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Non-starch polysaccharide compositions of rice grains with respect to rice variety and degree of milling

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Abstract

The chemical compositions of cell wall materials (CWM) in brown and milled rice were investigated using four rice varieties, Taichung Sen 10 (TCS10, indica), Tainung 67 (TNu67, japonica), Taichung Sen Waxy 1 (TCSW1, indica waxy), and Taichung Waxy 70 (TCW70, japonica waxy). The yield of CWM preparation, equivalent to total dietary fiber content, followed the order of TNu67 > TCS10 > the waxy cultivars. This order also held for the water solubility and pectic substance content of the CWM preparations and the compositional ratio of arabinose to xylose of all CWM samples. Comparatively, the nonwaxy CWM were rich in pectic substances and glucans; whereas the waxy CWM counterparts were dominant with hemicellulose plus cellulose and arabinoxylan-related polysaccharides. These results were more significant for the hot-water-soluble than insoluble parts and mainly dependent of rice variety rather than the degree of milling.

Keywords: Rice; Cell wall materials; Hemicellulose; Non-starch polysaccharide; Arabinoxylans

1. Introduction

The cell wall materials (CWM, namely non-starch polysaccharides) of cereal grains are constituted of cellulose microfibrils, hemicelluloses, and matrix materials such as pectic substances (Mod, Conkerton, Ory, & Normand, 1978). These CWMs offer cereal grains unique stability against cooking and are not readily digested by secretions of the human digestive system. During polishing brown rice into milled rice, CWM-rich bran waste is usually left up to 20–29% (Shibuya, Nakane, Yasui, Tanaka, & Iwasaki, 1985) and valuable to prepare CWM as dietary fiber for healthy foods, cereals, and dietary supplements (Wilkinson & Champagne, 2004).

Different categories of rice products (e.g. cooked rice, rice cakes, rice noodles, etc.) (Yeh, 2004) use different rice cultivars mainly based upon their amylose contents (AC). However, it remains unclear why some specific rice products having the most favored processing or eating quality are preferably made with some particular rice cultivars superior to other similar-AC counterparts. The properties of rice CWM, other than starch structural factors (Lai, Lu, & Lii, 2000), may be critical to modify the rheological or textural characteristics of a rice product, like the effects of pentosans (mostly arabinoxylans) in wheat product systems (Sasaki, Yasui, & Matsuki, 2000). Nonetheless, the influence of rice CWM on the quality of rice products remains unclear due to the ambiguity of rice CWM compositions.

It is known that the polysaccharides in alkali-extracted crude CWM preparations from milled rice are composed of uronic acid, arabinose, xylose, and glucose (Pascual &

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Juliano, 1983), partially resembling those from rice bran and germ (Maniñgat & Juliano, 1982). Arabinoxylans and β-glucans are frequently noticeable among cereal non-starch polysaccharides because parts of them are water soluble and provide precious functionality or physiological effects. It is therefore quite important to realize the details of the sugar compositions in rice CWM preparations regarding rice cultivar, the degree of milling, and water solubility, in order to understand their potential functionality and impacts on the starch-controlled physical properties of rice final products.

Accordingly, the saccharide compositions of rice CWM preparations and their hot water-soluble and water-insoluble parts were examined in this study, with respect to their cultivar and degree of milling. Two nonwaxy and two waxy rice varieties were selected for samples as brown rice and milled rice with the degrees of milling of 90% and 70% usually for cooked rice (Juliano, 1985b) and sake manufacture (Yoshizawa & Ogawa, 2004), respectively.

2. Materials and methods

2.1. Materials

Taichung Sen 10 (TCS10, nonwaxy indica,), Tainung 67 (TNu67, nonwaxy japonica,), Taichung Sen Waxy 1 (TCSW1, waxy indica,) and Taichung Waxy 70 (TCW70, waxy japonica,) were from the first crop of 1999 and obtained from the Taichung District Agriculture Improvement Station, Chang-Haw, Taiwan. Brown rice from these four rice varieties was milled to two degrees of milling, 90% and 70%, respectively. To isolate the CWM, brown rice and the resulting milled rice were ground into flours with a cyclone sample mill (Udy Corp., Boulder, CO) and passed through a 100-mesh sieve.

2.2. Preparation of rice CWM

CWM preparations from the rice flours were prepared according to the TDF methods (AOAC Methods 958.29, 991.43) (1995) as described by Lee, Rodriguez, and Storey (1995), using the TDF 100A enzyme kit (Sigma Chem. Co, St. Louis, MO, USA). Rice flour (100 g, dry basis) was first defatted by reflux with 20–50 volumes of 80% methanol for 1 h. The residue was then incubated in 0.05 M MES-TRIS buffer (pH 8.2) with heat-stable α-amylase (A3306, Sigma) at 95–100 °C for 30 min, followed by successively cooling to 60 °C, hydrolysis with protease (P3910, Sigma) at 60 °C for 30 min, adding 0.561 N HCl until reaching pH 4.0, and then incubated with amyloglucosidase (A9913, Sigma) at 60 °C for 30 min with continuous stirring. The mixture was then heated immediately at 100 °C for 10 min to inactivate the enzyme and added with 4 volumes of 95% ethanol (60 °C) to produce the CWM precipitate. The CWM precipitate was collected by consecutively centrifugation (10,000 rpm for 30 min at 22 °C), washing twice with each of 78% ethanol, 95% ethanol, and acetone, and finally lyophilization. The samples isolated from brown rice and milled rice with degrees of milling at 90% and 70% are designated as BRCWM, 90CWM and 70CWM, respectively, throughout the text. The preparation was done in triplicate.

2.3. Measurement of hot-water solubility of CWM

A 3 g dried original CWM sample was first fractionated with water at 10% (w/v) in a boiling water bath for 1 h, followed by centrifugation (18,000 rpm at 5 °C for 30 min) and freeze-drying to separate the hot-water soluble (HWS) from the insoluble (WIS) parts. The hot-water solubility of CWM was then estimated by the weight percentage based on the dry CWM preparation. The measurement was performed in triplicate.

2.4. Fractionation of CWM preparations

According to the method of Shibuya et al. (1985), CWM residue (20 mg) was treated with 5 mL of 0.05 M ethylenediamine-tetra-acetic acid (EDTA) and 0.05 M acetate buffer (pH 4.5) at 100 °C for 18 h (×2) to yield pectic substances. The hemicellulose in the CWM residue was further isolated with 5 mL of aqueous solutions of 4 N KOH and 0.1% $NaBH_4$ at room temperature for 18 h (×2), followed by washing with 5 mL of the same aqueous KOH solution and centrifugation to separate the KOH-soluble hemicellulose and KOH-insoluble cellulose materials. The KOH-insoluble residue was thoroughly washed with distilled water to yield cellulose. Recovery yield of each fraction was examined after freeze-drying. Each of CWM fractions was prepared in triplicate.

2.5. Sugar composition and uronic acid content analysis

For analysis of sugar compositions and uronic acid content, a portion of sample (1.0 mg) was hydrolyzed in a screw-capped test tube with 200 μL of 2 M TFA (trifluoroacetic acid) at 120 °C for 1 h (Albersheim, Nevins, English, & Karr, 1967; De Ruiter & Burns, 1986). TFA was immediately removed by evaporation at 50 °C under nitrogen. The dried hydrolysate was then frozen before analysis as follows. All following data were means of triplicate measurements.

2.5.1. Sugar compositions analysis

Sugar composition analysis was conducted by gas chromatography on the acetylated alditols of the above acid hydrolysates of CWM and their soluble and insoluble parts (HWS and WIS), which were prepared principally according to Albersheim et al. (1967). The acid hydrolysate of CWM was first reduced with 1.0 mL of sodium borohydride ($NaBH_4$) solution (10 mg/mL) plus one drop of 3.75 N NaOH per vial. After reaction at 25 °C for 1 h, excess borohydride was destroyed by adding glacial acetic acid dropwise until effervescence ceased. The alditol

solutions were then evaporated to dryness at 80 °C under dry nitrogen, followed by adding 1.0 mL of dry methanol to remove residual borate and repeated evaporation to dryness. Alditols were further acetylated with 1.0 mL of an acetic anhydride/pyridine mixture (10:1, v/v) in a capped vial at 121 °C for 2 h. The acetylated samples were then mixed thoroughly with a vortex mixer and centrifuged at 7000*g* for 20 min. Aliquots of the supernatants were then transferred to vials for gas chromatography analysis by a G-5000 gas chromatograph (Hitachi, Tokyo, Japan) equipped with an injector at 200 °C in a split injection mode (40:1) and with a Supelco SP-2330 coated (68% cyanopropyl–methylsilicone) fused silica column (0.25-mm i.d. × 30-m length) (Bellefonte, PA). The temperature was programmed: initial temperature of 170 °C for 1 min; heating at 5 °C/min to 210 °C, 2 °C/min to 225 °C, and then 1 °C/min to 235 °C; and holding at 235 °C for 10 min. A flame ionization detector was operated at 250 °C with nitrogen make-up gas to supplement the helium carrier gas.

2.5.2. Uronic acid analysis

Uronic acid content was detected according to the procedure mentioned by Blumenkrantz and Asboe-Hanson (1973). The acid hydrolysate of CWM was diluted to 0.4 mL with distilled water. Sodium tetraborate in concentrated sulfuric acid (2.4 mL, 4.76 g NaB_4O_7/L H_2SO_4) was added to the diluted sample, followed by heating in a dry block at 100 °C for 5 min. Upon cooling, 40 μL of 3-phenylphenol solution (150 mg of 3-phenylphenol in 100 mL of 0.125 M NaOH) was added and mixed thoroughly before colorimetric measurement. A Hitachi U-2000 spectrophotometer was used to measure uronic acid contents at a wavelength of 520 nm, using glucuronic acid to establish a standard curve.

2.6. Statistical analyses

Analysis of variance and the significance of differences among samples were analyzed with the ANOVA procedure and Duncan's multiple range test of SAS for Windows R 8.0 (SAS Institute Inc., Cary, NC), respectively.

3. Results and discussion

3.1. Yields, water solubility and polysaccharide fractions of rice CWM

Table 1 shows that the yields of CWM preparations, equivalent to the total dietary fiber content (TDF), were generally in the order of TNu67 > TCS10 ⩾ TCSW1 > TCW70. The CWM yields from brown rice (BRCWM) were greater by 3–4 wt% than those from the milled rice for the same rice variety. The differences in CWM yield between 90CWM and 70CWM appeared to be significant for the waxy but not nonwaxy cultivars. As to the water solubility (WS), it followed that TNu67 > TCS10 > both waxy cultivars. The CWM of the nonwaxy cultivars except TCS10 70CWM contained a significant amount of pectic substances rather than hemicellulose or cellulose, contrary to the waxy counterparts. For the nonwaxy cultivars, the polysaccharide compositions of BRCWM were similar to those of 90CWM, and both possessed greater cellulose contents than did the 70CWM. Generally, the higher the degree of milling, the lower was the WS, accompanying with a lower or higher cellulose content for the nonwaxy or waxy samples, respectively.

On the nutritional viewpoint, the yields suggest that the TDF of all rice CWM examined were greater than those reported for milled rice (Dreher, 1999; Pascual & Juliano, 1983; Shibuya et al., 1985), possibly due to different

Table 1
The yield, water solubility (WS) and polysaccharide fractions of rice CWM preparations

Source	CWM[A]	Yield (% in flour)	WS (%)	Pectic substance (%)	Hemicellulose (%)	Cellulose (%)
Nonwaxy						
TCS10	BRCWM	$12.5 \pm 0.5^{a,B}$	26.6 ± 0.8^{a}	43.7 ± 1.5^{a}	23.7 ± 1.2^{b}	32.7 ± 2.5^{a}
	90CWM	8.7 ± 0.1^{b}	19.1 ± 1.1^{b}	42.7 ± 1.5^{a}	26.0 ± 1.0^{b}	31.3 ± 3.2^{a}
	70CWM	8.4 ± 0.1^{b}	16.3 ± 0.9^{c}	36.3 ± 1.5^{b}	40.7 ± 0.6^{a}	22.7 ± 1.5^{b}
TNu67	BRCWM	13.5 ± 0.3^{a}	29.7 ± 0.2^{b}	41.0 ± 1.7^{c}	23.3 ± 2.3^{a}	35.7 ± 4.0^{a}
	90CWM	9.7 ± 0.1^{b}	31.8 ± 0.6^{a}	47.3 ± 1.2^{b}	25.3 ± 1.2^{a}	26.7 ± 1.5^{b}
	70CWM	9.2 ± 0.1^{c}	26.0 ± 0.2^{c}	62.7 ± 2.3^{a}	20.3 ± 0.6^{b}	17.0 ± 1.7^{c}
Waxy						
TCSW1	BRCWM	11.9 ± 0.4^{a}	14.8 ± 0.7^{a}	31.9 ± 1.9^{a}	41.1 ± 1.2^{a}	26.9 ± 0.8^{b}
	90CWM	7.7 ± 0.1^{b}	3.8 ± 0.1^{b}	30.7 ± 3.0^{a}	41.5 ± 1.4^{a}	27.8 ± 1.6^{ab}
	70CWM	5.9 ± 0.1^{c}	3.3 ± 0.1^{b}	29.8 ± 2.0^{a}	39.7 ± 0.6^{a}	30.4 ± 2.0^{a}
TCW70	BRCWM	9.7 ± 0.3^{a}	9.1 ± 0.8^{a}	28.3 ± 1.2^{a}	40.9 ± 1.1^{a}	30.8 ± 0.3^{c}
	90CWM	6.4 ± 0.2^{b}	8.2 ± 0.5^{b}	29.4 ± 0.8^{a}	33.1 ± 1.5^{b}	37.6 ± 2.2^{b}
	70CWM	4.0 ± 0.2^{c}	2.8 ± 0.1^{c}	30.8 ± 3.8^{a}	25.6 ± 0.9^{c}	43.6 ± 3.3^{a}

[A] BR and the numbers indicated for CWM represent their sources as brown rice and milled rice grains with a degree of milling of 90% or 70%.
[B] Means of triplicates ± standard deviations; means followed by different letters in a column for the same rice source differ significantly ($P < 0.05$).

CWM preparation methods. All BRCWM studied showed comparable TDF to wheat flakes, oat flour, whole-grain wheat flour, amaranth flour, and corn flour (TDF = 9.6–12.6 wt%) (Dreher, 1999).

3.2. Compositions of rice CWM

The results of sugar composition analysis (Table 2) illustrate that the acid hydrolysates of the TCS10 CWM samples were constituted principally of glucose, followed by xylose, arabinose, and small amounts of mannose or galactose. As compared with TCS10, TNu67 CWM had a noticeably higher level in glucose, lower in xylose, and somewhat lower in arabinose. In contrast to the nonwaxy sources, the waxy counterparts generally showed a higher content in xylose, possibly higher in mannose or galactose, and significantly lower in arabinose. The (ara + xyl) value that may suggest arabinoxylan composition in hemicellulose (Maniñgat & Juliano, 1982) accounted for 45–60 mol% of TCS10 and TCW70 CWM, but only 29–41 mol% of the TNu67 and TCSW1. The ratio of arabinose to xylose (R_{AX}) was in the order of TNu67 > TCS10 > TCW70 > TCSW1. The greater arabinose content and R_{AX} for BRCWM than for 90CWM and 70CWM were significant in the nonwaxy cultivars. The uronic acid content varied between 2.3% and 8.6%, greatest for the TCW70 and generally BRCWM (except for TNu67) >90CWM and 70CWM. This composition may be linked to galacturonic acid in pectins or glucuronic acid in xylans (Brett & Waldron, 1996). In general, the compositions of the CWM examined depended heavily upon rice varieties much more than the degree of milling.

3.3. Sugar compositions of HWS and WIS rice CWM

The sugar compositions of the acid hydrolysates of hot-water-soluble (HWS) and water-insoluble (WIS) parts from the above CWM preparations are given in Table 3. Generally, the HWS parts of the CWM examined except TCW70 70CWM contained predominantly glucose at 61–95 mol% for the nonwaxy cultivars and 42–65 mol% for the waxy. The other sugar compositions appeared to vary within a limited range for the nonwaxy samples; nonetheless, xylose excelled the others as the second majority for the waxy ones. As to the WIS parts except for TNu67 70CWM, arabinose, xylose, and glucose accounted for about 10–35, 28–41 and 22–43 mol%, respectively. The sums of arabinose and xylose contents were larger than the glucose contents, implying that arabinoxylans and related polysaccharides would constitute the majority of the WIS parts, except for TNu67 70CWM. This was contrary to the tendency for the HWS parts. Compositional variations in the remaining sugar (mannose and galactose) were likely not related to rice cultivar, water solubility (HWS and WIS), and degree of milling, despite some waxy WIS parts seemed possess a notable level of mannose and/or galactose. Generally, the R_{AX} were greatest for the WIS of TNu67 CWM, followed by TCS10 CWM parts except the HWS of 70CWM, and least for TCSW1 and TCW70 CWM parts. The arabinoxylan contents of the WIS parts were similar to the reported data of the CWM preparations from rice germ and bran (50–55%, $R_{AX} > 1$) (Maniñgat & Juliano, 1982; Shibuya et al., 1985).

3.4. Potential polysaccharide distribution of rice CWM

According to the known cereal cell wall polysaccharides (Gallaher, 2000; Jalili, Wildman, & Medeiros, 2001) and their solubility property (Juliano, 1985a; McCleary, 1986; Olson, Gray, Chiu, Betschart, & Turnlund, 1987), the HWS studied may be composed of mixed linkage β-(1 → 3, 1 → 4)-D-glucans, extractable pectic substances (e.g. arabinans, arabinogalactans, and galacturonans), and water-soluble hemicelluloses (e.g. some arabinoxylans,

Table 2
Sugar compositions of the acid hydrolysates of rice CWM preparations

Source	CWM[A]	Sugar composition (mol%)						R_{AX}[D]	Uronic acid (%)
		Arabinose	Xylose	Mannose	Galactose	Glucose	Ara+xyl[C]		
TCS10	BRCWM	23.0 ± 1.1[a,B]	27.3 ± 1.3[a]	1.3 ± 0.1[b]	2.2 ± 0.1[b]	45.6 ± 3.0[a]	50.3	0.84	5.6 ± 0.5[a]
	90CWM	19.5 ± 0.9[b]	28.8 ± 1.4[a]	5.9 ± 1.2[a]	6.6 ± 0.4[a]	39.3 ± 1.8[a]	48.3	0.68	3.0 ± 0.4[b]
	70CWM	18.9 ± 1.0[b]	25.7 ± 1.3[a]	6.0 ± 0.2[a]	7.0 ± 0.4[a]	42.4 ± 1.7[a]	44.6	0.73	2.3 ± 0.3[b]
TNu67	BRCWM	19.7 ± 1.2[a]	16.6 ± 1[a]	1.9 ± 0.1[c]	7.0 ± 0.3[a]	54.8 ± 1.8[b]	36.3	1.19	5.5 ± 0.3[a]
	90CWM	14.7 ± 1[b]	13.9 ± 0.9[a]	2.2 ± 0.0[b]	3.6 ± 0.1[b]	65.6 ± 1.7[a]	28.6	1.06	5.0 ± 0.5[a]
	70CWM	15.9 ± 1.0[b]	14.5 ± 0.9[a]	2.5 ± 0.1[a]	2.2 ± 0.1[c]	65.0 ± 1.8[a]	30.4	1.09	5.4 ± 0.5[a]
TCSW1	BRCWM	4.5 ± 0.2[a]	36.2 ± 1.0[a]	8.6 ± 0.5[a]	8.2 ± 1.7[a]	42.6 ± 0.9[a]	40.7	0.12	6.1 ± 0.1[a]
	90CWM	3.3 ± 1.7[a]	33.7 ± 2.5[a]	14.0 ± 2.8[a]	9.2 ± 2.3[a]	39.8 ± 1.0[b]	37.0	0.10	6.1 ± 0.1[a]
	70CWM	5.7 ± 0.9[a]	29.1 ± 3.8[a]	12.4 ± 5.8[a]	11.0 ± 2.1[a]	41.8 ± 1.1[ab]	34.8	0.19	4.7 ± 0.2[b]
TCW70	BRCWM	8.0 ± 0.4[a]	39.7 ± 1.9[a]	9.8 ± 0.4[a]	6.1 ± 0.3[a]	36.4 ± 1.6[a]	47.7	0.20	8.6 ± 0.2[a]
	90CWM	13.9 ± 4.0[a]	38.4 ± 8.9[a]	6.3 ± 0.4[b]	7.9 ± 1.0[a]	33.4 ± 4.3[a]	52.3	0.36	6.8 ± 0.2[b]
	70CWM	11.4 ± 2.4[a]	48.3 ± 2.9[a]	5.6 ± 1.6[b]	6.7 ± 1.6[a]	27.9 ± 2.1[b]	59.7	0.24	5.9 ± 0.1[c]

[A] BR and the numbers indicated for CWM represent their sources as brown rice and milled rice grains with a degree of milling of 90% or 70%.
[B] Means of triplicates ± standard deviations; means followed by different letters in a column for the same rice source differ significantly ($P < 0.05$).
[C] Ara+xyl was the total quantity of arabinose and xylose.
[D] Molar ratio of arabinose to xylose, estimated from the average data listed.

Table 3
Sugar compositions of the acid hydrolysates of hot-water-soluble (HWS) and water insoluble (WIS) parts from rice CWM preparations

	CWM[A]	Sugar composition (mol %)						R_{AX}[D]
		Arabinose	Xylose	Mannose	Galactose	Glucose	Ara+xyl[C]	
TCS10								
HWS	BRCWM	$7.9 \pm 0.6^{a,B}$	11.1 ± 0.8^{a}	7.2 ± 0.1^{a}	12.5 ± 0.3^{a}	61.3 ± 1.0^{b}	19.0	0.71
	90CWM	9.6 ± 1.4^{a}	10.4 ± 1.7^{a}	5.4 ± 1.1^{a}	9.8 ± 1.0^{b}	65.0 ± 2.7^{b}	20.0	0.92
	70CWM	2.8 ± 0.3^{b}	1.0 ± 0.1^{b}	1.4 ± 0.0^{b}	1.9 ± 0.0^{c}	92.8 ± 0.3^{a}	3.8	–[E]
WIS	BRCWM	27.4 ± 1.0^{a}	34.9 ± 1.2^{a}	4.4 ± 0.2^{b}	4.5 ± 0.3^{b}	28.7 ± 1.7^{a}	62.3	0.79
	90CWM	25.5 ± 1.1^{ab}	30.7 ± 1.3^{b}	5.3 ± 0.3^{a}	5.8 ± 0.4^{b}	32.7 ± 1.7^{a}	56.2	0.83
	70CWM	23.2 ± 1.0^{b}	29.8 ± 1.3^{b}	4.4 ± 0.2^{b}	12.6 ± 0.7^{a}	30.1 ± 1.5^{a}	53.0	0.78
TNu67								
HWS	BRCWM	4.3 ± 0.4^{a}	1.1 ± 0.10^{a}	1.9 ± 0.1^{a}	11.9 ± 0.2^{a}	80.8 ± 0.2^{c}	5.4	–
	90CWM	2.8 ± 0.3^{b}	1.0 ± 0.1^{a}	1.1 ± 0.0^{b}	8.7 ± 0.1^{b}	86.5 ± 0.2^{b}	3.8	–
	70CWM	2.0 ± 0.2^{b}	0.5 ± 0.1^{b}	1.2 ± 0.1^{b}	1.1 ± 0.0^{c}	95.2 ± 0.3^{a}	2.5	–
WIS	BRCWM	30.3 ± 1.5^{a}	29.4 ± 1.4^{a}	1.5 ± 0.2^{b}	5.4 ± 0.8^{a}	33.5 ± 3.9^{b}	59.7	1.03
	90CWM	30.8 ± 1.2^{a}	27.9 ± 1.1^{a}	2.6 ± 0.1^{a}	2.5 ± 0.2^{b}	36.1 ± 2.0^{b}	58.7	1.14
	70CWM	20.7 ± 1.2^{b}	16.9 ± 1.0^{b}	2.9 ± 0.1^{a}	1.9 ± 0.1^{b}	57.5 ± 2.0^{a}	37.6	1.22
TCSW1								
HWS	BRCWM	7.0 ± 0.6^{b}	28.4 ± 1.6^{a}	4.2 ± 0.7^{a}	7.5 ± 2.1^{a}	52.9 ± 2.3^{b}	35.4	0.25
	90CWM	6.1 ± 0.7^{b}	19.6 ± 0.9^{b}	5.5 ± 0.4^{a}	3.8 ± 1.1^{b}	65.0 ± 0.9^{a}	25.7	0.31
	70CWM	16.5 ± 2.5^{a}	25.1 ± 1.1^{a}	5.9 ± 2.2^{a}	4.6 ± 1.6^{ab}	47.9 ± 2.5^{c}	41.6	0.66
WIS	BRCWM	10.5 ± 1.6^{b}	41.4 ± 1.2^{a}	8.7 ± 3.3^{b}	6.8 ± 0.1^{a}	32.6 ± 2.8^{b}	51.9	0.25
	90CWM	12.8 ± 0.9^{ab}	31.8 ± 0.2^{c}	8.0 ± 0.2^{b}	4.3 ± 0.4^{c}	43.1 ± 0.5^{a}	44.6	0.40
	70CWM	14.4 ± 1.6^{a}	37.0 ± 0.9^{b}	13.4 ± 1.3^{a}	5.1 ± 0.9^{b}	30.2 ± 0.9^{b}	51.4	0.39
TCW70								
HWS	BRCWM	8.2 ± 0.5^{c}	32.0 ± 1.8^{b}	3.4 ± 0.1^{b}	6.0 ± 0.3^{a}	50.4 ± 1.9^{a}	40.2	0.26
	90CWM	21.5 ± 1.0^{a}	27.5 ± 1.3^{c}	3.1 ± 0.1^{b}	5.6 ± 0.3^{a}	42.4 ± 1.9^{b}	49.0	0.78
	70CWM	15.0 ± 0.6^{b}	39.8 ± 1.7^{a}	7.5 ± 0.4^{a}	3.6 ± 0.2^{b}	34.1 ± 1.7^{c}	54.8	0.38
WIS	BRCWM	29.7 ± 1.0^{a}	34.8 ± 1.2^{b}	6.0 ± 0.4^{b}	4.2 ± 0.3^{c}	25.3 ± 1.5^{a}	64.5	0.85
	90CWM	17.9 ± 0.6^{b}	39.6 ± 1.6^{a}	8.7 ± 0.5^{b}	11.8 ± 0.9^{a}	22.0 ± 0.7^{b}	57.5	0.45
	70CWM	9.6 ± 0.5^{c}	39.2 ± 1.9^{a}	15.3 ± 0.6^{a}	8.9 ± 0.5^{b}	27.0 ± 1.2^{a}	48.8	0.24

[A] BR and the numbers indicated for CWM represent their sources as brown rice and milled rice grains with a degree of milling of 90% or 70%. HWS, hot-water soluble parts; WIS, water-insoluble parts.
[B] Means of triplicates ± standard deviations; means followed by different letters in a column for the same part and rice source differ significantly ($P < 0.05$).
[C] Ara+xyl was the total quantity of arabinose and xylose.
[D] Molar ratio of arabinose to xylose, estimated from the average data listed.
[E] Not determined due to the negligible amount of xylose.

xyloglucans and galactomannans). Many of hemicellulose and cellulose molecules will remain in the WIS residues that are partially hydrolysable by acids for sugar composition analysis. According to the results of Table 2, the acid-hydrolysable components of the rice CWM would be mainly glucans and arabinoxylans, and glucans were dominant over arabinoxylans for the nonwaxy more than waxy CWM preparations and for the HWS more than WIS parts. Glucans present in the HWS parts may be mixed linkage β-(1 → 3, 1 → 4)-D-glucans with physiological potential like oat β-glucans (Dreher, 1999; Gallaher, 2000; Jalili et al., 2001; Normand, Ory, & Mod, 1987). However, glucans in the WIS parts may involve xyloglucans and cellulose that are less water-soluble but partially acid-hydrolysable. On the other hand, the (ara + xyl) values richer for BRCWM than for 90CWM or 70CWM (Table 2) recommend that arabinoxylans may be richer in the outer more than inner layers of the rice cultivars except TCW70.

The results of Tables 2 and 3 point to that the R_{AX} of rice CWM could vary from 0.1 to 1.2, noticeably interdependent of rice cultivar, degree of milling, and water solubility. This could explain why diverse R_{AX} values are found for the CWM preparations of rice or other cereals in literature. The R_{AX} of 1.4–1.6 reported for water-soluble CWM of some milled rice (Juliano, 1985a) were significantly higher than the R_{AX} of 0.5 for water-soluble arabinoxylans from cereal grains (Izydorczyk & Biliaderis, 1992, 1995). Alkali-extracted CWM from two Philippine milled rice have a R_{AX} of 0.73 and 0.96 (Juliano, 1985a), somewhat lower than the R_{AX} of 1.07 for alkali-soluble arabinoxylans from barley grains (Izydorczyk, Macri, & MacGregor, 1998). Accordingly, it needs more works to evaluate R_{AX} ratio as the index of compositional characteristics for

cereal CWM, since R_{AX} concerns not only arabinoxylans but also arabinans, arabinogalactans, and xyloglucans.

4. Conclusions

Generally, the water solubility and sugar compositions of the rice CWM examined were mainly governed by rice variety, rather than the degree of milling that influenced chiefly the water solubility. In contrast to the waxy rice cultivars, the nonwaxy rice showed greater TDF content and produced CWM with higher water solubility, pectic substance content, and the molar ratio of arabinose to xylose. The acid-hydrolysable components of the nonwaxy CWM and especially their hot-water parts were mainly from glucans, obviously different from arabinoxylans and related polysaccharides for the waxy counterparts. Because water-soluble glucans, arabinoxylans and water-insoluble CWM have their peculiar functionality and dietary significance, the glucans-rich nonwaxy rice may be better for tailored rice products with physiological benefits. And, the role of arabinoxylans in the quality of waxy rice products would be noteworthy.

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References

Albersheim, P., Nevins, D. J., English, P. D., & Karr, A. (1967). A method for the analysis of sugars in plant cell-wall polysaccharides by gas–liquid chromatography. *Carbohydrate Research, 5*, 340–345.

AOAC International (1995). *Official methods of analysis* (16th ed.). Gaithersburg, MD: AOAC International (Methods 958.29, 991.43).

Blumenkrantz, N., & Asboe-Hanson, G. (1973). New method for quantitative determination of uronic acids. *Analytical Biochemistry, 54*, 484–489.

Brett, C. T., & Waldron, K. W. (1996). The molecular components of the wall. In C. T. Brett & K. W. Waldron (Eds.), *Physiology and Biochemistry of Plant Cell Walls* (2nd ed., pp. 4–43). London: Chapman & Hall, 62, 231.

De Ruiter, J. M., & Burns, J. C. (1986). Rapid determination of cell wall monosaccharides in flacidgrass. *Journal of Agricultural and Food Chemistry, 34*, 780–785.

Dreher, M. (1999). Food sources and uses of dietary fiber. In S. S. Cho, L. Prosky, & M. Dreher (Eds.), *Complex Carbohydrate in Foods* (pp. 327–371). New York: Marcel Dekker.

Gallaher, D. D. (2000). Dietary fiber and its physiological effects. In M. K. Schmidl & T. P. Labuza (Eds.), *Essentials of functional foods* (pp. 273–292). Maryland: Aspen Publishers, Inc.

Izydorczyk, M. S., & Biliaderis, C. G. (1992). Influence of structure on the physicochemical properties of wheat arabinoxylan. *Carbohydrate Polymers, 17*, 237–247.

Izydorczyk, M. S., & Biliaderis, C. G. (1995). Cereal arabinoxylans: advances in structure and physicochemical properties. *Carbohydrate Polymers, 28*, 33–48.

Izydorczyk, M. S., Macri, L. J., & MacGregor, A. W. (1998). Structure and physicochemical properties of barley non-starch polysaccharides. II. Alkali-extractable β-glucans and arabinoxylans. *Carbohydrate Polymrs, 35*, 259–269.

Jalili, T., Wildman, R. E. C., & Medeiros, D. M. (2001). Dietary fiber and coronary heart disease. In R. E. C. Wildman (Ed.), *Handbook of nutraceuticals and functional foods* (pp. 281–293). New York: CRC Press.

Juliano, B. O. (1985a). Polysaccharides, proteins, and lipids of rice. In B. O. Juliano (Ed.), *Rice: chemistry and technology* (2nd ed., pp. 59–174). Minnesota, USA: The American Association of Cereal Chemists, Inc.

Juliano, B. O. (1985b). Criteria and tests for rice grain qualities. In B. O. Juliano (Ed.), *Rice: chemistry and technology* (pp. 443–524). Minnesota: The American Association of Cereal Chemists, Inc.

Lai, V. M.-F., Lu, S., & Lii, C.-y. (2000). Molecular characteristics influencing retrogradation kinetics of rice amylopectins. *Cereal Chemistry, 77*, 272–278.

Lee, S. C., Rodriguez, F., & Storey, M. (1995). Determination of soluble and insoluble dietary fiber in psyllium-containing cereal products. *Journal of AOAC International, 78*, 724–729.

Maniñgat, C. C., & Juliano, B. O. (1982). Composition of cell wall preparations of rice bran and germ. *Phytochemistry, 21*(10), 2509–2516.

McCleary, B. V. (1986). Enzymic modification and quantification of polymers based on a $(1 \rightarrow 4)$-β-glucan backbone. In G. O. Phillips, D. J. Wedlock, & P. A. Williams (Eds.). *Gums and stabilisers for the food industry* (3, pp. 17–28). London: Elsevier Applied Science Publishers.

Mod, R. R., Conkerton, E. J., Ory, R. L., & Normand, F. L. (1978). Hemicellulose composition of dietary fiber of milled rice and rice bran. *Journal of Agricultural and Food Chemistry, 26*(5), 1031–1035.

Normand, F. L., Ory, R. L., & Mod, R. R. (1987). Binding of bile acids and trace minerals by soluble hemicelluloses of rice. *Food Technology*(Feb), 86–90.

Olson, A. C., Gray, G. M., Chiu, M. C., Betschart, A. A., & Turnlund, J. R. (1987). Monosaccharides produced by acid hydrolysis of selected foods, dietary fibers, and fecal residues from white and whole wheat bread consumed by humans. *Journal of Agricultural and Food Chemistry, 36*, 300–304.

Pascual, C. G., & Juliano, B. O. (1983). Properties of cell wall preparations of milled rice. *Phytochemistry, 22*, 151–159.

Sasaki, T., Yasui, T., & Matsuki, J. (2000). Influence of non-starch polysaccharides isolated from wheat flour on the gelatinization and gelation of wheat starches. *Food Hydrocolloids, 14*, 295–303.

Shibuya, N., Nakane, R., Yasui, A., Tanaka, K., & Iwasaki, T. (1985). Comparative studies on cell wall preparations from rice bran, germ, and endosperm. *Cereal Chemistry, 6*(4), 252–258.

Wilkinson, H. C., & Champagne, E. T. (2004). Value-added rice products. In E. T. Champagne (Ed.), *Rice: chemistry and technology* (3rd ed., pp. 473–493). Minnesota: Eagan Press.

Yeh, A.-I. (2004). Preparation and applications of rice flour. In E. T. Champagne (Ed.), *Rice: chemistry and technology* (3rd ed., pp. 495–539). Minnesota: Eagan Press.

Yoshizawa, K., & Ogawa, Y. (2004). Rice in brewing. In E. T. Champagne (Ed.), *Rice: chemistry and technology* (3rd ed., pp. 541–567). Minnesota: Eagan Press.