USING RS4 RESISTANT WHEAT STARCH IN BAKING APPLICATIONS

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MGP®

THE CONCEPT OF RESISTANT STARCH

During consumption of a food containing starch, approximately 5% 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 into the different cells of the body to serve as a source of energy. Remnants of undigested foods (mainly dietary fiber) flow into the large intestine where they provide bulk or undergo microbial fermentation with the release of 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 was surprising since starch was widely thought to be a completely digestible carbohydrate as noted above. Those British investigators also found that raw starch from potato and green banana largely resisted digestion by mammalian alpha-amylase. 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 low level of dietary starch is resistant to hydrolysis by digestive enzymes, the words "resistant starch" were 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 in 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 plant cell wall such 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 plant 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 and high-amylose wheat are commercially available for use as resistant starch sources in food product development.

Examples of type 2 resistant starch, or RS2, are starch granules from raw potato, unripe or green bananas, and high-amylose corn. These 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 starches completely lose resistance to enzyme digestion upon cooking. On the other hand, heat-moisture treatment of high-amylose starches enhances their level of RS2. High-amylose corn starches with varying levels of RS2 resistant starch are currently sold in the market.

Highly associated, crystalline amylose represents resistant starch belonging to type 3 or RS3. Highly associated or crystalline amylose forms during a process termed retrogradation, which occurs when an amylose-containing starch is cooked and cooled. The level of RS3 generated during retrogradation depends on starch concentration, and on time and temperature. In the commercial production of an RS3 ingredient, an aqueous slurry of starch is repeatedly heated and retrograded to generate an increasing level of RS3. The intimate association of amylose molecules of long chain-length results in the formation of a water-insoluble, partially crystalline structure which resists digestion. 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 manufactured from tapioca starch, normal corn starch, and high-amylose corn starch are commercially available.

Type 4 resistant starch, 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 contribute 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 as described in U.S. Patent 5,855,946 is accomplished by cross-linking starch with sodium trimetaphosphate in the presence of small amounts of sodium tripolyphosphate. Two products made by such a process are MGP's Fibersym® RW and FiberRite® RW. The cross-links in those two resistant starches are diesters of a phosphate molecule. Phosphate diester linkages are ubiquitous in nature, occurring in DNA, RNA, and phospholipids, to name a few. Also, the level of phosphate substitution in Fibersym® or FiberRite® is low; only ~3% of glucose repeat units are phosphorylated. Even so, those phosphate cross-links in Fibersym® and FiberRite® limit the swelling of their granules in water, and such a tight structure and possible steric inhibition at an amylase's active site inhibit enzymatic digestion. Other phosphorylated cross-linked RS4 products are commercially available such as those made from tapioca and potato starches.

The fifth type of resistant starch, or RS5, was recently introduced as a new type of resistant starch. A starch-lipid or amylose-lipid complex forms when starchy foods, or purified amylose-containing starches, are heated or cooked in the presence of a lipid molecule containing a single fatty-acid chain. This durable single-helical complex offers resistance to enzymatic digestion based on its insolubility and steric hindrance to the active site of an amylase. Currently, there is no commercially-manufactured RS5 resistant starch available in the market.

ABOUT FIBERSYM® RW

Fibersym® RW, a phosphorylated cross-linked RS4 wheat starch, is an FDA-approved source of dietary fiber and is ideal for incorporation in foods that provide benefits related to health and wellness. It complies with FDA's new nutrition facts labeling regulations issued on May 27, 2016. Fibersym® is classified as RS4-type resistant starch, meaning it is indigestible in the upper gastrointestinal tract. It 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® allows formulators to boost the fiber content and lower calories of a diverse line of products while delivering health benefits to consumers. Applications include bread, pizza crust, flour tortillas, pasta and noodles, cookies, English muffins, breakfast cereals, pastries and bakery mixes. Health-wise, this superb ingredient lowers postprandial blood glucose and insulin levels, lowers blood cholesterol, and reduces waist circumference and body fat percentage (which can reduce the risk of being overweight or obese). It promotes gastrointestinal health by increasing colonic fermentation/short-chain fatty acid production and contributing to positive modulation of colonic microflora.

Fibersym® contains a maximum of 0.4% phosphorus and a minimum of 90% total dietary fiber (dry basis) when analyzed according to AOAC Method 991.43. Fibersym's calorie count is 35.1 kcal/100 g or ~0.4 kcal/g using the calculation procedure in the new nutrition-facts labeling regulations.

Fibersym® is labeled "modified wheat starch" in the ingredient statement of food product packages. 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® is certified Non-GMO Project Verified and has received both Kosher and Halal certifications. It also is certified as low FODMAP by Monash University in Melbourne, Australia.

MONASH UNIVERSITY LOW FODMAP CERTIFIED™

Monash University Low FODMAP Certified trade marks used under license by MGP Ingredients, Inc. A strict low FODMAP diet should not be commenced without supervision from a healthcare professional. A low FODMAP diet does not treat a disease but may help to meet nutritional needs with reduced gastrointestinal symptoms. Monash University receives a license fee for use of the Monash University Low FODMAP Certified trade marks.

NON GMO Project VERIFIED
nongmoproject.org

Key Points of Fibersym® RW:

- FDA-approved source of dietary fiber
- Fiber fortification (good/excellent source of fiber claim)
- Calorie reduction (~0.4 calories per gram)
- Beneficial physiological effects in humans
- 1:1 Flour replacement
- Low water holding capacity
- Smooth, non-gritty texture
- White, "invisible" fiber source
- Process tolerant
- Enhances crispiness
- Non-GMO Project Verified
- Low FODMAP Certified

Table 1. 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.

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 (Manhattan, KS), high-protein, high-fiber (HPHF) white or whole wheat bread doughs formulated with 11.6% Fibersym® (based on total formula weight) had higher water absorption and less mixing time (3 to 5 minutes shorter) than the control doughs (**Table 1**).

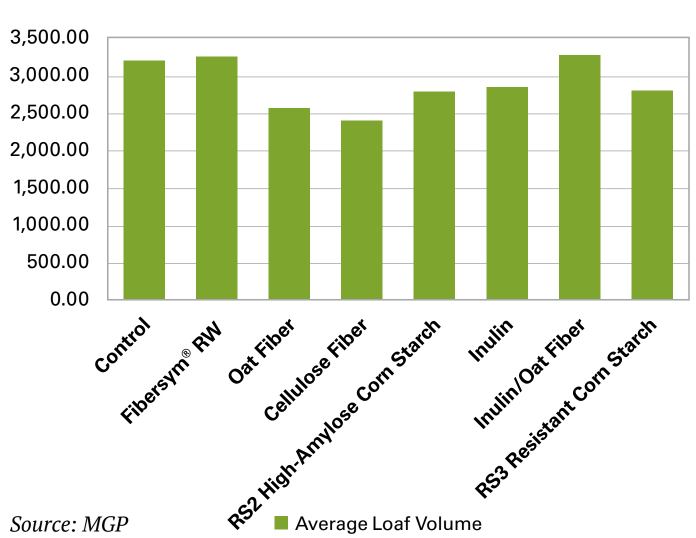
Proof times were about 17 to 20 minutes shorter, but bake times were 4 minutes longer compared to control doughs. HPHF breads displayed significantly greater volume (260 to 325 cc higher) than the corresponding control breads. Significant increases in moisture, protein, and dietary fiber along with reduction 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 bread firmed faster and more than the HPHF bread.

WHITE PAN BREAD

The performance in white bread of Fibersym® and other sources of dietary fiber was compared using a no-time dough 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 ("as is" moisture level) serving size of bread. Water absorption was varied to adjust for changes in water binding by the fiber samples. The doughs made with Fibersym, 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%), required longer mixing time, and water in the dough had to be added 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.

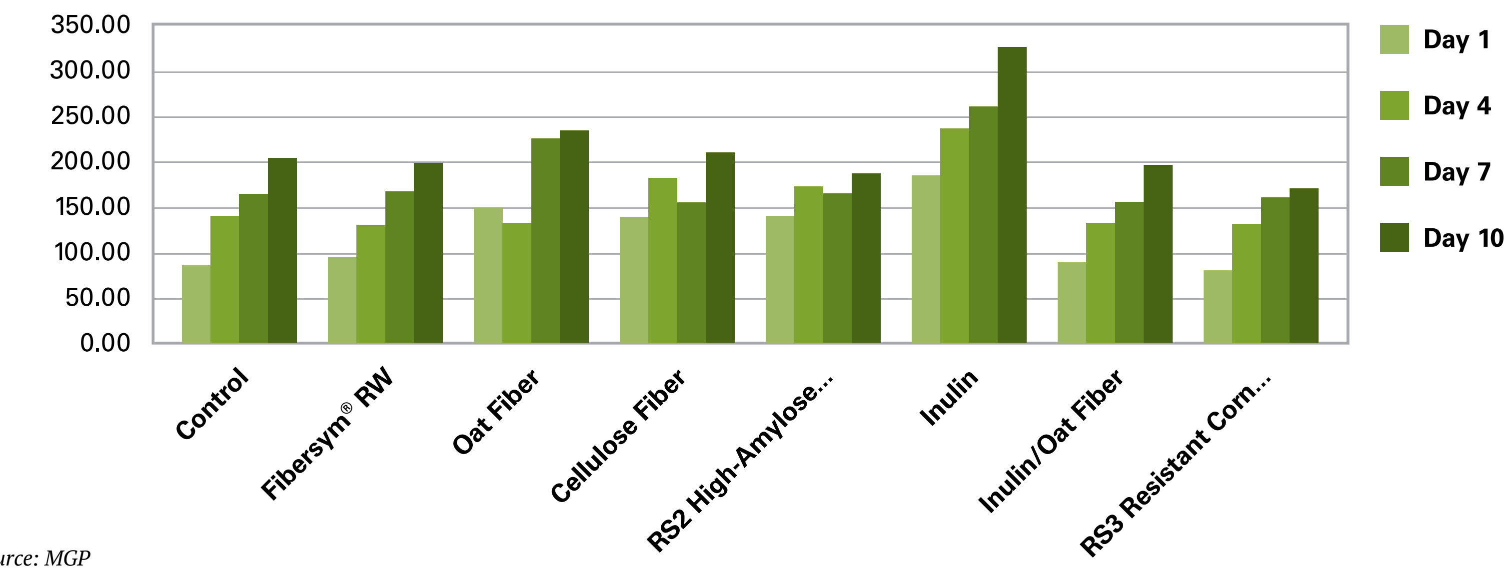
Dietary fiber has a weakening effect on the strength and structure of bread dough during proofing. This effect was most apparent with cellulose fiber. Its high water absorption and large particle size drastically weakened the strength of proofed dough. Inulin lengthened the proof time of the dough by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

Figure 1.** Average loaf volume of breads formulated with different **fiber sources.



Source: MGP

***Figure 2.** Bread firmness after storage for 1, 4, 7 and 10 days.*



Source: MGP

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

The texture and eating quality of bread formulated with Fibersym® was similar to the control bread and was 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 also had a 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® and other fiber sources, with the exception of inulin, are generally comparable in textural firmness compared to control bread (**Fig. 2**).

In a related study at Kansas State University, 1 part of Fibersym® 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).

U.S. Patent Application 2009/0252843A1 describes a high fiber flour-based concentrate prepared by mixing stone ground whole wheat (44.4%), inulin (6.7%), wheat protein (8.9%) and Fibersym® (40%). A high fiber bread was made by mixing 1 part of high fiber, flour-based concentrate and 3 parts of bread flour. The resulting bread has a dietary fiber content of 8-12 g per 100 g serving and had natural lightness, good mouthfeel, and without the traditional heaviness of high fiber breads.

In a 2017 Kansas State University study, commercial bread flour was replaced with 0 (control), 5, 10, 15, 20 or 25% Fibersym. Vital wheat gluten was added to each flour-Fibersym® blend to maintain the original flour protein content of 11.8%. White pan bread was prepared from the blends using a straight dough procedure with a 90-min fermentation. The optimum mixograph water absorption of doughs containing 5, 10, and 15% Fibersym® was the same as the control with no added Fibersym; however, doughs with 20 and 25% Fibersym® has 2% higher absorption (**Table 2**). Doughs with added Fibersym® increased mixing time ranging from 15-45 sec. There was no significant difference in loaf volumes between the control bread and those with 5-20% Fibersym; however, the bread containing the highest level of Fibersym® (25%) had a significantly lower loaf volume compared with the control bread (**Table 2**). Bread firmness increased and elasticity decreased during the 14-day storage period; however, addition of Fibersym® had no influence on the firmness and elasticity values compared to the control. Overall liking score by average consumers was similar between control bread and Fibersym-containing bread. The researchers concluded that Fibersym® did not have a significant effect on dough development, strength, extensibility or handling properties or on bread volume, texture, shelf life or consumer acceptance.

In U.S. Patent 9,668,488, a technology to make a low calorie, high fiber food product with good taste properties is described. The total dietary fiber within the food product arising from RS4 wheat starch comprises 14-60% and the caloric count is in the range of 1 to 3.25 calories per gram on a dry weight basis. The food product may be bread, cookies, cakes, crackers, muffins, brownies, pizza crust, doughnuts, biscuits, pie, wafers, pasta, instant noodles, and egg noodles among others.

***Table 2.** Effect of replacing flour by 5-25% of Fibersym® RW on dough and bread properties.*

Fibersym® RW, %	Water Absorption, %	Mix Time, min	Loaf Volume, cc	Overall Liking	Firmness after 14 days, g
0	62b	3.00d	845a	5.2a	1169a
5	62b	3.25c	829ab	-	1220a
10	62b	3.25c	804ab	-	1067a
15	62b	3.25c	799ab	4.8a	1139a
20	64a	3.50b	785ab	4.8a	1085a
25	64a	3.75a	765b	5.1a	1111a

Adapted from *Miller, R.A. and Bianchi, E. 2017. Effect of RS4 resistant starch on dietary fiber content of white pan bread. Cereal Chem. 94(2):185-189.*