Fibre sources for the food industry

BY I. T. JOHNSON

AFRC Institute of Food Research, Norwich Laboratory, Colney Lane, Norwich NR4 7UA

Few issues in human nutrition have captured popular attention in the way that dietary fibre has in recent years. The hypotheses of Burkitt *et al.* (1972), coupled with the considerable body of new knowledge which has been accumulated over the last decade or so, have led to a general consensus that the consumption of dietary fibre should rise significantly, and there is a very widespread awareness and acceptance of this view amongst consumers. The recommendations of the National Advisory Committee on Nutrition Education (1983) in this context were that average intakes should rise from 20 g fibre/d to about 30 g fibre/d (with fibre as defined by the Southgate method (Southgate, 1976)), and that this increase should come largely from high-extraction cereals. Similar, though less precise, recommendations have recently been published in the USA as part of The Surgeon General's Report on Nutrition and Health (1988). As Southgate (1988) has pointed out, it is very difficult to obtain this substantial increase in dietary fibre from a Western mixed diet unless it contains significant quantities of high-extraction cereal products. Such foods must through necessity be highly processed before consumption, and this has created important new marketing opportunities for bread and cereals manufacturers, as a glance at the shelves of any supermarket will confirm.

The original dietary fibre hypothesis was based on epidemiological evidence, and hence on comparisons of total fibre intake amongst populations. This has led to an over-preoccupation with the absolute content of dietary fibre in foods, together with a heated and as yet unresolved debate as to how this absolute content should be defined and measured. The definition of dietary fibre used in the present paper is that of Trowell *et al.* (1976): 'the sum of lignin and the plant polysaccharides which are not digested by the endogenous secretions of the human gastro-intestinal tract'. It should never be forgotten that all definitions of fibre encompass a range of polysaccharides with different physico-chemical properties and biological effects. The major components of dietary fibre and their principal sources are cell wall components (cellulose, hemicellulose, lignin and pectic substances), non-structural components (gums and mucilages) and industrial additives (modified cellulose, modified pectin, commercial gums and algal polysaccharides). Space does not permit a comprehensive discussion of the chemical and physical properties of the various materials but excellent reviews are available (for example, Selvendran *et al.* 1987).

It is a fundamental error to assume that any particular material which falls within the definition of fibre and has appropriate functional properties in foods, will automatically be of significant nutritional benefit to the consumer. In the present paper I shall discuss briefly three major physiological effects of fibre, together with the benefits to health with which they are believed to be associated. In each case the appropriate sources of fibre, the relevant foods, and some manufacturing strategies available to the food industry will also be reviewed.

LAXATIVE PROPERTIES

The ability of dietary fibre to increase faecal bulk, and hence to reduce both faecal transit time and muscular strain during the passage of stool, was identified by Burkitt & Trowell (1975) as an important mechanism in the prevention of diseases thought to be associated with chronically increased intra-colonic and intra-abdominal pressure. It remains the most widely recognized property of dietary fibre amongst consumers, many of whom apparently believe themselves to be constipated and in need of laxatives (National Advisory Committee on Nutrition Education, 1983). The use of dietary fibre supplements as a means of managing diverticulosis and haemorrhoids now appears to be widespread amongst gastroenterologists. By no means all components of dietary fibre increase faecal bulk to any significant extent; it is a property primarily of the insoluble and poorly fermentable components of cereal brans. In order to comply with the dietary goal of achieving a significant increase in fibre intake from foods rather than from non-culinary supplements, the fibre must be consumed in products which form a regular and substantial proportion of conventional Western diets. Bread and breakfast cereals are the obvious candidates for this role, as food manufacturers have been quick to realize.

Wheat bran is a widely used source of dietary fibre. It has long been accepted as a bulk laxative (Cowgill & Anderson, 1932) and has proven value in the management of large-bowel disorders (Findlay *et al.* 1974; Taylor & Duthie, 1976). It is a traditional ingredient which is widely accepted by consumers, and consumption of wholemeal bread and wheat bran-based breakfast cereals has risen substantially in recent years. Whole-wheat bread contains about 85 g dietary fibre/kg compared with approximately 25 g/kg in a typical white bread. However, the whole-wheat product has characteristic qualities of texture, colour and flavour which tend to limit its appeal, and this has led food technologists to seek alternative bread formulations and sources of fibre.

Purified α-cellulose prepared from wood-pulp is virtually 100% dietary fibre, of which about 90% is β–1,4-glucan. This material can be used to prepare high-fibre breads with a dietary fibre content three or four times higher than that of conventional products, but because the cellulose modifies the dough characteristics of the bread it is necessary to add increased levels of gluten and to modify the fat and moisture contents to achieve an acceptable texture.

Purified cellulose is poorly fermented by the colonic microflora of both the rat and man (Van Soest, 1984). In the rat there is an approximately linear relationship between both wet and dry faecal bulk and dietary intake of cellulose over a nutritionally significant range. In Fig. 1 this is illustrated by the wet weights and dry weights of faeces divided by food intakes of rats fed on a fibre-free diet or on a diet containing cellulose (100 g/kg) as Solka Floc. Wheat bran contains less than half the dietary fibre of Solka Floc. However, in Fig. 1 the corrected wet weight of faeces produced by animals fed on 100 g wheat bran/kg lies above the cellulose line when plotted at the appropriate level of dietary non-starch polysaccharide. The reasons for this are not clear but the undigested wheat bran particles may have a higher water-holding capacity because of their larger size (Cadden, 1986), and possibly because of their arabinoxylan content. Purified cellulose is known to increase faecal bulk to some extent in man (Hillman *et al.* 1983), but there have been relatively few studies, and nothing is known of its long-term effect on health. Its use in foods is banned in some countries and alternative high-fibre materials for use in foods have, therefore, been sought.

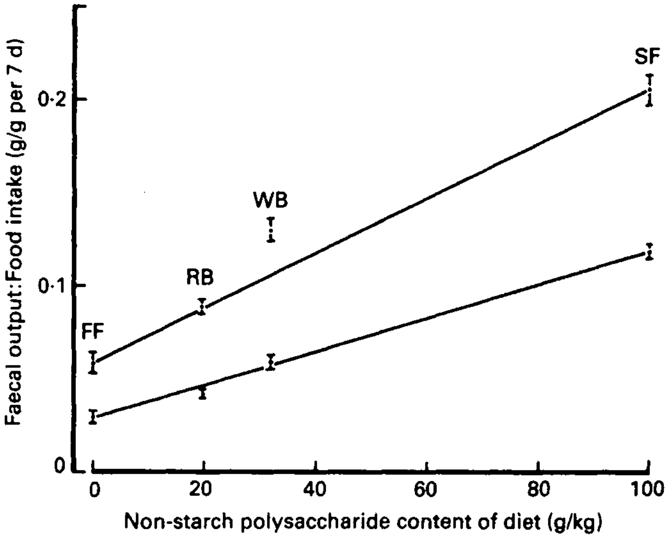

Fig. 1. The mean wet weight (upper line) and dry weight (lower line) of faeces/food intake of rats *v.* non-starch polysaccharide content of semi-synthetic diets. Apart from the fibre-free diet (FF) the diets contained rice bran (RB), wheat bran (WB) or cellulose as Solka Floc (SF) at a concentration of 100 g/kg dry weight. Each point is the mean value, with standard errors represented by vertical bars, for five pairs of rats (Johnson *et al.* 1989).

Amongst the materials which have been successfully incorporated into experimental bread formulations are field pea (*Pisum arvense*) hulls, maize bran and wild oat (*Avena sativa*) bran (Sosulski & Wu, 1988), as well as flax (*Linum usitatissimum*) and sunflower (*Helianthus annus*) hulls (Cadden *et al.* 1983). The latter materials had adverse effects on the quality of the bread, but pea and maize fibre can be used to prepare breads of acceptable quality with total dietary fibre contents of 150 and 210 g/kg dry weight respectively, compared with 40 g/kg for a comparable white bread (Sosulski & Wu, 1988). Pea hulls enhance faecal output in rats significantly, but their nutritional effects in man do not appear to have been fully evaluated.

Sugar-beet fibre and rice bran are examples of materials derived as by-products of raw-material processing, which can be made into versatile and palatable sources of dietary fibre by the application of food technology. With the thermal processing techniques such as extrusion cooking, or par-boiling of rice before milling (James & Sloan, 1984), rice bran can be stabilized to prevent the development of rancidity, and incorporated into breads and other products (Babcock, 1987). Fig. 1 indicates that the faecal bulking properties of rice bran are similar to those of wheat bran in the rat. However, recent studies with human volunteers suggest that dietary supplements of rice bran are slightly more effective than wheat bran as a means of increasing the output of stool and decreasing the faecal transit time (Tomlin & Read, 1988).

Apart from breads, breakfast cereals naturally lend themselves to the incorporation of dietary fibre in significant quantities. The use of whole grains in the formulation of breakfast cereals leads to products containing 2–3 g dietary fibre per serving, whilst the incorporation of wheat or maize bran can be used to prepare products containing up to 9 g per serving.

The effect of particular processing techniques on the biological properties of dietary fibre must be taken into account in product development. For example, particle size is known to influence the faecal bulking properties of wheat bran (Heller *et al.* 1980; Cadden, 1986). Extrusion cooking of wheat products leads to a redistribution of fibre from insoluble to soluble fractions (Bjorck *et al.* 1984). The choice and processing of particular materials for individual products is a matter for the food technologists, but their biological effects and suitability in relation to nutritional needs must be judged from the relevant scientific literature, or ideally from physiological studies in human subjects, using the particular product in question.

HYPOCHOLESTEROLAEMIC EFFECTS

Traditional diets amongst population groups with a low risk of coronary heart disease tend to be high in available carbohydrates and dietary fibre and low in fat (Keys, 1970). Recent epidemiological studies suggest an inverse correlation between the intake of fibre and the incidence of coronary heart disease in Western populations (Kushi *et al.* 1985). The mechanism of action is poorly understood, but the effect is probably partly due to a low intake of dietary fat and a consequent favourable plasma lipid profile. There is also a significant body of experimental work indicating that some components of dietary fibre have an independent hypocholesterolaemic effect, but it is important to realize that this is confined to water-soluble fractions. Plant gums which have been shown to reduce plasma cholesterol levels in man when given as a dietary supplement include the viscous storage polysaccharides guar gum (Jenkins *et al.* 1980) and locust bean gum (*Ceratonia siliqua*) (Zavorai *et al.* 1983), pectin from various sources (Judd & Truswell, 1982), and to a small extent gum arabic, which is an exudate gum with a low viscosity (Ross *et al.* 1983). Other materials of potential commercial importance include the β-glucan constituents of oat bran and as yet unidentified components of certain legumes (Anderson *et al.* 1984). Modified cellulose gums such as sodium carboxymethylcellulose (CMC) do not appear to reduce plasma cholesterol levels in man, but unlike the fermentable gums mentioned previously, they do increase faecal bulk in human subjects (Anderson *et al.* 1986).

Some of the highly viscous and physiologically active water-soluble gums are widely used in the food industry as a means of modifying texture in manufactured food products, but the intake of dietary fibre from such existing applications is negligible. Apart from their use in the specialized pharmaceutical products mentioned later, it is unlikely that the high-viscosity polysaccharides can be used to enrich foods to a nutritionally significant extent.

Low-viscosity polysaccharides on the other hand lend themselves much more readily to incorporation into a variety of food products, particularly beverages, soft drinks and soups, where they can often be used to replace starch as a thickener. It has been pointed out, for example, that in a typical soup containing 40 g starch/kg, 20 g can be replaced by a mixture of low-viscosity guar gum and CMC, to achieve a dietary fibre content close to 2%, with no detectable alteration in the rheological characteristics (Andon, 1987). It seems unlikely that such foods alone could be used to achieve a prolonged and physiologically significant increase in soluble fibre intake from an otherwise acceptable mixed diet, but in combination with legumes or other complex carbohydrate foods a clinically significant reduction in plasma cholesterol levels might be achieved.

In the previously mentioned context, oat products might provide a particularly important opportunity for new product development. Oat bran contains β-glucan, an unbranched, high-molecular-weight polysaccharide which develops a high viscosity in water and has a significant hypocholesterolaemic action in both experimental animals and man (Anderson *et al.* 1984). Recent reports from the USA indicate that less than 20 g oat bran/d can significantly reduce serum total cholesterol levels in young, healthy volunteers (Gold & Davidson, 1988). Moreover, the reduction occurred primarily in the low-density-lipoprotein-cholesterol subfraction which is believed to be an important factor in relation to coronary heart disease. Another recent paper suggests that oat bran may be a highly cost-effective alternative to pharmacological intervention as a means of reducing plasma cholesterol in individuals with abnormal cholesterol levels (Kinosian & Eisenberg, 1988). The incorporation of this material into palatable foods for long-term use in mixed diets, therefore, poses an important new opportunity for food manufacturers.

HYPOGLYCAEMIC EFFECTS

The usefulness of diets rich in dietary fibre in the management of diabetes melitus has been demonstrated by Anderson & Ward (1979) in the USA, and by Mann's group in the UK (Simpson *et al.* 1981). A considerable amount of work has been done on the physiological effects of various components of dietary fibre in the small intestine and their effect on the absorption and metabolism of glucose from carbohydrate foods (Jenkins *et al.* 1978; Johnson, 1984). Two mechanisms seem to be important. Soluble polysaccharides with a high viscosity increase the resistance to diffusion of nutrients within the lumen of the small intestine, and hence slow the movement of glucose through the boundary layer at the mucosal surface (Johnson & Gee, 1981; Edwards *et al.* 1988). This delays the uptake of carbohydrate and leads to a reduced rate of entry into the circulation (Blackburn *et al.* 1984). Second, the digestion of complex carbohydrate foods such as legumes is considerably slower than that of bread, rice or potatoes (Gee & Johnson, 1985). This appears to be due to the survival of intact cell walls, which enclose the starch granules in the cooked material, rather than, as is often assumed, to the presence of viscous polysaccharides (Wursch *et al.* 1986).

Two strategies are available for the exploitation of these effects in foods designed to elicit a relatively low blood glucose response in diabetics and others. The first is to incorporate highly viscous polysaccharides such as guar gum into carbohydrate foods. To be effective the foods must contribute a major proportion of the daily carbohydrate intake and bread is, therefore, the obvious candidate. Jenkins' studies in the 1970s were carried out with breads containing about 1 g guar gum per slice (Apling *et al.* 1977). Apling & Ellis (1982) subsequently developed a palatable, soft, guar gum bread. Other starchy foods such as pasta (Gatti *et al.* 1984) and biscuits (Ellis *et al.* 1988) also lend themselves to the incorporation of viscous polysaccharides, but they inevitably have distinctive texture and flavour characteristics which may make them unacceptable for general use.

The second approach is to try to preserve, in finished products, the inherent low digestibility of some high-fibre, complex carbohydrate foods. The presence of intact cell walls enclosing ungelatinized starch granules is associated with dietary fibre in plant foods, but their existence cannot be quantified by chemical analysis alone, even though the slow release of glucose can be observed in human subjects (Haber *et al.* 1977), and measured in vitro (Gee & Johnson, 1985). As might be expected, the use of extreme processing conditions seems to destroy this property. The blood glucose response to extruded or otherwise thermally processed potato and maize snacks is significantly higher than to conventionally cooked equivalents (Brand *et al.* 1985). Interestingly, there is a small increase in the total dietary fibre content of extrusion-cooked wheat flour, and some redistribution of dietary fibre from insoluble to soluble fractions (Bjorck *et al.* 1984).

The difficulty of preserving the intrinsic cellular structure of complex carbohydrates in manufactured foods may perhaps be circumvented by the use of food-manufacturing technology. Retrogradation of starch in thermally processed foods gives rise to a fraction which resists digestion by small-intestinal enzymes (Berry, 1986; Ring *et al.* 1988). The issue of whether or not this resistant starch fraction should or should not be classified as dietary fibre will not be raised here. The more interesting question is whether the material has biological effects which are similar to those of dietary fibre and can usefully be exploited in manufactured foods. Thermally processed high-amylose starches may have many of the properties which are associated with cell wall polysaccharides in 'whole' or unprocessed foods, but a substantial amount of further research will be needed to test this possibility.

To conclude, the impact of the dietary fibre hypothesis presents the food industry with both challenges and opportunities. There is little doubt that food technology can be used to make dietary fibre available to the consumer in a variety of new and palatable forms. However, the design of such products should not be based on the simple goal of achieving the highest possible fibre content from the cheapest possible source. If the consumer is to experience real nutritional benefits, it is essential that the use of processed fibre sources should be matched with a knowledge of their physiological effects.

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