There is considerable evidence worldwide linking poor dietary choices with increased risks of obesity, type 2 diabetes, and cardiovascular disease. Foods high in fat or sugar have been targeted as playing a role in the global obesity and diabetes crises, resulting in calls to reduce their levels in popular food products. According to U.S. dietary recommendations (15), total fat intake should contribute 35% to calorie intake, with <10% contributed by saturated fats. However, actual consumption of saturated fats is 10% higher than this recommendation (15). At the same time, sugar consumption is more than twice the recommended daily intake: the average American adult consumes 22 teaspoons of sugar/day compared to the suggested 9.5 teaspoons. This is similar to the United Kingdom, where sugar intake is more than 10% of the total dietary energy intake, which is again double the recommended amount and makes up one-fifth of carbohydrate energy intake (3,16).

In contrast to sugar and fat, fiber is receiving good publicity as a food ingredient due to its ability to increase satiety and improve digestive health. A diet high in fiber is associated with lower incidences of diseases such as cardiovascular disease, type 2 diabetes, and colorectal cancer (4). In response to these findings there have been calls made by governments worldwide to reduce the fat and sugar contents of foods while increasing their fiber content.

Despite campaigns by public health authorities and other agencies, however, consumption of whole grain- and fiber-enriched breads and other baked goods remains low. Less than 10% of the U.S. population meets the recommended daily fiber intake of between 25 and 38 g/day, with average consumption around 15–17 g/day (8). In general, consumers prefer the textural properties of baked products made with white (refined) flour to those made with whole grain flours. This presents a challenge in developing new products because the addition of fiber from sources such as bran fractions is known to negatively affect texture (12). However, with new sources of fiber becoming available and increased research into the functionality of fiber during baking, it is possible to develop new products that appeal to consumers without the negative attributes generally associated with traditional high-fiber products (10).

Globally there are a number of definitions used to describe dietary fiber. AACC International (1) states that “Dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood attenuation.” Dietary fibers include resistant oligosaccharides, resistant starch, and resistant maltodextrins (8). In a broader context, dietary fiber generally is associated with a diet rich in whole grain cereals, fruits, and vegetables.

Dietary fibers encompass a diverse group of nutrients that are classified according to their chemical composition (Fig. 1). Fiber compounds differ in terms of both their nutritional content and functionality. This makes it possible to gain functional benefits, for example sugar or fat replacement in certain products, by choosing an appropriate type of fiber (2,5,9).

Increasing Dietary Fiber Content

Despite the health benefits associated with the addition of dietary fiber to bread and baked products, there is still a reluctance to use them because their addition can affect bread quality negatively. According to Hartikainen and Katina (6) there are a number of functional challenges that must be overcome, including reduced bread volume, decreased dough strength, high water absorption, sticky dough, dark crumb color, and unpleasant flavor.

A study was conducted at Campden BRI with the aim of understanding these functional problems and developing strategies to solve them (11). A clear understanding of the impact of bran components on the water absorption and gas cell stability of dough is key to developing solutions.

Addition of dietary fiber increases the water absorption of dough. Soluble fibers such as guar gum and xanthan gum have high water absorption properties due to the nature of their branched structures, which are more open and readily interact with water. In contrast, wheat bran has medium water absorption properties due to the presence of hemicelluloses and pectin, and resistant starch has relatively low absorption properties due to its unbranched and compact structure (6).

Fig. 1. Examples of potential dietary fiber sources.
The main focus of the work performed by the Campden BRI team was wheat and oat brans because these are readily available in the bakery industry. As expected, the addition of these fibers decreased the specific volume of bread. There was a greater reduction in volume at the higher substitution level (20%) compared with the lower level (10%). Surprisingly, however, over the range of water addition rates studied (optimum ±2%) no effect on specific volume was found, suggesting that water addition level does not play an important role in the final product but is instead more important during processing.

**Fat Reduction**

Fat, in either saturated or unsaturated form, is the most calorie-dense nutrient. Replacing it is quite difficult, however, because it plays an important functional role in many bakery products. One such product is cookies—for example, shortbread dough can contain up to 35% fat by weight. Its role is to coat flour particles during the dough mixing stage, preventing gluten from absorbing water during mixing and becoming elastic and extensible. This gives cookies their characteristic “melt in the mouth,” crumbly texture.

Part of the research conducted at Campden BRI was the development of a novel fat replacement system that uses dietary fiber in an alginate gel-in-oil emulsion (14). Alginates are non-starch polysaccharides derived from many species of brown seaweed found around the world. There are many different types produced, with sodium alginate the type most commonly used in the food industry. Through a controlled interaction with calcium salts, a heat-stable gel is formed that can be used in a wide variety of food applications (7).

In the study, up to 75% of hard fat in short-dough cookies was replaced by an alginate gel-in-oil emulsion. However, the best results were achieved when replacing 50% of the fat with a 50:50 emulsion. This could be done without significantly affecting biscuit quality and equated to a >40% reduction in saturated fat (Fig. 2).

**Sugar Reduction**

Sugar (sucrose) is a key component of bakery products such as cakes and cookies, and its contribution to the bulk of these products is significant. In addition to providing sweetness, sucrose contributes to the baking process by influencing structural transformations, such as starch gelatinization, in both cookie dough and cake batter. It also contributes to an extended mold-free shelf life.

Standard yellow or high-ratio cake formulations, on average, contain 30% sugar. Research has been performed at Campden BRI on how sugar can be replaced directly with the soluble fiber inulin, which contains fewer calories than sugar (13). Inulin is a nondigestible oligosaccharide that is found in many plants and has approximately 10% of the sweetness of sugar (sucrose) and so can be used in combination with high-intensity sweeteners. It behaves as a bulking agent, contributing to the body and mouthfeel of the product, and has the advantage of a neutral flavor without any off-flavors. Once hydrated and after shearing it can form a particle gel network that can be used to support food structures (17).

In the study, up to 20% of the sugar in the formula was replaced with inulin. When compared with the control cake, specific volume was comparable, and both cakes had water activities of 0.84, which gave a predictive mold-free shelf life of 13 days at 25°C. Sensory quality also was evaluated using a grading system: the reduced-sugar cake achieved “good” for internal appearance and “fairly good” for external appearance, odor, flavor, and texture (Fig. 3).

**Conclusions**

The studies conducted at Campden BRI showed that levels of fat and sugar in baked products, such as cookies and cake, can

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be reduced using functional fibers like alginate and inulin. It also is possible to add up to 20% dietary fiber to bread, although this level of added fiber may have some negative effects on bread quality. Other methods for improving the quality of high-fiber products are currently being investigated, such as additional ingredients and treatment of wheat and oat brans.

References