Food Sci. Biotechnol. Vol. 15, No. 5, pp. 746 ~ 751 (2006)

Food Science and Biotechnology

Comparison of the Properties of Wheat Flours Supplemented with Various Dietary Fibers

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Abstract The effects of resistant starch (RS) and non-starch polysaccharide (NSP) addition on the properties of hard wheat flour were investigated. Total dietary fiber (TDF) levels of various NSP ranged from 78.3-100.0%, but TDF and RS levels of autoclaved RS3 and cross-linked RS4 were 16.1 and 35.0% and 13.2 and 90.9%, respectively. DF-supplemented flour increased swelling power, but RS4-supplemented flour exhibited the lowest it. Solubility increased with the addition of pectin and RS3, but decreased with the addition of cellulose and RS4. RS-supplemented flour had increased lightness (L), but decreased values of redness (a) and yellowness (b). RS3 and pectin increased the dough development time, but RS4, cellulose, and chitosan decreased it. The water absorptions of pectin- and RS4-supplemented flours increased, however the dough stability decreased. The initial pasting temperatures of RS- and NSP-supplemented flours increased regardless of amount added, but the maximum peak viscosity decreased for all except the pectin-supplemented flour.

Keywords: resistant starch, non-starch polysaccharide, TDF & RS levels, properties

Introduction

Dietary fiber (DF) for a long time was defined as plant cell wall materials and later was more specifically described as the indigestible remnants thereof (1, 2). In 2002, the FND (Food and Nutrition Board of the National Academy of Sciences, USA) adopted the following definition: Total dietary fiber (TDF) is the sum of DF and functional fiber. DF consists of non-digestible carbohydrates and lignin that are intrinsic and intact in plants while functional fiber consists of isolated, non-digestible carbohydrates and lignin that have beneficial physiological effects in humans (3). TDF includes non-starch polysaccharides (NSP), resistant starch (RS), and lignin. Soluble fiber can maintain the feeling of satiation after a meal, reduce calorie consumption, and reduce body weight. Because it prolongs the passage time through the digestive tract after food is ingested, the absorption of glucose is lowered and glucose resistance and insulin secretion are improved (4, 5). Insoluble DF is not digested in the small intestine and it stimulates intestinal movement by absorbing water. Nevertheless, it is fermented in the large bowel, produces short chain fatty acids and has been reported to have inhibitory effects toward colon cancer (4, 6).

RS is the sum of starch and the products of starch degradation that are not absorbed in the small intestine of healthy individuals. RS is classified into four different types, RS1 to RS4 (7). Because RS1 and RS2 are native starches, they will lose RS potential if gelatinized during food processing. RS3 is stable when heated above 100°C because retrograde amylose melts at about 155°C (8). Cross-linked RS4 is also known to be stable when processed as a food additive. Recently, with changing dietary patterns, the intake of DF is decreasing and its consumption is therefore recommended as an educational and marketing policy. Nevertheless, it is very difficult in modern society for individuals to satisfy the recommended daily amount of DF. Therefore, to consume the recommended daily intake of dietary fibers, 25-35 g including RS, DF must be added to be diet (2, 9, 10). RS has beneficial roles in human health and in processed foods. RS has physiological effects similar to DF and a variety of other properties of value in food production. Because RS has a bland flavor, low water binding capacity and small particle size, the addition of RS to some foods to increase its levels is recommended (11, 12). In some studies, it has been reported that RS addition to bread, rice cakes, and noodles, etc., raises the content of DF while maintaining the food quality (13-15).

The objectives of the present study were to compare the properties of various DF sources and DF-supplemented wheat flours. NSP selected for use in this study were pectin as soluble fiber, cellulose as insoluble fiber, and chitosan as animal fiber. Autoclaved RS3 and cross-linked RS4 prepared from wheat starch were also used.

Materials and Methods

Materials Wheat starch was purchased from Sinsong Food, Inc. (Nonsan, Korea). Hard wheat flour (1st grade) provided by Dongah Milling Co. (Incheon, Korea). Microcrystalline Cellulose (Comprecel. Mingtai Chemical Co., Ltd., Taoyuan, Hsien, Taiwan), pectin (CP Kelco. Atlanta, GA, USA), and chitosan (Novolite Chemicals Co., Ltd., Shanghai, China) were purchased from Daeheung Pharm. Co. (Seoul, Korea). Sodium trimetaphosphate (STMP) and sodium tripolyphosphate (STPP) used for the production of the cross-linked RS4 were purchased from Sigma Chemical Co. (St. Louis, MO, USA). The enzymes used for the analysis of TDF and RS levels were heat-stable α-amylase (A3306), protease (P3910), amyloglucosidase

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Received June 1, 2006; accepted August 2, 2006

(A9913), pancreatin (P7545, Sigma Chemical Co.), and pullulanase (Promozyme, Novo Nordisk, Denmark).

Preparation of RS RS3 was prepared by modifying the method of Sievert and Pomeranz (16) and Mun *et al.* (17). The wheat starch suspension (150 g) in 0.1% citric acid and 0.1% acetic acid (sb) in 300 mL distilled water was heated in a boiling water bath with shaking and autoclaved at 121°C for 1 hr. The heating-cooling process of starch suspension was repeated 3 times, after which the starch gel was dried at 40°C. Finally, the sample was ground into fine particles and passed through a 100 mesh (<150 μm) sieve. The cross-linked RS4 was prepared by Mun and Shin's method (18). Wheat starch (100 g, db) was mixed with 0.01 N HCl (100 mL) and the starch slurry was annealed at 50°C in a shaking incubator for 12 hr. The mild acid treated starch slurry was transferred to a beaker in a 45°C water bath and sodium sulfate (10%, sb) was added into beaker. The STMP/STPP mixture (99/1, 12%, sb) was placed in a beaker, was adjusted to pH 11.5 with 1.0 M NaOH (25 mL, 2.0%, sb), then warmed to 45°C and held for 3 hr with stirring. The slurry was adjusted to pH 6.0 by adding 1.0 N HCl. The starch was then collected by centrifugation, washed repeatedly with distilled water (200 mL × 5), and dried at 40°C in an incubator. The sample was ground into fine particles and passed through a 100 mesh, and used as RS4 sample.

Determination of general composition, TDF, and RS levels All assays were done in triplicate. Protein, lipid, ash, and moisture contents were measured by the AOAC method. TDF and RS levels of RS and NSP were measured using the AOAC method 991.43 (19) and the pancreatin-gravimetric method (20, 21). Because TDF and RS levels of RS4 were different with each analytical method, TDF and RS levels were determined by both methods.

Preparation of RS- and NSP-supplemented flour The ratio of RS and NSP to flour was 10%. Through analysis of TDF and RS levels, the cross-linked RS4 showed a higher TDF level (90.9%) than RS level (35.0%). Similar results were reported in Shin *et al.* (21). It is suggested that a healthy human body might completely digest RS. Therefore RS level of RS4 type starch was used for DF level in experiment. RS levels of 16.1 and 35% for RS3 and RS4, respectively, were 3-5 times lower than those of 80.8-100% for NSPs, the ratio of RS (20%) in mixed flour was 4 times higher than that of NSP (5%) as compared to the similar levels of TDF or RS in flours with DF.

Measurement of color value and swelling power of DF-supplemented flour The values of L (lightness), +a (redness), and +b (yellowness) of the RS- and NSP-supplemented flours were measured using a color meter (JX-777; Color Techno System, Tokyo, Japan) and the ΔE value was calculated to assess the color change compared to the control flour. The L, a, and b values of the standard white plate used were 98.27, 0.01, and -0.26, respectively. The swelling power and solubility of each DF material and the various DF-supplemented flours were determined at 30 and 95°C by Schoch and Leach's method (22).

Farinograms of doughs prepared from DF-supplemented flours Farinograms of RS- and NSP-supplemented flours were obtained according to the AACC method 54-21 (23) using a farinograph (SEW; C.W. Brabender instrument Inc., Duisburg, Germany) equipped with a 300 g bowl. From the farinograph, water absorption, dough stability, dough development time (min), mixing tolerance index (BU), and valorimeter values (v/v) were obtained.

Pasting properties of DF-supplemented flours The pasting properties of DF-supplemented flours were assessed using an Amylograph (C.W. Brabender instrument Inc.) according to the AACC method 22-10 (24). Samples (65 g, 14%, mb) in 450 mL distilled water were heated from 50 to 95°C at 1.5°C/min, and the initial pasting temperature, the maximum viscosity temperature, and the maximum viscosity were measured.

Statistical analysis Experiments were performed in at least duplicate. The data obtained were statistically evaluated using analysis of variance (ANOVA) and Duncan's multiple range test. The SAS package (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis.

Results and Discussion

TDF and RS levels and swelling power of various DFs TDF and RS levels of RS and NSP using the Prosky-AOAC and pancreatin-gravimetric methods are shown in Table 1. The values for commercial cellulose, chitosan, and pectin were 100±0.29, 100±0.02, and 78.3±0.18%, respectively, but RS levels of RS3 and RS4 were 16.1±0.17 and 35.0±0.09%, respectively. TDF levels of NSP were higher than RS levels of RS3 and RS4. The TDF level of RS4 using heat stable α-amylase, protease, and amyloglucosidase was much higher than the RS level of RS4 using pancreatic α-amylase and pullulanase, because cross-linking between the starch granular membrane and starch molecular chain inhibited digestion by heat stable α-amylase (21).

The swelling power of wheat flour at 30°C was 3.0. The swelling power of flour supplemented with the insoluble fibers, chitosan, cellulose, RS3, and RS4, were 7.4, 4.7, 4.8, and 3.9, respectively. The swelling power of pectin (42.8), a soluble fiber, was 4-14 times higher than the other fibers. The reason that RS4 showed the lowest value was due to the decrease swelling by hydration, because of cross-linking between amylose and amylopectin in the starch granule (21). At 95°C, the swelling power of wheat flour rapidly increased to 16.5 and that of RS3 which is composed of amorphous polymer (ca. 84%) increased from 4.8 to 8.8. The water absorption ability of the amorphous and crystalline region of the starch granules was also affected (21). The higher crystalline cellulose and cross-linked RS4 did not change greatly, but pectin had decreased swelling power at 95°C because some of the pectin molecules were dispersed in water by heating. However, the animal DF chitosan and cellulose were hardly affected by the change in temperature. This might be due to a higher degree of polymerization, but the reason

Table 1. TDF and RS levels, swelling power, and solubility of RS and NSP

Sample	TDF and RS level		Swelling power		Solubilitiy (%)	
	TDF[2)] (%)	RS[3)] (%)	30°C	95°C	30°C	95°C
Wheat flour	1.0±0.09[e1)]	3.5±0.07[e]	3.0±0.03[e]	16.5±0.48[b]	8.6±0.12[b]	31.3±0.03[b]
Cellulose	100.0±0.29[a]	100.0±0.26[a]	4.7±0.22[c]	4.0±0.03[f]	2.5±0.04[d]	1.1±0.04[f]
Chitosan	100.0±0.02[a]	100.0±0.02[a]	7.4±0.07[b]	7.9±0.05[d]	2.0±0.05[e]	1.2±0.03[e]
Pectin	78.3±0.18[c]	80.8±0.16[b]	42.8±0.09[a]	21.8±0.12[a]	91.1±0.13[a]	95.8±0.10[a]
RS3	13.1±0.17[d]	16.1±0.12[d]	4.8±0.03[c]	8.8±0.07[c]	7.1±0.05[c]	24.9±0.16[c]
RS4	90.9±0.09[b]	35.0±0.05[c]	3.9±0.04[d]	5.0±0.08[e]	1.0±0.07[f]	1.4±0.06[d]

1) Superscript means significantly different within column ($p<0.05$).
2) TDF level was measured using the AOAC method.
3) RS level was measured using the pancreatin-gravimetric method.

for this is not clear.

As shown in Table 1, the solubility of RS4, cellulose, and chitosan remained low, whereas pectin showed a high solubility regardless of temperature. The solubility of RS3 was markedly higher than that of RS4, because during the autoclaving-cooling cycles most of the starch molecules existed in the amorphous state (17, 25). Cross-linking suppressed the solubility of RS4 molecules (21). Chatakannonda *et al.* (26) reported that starch molecule movement was limited when the starch was cross-linked for modification.

General analysis, swelling power of RS- and NSP-supplemented wheat flours The general composition of wheat flour was 12.1% moisture, 12.7% protein, 0.9% crude lipid, and 0.5% ash. The protein, lipid, and ash contents of RS- and NSP-supplemented wheat flours were 10.9-12.2, 0.8-0.9, and 0.4%, respectively. The composition values of RS- and NSP-supplemented flours were lower than those of wheat flour itself. Significantly, protein content, which is the important factor for baking of the flour mixture, was reduced by 1.5-1.8% compared with the control after adding 20% RS to flour.

The swelling power and solubility of the RS- and NSP-supplemented wheat flour mixtures at 30 and 95°C are shown in Table 2. The swelling powers of all samples at 30°C were higher than those of the control flour, and at 95 °C the swelling powers of all wheat flour mixtures, except the pectin-supplemented wheat flour, decreased. The swelling power and solubility of DF-supplemented flours showed similar trends, but the values were not exactly same. Because the flour components could interact with polymer chains in RS and NSP, the swelling power and solubility of the mixed flours showed unexpected trends. Soluble carbohydrates leached from starch granules with increasing temperature above the gelatinization temperature (26, 27). The most important factors to control the solubility of the RS- and NSP-supplemented wheat flour mixtures were the amorphous and crystalline structure, interactions between molecules in the DF, the temperature, and the shear force.

When added to 10%, cellulose showed the lowest swelling power at 95°C and all samples except pectin were lower than the control flour. The solubility of the pectin-

Table 2. Swelling power and solubility of RS- and NSP–supplemented wheat flours

Sample conc.[2)] (%, fb)	Swelling power		Solubility (%)	
	30°C	95°C	30°C	95°C
Control	3.0±0.03[gh1)]	16.5±0.48[c]	8.6±0.12[c]	31.3±0.03[e]
Cellulose-10	3.4±0.21[efg]	13.5±0.44[g]	7.8±0.41[d]	28.5±0.26[h]
Chitosan-10	3.7±0.14[bc]	14.2±0.76[f]	6.6±0.13[e]	31.0±0.14[e]
Pectin-10	4.2±0.11[a]	17.8±0.21[b]	19.7±0.53[a]	40.7±0.40[a]
RS3-10	3.5±0.15[def]	15.4±0.18[de]	8.6±0.08[c]	31.8±0.26[e]
RS4-10	3.0±0.26[gh]	14.1±0.42[fg]	6.4±0.37[e]	29.2±0.72[f]
Cellulose-5	3.3±0.20[fg]	15.0±0.06[de]	8.4±0.07[c]	29.8±0.57[f]
Chitosan-5	3.6±0.11[cde]	15.7±0.32[d]	6.8±0.16[e]	34.0±0.15[d]
Pectin-5	3.8±0.18[b]	19.5±0.43[a]	15.8±0.56[b]	35.4±0.46[b]
RS3-20	3.6±0.17[cd]	14.7±0.44[ef]	9.0±0.09[c]	34.7±0.17[e]
RS4-20	3.1±0.11[g]	12.3±0.42[h]	5.8±0.31[f]	28.6±0.4[gh]

1) Superscript means significantly different within column ($p<0.05$).
2) Percentage of TDF and RS added to flour was based on flour (14%, mb).

Table 3. Color values of RS- and NSP–supplemented wheat flours

Sample conc.[2)] (%, fb)	Color value[4)]			
	L	a	b	ΔE[3)]
Control	95.76±0.14[f1)]	0.19±0.03[d]	10.80±0.13[c]	0
Cellulose-10	96.03±0.25[d]	0.13±0.02[e]	10.13±0.23[f]	0.72±0.18[e]
Chitosan-10	95.62±0.13[h]	0.33±0.03[c]	11.39±0.41[a]	0.62±0.28[f]
Pectin-10	95.15±0.38[i]	1.24±0.04[a]	10.93±0.16[b]	1.22±0.24[d]
RS3-10	96.50±.0.11[a]	-0.76±0.03[j]	9.17±0.09[h]	2.03±0.05[b]
RS4-10	96.34±0.13[c]	-0.42±0.02[g]	9.04±0.08[i]	1.95±0.05[c]
Cellulose-5	95.93±0.21[e]	0.05±0.02[f]	10.18±0.36[e]	0.66±0.24[f]
Chitosan-5	95.72±0.23[g]	0.21±0.03[d]	10.94±0.50[b]	0.15±0.38[h]
Pectin-5	95.71±0.73[g]	0.44±0.04[b]	10.32±0.71[d]	0.54±0.83[g]
RS3-20	96.43±1.56[b]	-0.61±0.05[i]	9.30±0.25[g]	1.83±1.43[d]
RS4-20	96.45±0.91[b]	-0.50°æ0.03[h]	8.94±0.14[j]	2.10±0.77[a]

[1)]Superscript means significantly different within column (p<0.05).
[2)]Percentage of TDF and RS level added to flour was based on flour (14%, mb).
[3)]ΔE is the total color change compared to color values of the control flour.
[4)]Color values represent L (lightness), a (+ redness/- greenness) and b (+ yellowness/- blueness).

supplemented flour was the highest, regardless of temperature, and that of RS3-supplemented flour was similar to the control flour. Notably, the insoluble dietary fibers, cellulose, chitosan, and RS4 decreased water absorption, swelling power, and solubility of the control flour.

Color The lightness (L), redness (+a), and yellowness (+b) values of RS-and NSP-supplemented flours are shown in Table 3. The values for wheat flour were 95.76, 0.19, and 10.80, respectively. Comparing the 10% RS- and NSP-supplemented wheat flours, the chitosan- and pectin-supplemented flours showed a decreased L value, but had the highest +a and +b values. The RS-supplemented flours had a substantially increased L value, but decreased +a and +b values compared to the NSP-supplemented flours. The color differences between the control and RS-supplemented flours were higher than NSP-supplemented flours. RS-supplemented flours had higher lightness and whiteness values than NSP-supplemented flours, indicating that RS addition would improve the product's color and quality.

Mixing characteristics of RS- and NSP-supplemented flours The farinogram characteristics of the flours with added RS and NSP, as measured by farinograph, are shown in Fig. 1. Gluten is the component that plays an important role during the developing and baking of dough by providing extensibility and viscoelasticity (28-31). As shown in Table 4, the water absorption of dough prepared from RS- and NSP-supplemented wheat flours was greatly increased, because water absorption is influenced not only by the protein content, particle size, and damaged starch contents of wheat flour but also by fiber materials (32, 33). Cho and Lee (31) reported that water absorption increased with increasing DF contents. The water absorption of flour dough was 60.3% and it increased slightly with the addition of RS or NSP to the dough. The water absorption of the 10% RS- and NSP-supplemented doughs, except dough with added pectin, ranged from 63.5-65.4%. Water absorption was highest in the pectin-supplemented flour, because the high swelling power of pectin affected water absorption of the dough. However, the viscosity curve on the farinogram presented an unstable pattern (Fig. 1C) which made the formation of a gluten network with soluble pectin difficult. RS3 showed a higher water absorption in insoluble fibers, because RS3 is composed of a higher amorphous region compared to other fibers (25). If the dough development time was too short, it was difficult to mix the dough ingredients completely, which rendered the dough unsuitable for bread flour. The dough development time of the control flour dough was 2.4 min. RS3 and pectin addition increased the dough development time depending on the amount added. However, higher RS4, cellulose and chitosan contents slightly decreased the time. Song *et al.* (25) reported that the dough development time of RS3-supplemented dough increased, because when

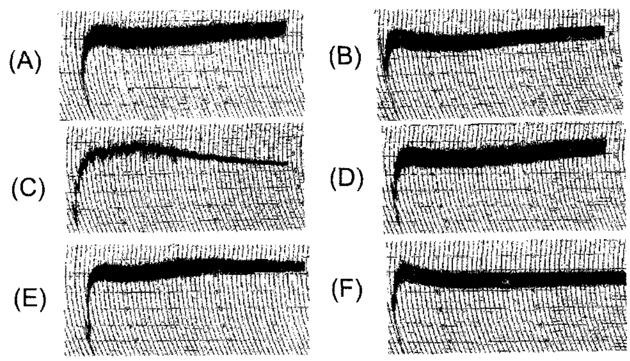

Fig. 1. Farinograms of RS-and NSP-supplemented wheat flour doughs (10%, fb). A, Control; B, Cellulose-supplemented; C, Pectin-supplemented; D, Chitosan- supplemented; E, RS3- supplemented; F, RS4- supplemented flour doughs.

Table 4. Farinograph data of RS- and NSP–supplemented wheat flour doughs

Sample conc.[1] (%, fb)	Water absorption (%)	Stability (min)	Development time (min)	Weakness (BU)	Valorimeter value (v/v)
Control	60.3	20	2.4	5	66
Cellulose-10	63.7	20	1.7	20	63
Chitosan-10	64.1	20	2.5	0	70
Pectin -10	80.6	9.4	8.0	110	71
RS3-10	65.4	20	2.5	5	68
RS4-10	63.5	20	2.0	40	56
Cellulose-5	62.0	20	2.7	0	70
Chitosan-5	62.6	20	2.6	20	62
Pectin-5	76.8	6.3	6.5	140	62
RS3-20	70.4	20	4.0	-40	78
RS4-20	65.7	4.8	1.9	60	53

[1]Percentage of TDF and RS added to flour was based on flour (14%, mb).

the RS3-supplemented wheat flour began to mix with water, the amorphous region of RS3 was hydrated first and gluten formation was delayed because protein hydration was slowed. Kim *et al.* (32) reported variation in the hydration rate of starch with different particle sizes, and also the hydration rate of dough influenced the dough development time. The dough stability time of all samples except those with added RS4 (20%) and pectin (5 and 10 %) was 20 min. The dough weakness of the control flour was 5 BU, and that of RS4-supplemented wheat flour increased to 40 BU when added to 10%, and to 60 BU when added to 20%. Pectin addition also increased the dough weakness from 5 BU to 110-140 BU and showed the highest value of all samples tested. With the addition of RS3, cellulose (5%), pectin and chitosan (10%), the valorimeter values increased relative to the control flour.

Pasting properties The pasting characteristics of the RS- and NSP-supplemented flours by amylograph are shown in Table 5. The initial pasting temperature of wheat flour and flour with cellulose (5%) was 59.5°C. The initial pasting temperatures of most samples increased with increasing DF addition, but that of chitosan-supplemented flour decreased slightly, and that of RS-supplemented flour did not change. The initial pasting temperature of pectin-supplemented flour was the highest among the samples tested. Im and Kim (34) reported that dietary fibers and minerals in green tea powder delayed the gelatinization of starch. The maximum viscosity of DF-supplemented flours except flour with added pectin (1170, 1470 BU) was lower than the control flour (800 BU) and decreased with increasing levels of DF. The reason that pectin-supplemented flour showed the highest viscosity might be because pectin is a soluble fiber and also increases the viscosity of the soluble starch fraction during heating.

The maximum viscosity temperature of flour with 5% cellulose (96°C) was the highest, followed in order by 10% chitosan (95.5°C), 5% pectin (95.1°C), and 10% RS3 (94.6°C). Except for the RS4-supplemented flour, the maximum viscosity temperature decreased with increasing levels.

Table 5. Amylograph data of RS- and NSP–supplemented wheat flours

Sample conc.[1] (%, fb)	Initial pasting temperature (°C)	Maximum viscosity temperature (°C)	Maximum viscosity (BU)
Control	59.5	91.8	800
Cellulose-10	61.0	91.8	580
Chitosan-10	61.0	91.9	310
Pectin-10	62.9	90.5	1492
RS3-10	61.8	94.6	660
RS4-10	61.0	92.5	660
Cellulose-5	59.5	96.0	720
Chitosan-5	61.8	95.5	720
Pectin-5	62.5	95.1	1170
RS3-20	61.0	91.0	490
RS4-20	61.0	93.0	580

[1]Percentage of TDF and RS added to flour was based on flour (14%, mb).

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