National Starch LLC
10 Finderne Avenue, Bridgewater, NJ 08807
www.foodinnovation.com

Barbara A. Davis, PhD, RD
Vice President, Scientific Strategy
HealthFocus International
100 2nd Avenue N, Suite 220
St. Petersburg, FL 33701

22 April 2008

2010 Dietary Guidelines Advisory Committee
C/O Carole Davis, Co-Executive Secretary
Center for Nutrition Policy and Promotion
United States Department of Agriculture
3101 Park Center Drive, Room 1034
Alexandria, VA 22302

Dear Chairman Van Horn and Advisory Committee Members:

Thank you for the opportunity to submit comments regarding the 2010 Dietary Guidelines for Americans. These comments have been prepared on behalf of National Starch, supplier of Hi-maize® resistant starch (RS) from high-amylose corn. The purpose of this document is to present scientific data in support of the physiological significance of resistant starch in the diet, beyond the benefits acknowledged for traditional fiber, for the DGAC to review and consider recognizing resistant starch as a dietary fiber of special importance.

We are aware that some DGAC members have considerable expertise in resistant starch. These comments are meant to provide a brief overview of resistant starch for those less familiar and then highlight the documented health benefits, with particular emphasis on data that has been published in the past 5 years.

Benefits attributed to RS consumption encompass gastrointestinal effects such as enhanced bowel function, fermentation and modification of microflora composition, and systemic benefits including improved glycemic control and insulin sensitivity, as well as weight management.[1] RS as an ingredient serves as a well-tolerated source of fiber that is easily incorporated into commonly consumed foods without modifying sensory qualities. As such, it represents an important means for increasing fiber intake for Americans.

It is important to note that the benefits attributed to RS are significant because they are related to health issues that impact many Americans and that are of considerable concern to consumers; these include diabetes, obesity, insulin sensitivity, gastrointestinal health and cardiovascular disease. Therefore, helping consumers to understand the potential benefits of RS consumption by highlighting this fiber source in the 2010 Guidelines is warranted.

1. Resistant Starch Defined

Despite the historical belief that starch is completely digested, it has been recognized that certain types do escape digestion within the small intestine. Resistant starch was defined in 1992 to be the sum of starch and products of starch degradation not absorbed in the small intestine of healthy individuals.[2] RS was recognized as a dietary fiber by the Food and Nutrition Board of the Institute of Medicine in 2001[3] and at an international level when a definition for dietary fiber was agreed upon at the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) in 2008.[98]

A variety of factors, including source, ripeness, processing, preparation and storage of food influence the amount of RS present in starch-rich foods.[4] The four classes of RS are defined in Table 1.

Table 1. Four classes of Resistant Starch[5-7]

Class	Description	Example of Sources*
RS1	Starch that escapes digestion in the small intestine due to physical protection by the food matrix (i.e., hull, shell, seed casing).	Whole grains, seeds, legumes Commercial Ingredient: Hi-maize® whole grain corn flour
RS2	Raw starch granules (ungelatinized) with compact structure which limits accessibility of digestive enzymes.	Green banana, raw potato, high-amylose corn starch, raw whole grain flours. Commercial Ingredient: Hi-maize® high-amylose starch and whole grain flour
RS3	Retrograded starch in which parts of the starch chains can crystallize into components that are less digestible. Most often, this occurs by cooking and cooling starch-containing foods.	Cooked and cooled starches – corn, potato, pasta, rice Commercial Ingredient: Actistar RM®, Promitor®, NOVELOSE® 330
RS4	Not found naturally in foods. Starch that has been chemically modified to introduce bonds that are not digestible by human enzymes. The potential benefits of this type of resistant starch are largely unknown.	Does not occur in nature. Ingredient sources of modified RS produced from wheat and tapioca are available Commercial Ingredient: Actistar RT®, Fibersym®

*Hi-maize and NOVELOSE are trademarks of National Starch, Actistar is a trademark of Cargill, Fibersym is a trademark of MGP and Promitor is a trademark of Tate& Lyle.

2. Resistant Starch Is Well-Studied

Over the past twenty years, there have been more than 280 publications describing research conducted with natural forms of RS, including 83 clinical trials, 151 animal and 47 in vitro studies from leading investigators and research institutions worldwide on resistant starch from high amylose corn. Resistant starch from high-amylose corn (RS2-HAM) is the most thoroughly studied RS and therefore will be the focus of this summary, although data from other RS will be noted where it is available. There are no published studies on RS4 and very few clinical trials examining health effects of other commercially available RS ingredients.

The available research creates a foundation for defining the significance of RS in the human diet by uncovering health benefit targets, documenting health effects in humans and identifying potential mechanisms of action.

3. Sources of RS as an Ingredient

- **Resistant starch is a natural component of many foods.** Consumption of resistant starch from the typical diet is estimated to be approximately 4.9 g/d (range 2.8 – 7.9 g/d) for Americans over 1 year of age.[8] Primary sources contributing to this intake are breads, cooked cereals/pastas, and vegetables (other than legumes), which account for about 60% of RS consumption in the American diet. These intakes are slightly lower than what has been shown to confer beneficial effects on glycemic management[9] but are well below the amounts demonstrated to positively affect digestive health.[4] However, as is shown in the study conducted by Jarvi and colleagues[10] when the typical RS intake is increased using foods containing a commercial RS ingredient, beneficial health effects can be achieved through simple dietary modifications.

- **Development of commercial RS ingredients will play a significant role in consumer acceptability of high-fiber foods**. Commercial resistant starch ingredients serve as an important source of this fiber. As identified in Table 1, several commercial RS ingredients are available to food manufacturers. Because of the physical properties of RS, including a bland flavor and small particle size (similar to traditional corn starch), these ingredients enable the development of high fiber breads, muffins, cereals and pasta products that not only have the added benefit of high fiber content, but also have improved appearance, mouthfeel, texture and taste over traditional added-fiber products.[11] These are very significant factors in consumer acceptance of fiber-enriched foods. Data from the HealthFocus International US Trend Survey[12] show that only 18% of shoppers are willing to give up taste for health benefits. High-fiber products produced using RS will mean that consumers won't have to give up the good-tasting foods they are accustomed to eating in order to increase the fiber content of their diet. This could enhance compliance of diets containing significantly more fiber than is present in the American diet today.

- **Functional benefits for RS2 from high-amylose corn cannot be extended to other RS ingredients.** With the exception of RS2 from high-amylose corn, there are very limited data on the health benefits of commercially available RS ingredients. Animal and in vitro studies suggest that the nutrient utilization and intestinal fermentation are different for different types and sources of resistant starch.[13-16] Based upon this preliminary evidence, the benefits documented for high-amylose corn RS2 cannot be assumed for other sources of RS.

- **RS is a well-tolerated Fiber.** Gastrointestinal (GI) tolerance has been frequently measured in clinical studies evaluating efficacy endpoints of RS and this fiber source has been shown to be well tolerated. In addition, one study, published so far only in abstract form,[17] was designed specifically to evaluate tolerance of RS2 on symptoms of fermentation. The authors report no significant negative effects on a number of tolerance parameters including bowel frequency, abdominal distension, flatulence, GI upset and breath hydrogen production from consumption of RS in doses up to 60g per day. In their review of GI effects of low-digestible carbohydrates including RS, Grabitske & Slavin[18] conservatively estimated tolerance at 45g for RS. These levels are above those amounts shown to confer beneficial

effects in clinical studies, making dietary RS consumption a viable option for helping to achieve fiber intake goals and related health benefits.

4. Traditional Fiber Benefits and More

Similar to other well-studied fibers, it has been well documented that RS reaches the large intestine intact. Because it is not digested in the small intestine, RS has a lower energy content than digestible carbohydrates. The consequence of significant amounts of RS reaching the large intestine is the potential for fermentation by colonic micro-organisms. Short chain fatty acids (SCFA) produced in response to fermentation of RS are thought to be responsible for much of the intestinal and systemic effects reported for this fiber.[19]

RS can help achieve dietary fiber intake recommendation goals, but in addition, can provide specific benefits beyond those traditionally associated with dietary fiber. Specifically, research has concentrated on glucose and insulin response, digestive/GI health (including biomarkers of large bowel health, colon cancer and diarrheal disease) and more recently satiety/weight management.

a. Glycemic Control

Replacement of high glycemic foods such as white breads, bakery products, rice, pasta and potatoes with low glycemic foods including whole grains and fiber may help to reduce risk of metabolic syndrome, diabetes, obesity and cardiovascular disease.[20-21] Numerous investigations have provided data in support of a beneficial effect of RS2 on various parameters of glycemic control, including glucose response, insulin response, glucose response of subsequent meals and insulin sensitivity.

- **Twenty-three studies investigating RS2 have shown a reduced glycemic response in at least one type of glycemic measurement.** Thirty one clinical studies evaluated the impact of RS2-containing foods on glycemic response.[22-54] Experimental designs varied, but 21 published reports[23,24,26-28,31-35,37,38,40-43,45,46,48-50,52-54] and 2 unpublished studies[29,51] demonstrated a reduction in glycemic response following RS2 consumption compared to control carbohydrate. Eight investigations[22,25,30,36,39,44,47,55] found no significant difference in glycemic response from RS2 consumption. Many factors, including portion sizes, food types, macronutrients and relative amounts of RS2 could account for the contradictory results. For example, 4 of the 9 studies comparing glycemic response of equivalent amounts of available carbohydrates showed no significant differences among groups.[44,47,48,55] In this method, more food is consumed in the RS group vs. control groups to achieve a similar available carbohydrate load and could account for the mixed results using this design. It is important to note that the glycemic reducing benefit of RS is achieved by its substitution for high glycemic carbohydrates.

- **Insulin response is blunted by RS2.** Eighteen clinical studies have demonstrated a reduced insulin response,[23,24,26,28,29,31,33-35,37,38,40-43,45,46,48,49] while seven showed no significant difference[27,30,33,36,37,39,47] vs. control from dietary consumption of RS2. Again, these studies utilized a variety of designs including different amounts of RS2, test meal composition, length of RS2 consumption (from one meal to 4 weeks prior to testing), population (healthy vs. type 2 diabetes) and control substance. Despite these

methodological differences, a majority of studies have demonstrated a positive effect on insulin response with RS2 ingestion.

- **Insulin sensitivity is increased by RS2.** Three clinical trials[43,46,53] have also evaluated insulin sensitivity in response to RS2 consumption. All three reported enhanced insulin sensitivity measurements in response to meal tolerance tests when RS2 was consumed for 1 day[43] or 4 weeks.[46,53] In two of the studies, the control included the same quantity of glycemic carbohydrates as the test meal to control postprandial glycemic responses and allow for fermentation effects to be evaluated. Using this approach, the authors concluded that the observed effect on insulin sensitivity was generated by a fermentation or large intestinal mechanism. While both studies by Robertson[43,46] were conducted in healthy adults, Zhang[53] tested insulin sensitivity in individuals with Type 2 Diabetes, suggesting a role for RS in helping to maintain healthy insulin levels in both populations.

RS and Glycemic Control Summary: ***A majority of studies investigating the impact of RS2 on various glycemic parameters strongly suggest a role for this ingredient in glycemic management. While some inconsistent results have been documented, the majority of studies show a positive effect. Differences may be explained by design issues. Additional studies are needed to define long-term optimal levels of RS2 intake for beneficial effects on glycemic parameters and to better understand mechanisms responsible for the these effects. However, available data do support incorporation of resistant starch into the diet to help manage glycemic response and thereby help to reduce risk for a number of diseases associated with poor glycemic control.***

b. Gastrointestinal Health

- **RS has been repeatedly shown to support intestinal health.** Biomarkers of intestinal health may be classified into measures of functional, fermentation products and colonic flora composition. Routine measures commonly used in the 18 studies conducted to investigate the role of RS in digestive health included fecal weight, short-chain fatty acid (SCFA) production, fecal pH, transit time and stool frequency among others. Positive results following RS consumption were demonstrated for at least one biomarker in all but a single study. A summary of the results for key biomarkers is provided in Table 2.

Table 2. Impact of RS Consumption on Key Biomarkers of Digestive Health

Marker	Total	Positive	NSD[a]
Stimulation of SCFA production (especially butyrate)	**14**	10 [29,37,46,55-61]	4 [35,62-64]
Reduction of fecal pH	**8**	4 [37,57,59,65]	4 [58,60,63,64]
Increase in fecal weight	**16**	10 [55,57-59,61-63,65-67]	6 [9,35,37,60,64,68]
Reduced transit time[b]	**4**	1 [57]	2 [63,65]
Stool frequency	**5**	2 [35,37]	3 [58,60,62]

[a]NSD = no significant difference

[b]One study also showed a negative effect on transit time[99]

These data show that RS is fermented in the large intestine, as evidenced by increased SCFA production and resulting decreased fecal pH. This may be responsible for much of the biological activity attributed to RS as is described below in Section 5. Results also demonstrate that whereas transit time does not appear to be reduced by RS, increased fecal weight and stool frequency have been observed in a majority of studies and supports some mild beneficial effects of RS on regularity.

Resistant starch (particularly HAM-RS) has been demonstrated to: provide increased energy for the colon and to increase colonic blood flow through SCFA production,[69,70] decrease ammonia and phenol concentrations,[57,71] decrease the cytotoxicity of fecal water,[58] increase fecal starch,[9,57-60,63,71,72] increase the number of beneficial bacteria in the colon[6,73,74] and decrease secondary bile acid metabolism.[58,63,64]

- **Resistant Starch has beneficial effects attributed to reduced colon cancer risk.** A role for RS in colon health including reduced risk for colon cancer has been suggested by several lines of evidence, including data from epidemiologic,[75] animal and human studies. As discussed above, clinical studies of RS consumption have repeatedly documented increased SCFA production in the colon.[29,37,46,55-61] While mechanisms for the anti-neoplastic effects of butyrate have not been fully established, this compound has been demonstrated to affect many processes that are critical to tumorigenesis.[76] In addition, ammonia and other nitrogen-containing compounds related to increased colon cancer risk[77,78] are decreased by RS consumption.[57,71]

- **Emerging evidence on RS consumption and colon cancer warrants further evaluation.** Seven published studies have investigated dietary intake of RS, for durations of one week up to four years, on various colon cancer-related endpoints have shown mixed results. Study populations ranged from healthy individuals to those with adenomas to a high-risk population of subjects with genetic predisposition for colon cancer. Four studies assessed colonic cell proliferation[35,64,66,79] and found no significant effect of RS consumption on this index. Burn and colleagues[80] showed that RS consumption for up to 4 years did not prevent colon cancer in a high-risk population of subjects with a genetic pre-disposition to the disease. Two studies[58,81] showed more positive effects of RS consumption including decreased colonic cell proliferation along with favorable regulation in expression of two cancer-related genes.[81] Given the consistent positive effect of RS on SCFA production in the human colon and the known anti-neoplastic role of butyrate, additional studies to understand the potential for dietary RS consumption to reduce colon cancer risk in humans are indicated.

- **Epidemiological evidence is supportive for a protective effect of RS**. One study[82] found that a South African population consuming high levels of cooked and cooled corn, containing high levels of retrograded RS3 and low levels of dietary fiber had significantly lower levels of colorectal cancer compared to another South African population consuming higher levels of dietary fiber, but lower levels of RS. The authors suggested that the fermentation of RS could be responsible.[82]

RS and Colon Health Summary: ***An abundance of research supports the beneficial effects of resistant starch for colon health. Specifically, RS fermentation increases***

SCFA production in the large intestine, which affords numerous functions. SCFAs serve as an energy source for colonocytes, lower pH, increase colonic blood flow, and promote growth of healthy cells by influencing cellular differentiation, proliferation and absorptive processes.[70] Additionally, RS provides a mild laxation effect to help promote bowel function. A role for RS in reducing risk of colon cancer is a promising area that deserves further scientific inquiry.

c. Weight Management

- **Evidence supports an emerging role for RS in weight management through multiple mechanisms.** The fact that RS is not digested in the small intestine has several potentially significant implications for weight control. First, at ~2.8 kcal/g, including the contribution from fermentation products,[32] it provides 70% of the energy value of digestible starch, thereby enabling development of lower calorie foods. Second, as a source of fiber, it has the potential to increase satiety. And third, lower postprandial glycemia and insulinemia as well as increased insulin sensitivity and lipid oxidation have been shown in response to RS consumption and could have positive consequences for weight management.

  Fifteen clinical studies[26-28,38,43,44,46,50,52-55,83-85] have investigated the effects of resistant starch consumption on multiple weight management-related endpoints. Ten of these studies investigated satiety as one of the parameters[26-28,38,52,54,55,83-85] and six examined metabolic factors including insulin response, sensitivity and glycemic effects with the objective of understanding the role of RS on these parameters in relation to weight.[43,44,46,50,53,54]

- **Beneficial effects of RS on glycemic control could be beneficial in weight management, reducing risk of metabolic syndrome.** Exaggerated glucose and insulin responses may lead to the development of insulin resistance. A consequence of prolonged insulin resistance is the development of a cluster of conditions known as metabolic syndrome[86] that include abdominal obesity, type-2 diabetes or abnormalities in blood glucose, hypertension and cardiovascular disease known as metabolic syndrome. Attenuated glycemic and insulin responses as well as increased insulin sensitivity documented in response to RS consumption may help to prevent the development of insulin resistance, thereby potentially reducing risk for metabolic syndrome and associated diseases including obesity.

- **Preliminary evidence suggests RS may increase lipid oxidation.** In addition to the effects observed for carbohydrate metabolism, results from one clinical study have demonstrated RS may also influence lipid metabolism.[44] Specifically, the authors observed an increase in fat oxidation over the 24 hour postprandial/postabsorptive period in response to inclusion of 5.4% RS in a single meal. Additional research is required to further evaluate this relationship, to determine whether this is another mechanism through which RS may exert weight management benefits.

- **Investigations using satiety as a primary endpoint suggest a role for RS in helping to promote a feeling of fullness following consumption.** Satiety was used as the primary endpoint in only two of the ten studies that evaluated this parameter.[83,84]

Interestingly, in both of these studies, RS was demonstrated to lower appetite scores and increase satiety, respectively, compared with control treatments. Note that the Willis[84] study is provided as an accompaniment to these comments as an example of the impact of RS on satiety because it is the only double-blind, randomized study with satiety as the primary endpoint. In addition, it highlights the fact that all fibers are not the same in eliciting a satiety effect as this study compared satiety effects of five different fibers.

- **Research designs evaluating satiety as a secondary endpoint show mixed results.** In the remaining studies that examined satiety as a secondary endpoint, 4 demonstrated a positive effect,[26,52,54,55] three a negative effect[28,38,85] and one showed no significant difference[27] between RS consumption and satiety vs. control. Because of the varied approaches in the study designs, including when the RS was consumed in relation to a meal, the composition and caloric content of the test meals, control over food consumption during the experimental period, when satiety was measured, the amount of RS tested, the duration of RS supplementation provided, multiple factors might explain the inconsistent results. Of significance, is the fact that the majority of these studies were not designed primarily to evaluate satiety, but rather around other endpoints.

- **Emerging scientific evidence supports a role for fermentation of RS in satiety**. Three recent animal studies show that the expression of satiety hormones PYY and GLP-1 is influenced by RS consumption.[87,88,89] Both gene expression and plasma protein levels of these hormones were increased in response to dietary RS and remained elevated for 24 hours. The authors postulate that fermentation of RS is responsible for the hormone regulation as SCFA production in the large intestine was associated with PYY and proglucagon gene expression.[89] Upregulation of GLP-1 by SCFA has been previously documented in response to dietary fiber intake in animal studies.[90-91] Additional studies are needed to confirm this mechanism and to validate this response in humans.

RS and Weight Management Summary: ***The relationship between resistant starch consumption and satiety is supported by 6 of the 10 studies evaluating this association. Additional well-controlled studies are warranted since both investigations specifically designed with satiety as the primary endpoint documented a beneficial effect. Further information about optimal intake levels and timing are also needed.***

d. **Other Proposed Benefits**

- **RS added to Oral Rehydration Solutions (ORS) enhances diarrhea treatment.** Although studies evaluating the effectiveness of RS consumption on diarrhea were all conducted in unhealthy populations, because of the compelling effectiveness observed, it is worthy of brief mention here. Four randomized, controlled dietary intervention trials were conducted, in children,[92,93] adolescents and adults[94] and adults[95] who were suffering from diarrhea. Compared to standard therapy, addition of RS to ORS shortened duration of diarrhea, reduced stool output and/or decreased fecal weight. It is postulated that SCFA produced from RS fermentation is responsible for the observed treatment benefits. Monira and colleagues[93] showed that treatment with RS

containing ORS resulted in enriched fecal bacterial diversity within a day after treatment began, with statistical differences observed by three days.

- **Foods containing RS have the potential to provide sustained energy delivery.** In contrast to digestible carbohydrates that release their energy within 2-4 hours following meal consumption, RS releases energy for as long as 36-48 hours[19] via fermentation and SCFA production. This coupled with the attenuation of glycemic and insulin response induced by RS consumption, reduces energy availability immediately following a meal and extends the period of time over which energy is available. Tiredness/lack of energy is a top issue that concerns 50% and affects 38% of consumers in the US.[12] Eighty-two percent of consumers report high interest in foods/drinks that could offer the benefit 'helps to improve physical energy.'[12] The availability of foods which safely provide the energy benefit consumers are seeking while adding to daily fiber needs is an important contribution to the American diet.

5. The Metabolic Role of Resistant Starch Fermentation Products

The degree to which dietary fibers are fermented vary considerably, depending on many factors including the type of fiber, its physical form and the microflora present in the large intestine.[96] It is well documented that resistant starch is fermented in the large intestine, as evidenced by numerous human, animal and in vitro investigations.[19,29,37,46,55-61] The end products of this fermentation, namely SCFAs, have been linked to the many health benefits shown for RS. **Table 3** lists the potential roles of SCFAs in these health benefits. Additional studies designed to investigate the mechanisms responsible for benefits associated with RS will continue to define the types and amounts necessary to elicit desired responses.

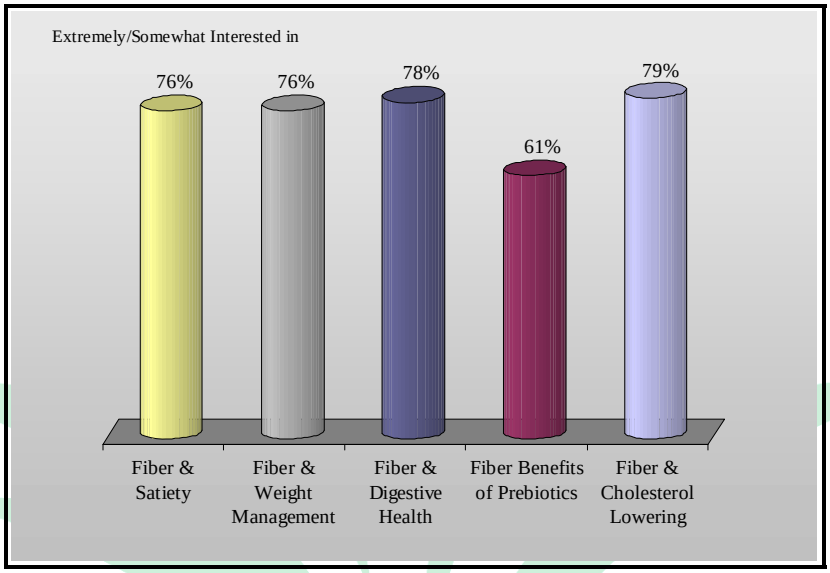
Table 3. Documented and Putative Roles for SCFAs in Resistant Starch Health Benefits

Health Benefits of RS	Association with SCFAs
Improved Glycemic Control	• **Reduce circulating free fatty acids** • **Enhance insulin sensitivity**
Colonic Health	• **Lowers pH = reduced secondary bile acid formation, modifications in microflora** • **Serve as an energy source for colonocytes** • **Enhance mineral and fluid absorption** • **Promote colonic blood flow** • **Stimulate colonic muscular contractions** • **Prevent colonic atrophy** • **Inhibit malignant cell growth**
Weight Management	• **Increase lipid oxidation** • **Decreased dietary carbohydrate oxidation** • **Increased expression of satiety hormones**

6. Consumer Interest in Health Benefits

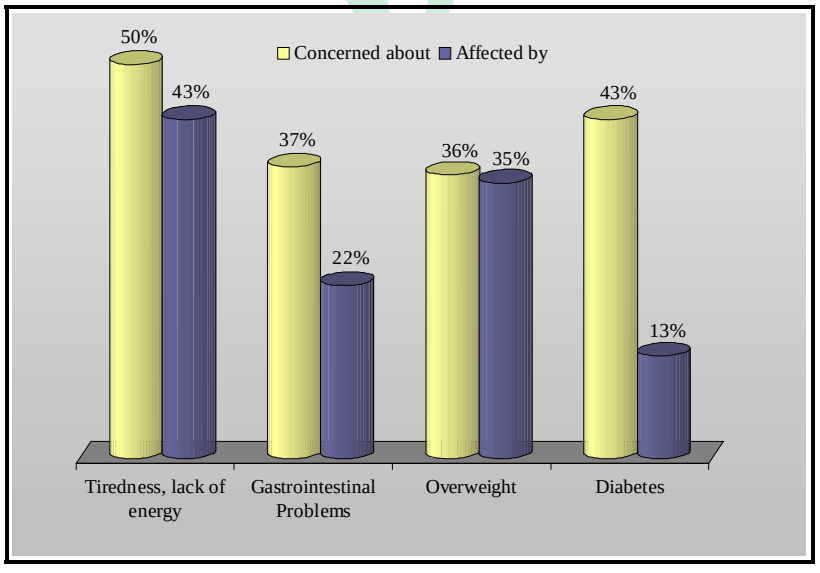
- **Consumers know the important role fiber plays in their diet.** In the 2009 HealthFocus International Trend Survey, 83% of primary grocery shoppers strongly agree/agree with the statement "Eating fiber is important to reduce my risk of obesity, cancer and heart disease." About half of these shoppers act on their belief, specifically choosing foods because they are high in fiber. And, 47% report always or usually maintaining a high fiber diet.[12]

Figure 1. Interest in Health Benefits related to Fiber.



- As shown in **Figure 1**, a vast majority of shoppers express interest in the various benefits provided by fiber. This is due in part to their concern over related health issues (**Figure 2**).

Figure 2. Health Concerns & Issues of US Shoppers.



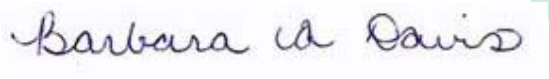
- However, current estimates of fiber intake confirm that most Americans are not meeting their 25g/d requirement. CSFII data show that men are consuming 16.5-17.9 g/d and women ingest 12.1-13.3 g/d.[97] Only 43% of shoppers say they have increased their consumption of fiber in the past two years.[12] This number has only increased 10 points since 1996 and during the past decade the number of shoppers who say their fiber intake has remained the same has held steady at approximately 50%. This demonstrates the importance of helping consumers become aware of the other sources that will assist them in meeting adequate fiber intakes. In a study aimed at understanding consumer interest in the benefits provided by RS, HealthFocus International[12] found that purchase intent for pasta, bread, and cereals would increase if these foods could 'help to maintain healthy blood sugar,' 'help to burn calories,' or 'provide sustained, natural energy.'

6. Summary & Conclusions

Highlighting the significance of resistant starch as an important source of fiber in the American diet is warranted. Documented and emerging evidence demonstrate numerous beneficial health benefits of resistant starch consumption, including gastrointestinal health, glycemic control and weight management. Raising awareness of this fiber through mention in the 2010 Dietary Guideline recommendations is appropriate at this stage given the available scientific data supporting its biological activities and the availability of analytical methodology for quantifying dietary RS content of foods.[5,100]

We appreciate the opportunity to submit these comments.

Respectfully,



Barbara A. Davis, PhD, RD
Vice President, Scientific Strategy,
HealthFocus International

Richard Barndt, PhD
Director, Product Assurance & Regulatory Affairs
National Starch

Rhonda S. Witwer, BS, MBA
Senior Business Development Manager, Nutrition
National Starch

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