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Fat and sugar substitutes: implications for dietary intakes and energy balance

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Public concern with body-weight management or other potential effects of excessive fat or sugar consumption have prompted massive industrial efforts in the development and marketing of intense sweeteners, bulk sweeteners, and fat replacement ingredients and technologies for macronutrient reduction in foods. The range of materials used and proposed for use as sugar and fat substitutes, and their different properties and applications, are discussed at length in the food science literature and other sources (for example, Setser & Racette, 1992; Khan, 1993; Schiffman & Gatlin, 1993; Lucca & Tepper, 1994). The present review highlights the nutritional implications of the consumption of reduced-energy foods produced by use of substitutes for sugar and/or fat, considering what these materials might replace, and focusing on potential influences on macronutrient intakes and weight control in the general population.

INGREDIENTS FOR SUGAR AND FAT SUBSTITUTION

Sugar substitutes

Since the serendipitous discovery of saccharin over 100 years ago, a very large number of man-made and naturally-occurring sweeteners have been identified and proposed for use in foods (Marie & Piggott, 1991; Sardesai & Waldsham, 1991; Hough, 1993; Schiffman & Gatlin, 1993; Birch, 1997), primarily for the replacement of sucrose. Sugar substitutes are generally categorized as either intense or bulk sweeteners, and some of the more common examples are listed in Table 1.

Intense sweeteners can deliver a sweetness intensity which would equate to 10–20 000 or more times greater weights of sucrose (Birch, 1997), and are either not metabolized or appear in foods at concentrations so low as to make a negligible contribution to energy intakes. However, their use also often requires simultaneous modification of the food matrix by addition of other ingredients to replace the structural, rheological, or bacteriostatic properties of sucrose (see Nicol, 1993). Intense sweeteners are used in a wide range of food products and commercial flavour mixes, but the main dietary source is beverages, followed by use as 'tabletop' sweeteners, and lesser amounts in food applications (Hinson & Nicol, 1992) such as yoghurts, jams, and prepared desserts.

Bulk sweeteners primarily include a range of sugar alcohols which, as the name implies, are used in foods at levels roughly comparable with sucrose. In addition to these, several mono- and disaccharides, particularly fructose, are increasingly used in place of sucrose in foods. Bulk sweeteners are typically used to confer specific taste or other functional advantages, and for their ability to replace the textural and mouthfeel qualities of sucrose. Although sugar alcohols typically impart about the same or less sweetness than an equal weight of sucrose, they have low cariogenicity and some deliver an appealing mouthfeel, and therefore are widely used in chewing gum and confectionery (and toothpaste). Bulking agents, such as a range of different oligosaccharides (Crittenden & Playne, 1996) and polydextrose (Setser & Racette, 1992) may impart little sweetness to foods, but these and some of the sugar alcohols are used to produce a desired texture, with appropriate taste quality derived from combination with intense sweeteners.

Table 1. *Sugar substitutes in common use*

	Approximate sweetness (sucrose equivalents)*
Intense sweeteners	
Acesulfame K	200
Aspartame	180
Cyclamate	30
Neohesperidin dihydrochalcone	200
Saccharin	300
Sucralose†	600
Thaumatin	2500
Bulk sweeteners	
Sorbitol	0·7
Mannitol	0·6
Xylitol	0·9
Lactitol	0·4
Maltitol	0·75
Isomalt	0·6
Bulking agents	
Oligosaccharides	0·3–0·6
Polydextrose	Not sweet

* The appropriate relative weight of sucrose required to deliver the same maximum sweetness intensity is estimated from a range of values, and can vary considerably between different food applications, individuals, and assessment methods.

† Not currently approved for use in the European Union.

Sugar alcohols, oligosaccharides, and polydextrose may undergo variable degrees of bacterial fermentation in the colon (Livesey *et al.* 1993; Bornet, 1994; Gibson *et al.* 1996), yielding a range of metabolizable by-products and making the physiological fuel values of such materials difficult to determine with precision. Typical values for sugar alcohols are in the range of 8–15 kJ/g, with a value of 10 kJ/g currently applied for labelling purposes in the EU (Livesey, 1991; Van Es, 1991; Bornet, 1994), compared with 17 kJ/g for fully metabolizable carbohydrates. The physiological fuel values for polydextrose and oligosaccharides are generally found to be in the lower range of 4–8 kJ/g (Ranhotra *et al.* 1993; Achour *et al.* 1994). Unpleasant gastrointestinal side-effects of high intakes of sugar alcohols and resistant oligosaccharides place limits on their presence in the food supply (see p. 830).

Fat substitutes

Some examples of current and proposed ingredients for fat replacement are listed in Table 2. These comprise a varied range of materials, which can substantially differ in potential applications and physiological effects. Their functional and sensory properties and limitations are discussed in detail in other sources (for example, Iyengar & Gross, 1991; Lindley, 1993; Lucca & Tepper, 1994).

Carbohydrate (CHO)- and protein-based fat-replacement materials can be considered to be nutritionally well understood, and generally present little toxicological or physiological concern at proposed levels of use. Although these materials suffer from very significant sensory and functional limitations as general fat substitutes, they are presently used in a range of foods, and are particularly effective in delivering fat-like textures where the final product has a significant water content and is not exposed to extremely high temperatures or temperature variations. They do not participate in the

Table 2. *Examples of current and proposed ingredients for fat replacement*

Carbohydrate and protein-based
Modified glucose polymers
Modified starches
e.g. from tapioca, maize, potato, rice, oats
NSP
e.g. pectins, gums, marine colloids, cellulose derivatives
Native proteins
e.g. gelatin, maize protein, whey-protein concentrate
Microparticulated proteins
Lipid-based
Fatty acid esters of sugars or sugar alcohols
e.g. olestra
Other non-absorbed or poorly-absorbed non-triacylglycerol lipids
None currently approved
Structured lipids containing specific fatty acids
Medium-chain triacylglycerols
Emulsifiers and functional ingredients
e.g. polyglycerol esters, mono- and diacylglycerols, lactylates, lecithin

development of many characteristic and desired fat-associated flavours, and flavour adjustment around these ingredients is often problematic.

Ingredients in the other major category, the lipid-based materials, can have functional and sensory characteristics very similar to the fats they might replace, and therefore offer much broader scope for potential applications. In particular, they can potentially provide both the characteristic texture and flavour effects of native fats. Some of the materials in Table 2 are completely resistant to hydrolysis in the gut, being excreted intact, and therefore having essentially no metabolizable energy value. However, uncertainties about the long-term safety, and particularly nutritional and gastrointestinal effects has been an obstacle to the wider approval and food use of non-absorbable lipids (discussed on p. 831). Only one of these materials, a mix of hexa-, hepta-, and octa-fatty acid esters of sucrose ('sucrose polyester'; now assigned the generic name olestra), has recently been approved in the USA for use only in savoury snack food products. Several more recently developed materials take advantage of the incomplete absorption of naturally-occurring long-chain saturated fatty acids, and the lower energy density of medium- and short-chain fatty acids. These are used to generate structured triacylglycerols with a reported energy density of approximately 20 kJ/g, compared with 38 kJ/g for a typical mix of dietary fats (Peters *et al.* 1991; Finley *et al.* 1994). The sensory and functional characteristics of these fats make them suited to certain applications, and their primary use thus far has been in chocolate confectionery, baked goods and fillings. At the present time, these have not yet been approved for food use in the UK or EU, but are being used in other countries including the USA.

Polyglycerol esters and a range of other emulsifiers and stabilizers form an intermediate category. Depending on the material, their functional and metabolic properties may vary quite widely. These materials may be partially or wholly digestible, but are generally used (as part of an aqueous emulsion or suspension) at rather low concentrations relative to the quantity of fat they might replace (Setser & Racette, 1992).

NUTRITIONAL ASPECTS OF SUGAR AND FAT SUBSTITUTES

Sugar substitutes: specific nutritional issues

There is no specific essential role for sucrose in human diets, although it currently makes a substantial contribution to energy intakes in many cultures, and generates a range of physiological responses. Primary concerns which have prompted development and marketing of substitutes relate to dental caries, glycaemic control, and energy balance, although other health effects have also been suggested (Department of Health, 1989). Many materials used in place of sucrose may offer lower cariogenicity than fermentable sugars in certain food applications (e.g. chewing gum; Wennerholm *et al.* 1993), and sugar substitutes also have been used extensively in foods and diets for diabetes (Finer, 1991). However, it is clear that the commercial promotion and public interest in these ingredients is overwhelmingly oriented toward their putative role in weight control.

While there are possible toxicological concerns relating to certain specific intense sweeteners, these substances do not generally raise special nutritional issues beyond those relating to the replacement of sucrose per se. However, because there is little small intestinal hydrolysis or absorption of sugar alcohols and bulking agents (see Livesey *et al.* 1993), they reach the large bowel intact and can generate a range of potentially harmful, unpleasant, and also possibly beneficial side-effects (Gibson *et al.* 1996). The most common and noticeable unpleasant effects of high intakes include diarrhoea, cramps and flatulence, which have been reported to occur at single doses of as low as 10 g sorbitol (Finer, 1991; Bornet, 1994), and which prevent many of these ingredients from use in a wider range of applications or at higher concentrations.

Fat substitutes: specific nutritional issues

Fats in foods may be seen as serving three basic nutritional functions: (1) a source of essential fatty acids; (2) a carrier and source for fat-soluble vitamins; (3) a source of energy for storage or oxidation. Clearly, the only nutritional requirements which must be fulfilled by fats are those established for essential fatty acids and fat-soluble vitamins, and it is apparent that the needs for these can be satisfied by diets quite low in total fat content. However, there has been some concern expressed in situations where substitution for fats reduces not only the concentration but also the bioavailability of these nutrients.

At present, there is little concern about the likelihood of essential fatty acid deficiencies occurring as a result of use of foods containing fat substitutes, even with substantial reductions in fat intakes. It is conceivable, however, that very high levels of fat substitution centred on particular food categories could affect the levels and ratios of specific unsaturated, saturated, *n*-6 and *n*-3 fatty acids in the diet. With further resolution of the requirements for *n*-3 fatty acids and their roles in health and disease, there may be greater concern also about intakes of selected populations. These issues are speculative, but may merit future consideration if certain individuals or population groups were to become extremely heavy users of fat-substituted products, combined with significant changes in nutritive fat sources.

The different categories of fat-substitute materials differ markedly in their potential physiological effects. Most of the CHO- and protein-based materials are partially or fully digested and absorbed, but may effect a reduced-energy product by virtue of their low energy density when used in foods. Influences on other food components or nutrients in the gastrointestinal tract in this case are generally minimal, although some materials such as cellulose and certain gums which are resistant to digestion may act as bulking and adsorbing agents within the gut. In large quantities, these could adversely affect the absorption of some micronutrients, particularly minerals, and possibly produce a laxative effect; however, these effects are well known, and have not generally been a major concern with regard to consumption of these materials as fat substitutes at anticipated levels. Studies carried out with currently available ranges of reduced-fat foods (not containing olestra) have found little effect on measures of micronutrient intakes or related biochemical measures (Velthuis-te Wierik *et al.* 1996; D. J. Mela, S. J. Gatenby, J. I. Aaron and G. Morton, unpublished results).

Non-absorbable lipids achieve their nutritional properties by resistance to hydrolysis by human digestive enzymes and bacterial populations within the gastrointestinal tract. They are therefore excreted intact, and may function as a pool of solvent for other lipophilic materials throughout the length of the gut (see Jandacek, 1984), reducing the bioavailability of dietary components such as some vitamins, cholesterol, and other compounds of biological interest. Within this category, the vast bulk of human nutritional research has been carried out using olestra.

In normal healthy adults, vitamin D is only conditionally required from foods, and olestra appears to cause little impairment of vitamins D or K status (Glueck *et al.* 1982; Mellies *et al.* 1985; Jones *et al.* 1991*a,b*). Nevertheless, some concern has been directed toward certain populations at risk (e.g. elderly or clinical populations, individuals with low sunlight exposure). Much greater concern has been directed toward vitamins A and E, as decreased absorption of carotenoids and vitamin E have been associated with decreases in plasma vitamin levels in several studies using unsupplemented preparations of olestra (Fallat *et al.* 1976; Glueck *et al.* 1979, 1982, 1983; Mellies *et al.* 1983, 1985; Weststrate & van het Hof, 1995). The current approval of olestra in the USA requires that it is supplemented with vitamins A, D, E, and K, at levels calculated to offset any losses. This has been a prominent issue in the regulatory considerations for these types of fat substitutes, and the possible nutritional effects are likely to be carefully monitored.

The issue of possible effects of olestra on carotenoids and other phytochemicals remains contentious. Weststrate & van het Hof (1995) reported that 12 g olestra/d, eaten with main meals, prompted marked decreases in plasma levels of β-carotene, lycopene, β-cryptoxanthan and lutein, and levels of β-carotene and lycopene were significantly reduced by intakes of only 3 g/d. However, simultaneous ingestion of the olestra and carotenoids together within meals is a condition which maximizes the opportunity for olestra to interfere with absorption. It is not clear if this result is directly relevant to the use of olestra in savoury snack foods, which might not commonly be consumed together with major carotenoid sources, hence limiting the probability of interactions posing a meaningful risk to carotenoid status. Potential effects of olestra on these and other phytochemicals with putative health benefits remains perhaps the major substantive concern relating to its long-term nutritional effects. In addition, olestra consumption may produce gastrointestinal discomfort and loose stools, effects which will differ between individuals and are more likely at relatively higher (although not necessarily exceptional) levels of consumption. While potentially unpleasant, these have not generally been viewed as posing a significant health risk. Inevitably though, the nutritional and other concerns which have limited the application of olestra to a very small segment of the food supply also greatly limit any potential overall benefits which might ensue from its use.

Sugar substitutes: influence on dietary intakes

Data from experimental studies (Naismith & Rhodes, 1996; Mela, 1997) and theoretical considerations (Beaton *et al.* 1992; Anderson & Leiter, 1996) suggest that replacement of sugars with intense sweeteners should lead to a reduction in CHO intake (as sugars), but perhaps also to a higher proportion of dietary energy being derived from fat. In a prospective intervention trial, we found that high-sucrose consumers who adopted use of reduced-sugar products significantly increased the proportion of energy from fat in their diets (Gatenby *et al.* 1997; Mela, 1997). However, while there is also ample evidence that fat and sugar intakes tend to be negatively correlated within and between many populations (Gibney, 1990; Lewis *et al.* 1992; Gibson, 1993; Baghurst *et al.* 1994), the so-called 'sugar–fat seesaw' (McColl, 1988), the limited cross-sectional data available do not support a link between intense-sweetener use and either sugar or fat intakes (Chen & Parham, 1991; Anderson & Leiter, 1996).

Models predicting that intense sweetener use might result in lower CHO and greater fat intake, rest on the assumptions that (1) consumers actually replace sugar-sweetened products with the sugar-substituted versions, and (2) that individuals exhibit energy compensation which is not food- or macronutrient-specific. Most experimental feeding studies suggest that the latter is generally true; however, there is surprisingly little evidence that individual or population use of sugar substitutes has any significant influence on macronutrient intakes, including intakes of sugars.

Long-term population data using reliable and consistent measures of sucrose, added sugar, or sugar-substitute intakes are not readily available, and can be difficult to interpret (Anderson & Leiter, 1996). Analyses of adjusted commodity disappearance data suggest that the amount of sucrose available for consumption in the UK rose from 95 g/d per capita in 1980–1, to a high of 102 g/d per capita in 1988–9, falling to an estimated 90 g/d per capita in 1995–6 (C. Ruxton, personal communication). These data almost certainly overestimate actual sucrose intakes; nevertheless, because of falling average total energy intakes during this period (Black, 1991; Ministry of Agriculture, Fisheries and Food, 1991, 1996), the general trend overall for 1980–1995 is towards a modest increase in the percentage of energy derived from sucrose, despite a dramatic concomitant growth in the availability and consumption of sugar-substituted food products. Data from the USA also show no meaningful decline in use of energy-containing sweeteners in parallel with expansion of the intense sweetener market.

There is very little experimental information addressing the issue of how use of sugar substitutes relates to macronutrient intakes. In a small cross-sectional study, Chen & Parham (1991) found no clear evidence that greater use of intense sweeteners was associated with lower sugar consumption. Although the presentation and statistical analyses of data in that study are limited, they show no clear association between intense sweetener use and relative macronutrient composition of the diet, including sugars. These results are consistent with the view that intense sweeteners were added to the diet, rather than replacing and causing a reduction in the consumption of dietary sugar sources. However, there is a need for more information on the specific food selections of users and non-users of sugar substitutes, which might give an indication of the manner in which these are incorporated into the diet, replace certain foods and macronutrients, and perhaps generate increases in the consumption of others.

The available information is consistent with the notion that, in practice, sugar-substituted foods are commonly added to pre-existing diets rather than specifically used in place of sugar-containing foods. Given this, and that much of sugar-substitute use is in products with negligible macronutrient or energy content (e.g. 'diet' beverages and

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'tabletop' sweeteners), the impact of additional intense sweetener intakes on intakes of sugars or total energy or, indeed, intakes of any macronutrients (or micronutrients) could actually be very small. This view of consumer behaviour should be borne in mind in extrapolating from research studies based on the assumption of direct substitution.

Fat substitutes: influence on dietary intakes

Modelling studies indicate that marked reductions in fat intake could be achieved through use of a limited number of reduced-fat alternative products, at least amongst individuals who usually eat particular items with high frequency (Lyle *et al.* 1991), although many different dietary approaches could be taken to reach the same effect (Smith-Schneider *et al.* 1992). More recently, Patterson *et al.* (1996) carried out a simulation based around estimated energy and fat intakes from a food-frequency questionnaire which included options for respondents to specify their use of a range of fat-reduction practices, including consumption of reduced-fat alternatives. Computations based on recoding these options to their full-fat alternatives revealed a marked influence on estimates of fat and energy intakes, and provide an indication of the relative impacts which would be attributed to specific behaviours or food exchanges. As with sugar substitutes, the models described previously largely assume direct substitution for full-fat products by their reduced-fat alternatives.

There is a growing body of relevant prospective intervention studies relating to use of reduced-fat foods. Kristal *et al.* (1992) did not specifically quantify the impact of use of fat-substituted foods per se, but reported that their use was easily adopted and highly acceptable, although not necessarily the most effective of several approaches used to achieve reductions in fat intakes by subjects given extensive dietary and behavioural counselling. Intervention trials focusing specifically on use of reduced-fat foods indicate that their use should contribute to a reduction in the proportion of energy derived from fat (Gatenby *et al.* 1995, 1997; Westerterp *et al.* 1996; de Graaf *et al.* 1997). In these trials, subjects were not fixed into strict dietary or food selection regimens, and had the opportunity to simultaneously purchase and consume modified and traditional items of any composition, and hence the potential to achieve any final level of relative macronutrient intake. This methodological approach contrasts with more-controlled studies where subjects have been placed on regimens of relatively fixed composition (for example, Kendall *et al.* 1991) or been assigned very clear and prescriptive dietary targets (e. g. for fat intake or weight loss).

In studies carried out in our laboratory (Gatenby *et al.* 1995, 1997), consumers purchasing and using reduced-fat food products from retail shops for 6- or 10-week periods significantly reduced their fat intakes, and similar effects have been observed in a 6-month multicentre trial in The Netherlands, in which subjects were given commercially-available reduced-fat products (Westerterp *et al.* 1996; de Graaf *et al.* 1997). However, in these studies, it is apparent that the reductions in fat intake amongst users of the reduced-fat foods almost entirely occur amongst those subjects with a starting fat intake above 35% of energy, with little change occurring amongst subjects with moderate or low initial fat intakes (de Graaf *et al.* 1997; Mela, 1997).

ROLE OF SUGARS AND FATS IN ENERGY BALANCE

Evaluation of the effect of fat and sugar substitutes on energy balance must consider the peri- and postprandial effects of the macronutrients these materials would replace. It is increasingly apparent that sugars and fats have very different roles in appetite control, energy metabolism and fat deposition, and variation in these components in freely-selected (but not necessarily in fixed, isoenergetic) diets could be expected to have significantly different implications for energy balance. In particular, information coming from investigations of biochemistry, metabolism, eating behaviour, epidemiology and feeding trials all support a causal role for high-fat, energy-dense foods and diets in the development of overeating and obesity, whereas the same lines of evidence suggest that sugar and CHO consumption may be considered protective or at least neutral (for reviews, see Swinburn & Ravussin, 1993; Astrup & Raben, 1995; Prentice, 1995; Weststrate, 1995; Mela, 1996; Poppitt & Prentice, 1996; Shah & Garg, 1996). Based on this, substitution for fat would seem likely to be a helpful approach to the prevention of overweight, although only if it is associated with meaningful reductions in fat intakes and perhaps also energy density (Poppitt & Prentice, 1996). On the other hand, simple substitution for sugar in foods may be a questionable strategy for weight loss or control, particularly if associated with compensatory increases in fat consumption, unless it can be clearly shown to be associated with a reduced energy density. In either case, effectiveness would ultimately rest on averting any physiologically- or cognitively-based responses which might prompt paradoxical increases in energy intakes or marked deviations in food selection patterns.

Although the preceding discussion points to fat restriction as an important part of obesity prevention, the specific advantages of low-fat diets in weight-loss programmes have less objective support, despite the fact that this a cornerstone of most current dietary approaches to weight loss. A large number of studies have found modest spontaneous weight loss occurring on *ad libitum* diets which are substantially reduced in fat content (Kendall *et al.* 1991; Retzlaff *et al.* 1991; Sheppard *et al.* 1991; Chlebowski *et al.* 1993; Raben *et al.* 1995; Schaefer *et al.* 1995), and a greater weight-loss response has been observed in overweight individuals relative to lean individuals (Siggaard *et al.* 1996). Some, but not all, trials specifically focused on weight reduction have also found that *ad libitum* very-low-fat diets can produce and maintain weight loss comparable with more traditional energy-restricted diets (Schlundt *et al.* 1993; Shah *et al.* 1994; Jeffery *et al.* 1995; Tuobro & Astrup, 1996).

In contrast to the situation with fat, there are few data which would support specific restriction of sugar consumption as a part of weight-loss strategies. Data from a 'pilot' study by Kanders *et al.* (1988) is often cited as evidence of the benefits of use of intense sweeteners in slimming, although the actual results produce little evidence for such an interpretation. Recent studies have failed to identify any benefit of sucrose restriction in weight-loss diets (Raben *et al.* 1996; Surwit *et al.* 1996; West & de Looy, 1996), although there are few data on long-term acceptability or compliance with diets containing sugars *v.* sugar substitutes.

MACRONUTRIENT SUBSTITUTES AND ENERGY INTAKE

There is a large volume of studies assessing the influences of sweetness and sugar substitutes on appetite and energy intake, and a smaller number of studies focusing on fat substitution. The vast majority of this literature comprises short-term experiments, based in the laboratory and/or using covert manipulations of preloads or foods, and focused on regulation of hunger, satiety, and eating. The scientific roots of debates which have emerged within this body of work are too intricate to address here, but previous reviews cite and describe specific experiments and differences in their design, findings, and interpretation (Rolls, 1991; Blundell & de Graaf, 1993; Bellisle & Perez, 1994; Blundell & Rogers, 1994; Anderson, 1995; Rolls & Hammer, 1995; Blundell *et al.* 1996; Mela, 1996).

The amount of energy eaten within a test meal (satiation) is often observed to be related to the energy density of foods provided; hence, there is a tendency to overeat higher-fat meals (Blundell *et al.* 1996), notably even when fat is directly compared with sucrose (Green *et al.* 1994), and to undereat when familiar foods are manipulated in a way which reduces their energy content below normal. This is not necessarily a direct effect of food composition, but may reflect the fact that much of normal food intake is guided by social norms and customary eating patterns (e. g. habitual numbers, volumes, or weights of particular food items consumed at a sitting). Provision in a single test meal of a range of foods which are uniformly very high or very low in energy density, or covertly manipulated, may allow limited opportunity for either post-ingestive physiological signals to influence the size of the meal, or for longer-term cognitive controls over eating to develop.

Many studies have focused on the ability of foods to suppress hunger and subsequent eating (satiety), by using a fixed experimental preload, followed by subsequent measurement of *ad libitum* intake of test meal comprising a range of food items. These types of studies indicate that there is a general tendency toward compensation for most or all of moderate covert reductions in the energy content of preloads through use of sugar and fat substitutes in place of traditional ingredients, if subjects are allowed *ad libitum* access to a wide choice of foods (Bellisle & Perez, 1994). This compensation invariably takes the form of a mixed diet of normal composition; i.e. it is not usually found to be macronutrient specific. However, there are many situations where individual differences or experimental design allows specific sources of variance in short-term stimulation or suppression of eating to be observed (Blundell & Rogers, 1994; Rolls *et al.* 1994; Rogers *et al.* 1995; Blundell *et al.* 1996). In particular, there may be a difference in the 'satiety value' of macronutrients, and there is evidence that energy added as fat may have a weaker effect on suppressing subsequent hunger and eating than energy from CHO (Rolls *et al.* 1994; Blundell *et al.* 1996).

This body of research has generated some important principles relevant to understanding the potential behavioural responses to sugar and fat substitutes in foods; however, these types of studies also have many limitations. Most notably, they have been primarily designed to examine the psychobiological aspects of hunger and satiety, not to characterize the actual dietary behaviour of consumers in natural situations. Even quite marked behavioural effects seen in highly controlled experiments may explain only a small part of the variance in eating behaviour where many other factors are influencing decisions of what, when, and how much to eat. It is therefore unfortunate that this work makes up such an overwhelming part of the literature on the topic that it forms the basis of most scientific reviews, and that the results have inevitably been extrapolated far beyond the issues which were actually addressed. Clearly there is a need to broaden the research base in this area, in order to encompass time periods and conditions which allow for development of physiological or cognitive behavioural regulatory responses which may become meaningful with continued experience and intakes of macronutrient-substituted foods (Bellisle & Perez, 1994; Mela, 1996).

CONSUMER BEHAVIOUR ISSUES

There are many outstanding issues relating to the way commercially-available fat- and sugar-substituted foods might be used by consumers in practice. Will consumers be directed toward use of certain foods (e. g. those traditionally high in fat or sugar) which are presently avoided on nutritional grounds? Does the use of 'healthy' modified foods perhaps diminish motivation to comply with other dietary guidance (e. g. for fruit and vegetables)? Laboratory studies have suggested that individuals might respond counter-intuitively to information on fat content (e. g. inappropriately increasing fat or energy intakes; Caputo & Mattes, 1993; Aaron *et al.* 1995; Shide & Rolls, 1995), although this has not been apparent in intervention trials using commercial products under realistic acquisition and consumption conditions (Gatenby *et al.* 1995, 1997). Nevertheless, for both fat- and sugar-substituted products there remain questions about how consumers respond to nutritional and marketing claims, in terms of overall food consumption patterns.

At present, full publications of population studies which relate energy and nutrient intakes and body-weight status to actual consumption data for macronutrient-substituted foods are virtually non-existent. Existing databases from national surveys and dietary intervention trials provide a wealth of data on food and nutrient intakes, anthropometric, demographic, and biochemical measures. Most of these have sufficient specificity that it should be possible to characterize individuals practising particular dietary patterns, e.g. levels of use of macronutrient-substituted foods. Such studies have the tremendous advantage of assessing what is happening in practice amongst large numbers of consumers and specific population subgroups, although the data necessarily rely on self-reports of varied quality, and can identify only associations, not causality.

There is also a potential issue of economic costs to consumers for use of products with reduced energy density produced with fat and sugar substitutes. Assuming that these products cost as much or more than their traditional counterparts, and that their use is accompanied by at least partial (and more likely, complete) energy compensation, it necessarily follows that the total volume of food consumed, and hence cost to the consumer, must increase with use. While this could be seen as an economic benefit to the food industry, it may be an issue which bears upon the appropriateness of use of such products within a broader public health strategy, at least for some consumers.

CONCLUSIONS

Despite a long history and widespread use of macronutrient substitutes, many significant questions about their nutritional implications remain unanswered. What are the dietary implications for ordinary consumers purchasing fat- and sugar-substituted foods in the shops and using them *ad libitum*? Do these products help to reduce overall fat or sugar intakes, or aid in weight control? Do specific fat- and sugar-substitute technologies and ingredients generate acceptable nutritional benefit : risk ratios? Ultimately, the dietary implications of fat and sugar substitutes will reflect not only the composition of commercial food products made with them, but the overall behaviour of consumers, the shifts in food choice, and the actual patterns of nutrient and energy intakes which result from informed use in normal eating. At present, modest use of fat and sugar substitutes seems unlikely to cause harmful (or beneficial) changes in nutritional variables, although there are real concerns relating to certain specific ingredients.

In terms of the prevention of overweight and obesity, there is a consensus developing from several lines of research that fat reduction should be beneficial, whereas specific limitations in consumption of sugars may not be directly relevant, or potentially even deleterious. There is little clear evidence of dietary benefits from sugar substitutes as they are presently used, and concerns that their use may produce compensatory increases in fat consumption. Substitution for fat looks more promising, but only if it is associated with meaningful reductions in fat or energy density, and does not deflect consumers from adopting other 'healthy' eating guidance. Clearly, unless part of a wilful effort to reduce intakes or control diet composition, consumers are likely to compensate for most or all of the energy reduction of macronutrient-substituted foods, probably by consumption of a mixed diet. Research to date has tended to focus heavily on short-term and laboratory-based experiments under controlled conditions, but the answers to the questions posed will require greater consideration of the long-term behaviours of consumers consuming real foods under normal conditions.

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