Properties · Functions · Benefits

Fibersym® RW

Resistant Wheat Starch

Superior Dietary Fiber Source

MGP®

CREATING BETTER SOLUTIONS...NATURALLY

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About MGP

Founded in 1941, in Atchison, Kansas, MGP has been serving the food industry for nearly seven decades. Through the years, we have pioneered the development of specialty proteins and starches derived principally from wheat, resulting in a wide range of superior ingredient solutions for a host of product applications. These solutions provide a multitude of functions and benefits for bakery and prepared foods, including processing improvements, moisture management, shelf-life extension, fiber enrichment, fat reduction and texture enhancement.

MGP's applications scientists work closely with our sales team to provide technical support to customers by addressing specific needs and/or helping define the value and performance of our ingredients for targeted uses. They are available to work directly with customers at their facilities or at our fully equipped, state-of-the-art Technical Innovation Center to assist in the development of product formulations. Meanwhile, our research scientists direct their expertise and resources toward the development and refinement of new and innovative ingredients for the future.

In short, we recognize that our customers want a reliable partner who can effectively support their objectives and boost product success. With our specialty ingredient solutions, decades of experience and technical know-how, we at MGP are equipped to meet customers' needs.

OUR MISSION

"To provide our customers with superior valued-added ingredients derived from natural sources."

About Fibersym® RW

Fibersym® RW Resistant Wheat Starch is ideal for incorporation in foods that emphasize benefits related to health and wellness. This RS4 starch is a convenient and rich source of dietary fiber that can be formulated in a wide array of foods with minimal processing adjustments. Possessing a clean flavor, smooth texture and white appearance, in combination with its low water-holding properties, Fibersym® RW allows formulators to boost the fiber content of a diverse line of products. These applications include bread, pizza crust, flour tortillas, pasta and noodles, cookies, muffins, breakfast cereals, pastries and bakery mixes. This superb ingredient acts as a prebiotic and can reduce the caloric content of foods while providing a high source of dietary fiber.

The Concept of Resistant Starch

During consumption of food containing starch, partial digestion of starch occurs in the mouth during mastication through the action of salivary alpha-amylase. When the food reaches the stomach, it gets mashed by the churning action of this organ and pepsin starts digesting the protein component of the food. The high acidity in the stomach deactivates the salivary alpha-amylase. Thus, no enzymatic starch digestion happens in the stomach. The mashed food travels next to the small intestine where pancreatic enzymes and bile act on the food. Final digestion occurs in the brush border of the small intestinal epithelium, resulting in absorption of glucose, amino acids and fatty acids into the blood stream. The presence of glucose in the blood triggers the pancreas to produce the hormone insulin, which helps transport glucose to the different cells of the body to serve as a source of energy. Remnants of undigested foods (mainly fibers) flow into the large intestine where they undergo microbial fermentation into gases and short-chain fatty acids.

In 1982, while working on a testing methodology to quantify the content of non-starch polysaccharides (dietary fiber components) of foods by enzyme digestion, British scientists discovered that the "fiber residue" of bread and cooked and cooled potatoes contains enzyme-resistant starch. This is surprising since starch is widely known to be a completely digestible carbohydrate as noted above. This resistance to digestion was confirmed in humans when researchers recovered undigested starch in the effluents of ileostomy patients. (Note: An ileostomy is a surgical procedure in which the ileum of the small intestine is attached to the abdominal wall in order to bypass the large intestine. Digestive waste then exits the body through an artificial opening.) With the discovery that a small, but variable portion of dietary starch is resistant to hydrolysis by the digestive enzymes, the word "resistant starch" was coined.

A decade after resistant starch became firmly ingrained in the vernacular of food, nutrition and health professionals, the official definition for resistant starch was developed, which states that it is "the sum of starch and products of starch degradation not absorbed in the small intestines of healthy individuals". Resistant starch is included in the definition of dietary fiber, and is considered a third kind of fiber in addition to insoluble fiber and soluble fiber.

Not all resistant starches are the same. In fact, they are classified into five types. Type 1 or RS1 occurs in whole grains or incompletely- or coarsely-milled cereal grains, seeds and legumes. Examples are cracked wheat, farina, semolina, red beans, pinto beans and white beans. The starch granules are encapsulated within a cell wall so that the digestive enzymes are prevented or delayed from having access to them. The gastrointestinal tract of humans lacks enzymes capable of degrading the components of cell walls in order to expose the physically-shielded starch granules. The amount of RS1 is affected by processing and can actually be decreased or eliminated by complete disintegration or fine milling. Flours and meals from high-amylose corn and flours from high-amylose barley are commercially available for use as resistant starch sources in food product development.

Examples of type 2 or RS2 are starch granules from raw potato, unripe or green bananas, and high-amylose corn. Their starch granules are resistant to enzymatic digestion by virtue of their inherent crystalline structure. Like RS1, the amount of RS2 can be affected by processing. Raw potato and raw banana starch lose resistance to enzyme digestion upon cooking. High-amylose corn starch with varying levels of RS2 resistant starch contents are currently sold in the market.

Recrystallized amylose or retrograded amylose represent resistant starch belonging to type 3 or RS3. Retrogradation is a time- and temperature-dependent process after starch has been cooked or gelatinized. RS3 can also be formed during heat-moisture treatment or annealing of starch granules. The intimate association of amylose results in the formation of water-insoluble semi-crystalline structures, thereby preventing the enzyme from digesting them. This type of resistant starch can be generated in processed foods as in cooked and cooled potato, and cooked and cooled rice, as well as in bread and corn flakes. RS3 products based on tapioca starch, normal corn starch, and high-amylose corn starch are commercially available.

Type 4 or RS4 occurs in chemically modified starch. All forms of chemically modified starch have varying degrees of resistance to enzyme digestion. Some of MGP's modified wheat starch products like Midsol™ 1, Midsol™ 46 or Pregel™ 40 offer some resistance to digestion, but the magnitude of resistance is low and they offer no commercial value as a significant source of resistant starch. One form of modification that is accomplished by cross-linking starch with sodium trimetaphosphate in the presence of small amounts of sodium tripolyphosphate imparts the highest level of resistance to enzyme digestion. Two products made by such a process are MGP's Fibersym® RW and FiberRite® RW. Due to the high degree of cross-linking, these two starches have limited swelling when heated and their tight structure coupled with steric effect inhibit enzymatic digestion. Through MGP's sublicensing agreements, other RS4 commercial products are available such as those made from tapioca starch that has been modified using the same technology as Fibersym® RW.

The fifth type, or RS5, was recently introduced as a new type of resistant starch. A starch-lipid or amylose-lipid complex forms when starchy foods are heated or cooked in the presence of fats or lipids. This durable complex offers resistance to enzymatic digestion based on steric hindrance by the complex. Currently, there is no commercially-manufactured RS5 resistant starch available in the market.

Physical Properties of Fibersym® RW

The production of Fibersym® RW, a food grade cook-up resistant starch, involves the treatment of wheat starch with sodium trimetaphosphate (a cross-linking agent) and sodium tripolyphosphate (a substituting agent). This process yields a highly cross-linked wheat starch containing small levels of substituents. The levels of chemicals used during the reaction and the residues in the final product (no more than 0.4% phosphorus) comply with Title 21 of the Code of Federal Regulations Part 172.892. The chemical name for Fibersym® RW is phosphated distarch phosphate. Its Chemical Abstract Service (CAS) Number is 977043-58-5 and the E-number is 1413.

Fibersym® RW delivers a minimum total dietary fiber of 85% (dry basis) using the AOAC Method 991.43. The fiber exists primarily as insoluble fiber.

A cross-linked RS4 resistant wheat starch was reported by Kansas State University (Manhattan, KS) scientists to contain 93.4% total dietary fiber and 0.38% phosphorus. The RS4 product is identical to the parent native wheat starch granules in appearance as viewed by scanning electron microscopy and gives the same A-type x-ray diffraction pattern. When heated at 8% starch concentration from 30ºC to 95ºC in a cooking viscometer like an amylograph, no pasting curve was observed. The cross-linking bonds restrict the swelling of the starch granules and impart increasing resistance to alpha-amylase digestion as phosphorus incorporation increases. When analyzed by differential scanning calorimetry, it showed elevated initial, peak, and conclusion temperatures (4.3ºC to 10.5ºC higher) versus the parent native wheat starch, and a slight reduction in enthalphy of gelatinization (0.9 J/g lower).

A cross-linked RS4 resistant wheat starch with 72.9% total dietary fiber exhibited a low swelling power of 2.8 g/g at 95ºC and a solubility at 95ºC of 0.5% as reported by Kansas State University researchers. Compared to other cereal starches, it showed similar water vapor sorption and desorption isotherms at 25ºC and at water activities below 0.8.

Upon heating starting at 35ºC, scientists at the University of Nebraska (Lincoln, NE) found that the granular structure of Fibersym® RW remained essentially unchanged up to 60ºC. Above 65ºC, the granules became increasingly swollen, and at 75ºC, the granules lost their original morphology. The enthalpies of gelatinization were unchanged from 35ºC to 60ºC and gradually disappeared between 60ºC to 85ºC, indicating the disruption of intermolecular interactions by heat. This phenomenon coincided with the gradual decrease in crystallinity and the conversion of the A-type x-ray diffraction profiles into increasingly amorphous forms within the same temperature range. It also coincided with the gradual disappearance of the endothermic peak.

Physiological Benefits of Fibersym® RW

Dietary fibers promote a number of physiological benefits, including the following: decrease intestinal transit time; fermentable by colonic bacteria, reduced blood total and/or LDL cholesterol; and reduced post-prandial blood glucose and/or insulin. All of these benefits can decrease the risk of lifestyle diseases such as obesity, diabetes, hypertension, cardiovascular disease and cancer. Resistant starch, which is included in the definition of dietary fiber, demonstrates similar physiological benefits.

Blood Glucose and Insulin Regulation

In a study conducted in a Canadian Laboratory, human subjects were fed 142 grams of control and test muffins after an overnight fast. The test muffins were formulated with 32% Fibersym® RW and the control muffins contained 32% native wheat starch. Dietary fiber intake by the subjects was 25 grams and 2 grams, respectively. **Post-prandial blood glucose was lower and insulin was significantly**

reduced in the Fibersym® RW muffins compared to the control muffins. It was also observed that insulin rose more gradually for the Fibersym® RW muffins than the control muffins, indicating that Fibersym® RW was slowly absorbed. Different types of resistant starch elicit significantly different glycemic responses as evident when RS2-type resistant high amylose corn starch was compared with Fibersym® RW, an RS4-type resistant wheat starch. This study was conducted at Kansas State University, where eleven healthy subjects were recruited and asked to consume on three separate occasions 30g of either dextrose, RS2 starch or Fibersym® RW. Blood glucose was measured before and over the following two hours. The glucose response (Figure 1a) and the incremental area under the curve (Figure 1b) of Fibersym® RW ($RS4_{XL}$) were significantly decreased compared with RS2 starch and dextrose (DEX).

In another collaborative study with Kansas State University, nutritional bars formulated with 34% Fibersym® RW demonstrated decreased postprandial blood glucose levels in healthy older adults compared to a glucose beverage and a nutritional bar formulated with puffed wheat. The data revealed that the puffed wheat bar and Fibersym® RW bar had Glycemic Index (GI) values of 53 and 36, respectively. It is likely that the Fibersym® RW bar was digested over a longer period of time, leading to more steady blood glucose levels.

A follow-up study was conducted using healthy younger adults as subjects. Using the standard glycemic index protocol, the study involved 13 healthy, younger adults who were fed two nutritional bars, as well as a control glucose drink, after a 12-hour overnight fast. Puffed wheat (PWB) was formulated in a nutritional bar and Fibersym® RW ($RS4_{XL}$) was incorporated in a second nutritional bar by totally replacing puffed wheat in the formula (Table 1). All the other ingredients were kept identical.

FIGURE 1: The glucose responses to 30 g of carbohydrate from three treatments (DEX, RS2 and $RS4_{XL}$). Panel (a) depicts the glucose changes over time, while panel (b) depicts the incremental area under the glucose curve. Data presented are mean ± SE; significance was set at $P < .05$; and, different letter indicate difference between treatments.

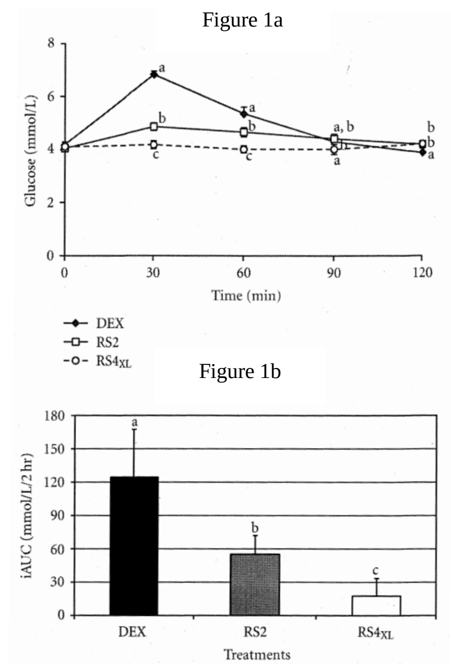

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TABLE 1: Ingredients and their concentrations by relative weight (% total) in the test bars.

	PWB	$RS4_{XL}$
Puffed Wheat[a]	34	—
Resistant Starch type 4[b]	—	34
Corn Syrup[c]	20	20
Wheat Germ[d]	18	18
Brown Sugar[e]	11	11
Water[f]	10	10
Gum Acacia[g]	6	6
Panodan 150K[h]	1	1

[a] Quaker Oats
[b] Fibersym RW; MGP Ingredients, Inc.
[c] Karo light corn syrup
[d] Kretschmer Original Toasted
[e] C&H Pure Cane Sugar, golden brown
[f] Tap water (Manhattan, Kan)
[g] TIC Gums
[h] Danisco

Reproduced with permission from *Al-Tamimi, E.K., Seib, P.A., Snyder, B.S., and Haub, M.D. 2010. Consumption of cross-linked resistant starch (RS4XL) on glucose and insulin responses in humans. J. Nutr. Metab. 2010: Article ID 651063.*

The two bar samples and the glucose (GLU) drink each delivered around 50 grams of available carbohydrates (Table 2).

TABLE 2: Nutrient composition of each treatment per dose (GLU = 198 mL; PWB = 65 g; RS4 = 80 g).

	GLU[a]	PWB[b]	$RS4^{b}_{XL}$	Δ[e]
Total Energy (kcal)	200	261	326	(65 kcal, 125%)
Carbohydrate (g)				
Total	50	56	71	(15 g, 127%)
Available[c]	50	51	51	(0 g, 0%)
Total Dietary Fiber (g)[d]	—	5	20	(15 g, 400%)
Fat (g)	—	1	2	(1 g, 200%)
Protein (g)	—	7	6	(1 g, 86%)

[a] glucose tolerance test beverage (Sun-Dex, Fisher Scientific, Houston, Tex)
[b] Crude nutrient composition was determined by proximate analysis (total energy, total fat, total protein, total carbohydrate).
[c] derived by subtracting total dietary fiber from total carbohydrate.
[d] dietary fiber analysis was performed by Medallion Laboratory (Minneapolis, Minn).
[e] difference (subtraction value, % value) between bars.

Source: *Al-Tamimi et al 2010.* Used with permission.

Blood glucose and insulin levels were monitored over a 2-hour period after the samples were consumed.

Figure 2 displays the blood glucose and insulin responses as affected by each treatment. Both peak and incremental areas under the curve for glucose and insulin were significantly lower following ingestion of the bar containing Fibersym® RW compared to the puffed wheat bar and control glucose drink (Table 3).

A very noteworthy outcome of the study was that Fibersym® RW significantly attenuated the glycemic and insulinemic responses even when high glycemic ingredients such as brown sugar and corn syrup represented 31% of the nutritional bar formula.

These results also demonstrated that consumers may not need to avoid foods containing corn syrup or sugar for the purpose of regulating their blood glucose and/or insulin levels as long as the food is formulated with Fibersym® RW. Both corn syrup and sugar are in the national limelight, being critically targeted for potentially contributing to the obesity and diabetes epidemic. **These results demonstrate that Fibersym® RW could be an important ingredient in foods for helping prevent type 2 diabetes and other health issues related to glucose regulation.**

FIGURE 2: Depiction of the glucose (a) and insulin (b) responses over two hours following the consumption of each (Glu, PWB, and RS4) treatment. Values represent each mean ± SE. A; significant difference with PWB; B: significant difference with RS4.

Figure 2a

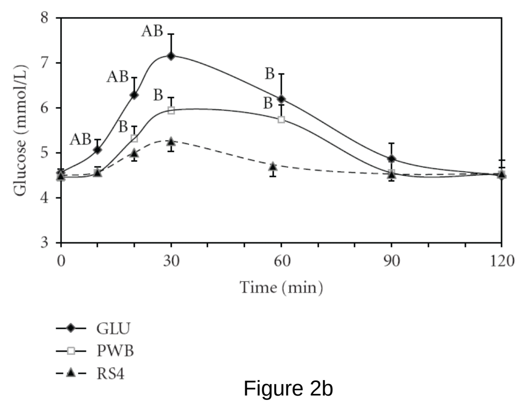

Figure 2b

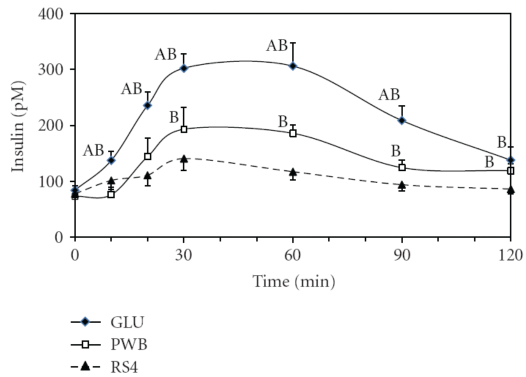

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Table 3: Values for the incremental areas under the curves of glucose and insulin concentrations during each trial. Mean ± SE; different letters within a row indicates significant difference ($P < .05$).

	GLUC	PWB	$RS4_{XL}$
Glucose			
iAUC (mmol/L · 2 hr)	140 ± 31^{A}	84 ± 17^{B}	28 ± 11^{C}
Peak (mmol/L)	7.30 ± 0.5^{A}	6.33 ± 0.3^{B}	5.40 ± 0.2^{C}
Increase (%)	60.5 ± 10^{A}	42.7 ± 6^{A}	20.4 ± 3^{B}
Insulin			
iAUC (mmol/L · 2 hr)	$17{,}575 \pm 2{,}236^{A}$	$8{,}758 \pm 1{,}132^{B}$	$3{,}659 \pm 974^{C}$
Peak (pM)	344 ± 36.7^{A}	211.5 ± 20.1^{B}	162.3 ± 22.6^{C}
Increase (%)	335 ± 53.2^{A}	243.0 ± 49.3^{B}	126.3 ± 45.8^{C}

Source: *Al- Tamimi et al 2010.* Used with permission.

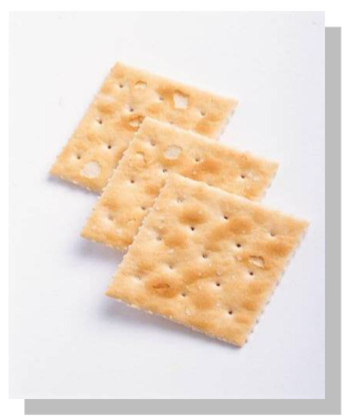
Impact on Gastrointestinal Health

Physical activity, portion control and wholesome foods define a person's healthy lifestyle. While the first two items are behavioral in nature, the third one can be designed in most foods. Food developers have previously associated the end-use quality of foods from the moment of growing the crop to the time the processed food is served and consumed – the so-called "From Farm to the Table" pathway. Recently, with health and wellness resonating well with consumers, this connection is being transformed into a "From Farm to Fitness" pathway.

The lower gut or gastrointestinal tract (commonly called the large bowel or colon) was originally thought to be an organ in the human body for processing waste (undigested residues) after food is consumed. There was limited awareness that human health may lie in the gut as researchers have recently uncovered.

The human gut harbors extremely dense and highly diverse microbial communities called microbiota consisting of over 500 different bacterial species whose cell numbers exceed 100 billion per gram. The gut is a complex microbial ecosystem as it is a nutrient-rich, open system with a constant temperature and continuous turnover. For survival, these obligate anaerobic microorganisms have to reproduce at a rate sufficient to avoid washout or have an ability to attach to or colonize host tissues. The makeup of microorganisms inhabiting an individual's gastrointestinal tract represents a fingerprint, which differentiates him or her from another individual. The bacteria that colonize the large intestine have access only to the dietary residue that evades digestion by host enzymes in the upper gut or small intestine.

Microorganisms in the lower gut can help with digestion, stimulate cell growth, strengthen the immune system, break down toxins and/or protect against some diseases. In particular, bifidobacteria are considered health-promoting microorganisms as they demonstrate anti-tumor activity and have demonstrated prophylactic and therapeutic benefits for colon cancer and chronic inflammation in animals. In addition, bifidobacteria have been shown to be associated with benefits in glucose tolerance, insulin response and cholesterol metabolism in animals. Other microorganisms, however, function differently as they may contribute to Western lifestyle diseases such as obesity, type 2 diabetes, coronary heart disease, inflammatory bowel disease or cancer. The



key to good health is promoting the proliferation of beneficial microorganisms and reducing the unfriendly ones.

Recently, consumers have been exposed to food products that are infused with a cocktail of friendly bacteria (called probiotics) such as yogurts, smoothies, snack bars, cereal products and even pills. These products are touted to regulate digestive health. Understanding the role of gut microorganisms helps consumers adjust their eating practices and assists food scientists in designing or tailoring foods that can address health concerns.

There is prevailing evidence that the microbiota responds to changes in the diet, in particular to the type and quantity of dietary carbohydrates. Resistant starches escape digestion and absorption in the human small intestine and reach the large bowel where they serve as substrate for fermentation by the large bacterial populations residing there. Scientists have discovered that fermentation of resistant starch in the colon has beneficial health effects to the host.

Through collaboration with the University of Nebraska a project was initiated to determine the impact of MGP's resistant wheat starch, Fibersym® RW, on gut microbiota composition and metabolism. The aims of the study were to determine if resistant starch shows prebiotic properties *in vivo* and to gauge the impact on gastrointestinal microbial composition and metabolism. A prebiotic is defined as a non-viable food component, ingredient or supplement that selectively modulates the microbiota of the digestive ecosystem, and confers benefits upon the host's well-being and health. The feeding study characterized the effect of resistant starch on the composition and metabolism of gut microbiota in human subjects using modern, culture-independent molecular techniques and analytical methods such as polymerase chain reaction and denaturing gradient gel electrophoresis.

Ten healthy, non-vegetarian human subjects (5 males and 5 females) between 23-38 years of age were recruited for the study. None of the subjects had been on antibiotics within 3 months prior to the beginning of the study or during the study. The study was conducted over a 17-week period during which the subjects maintained their usual lifestyles while consuming as a supplement snack crackers formulated with Fibersym® RW, RS2 high-amylose corn starch, or native wheat starch (control). The snack crackers were prepared by the American Institute of Baking International in Manhattan, Kansas.

The results of the study were presented at the 2009 IFT Annual Meeting. Both types of resistant starch were well tolerated by the subjects at a dose of 33 grams of fiber per day for three weeks. The population or cell count of bifidobacteria was significantly higher when Fibersym® RW and RS2 high-amylose corn starch crackers were consumed as compared to bifidobacterial population during consumption of the control crackers. On average, Fibersym RW crackers increased the amount of bifidobacteria by 350%, while RS2 high-amylose corn starch crackers increased bifidobacterial counts by 210%. The specie of bifidobacteria that increased in population was identified to be *Bifidobacterium adolescentis,* a friendly, non-pathogenic organism that resides in the gut of healthy humans. This microorganism has been reported in the literature to synthesize various B vitamins that are beneficial to the nutritional health of humans. As a producer of the vitamin folate in the colon, *Bifidobacterium adolescentis* protects the colon against inflammation and cancer. It is also capable of metabolizing carbohydrates that is later converted by other microbes to short-chain fatty acids such as acetate, propionate and butyrate to be used as energy sources.

Fibersym® RW has a remarkable advantage over RS2 high-amylose corn starch. It took 2-3 weeks of consuming RS2 high-amylose corn starch crackers

before the increase in cell counts of *Bifidobacterium adolescentis* became obvious, while Fibersym® RW crackers showed a marked response within the first week of ingestion. Thus, the positive effect occurs faster for Fibersym® RW compared to RS2 high-amylose corn starch. A follow-up feeding study confirmed that administration of Fibersym® RW crackers resulted in a significant population increase of *Bifidobacterium adolescentis* within 2-4 days after consuming the crackers.

This study provided evidence that both Fibersym® RW and RS2 high-amylose corn starch show bifidogenic potential. **Fibersym® RW had a higher bifidogenic effect and the increase in bifidobacterial numbers was more immediate.**

Further experimentation on Fibersym® RW showed that phylum-level changes resulted in a significant increase in Actinobacteria (e.g. bifidobacteria) and Bacteroidetes, while decreasing the level of Firmicutes (Table 4). **A low Firmicutes/Bacteroidetes ratio has been shown in the literature to be associated with lean human subjects, which is linked to decreased capacity for energy harvest as it relates to weight loss**. Bifidobacteria are known to be strongly correlated with immunological and metabolic improvements of Type 2 diabetes and high blood cholesterol levels in animal models. Furthermore, Fibersym® RW reduced the level of Erysipelotrichaceae (Table 4), a bacterial family that includes members that have been shown in the literature to be positively associated with an increase in liver fat in women. At the species level, Fibersym® RW increased the populations of *Bifidobacterium adolescentis* as stated earlier and also *Parabacteroides distasonis* (Figure 3).

TABLE 4: Abundance of bacterial taxa that were impacted by resistant starch consumption in fecal samples of ten human subjects as determined by pyrosequencing of 16S RNA tags. RS2 is RS2 high-amylose maize starch; RS4 is Fibersym® RW; Control is native wheat starch.

Proportion of bacterial taxa expressed in percentage (Mean ± SD)

	RS2[1]	RS4[1]	Control[1]	Baseline[2]	Washout[3]	P-value[4]
Phylum						
Firmicutes	**75.9±13.4**	*65.6±15.0*	**79.6±9.6**	78.2±7.5	78.1±8.5	0.0010
Bacteroidetes	*10.1±6.6*	**16.3±9.7**	*10.4±6.9*	12.7±6.5	12.2±5.8	0.0028
Actinobacteria	6.1±6.4	**11.4±12.5**	*4.1±3.1*	3.1±2.5	4.1±3.2	0.0334
Family						
Bifidobacteriaceae	5.8±6.0	**11.1±11.7**	*3.0±2.5*	2.1±1.7	2.8±2.2	0.0262
Porphyromonadaceae	*0.6±1.0*	**3.4±1.9**	*0.5±0.3*	0.6±0.4	0.5±0.4	0.0002
Ruminococcaceae	**24.8±13.6**	*16.7±7.4*	**23.2±9.7**	19.3±7.4	20.7±7.6	0.0031
Erysipelotrichaceae	3.1±2.8	*2.6±2.6*	**3.9±3.2**	4.7±4.9	3.9±3.1	0.0279
Genus						
Faecalibacterium	9.7±4.4	*7.8±3.4*	**10.8±4.7**	8.4±4.2	8.8±2.9	0.0336
Parabacteroides	*0.6±1.0*	**3.4±1.9**	*0.4±0.5*	0.5±0.3	0.5±0.4	0.0002
Bifidobacterium	4.5±4.9	**8.9±10.2**	*2.2±1.7*	1.5±1.3	2.1±1.6	0.0342
Dorea	*1.7±1.2*	*1.6±1.2*	**3.0±2.0**	2.9±2.2	2.7±2.0	0.0030
Species (OTUs)						
B. adolescentis	3.7±4.5	**7.9±10.3**	*1.7±1.9*	1.5±1.2	1.8±1.3	0.0347
P. distasonis	*0.2±0.4*	**1.5±1.0**	*0.2±0.1*	0.2±0.1	0.2±0.2	0.0002
R. bromii	**4.1±5.1**	*1.2±1.3*	2.6±3.2	1.0±1.1	2.0±1.5	0.0479
F. prausnitzii	4.8±2.6	*3.6±2.0*	**5.6±3.1**	4.2±2.8	4.2±2.4	0.0160
E. rectale	**8.3±7.1**	*3.4±2.3*	4.9±4.0	5.4±2.9	4.7±2.0	0.0301
D. formicigenerans	1.2±1.0	*1.0±1.1*	**2.2±1.6**	2.3±1.8	1.9±1.7	0.0140
C. clostridioforme	2.6±2.4	**3.4±2.5**	*1.2±0.8*	1.4±1.3	1.5±1.2	0.0126
Clostridiales spp.	*0.3±0.6*	**0.9±0.9**	0.7±0.8	0.2±0.4	0.8±0.7	0.0322

[1]The bacteria populations are averages of all three time points of feeding periods.
[2]The bacteria populations are averages of the two time points of the baseline period.
[3]The bacteria populations are averages of all the six time points of the three washout periods.
[4]Bacterial populations during the dietary treatments were compared to each other with repeated measures ANOVA and Tukey's post hoc test. Numbers in bold represent proportions that were significantly higher than numbers shown in italic.

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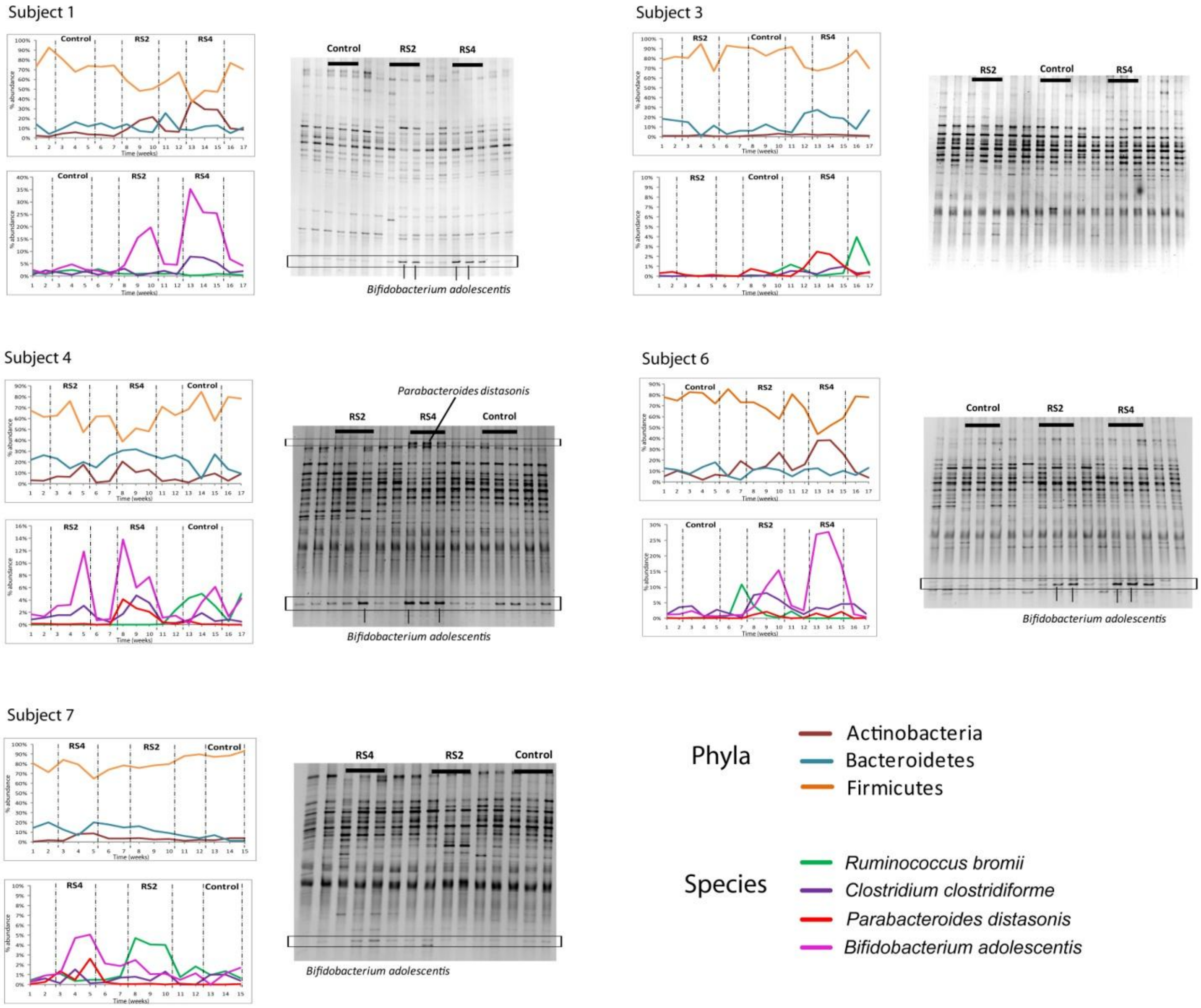
Weekly symptom diaries documented by the subjects revealed no significant detrimental effects on bowel movement, stool consistency, or discomfort, but a moderate increase in flatulence was observed (Table 5). This indicates that Fibersym® RW at doses of 33 grams per day is well tolerated by human subjects.

FIGURE 3: Temporal dynamics of the human fecal microbiota in response to the consumption of crackers containing native (control) and resistant starches in five human subjects. RS2 is RS2 high-amylose maize starch; RS4 is Fibersym® RW; Control is native wheat starch.



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In an animal feeding trial using hamsters conducted at Kansas State University, a diet formulated with resistant wheat starch was compared with a cellulose diet. Both diets contained 10% total dietary fiber. Animals on a resistant wheat starch diet consumed less feed and gained less weight than those on the cellulose diet. While total serum cholesterol was not significantly different between the two diets, the HDL cholesterol ("good" cholesterol) was significantly higher in the resistant wheat starch diet. The calculated LDL cholesterol ("bad" cholesterol) and VLDL cholesterol were lower in the serum of animals consuming the resistant wheat starch diet than the cellulose diet. Analysis of the cecum of hamsters for fermentation products showed elevated levels of total short chain fatty acids in the resistant wheat starch diet compared to the cellulose diet. In particular, butyric acid, which is protective against colon cancer, was produced in significantly higher quantities in the resistant wheat starch diet.

TABLE 5: Mean ± standard deviations of weekly symptoms reported by the subjects in a scale from 1 (best) to 5 (worse). RS2 is RS2 high-amylose maize starch; RS4 is Fibersym® RW; Control is native wheat starch.

	RS2	RS4	Control	None
Bowel movement	1.73 ± 0.83	1.90 ± 0.93	1.73 ± 0.77	1.74 ± 0.59
Stool consistency	2.07 ± 1.29	2.23 ± 0.92	2.03 ± 0.91	2.00 ± 0.83
Discomfort	1.65 ± 0.65	1.87 ± 0.79	1.50 ± 0.55	1.53 ± 0.40
Flatulence*	2.42 ± 1.28	2.27 ± 1.00	1.37 ± 0.58	1.54 ± 0.43
Abdominal pain	1.63 ± 0.79	1.47 ± 0.67	1.40 ± 0.60	1.36 ± 0.62
Bloating	1.67 ± 0.98	1.40 ± 0.52	1.07 ± 0.14	1.29 ± 0.45

* Significant differences were detected by ANOVA ($P < 0.05$). Tukey's post-hoc test did not detect significance in pair-wise comparisons.

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The butyrogenic effect of MGP's Fibersym® RW can be easily demonstrated in in vitro fermentation rather than in vivo technique, as butyric acid is absorbed by the epithelial cells in the colon. In a study conducted at the University of Toronto, Fibersym® RW was gelatinized and then digested *in vitro* by pepsin (to simulate stomach digestion) and pancreatin-bile (to simulate small intestinal digestion and absorption). The indigestible residues were subsequently fermented by inoculating with fresh human fecal microbiota (to simulate large bowel fermentation). The results demonstrate that 82% of Fibersym® RW was recovered as indigestible residues, which upon fermentation produced gas that increased linearly over the 24-hour fermentation period (Table 6) and short chain fatty acids that increased during the 24-hour period, but tended to level off after 8 hours (Table7).

Acetate was the major short chain fatty acid followed by butyrate and propionate, with a corresponding molar ratio of 59:23:19. These short chain fatty acids have been known to be the major energy source of colon cells, and tend to lower colonic pH, allowing the favorable growth of beneficial microorganisms. In particular, the increase in butyrate, which is the preferred substrate by colon cells, may be protective against colon cancer as it is known to decrease cell proliferation and increase apoptosis (programmed cell death) and cell differentiation.

TABLE 6: Cumulative total gas production (ml/g of starch) at various times upon fermentation of indigestible residues obtained from Fibersym® RW.

	Fermentation Time (hr)			
Sample	4	8	12	24
Fibersym® RW	78.0 ± 0a	118.5 ± 5.8b	153.3 ± 5.8c	214.2 ± 2.8d

Adapted with permission from *Thompson, L.U., Maningat, C.C., Woo, K., and Seib, P.A. 2011. In vitro digestion of RS4-type resistant wheat and potato starches, and fermentation of indigestible fractions. Cereal Chem. 88:72-79.*

TABLE 7: Cumulative short chain fatty acid (SCFA) production (mmol/g of starch) at various times of indigestible residues obtained from Fibersym® RW[a].

	Fermentation Times (hr)			
SCFA[b,c]	4	8	12	24
Fibersym® RW				
C1	0.50 ± 1.08ab	0.69 ± 0.10ab	0.76 ± 0.15a	0.00 ± 0.00b
C2	1.85 ± 0.35a	2.87 ± 0.27ab	3.44 ± 0.03ab	3.85 ± 0.21b
C3	0.39 ± 0.02a	1.05 ± 0.03b	1.10 ± 0.04b	1.22 ± 0.04b
iC4	0.01 ± 0.01a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
C4	0.40 ± 0.10a	0.93 ± 0.08b	1.32 ± 0.00bc	1.50 ± 0.05c
iC5	0.04 ± 0.03a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
C5	0.05 ± 0.03a	0.04 ± 0.00a	0.04 ± 0.01a	0.01 ± 0.01a
Total	3.25 ± 0.60a	5.58 ± 0.48ab	6.66 ± 0.21b	6.58 ± 0.30b

[a] Mean ± SEM; Mean values (± SEM) in the same row followed by different letters are significantly different ($P < 0.05$).

[b] SCFA, short chain fatty acids; C1, formic acid; C2, acetic acid; C3, propionic acid; iC4, isobutyric acid; C4, butyric acid; iC5, isovaleric acid; C5, valeric acid.

[c] Fractional molar ratio of C2:C3:C4 at 24 hr for Fibersym® RW = 0.586:0.186:0.228.

Adapted with permission from *Thompson, L.U., Maningat, C.C., Woo, K., and Seib, P.A. 2011. In vitro digestion of RS4-type resistant wheat and potato starches, and fermentation of indigestible fractions. Cereal Chem. 88:72-79.*

This study also indicated that the calculated caloric contribution of Fibersym® RW was one-third lower than unmodified starch, illustrating its applicability in reduced-calorie food formulations. Microscopic examination of the indigestible residues revealed that the pattern of enzyme digestion is by surface erosion (Figure 4). This pattern of enzyme attack concurs with that observed with the indigestible residues recovered after performing AOAC Method 991.43 on Fibersym® RW (Figure 5).

Short-Chain Fatty Acids

Acetic Acid	CH_3COOH
Propionic Acid	CH_3CH_2COOH
Butyric Acid	$CH_3CH_2CH_2COOH$

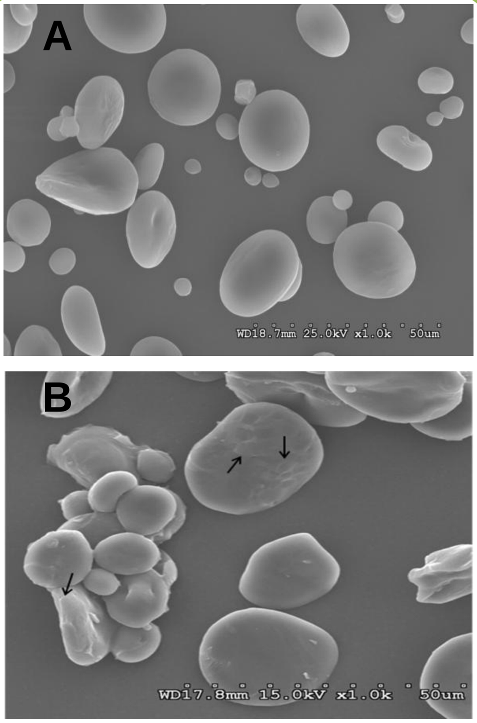

FIGURE 4 (Right): Scanning electron micrographs of Fibersym® RW (A) and indigestible residues after cooking in water (boiling water bath) followed by in vitro digestion with pepsin and pancreatin-bile (B). Arrows indicate areas with surface erosion or pieces peeling off.

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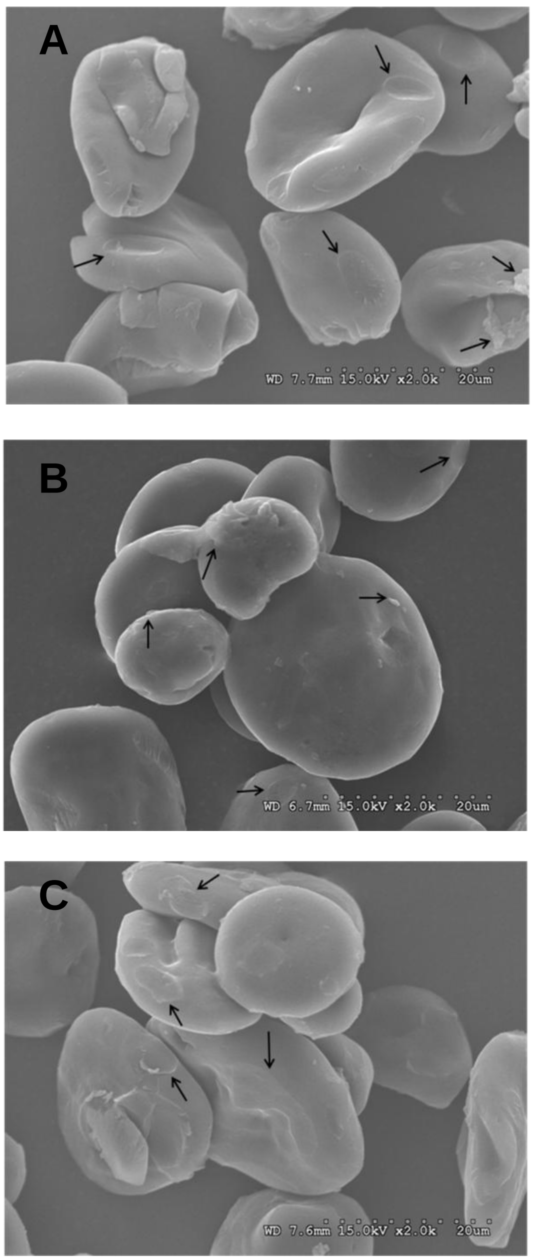
FIGURE 5 (Below): Appearance of Fibersym® RW after hydrolysis with alpha-amylase (A); after hydrolysis with alpha-amylase and protease (B); and after hydrolysis with alpha-amylase, protease, and glucoamylase (C) according to total dietary fiber determination by AOAC Method 991.43. Arrows indicate areas with surface erosion or pieces peeling off.



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Role in Weight Management

One of the most visible, but challenging, medical conditions to treat is obesity, which is defined as a body mass index exceeding 30. Body mass index, or BMI, is a rough estimate of a healthy body weight based on the height of an adult individual. It is calculated by dividing a person's weight in kilograms by the square of his or her height in meters. A BMI of 18.5-24.9 is considered normal weight, a range of 25-29.9 is considered overweight, and less than 18.5 is underweight. It is estimated that an average American male has gained 17.1 pounds since 1998, while the average female has gained 15.4 pounds.

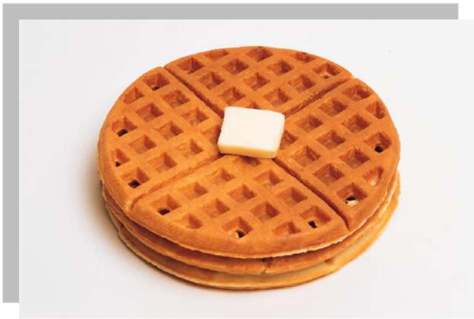
The statistics on obesity are disturbing. Two-thirds of adult Americans are considered either obese or overweight. Among American youth, the percentage of obese or overweight is around 30%. In a recent CNN report, overweight children have been labeled "coronary time bombs," as they are likely to develop heart disease when they grow into adulthood.

The prevalence of obesity in the U.S. was documented in a recent report by Trust for America's Health and the Robert Wood Johnson Foundation. Mississippi topped the list as the most obese state in the nation, while Colorado is the least obese state. Leading medical experts rated Mississippi to also have the worst record of diabetes and heart disease nationwide.

In 2008, obese persons in the U.S. who are 30 or more pounds over a healthy weight cost the country $147 billion in weight-related bills. In 2018, more than 40% of adults will be obese and spending for this weight problem will balloon to $344 billion according to a study at Emory University, Atlanta. The high price tag is simply because obesity is not a singular medical condition. Being overweight or obese is also associated with Type 2 diabetes, heart disease, high cholesterol, hypertension, osteoarthritis, stroke, sleep apnea, asthma, cancer, and kidney and gall bladder disease. Obesity is responsible for about 100,000 cancer cases each year. Such alarming information about obesity and its toll on the human body has led to myriads of studies to deter its occurrence.

How is fiber or resistant starch related to weight management? Evidence exists based on food consumption data and clinical studies regarding the inverse relationship between fiber and obesity. Those who ingested the most dietary fiber had lower mean energy intakes and lower BMI values, while those ingesting the least fiber tended to be the most obese.

Body weight is a reflection of the balance between two variables: the calories a body takes in and the calories it burns off. It is proposed that fiber acts as a physiological obstacle to energy intake by several mechanisms, which helps explain the role of fiber in weight management. Diets with adequate fiber are generally less energy dense (low caloric count). Furthermore, diets with sufficient fiber occupy greater food volumes (or bulk), which may curb intake of other foods. When ingested, the large food volume stays in the stomach longer, resulting in an increased sensation of fullness. Fiber or resistant starch reduces glycemic response and promotes satiety, which is a feeling that comes after eating a meal and inhibits a person from eating again within a relatively short time span.



Fibersym® RW has a low caloric count (one-third lower than unmodified starch), which demonstrates its usefulness in reduced-calorie foods. As reported in the previous section, hamsters fed with a resistant wheat starch diet consumed less feed and gained less weight than those administered a cellulose diet. In human studies, consumption of an energy bar formulated with Fibersym® RW has a bluntening effect on blood glucose and insulin response.

Functional Performance of Fibersym® RW in Foods

Product developers add Fibersym® RW in food products to boost fiber content for nutrient labeling claims. Two nutrient claims can be applied to food products with respect to the level of dietary fiber per serving size. A "good source of fiber" claim means at least 2.5 grams of fiber (but not more than 4.9 grams) per serving size. Nutrition Facts panels on food packages do not normally report fractional numbers, so a "good source of fiber" will be seen as 3 grams or 4 grams of fiber per serving size. Another nutrient claim is "excellent source of fiber", which means that a given food will deliver at least 5.0 grams of fiber per serving size. It should be noted that serving size differs among consumer food products. The U.S. Food and Drug Administration (FDA) define serving sizes of food products in Title 21 of the Code of Federal Regulations Part 101.12.

The recommended ingredient labeling statement for Fibersym® RW is "modified wheat starch". This label declaration complies with Title 21 of the Code of Federal Regulations Part 172.892 and the Food Allergen Labeling and Consumer Protection Act of 2004. Fibersym® RW received both Kosher and Halal certifications. There is no commercially-grown wheat in the U.S. that is bioengineered or genetically modified (GMO). Because the ingredients used are non-GMO and the source of raw material wheat is 100% domestic, Fibersym® RW is considered non-GMO.

Food product formulators can take advantage of the following key points of Fibersym® RW over other resistant starches as well as conventional dietary fiber sources. It has the highest level of total dietary fiber (85% minimum, dry basis) versus other resistant starches. Because of less usage levels in food formulations, end-users can realize cost savings. Fibersym® RW is white in color, making it an ideal source of "invisible" fiber. For example, it does not detract from the appearance of bakery products, which makes it perfectly suitable for white bread and cake applications. The small particle size provides a smooth, non-gritty texture in food products versus the coarse granulation and gritty particles of cereal brans. Fibersym® RW absorbs approximately the same amount of water as wheat flour. This low water-holding capacity requires little or no formulation changes with respect to water absorption, mixing time and baking time of dough products. It is highly compatible with flour-based foods such as bakery products, pasta and noodles. The wheat starch present in flour has the same size, shape and surface properties as the wheat starch-based Fibersym® RW.

Key Points of Fibersym® RW

- Fiber fortification (good/excellent source fiber claim)
- Flour replacement
- Low water-holding capacity
- Smooth, non-gritty texture
- White, "invisible" fiber source
- Process tolerant
- Low caloric contribution
- Low glycemic/insulin response
- Bifidogenic effect

Fibersym® RW has low caloric contribution. The calculated caloric count is 0.6 calories per gram compared to native wheat starch that contributes 4 calories per gram. As discussed in the section under Physiological Benefits, Fibersym® RW promotes gastrointestinal health and attenuates blood glucose and insulin response in humans.

Proven Benefits of Fibersym® RW as a Dietary Fiber Source

High-Protein, High-Fiber Breads

In a study conducted at the American Institute of Baking International, high-protein, high-fiber (HPHF) white or whole wheat bread doughs formulated with 11.6% (based on total formula weight) Fibersym® RW had higher water absorption and less mixing time (3 to 5 minutes shorter) than the control doughs (Table 8).
Proof times were about 17 to 20 minutes shorter, but bake times were 4 minutes longer compared to control doughs. HPHF breads displayed significantly greater volume (260 to 325 cc higher) than the corresponding control breads. Significant increases in moisture, protein, and dietary fiber along with reduction in calories were achieved using the HPHF formulas. Caloric reduction was adequate to meet the requirements for labeling as "reduced calorie" products. Texture analysis over a 10-day storage period demonstrated that the control breads were the quickest to firm, but HPHF breads resisted firming to a much greater extent.

White Pan Bread

The performance in white bread of Fibersym® RW and other sources of dietary fiber was compared using a no-time dough

TABLE 8: Dough and bread characteristics of control and high-protein, high-fiber (HPHF) formulas

Property	White Flour		Whole Wheat Red Flour		Whole Wheat White Flour	
	Control	HPHF	Control	HPHF	Control	HPHF
Absorption, %	63	77	69.7	78	75.7	80
Mixing time, min.	10	5	8.5	5	8	5
Proof time, min.	68	45	53	36	52	34
Bread volume, cc	2441	2766	2200	2460	2144	2416
Specific volume, cc/g	5.18	6.06	4.63	5.32	4.52	5.21
Total Quality Score	83.8	79.4	86.5	80.7	80.2	78.5
Moisture, g/100g	35.9	39.8	35.3	39.9	36.4	39.6
Protein, g/100g	8.6	17.6	11.6	17.8	10.8	17.6
Dietary fiber, g/100g	2.0	17.7	6.4	19.0	6.8	19.2
Calories, kcal/100g	258	185	245	179	241	180

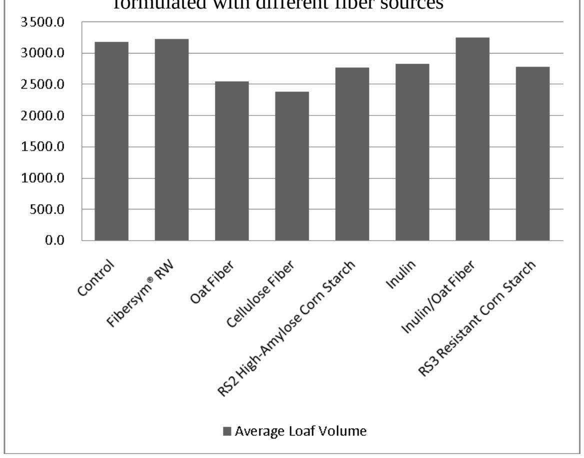
Adapted from *Maningat, C., Bassi, S., Woo, K., Dohl, C., Gaul, J., Stempien, G., and Moore, T. 2005. Formulation of high-protein, high-fiber (low-carbohydrate), reduced calorie breads. AIB Tech. Bull. 27(4):1-16.* Used with permission.

formula. The bread flour in the control formula was substituted with an equal amount of fiber sample to achieve a dietary fiber level of 5 grams per 50 grams serving size of bread. Water absorption was varied to adjust for changes in water binding by the fiber samples. The doughs made with Fibersym® RW, RS2 high-amylose corn starch, and RS3 resistant corn starch were the most convenient to process. Only slight changes in overall absorption level and mixing time were implemented. The doughs made with oat fiber and cellulose fiber required high water absorption and were challenging to work with to attain the targeted dietary fiber level. Inulin has lower water absorption (54%) than the control (63%), but required longer mixing time and adding the water in four stages to produce an acceptable dough. Efforts to produce a suitable dough using a wheat dextrin as a source of fiber were unsuccessful.

Dietary fiber has a weakening effect on the strength and structure of bread dough during proofing. This effect was most apparent with cellulose fiber. Its high water absorption and large particle size drastically weakened the strength of proofed dough. Inulin lengthened the proof time of the dough by 3.5 hours, which would require a significant increase in yeast level. The proofed strength and appearance of the dough formulated with Fibersym® RW looked identical to the control dough, whereas doughs containing RS2 high-amylose corn starch and RS3 resistant corn starch demonstrated slight weakness.

Fibersym® RW required 22 minutes of baking at 410ºF. The other fiber sources took the same length of baking time at 410ºF, but inulin required baking for 28 minutes at 375ºF to avoid excessive browning. Loaf volume for breads formulated with Fibersym® RW and a 1:1 blend of inulin and oat fiber exceeded the loaf volume of the control bread (Figure 6).

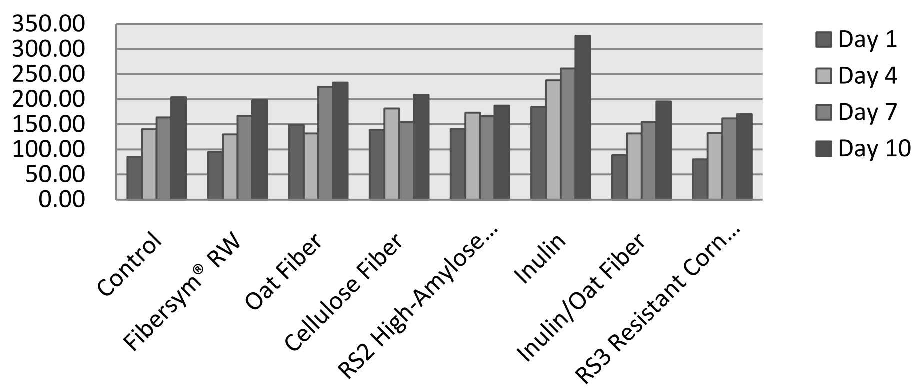
FIGURE 6: Average loaf volume of breads formulated with different fiber sources



Source: *MGP.*

The texture and eating quality of bread formulated with Fibersym® RW was similar to the control bread and more superior to the other bread samples. Both RS2 high-amylose corn starch and RS3 resistant corn starch yielded breads with very open texture and coarse crumb. Breads formulated with oat fiber and cellulose fiber had very open texture with large cell structures. Furthermore, the breads had poor palatability and mouthfeel. Inulin imparted a tight crumb structure with a firm and dry texture. Changes in bread firmness were assessed by measuring the texture of bread samples after 1, 4, 7 and 10 days of storage. Fibersym® RW and other fiber sources, with the exception of inulin, are generally comparable in textural firmness compared to control bread (Figure 7).

FIGURE 7: Bread firmness after storage for 1, 4, 7 and 10 days



Source: *MGP*.

In a related study at Kansas State University, 1 part of Fibersym® RW was blended with 9 parts of wheat flour to produce white pan bread. A wheat starch formula used 1 part of wheat starch blended with 9 parts wheat flour, and a control formula used 100% wheat flour. The specific volume (5.96-6.07 cc/g) was slightly lower and the bread slightly firmer (427.8-475.2 g) for both the Fibersym® RW and wheat starch formulas compared to the control wheat flour formula (6.28 cc/g; 406.9 g).

Flour Tortillas

Flour tortillas represent one of the fastest growing categories of bakery products in the U.S. Because of their wide acceptance, they have moved from being an ethnic (Hispanic) food to being part of a typical American diet. To determine the effect of fiber fortification on properties and consumer acceptability of flour tortillas, a study was initiated by Texas A&M University (College Station, TX) using 5%, 10% and 15% levels of incorporation of Fibersym® RW. The processing of tortillas with 5%-15% Fibersym® RW generated doughs that were soft, extensible and easy to press . As shown in Table 9, the weights of Fibersym® RW-fortified tortillas are practically similar to the control tortillas. Although the thickness tends to decrease with 10% and 15% usage levels, their diameters are significantly larger than the control tortillas. The thickness of tortillas with 5% Fibersym® RW is similar to the control tortillas, but the diameter tends to increase. These dimensional differences resulted in a calculated specific volume that tends to increase as the dosage of Fibersym® RW increases. The opacity of the flour tortillas tends to increase with the addition of Fibersym® RW.

Freshly-made tortillas containing Fibersym® RW were softer and more tender than the control tortillas based on lower deformation modulus after texture analysis. Storage of tortillas for 16 days had the general effect of increased force to deform, decreased extensibility, and reduced work to crack, or rupture the tortilla. A sensory evaluation of one-day old tortillas showed comparable appearance and flavor, but texture was significantly more tender for 10% and 15% Fibersym® RW-fortified tortillas compared to the control tortillas (Table 9). Tortillas with 15% Fibersym® RW had significantly higher overall acceptability scores than the control tortillas.

TABLE 9: Properties of flour tortillas fortified with Fibersym® RW

		Level of Fibersym® RW		
Parameter	Control	5%	10%	15%
Weight, g	40.5	40.8	40.2	39.3
Thickness, mm	3.00	3.00	2.82	2.81
Diameter, mm	164	169	177*	176*
Specific Volume, cc/g	1.57	1.64	1.72	1.74
Opacity, %	75	85	88	90
Texture Score	6.7	7.1	7.8*	8.2*
Overall Acceptability Score	6.6	6.3	7.0	7.5*

*Indicates significant difference from control (P<0.05) Adapted from *Alviola, J.N., Jondiko, T., and Awika, J.M. 2010. Effect of cross-linked resistant starch on wheat tortilla quality. Cereal Chem. 87:221-225.* Used with permission.

Sugar-Snap Cookies

A study conducted by Kansas State University compared the performance of Fibersym® RW and RS2 potato starch in sugar-snap cookies. Both starches produced cookies with top grain and spread factors comparable to the control flour (Table 10). However, cookies made with Fibersym® RW exhibited similar snapping force and RS2 potato starch demonstrated significantly lower snapping force when compared to the control cookie.

TABLE 10: Properties of sugar-snap cookie formulated with Fibersym® RW and potato starch

	Spread Factor	Top Grain	Snapping Force, kg
Flour (Control)	107.9a	Good	9.22a
Fibersym® RW/Flour (1:9)	110.8a	Good	9.30a
Potato Starch/Flour (1:9)	113.8a	Good	7.35b

Note: Vales followed by different letters in the same column are significantly different at 5% level.
Adapted from *Yeo, L.L. and Seib, P.A. 2009. White pan bread and sugar-snap cookies containing wheat starch phosphate, a cross-linked resistant starch. Cereal Chem. 86:210-220.* Used with permission.

Extruded Breakfast Cereals

To study the effect of extrusion on fiber retention of Fibersym® RW when formulated in breakfast cereals, a study was conducted at Wenger Technical Center (Sabetha, KS). Five blends consisting of a control blend and four other blends differing in the levels of Fibersym® RW were prepared. The control blend consisted of 42% whole corn flour, 30% long grain rice flour, 20% whole oat flour, 6% sugar and 2% salt. The four treatment blends were formulated with Fibersym® RW, replacing 5%, 10%, 15%, and 20% of whole corn flour with the other ingredients remaining the same. Ring-shaped breakfast cereals were prepared in duplicate from the blends using a TX-57 twin-screw extruder at approximately similar processing conditions with an extruder shaft speed of 200 rpm and die temperature of 118ºC. Both the blends and the extruded breakfast cereals were analyzed by an outside laboratory for moisture and total dietary fiber by AOAC Method 991.43. Fiber content on a dry basis and fiber retention are depicted in Table 11.

TABLE 11: Survivability of Fibersym® RW during extrusion of a ring-shaped breakfast cereal

Level of Fibersym® RW	% Fiber (d.b.) of Dry Blend (Before Extrusion)	% Fiber (d.b.) of Extruded Breakfast Cereal	% Fiber Retention
0%	6.4	5.6	88.1
5%	10.6	9.4	88.7
10%	14.2	11.6	81.7
15%	18.0	14.8	82.2
20%	21.3	16.6	77.9

Source: *MGP*.

Table 12: Properties of ring-shaped, extruded breakfast cereals formulated with different levels of Fibersym® RW

Level of Fibersym® RW, %	Product density, kg/m^3	Diameter, mm	Crispiness of dry cereal ring, g	Crispiness of cereal rings soaked in milk (5 min.), g
0	66	15.17	8282	314
5	72	14.67	7835	438
10	73	14.05	8963	438
15	84	13.23	9398	784
20	86	13.15	11040	992

Source: *MGP*.

The total dietary fiber content of the dry ingredient blends increased by roughly 3.6% for every 5% added Fibersym® RW. Total dietary fiber loss during extrusion processing increased as Fibersym® RW level increased; however a high percentage (78 – 89%) of the total dietary fiber content was retained in the final product. Product density (Table 12) increased as level of Fibersym® RW increased but no effect on the specific mechanical energy was observed. X-ray microtomography showed that Fibersym® RW did not affect internal cell wall thickness, size or porosity. Addition levels of 5 and 10% had no effect on expansion, physical appearance, initial crispness or bowl life of the cereal rings. Higher levels of incorporation (15% and 20%) decreased cereal ring diameter, but increased initial (dry) product crispness and extended bowl life (Table 12). In general, moisture content and moisture uptake of the cereal rings during soaking in milk was not affected by the level of Fibersym® RW in the formula. Furthermore, moisture content and moisture uptake did not appear to influence the crispness of milk-soaked cereal rings.

Pasta

In conjunction with the addition of Arise® 6000, a high-performance wheat protein isolate produced by MGP Ingredients, the functionality of Fibersym® RW in spaghetti was evaluated in a study conducted at North Dakota State University (Fargo, ND). Dry (raw) spaghetti made from a blend of 1.7-3.4% Arise® 6000, 12.6-12.8% Fibersym® RW, and 84.0-85.5% semolina increased in brightness (L value) but yellowness (b value) was unaffected compared to the control spaghetti (100% semolina).Water absorption of cooked spaghetti decreased from 3.1 g/g for the control and 2.8-2.9 g/g for the spaghetti formulated with Arise® 6000 and Fibersym® RW. Cooking loss tended to decrease from 4.4% (control spaghetti) to 3.7% for spaghetti containing 3.4% Arise® 6000 and 12.7% Fibersym® RW, while the eating texture tended to get firm with the addition of 2.5-3.4% Arise® 6000 and 12.6-12.7% Fibersym® RW (6.4-6.5 gcm) compared to the control spaghetti (6.0 gcm).

TABLE 13: Properties of raw and cooked spaghetti formulated with Fibersym® RW and Arise® 6000

Parameters	Spaghetti Sample	
	100% Semolina (Control)	40% Semolina, 12% Arise® 6000, 48% Fibersym® RW
Raw Spaghetti		
Brightness (L value)	60.6	66.2
Yellowness (b value)	4.0	3.4
Cooked Spaghetti		
Cooking Time, min	11.0	14.0
Water Absorption, g/g	2.8	2.3
Cooking Loss, %	5.6	4.0
Firmness, gcm	7.2	8.0

Source: *MGP*.

In a second study at North Dakota State University, a higher level of Fibersym® RW (48%) and Arise® 6000 (12%) was blended with semolina (40%) and processed into spaghetti. As shown in (Table 13)**,** the raw spaghetti formulated with Fibersym® RW and Arise® 6000 decreased in yellowness, but increased in brightness compared to the control spaghetti. Cooking time increased by three minutes, but both water absorption and cooking loss decreased for the spaghetti formulated with Fibersym® RW and Arise® 6000. Texture analysis revealed an increase in firmness upon incorporation of the two additives.

In yet another study, the addition of egg white powder was evaluated in conjunction with the use of Fibersym® RW and Arise® 6000 in a spaghetti formula. The color of dry spaghetti was slightly affected as the brightness tended to decrease (L value: 60.1 versus 59.0) and yellowness tended to increase (b value: 39.8 versus 40.7) compared to the control spaghetti. As expected, cooking time increased and both water absorption and cooking loss decreased (Table 14). A significant increase in firmness of cooked spaghetti was observed.

Asian Noodles

White salted noodles, Chinese-style noodles (Chuka-men) and instant fried noodles formulated with a blend of Fibersym® RW and Arise® 6000 (84:16 ratio) were prepared in the laboratory of Wheat Marketing Center (Portland, OR). Noodle flour was substituted by a 10% and 30% of Fibersym® RW/Arise® 6000 blend.

During noodle making, all of the above Asian noodles have acceptable processability and machinability.

Incorporation of the Fibersym® RW/Arise® 6000 blend in white salted noodle tends to increase lightness, but tends to decrease yellowness. The yellowness of Chuka-men noodles tends to decrease as the level of substitution increases. The color of Chuka-men noodles was acceptable at a 10% substitution level only. The instant fried noodles have acceptable lightness and yellowness. The addition of Fibersym® RW/Arise® 6000 tends to decrease the water absorption of cooked noodles for all three noodle types. Using a TA.XT2 texture analyzer, all Asian noodles formulated with Fibersym® RW/Arise® 6000 at 10 and 30% levels have acceptable bite, springiness, and mouthfeel.

TABLE 14: Cooking properties of spaghetti containing Fibersym® RW, Arise® 6000, and egg white powder

Parameters	Spaghetti Sample	
	100% Semolina (Control)	81% Semolina, 12% Fibersym® RW, 2 % Arise® 6000, 5% Egg White Powder
Cooking Time, min	9.25	10.0
Water Absorption g/g	3.0	2.6
Cooking Loss, %	5.2	4.4
Firmness, gcm	5.8	12.2

Source: *MGP*.

Snacks

Indirect expanded snacks formulated with 5% and 10% Fibersym® RW were prepared in the Food Processing Center of the University of Nebraska (Lincoln, NE). The control snack contained 30% tapioca starch, 58% wheat flour, 10% corn flour, 0.5% monoglycerides, 1% salt and 0.5% sodium bicarbonate. Fibersym® RW was incorporated by replacing 5% or 10% of tapioca starch with the rest of ingredients kept the same. Snack pellets were prepared using a TX-57 twin-screw extruder, and the dried pellets were expanded by frying in oil. The expanded snack products containing Fibersym® RW appeared lighter in color compared to the control. Due to lesser axial and radial expansion, the Fibersym® RW-formulated snacks had heavier bulk density than the control. Interestingly, fat absorption was decreased from 26% for the control to 19%-22% upon the addition of 5% or 10% Fibersym® RW. In addition, Fibersym® RW increased the crispiness of the snack products as indicated by the higher linear distance and mean number of major peaks when measured by TA.XT2 texture analyzer (Table 15).

TABLE 15: Crispiness texture analysis of indirect expanded snacks formulated with Fibersym® RW

Crispiness Parameters		
Level of Fibersym® RW	Linear Distance	Mean Number of Major Peaks
0%	1949	17.0
5%	2417	26.8
10%	2251	23.5

Source: *MGP*.

Confectioneries

To create healthy, indulgent confectionery products, Fibersym® RW was successfully formulated at a level of 5% in crème, caramel, marshmallow, and sugar-free confectionery bars. Fibersym® RW has a fine particle size and contributed smoothness to the finished products. It was easily dispersed in the formulas with no clumping issues. The sensory attributes of flavor, texture, and color of the four confectionery products were comparable to the control formulas.

Appendix

The Following is a Listing of Publications on Cross-Linked RS4-Type Resistant Starches:

1. Thompson, L.U., Maningat, C.C., Woo, K., and Seib, P.A. 2011. In vitro digestion of RS4-type resistant wheat and potato starches, and fermentation of indigestible fractions. Cereal Chem. 88:72-79.
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