formations of polysaccharide molecules, which result in different physicochemical properties (*6*). In sweet potato DF, apart from cellulose, pectin, hemicellulose, and lignin contents, it is possible some other components (e.g., starch, protein, phenols, pigments, and soluble oligosaccharides) can affect the properties of sweet potato DF.

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