

## Changes in dietary energy with novel proteins and fats

BY PETER N. GILLATT AND SUSAN M. LEE

*Leatherhead Food Research Association, Randalls Road, Leatherhead, Surrey KT22 7RY*

Obesity and heart disease are two of the major health concerns in the Western world.

As a consequence of these and other nutritional concerns, it has been suggested that the amount of energy derived from fat in the diet should be reduced. Many of the nutritional factors involved are not fully understood but the perceived health issues have led to increasing pressure into ways of reducing the fat content of foods.

A number of products that are intended to aid a reduction in fat intake are already available; for example, low-fat spreads and milks, oven chips and aerosol creams.

It must be remembered, however, that without fat, meals often lack flavour and other pleasant organoleptic properties that are associated with fatty foods. Additionally, it is clear that there are nutritional needs for oils and fats and, although a reduction in the amount of fat consumed might be beneficial, a balanced diet containing fat is essential.

Nonetheless, for some time investigations have been undertaken in an attempt to find the ideal fat substitute. Studies on the digestibility of rapeseed oil were carried out by Deuel (1948), and several workers, including Channon & Collinson (1929), have studied the absorption of mineral oils.

In the mid to late 1980s, a number of potential replacements of fat were proposed and some have gained 'generally regarded as safe' (GRAS) status, and are incorporated into foods sold in the UK. There are, however, certain obstacles that threaten the development of fat substitutes. For example, more information regarding the potential metabolism of unabsorbed fat in the gut might be required. In addition, concern has been expressed over the potential of certain fat substitutes to reduce the absorption of fat-soluble vitamins. Unlike many other food additives or ingredients, the probably high intakes of fat substitutes will mean that certain fat mimetics will require most considerable safety testing.

Nutritionists are also concerned that the use of fat substitutes will encourage poor eating habits since large quantities of ice-cream and snacks, for example, might be consumed at the expense of fruit and vegetables. It should be remembered, however, that fat substitutes provide less energy than conventional fats and, thus, they provide a means for reducing dietary fat to levels recommended by the National Advisory Committee on Nutrition Education (1983) and Committee on Medical Aspects of Food Policy, Department of Health and Social Security (1984) reports. In addition, certain fat substitutes are associated with a lowering of blood cholesterol levels.

It is the purpose of the present paper to review the three main groups of fat mimetics and to examine their properties and uses. It may be considered that fat mimetics fall into two main groups: those based on gels formed from modified starch or proteins and those based on fatty acids or fatty alcohols that are esterified to a number of components in such a way that metabolism of these compounds does not take place.

### THE MALTODEXTRINS

This group of compounds is based on starch and, when incorporated into food products, might be considered to be high in water and low in solids. A number of products of this

type are available at present such as N-Oil, a tapioca dextrin produced by National Starch and Chemical Corporation, and Paselli SA2, a potato starch maltodextrin, produced by Avebe America Inc.

*Starch-hydrolysis products (SHP)*. These materials were first produced in East Germany, and SHP may be considered to be a gellifying maltodextrin from which a thinnish opaque gel that contains approximately 750 g water/kg can be produced; the gel contains very small insoluble starch particles (Anon, 1981; Hannigan, 1981).

SHP are manufactured from commercial white potato starch, by slurring and partially degrading the carbohydrate with  $\alpha$ -amylase (EC 3.2.1.1). In order to obtain the required degree of starch degradation the process is carefully controlled and is stopped by heat so that the final product has a dextrose equivalent of between 5 and 8.

SHP are free-flowing white powders that are soluble in cold aqueous liquids either following homogenization or by heating at 80° (180°F). On cooling, solutions that contain more than 200 g dry matter/kg form spreadable shiny white gels that melt at between 50 and 90°.

SHP are miscible with water, butter, margarine and lard and are partially miscible with vegetable oils. As a result of their miscibility with fat and their attractive 'mouth-feel', SHP are claimed to be very useful fat extenders in food emulsions. The latter are stable and do not undergo phase separation on storing, even at refrigerator temperatures.

*Maltrin MO40*. This product was developed by the Grain Processing Corporation and is a digestible, spray-dried carbohydrate produced from maize starch, and can partially replace oil in a number of foods (Morris, 1984; Haumann, 1986). It is a low-dextrose-equivalent maltodextrin, which contains approximately 980 g penta- and higher oligosaccharides/kg. As a result of low hygroscopicity this product has a creamy, fat-like texture (Labarge, 1988). A solution containing 250 g solids/l gives rise to a soft white heat-reversible gel, which has been considered to have an appearance similar to that of shortenings (Haumann, 1986). Being totally digestible it has an energy value of 16.7 kJ (4 kcal)/g carbohydrate. However, a 250 g/l solution may be prepared, the resulting gel would then contain only 4.2 kJ (1 kcal)/g. This compares very favourably with the 37.7 kJ (9 kcal)/g derived from fat which it may replace.

SHP and maltodextrins are considered to have many benefits, being natural products, of low energy value, which may be further reduced when more water can be incorporated into the gels. Additionally, the raw materials used for the production of SHP are cheap and readily available. There is also an increasing body of opinion that suggests more carbohydrate should be consumed by the public, at the expense of fat.

#### POLYDEXTROSE

This product was invented by Pfizer in Connecticut, USA, while a number of polysaccharides were being explored for their potential as low-energy replacements for sugar and as partial substitutes for fat, flour and starch (Rennhard, 1973; Pfizer Inc., 1976; Leibrand *et al.* 1985). Polydextrose is marketed primarily as a bulking agent but, as a result of its texturizing properties, whereby it improves 'mouth-feel', it has also found use as a fat substitute.

Polydextrose has a high molecular weight compared with sugars and oligomers, but because it contains a large amount of branching (thereby being unable to self-associate) the solubility of the product increases and the viscosity decreases, giving rise to the

properties outlined previously. It is prepared by high-temperature polymerization of glucose under catalytic conditions and is composed almost entirely of randomly cross-linked glucose polymers with many different glucosidic bonds, but with the 1,6-bond predominating.

The random and high degree of branching that is inherent to polydextrose is considered to make it resistant to digestive enzymes of the small intestine. Some polydextrose is hydrolysed, which results in the compound having a lower energy value than the available carbohydrates. As with the SHP, it will be seen that the energy density of this product is low in comparison with that of triacylglycerol-fat (Leibrand *et al.* 1985; Labarge, 1988).

Metabolic balance tests have shown that polydextrose does not interfere with the absorption and utilization of essential vitamins, minerals or amino acids. In toxicity studies on rats, polydextrose was included in the diet for the lifetime of the animals, without deleterious effect. This compound has been approved by the USA Food and Drug Administration (FDA) for use in certain baked goods and baking mixes. It has also been used in chewing gums, confectionery, salad dressings, frozen dairy desserts, puddings and sweets.

#### SIMPLESSE

Simplese is a dairy-based, fat mimetic containing ultrafiltered egg white, condensed skim milk, water, sugar, pectin, lecithin and citric acid (Nutrasweet Publicity Material). It has recently been granted GRAS status by the FDA. Simplese is produced by heating and blending (possibly under very high shear) using a process called microparticulation. The process coagulates the proteins into a gel structure. The spheroidal particles produced are very small, between 0.1 and 2  $\mu\text{m}$ . It is important that the diameter of the particles is of this order, since with individual spheres having a diameter greater than 3  $\mu\text{m}$  the tongue will perceive the product as particulate matter, rather than fluid. The tiny size and round shape of the particles in Simplese allow them to move freely, thereby creating a smooth, rich creamy texture usually associated with fat or fatty products (Anon, 1988; McCormick, 1988). In its hydrated form, Simplese provides 5.6 kJ (1.3 kcal)/g and will replace 1 g fat (Gillis, 1988). In addition to frozen desserts, the fat substitute might be used in dairy products such as yoghurt and cheese products. It also offers great potential as a fat substitute for use in a number of traditionally high-fat products, such as ice-creams, mayonnaise and margarines.

A petition filed by Nutrasweet in 1988 for GRAS status has now been granted by the FDA. The manufacturing company has indicated that there is little or no evidence relating to health problems from the consumption of microparticulated proteins, and further suggests that many such compounds exist in nature.

The major disadvantage with Simplese is its heat-sensitivity. Consequently, if it is to be used in products that are exposed to high temperatures it must be incorporated after the heat treatment. Simplese might, for example, be acceptable if applied as a margarine-type spread to warm toast, but would not find use as a frying oil or baking shortening.

#### SUCROSE POLYESTERS (SPE)

This group of compounds is part of a much larger class, which might be described as carbohydrate polyesters. Procter and Gamble has made this group of compounds very

well known, under the trade name, Olestra. Ironically, SPE were discovered by Procter and Gamble during studies undertaken with the aim of establishing a new, easily digestible, high-energy fat for infants who were intolerant to milk.

SPE is a non-absorbable fat-like material consisting of hexa-, hepta- and octa-esters of sucrose and, generally, long-chain fatty acids. It is important that the number of substitutions of the hydroxyl groups on the sucrose is in excess of four, since those compounds containing only three fatty acid esters will be hydrolysed and digested. As the degree of substitution increases the ability of digestive enzymes to hydrolyse the ester linkages is decreased and when the value is 6 (or greater) the amount of SPE hydrolysed is below 0.01% (Mattson & Volpenhein, 1971).

The fatty acids esterified to the sucrose ideally contain between C<sub>14</sub> and C<sub>18</sub>; if the fatty acid is less than C<sub>10</sub>, hydrolysis of the ester linkage is more likely. This observation lends support to the view that the reason for the lack of metabolism of SPE is the stearic hindrance by long-chain fatty acids on the digestive enzymes.

There is a variety of synthetic pathways for the production of SPE (Rizzi & Taylor, 1976, 1978). Patents with improved methods were issued to Volpenhein (1985*a,b*) and Yamamoto & Kinami (1986).

As recently as January 1990, Akoh & Swanson (1990) suggested that conditions for SPE production had been further improved by reacting sucrose octaacetate with the fatty acid methyl esters of salad oils; yields of almost 100% of purified SPE were obtained.

The physical properties of SPE depend on the fatty acids used in its production. For example, SPE made from unsaturated fatty acids, such as those found in sunflower-seed oils, or short-chain length acids, are free-flowing liquids. However, with saturated long-chain acids a high-melting solid is formed.

It has been stated (Boggs, 1986) that the taste, appearance, surface tension, interfacial tension, aroma and lubricity of SPE are indistinguishable from those of triglycerides with the same fatty acids. It has been suggested that SPE acts as an organic solvent in the intestine and as such it has the ability to remove from the body potentially toxic materials, such as the lipophilic pesticides DDT (Boggs, 1986; Labarge, 1988). The cholesterol-lowering properties of SPE have been widely reported (Fallat *et al.* 1976; Mattson *et al.* 1976; Mellies *et al.* 1985; Grundy *et al.* 1986). These and other studies suggest that SPE has the ability to reduce plasma cholesterol by increasing the excretion of cholesterol and its metabolites but without affecting bile acid excretion.

Total and low-density-lipoprotein cholesterol concentrations in the circulation, which are believed to be deleterious to health, are reduced but there is little effect on high-density-lipoprotein cholesterol, which is thought to have a positive effect on health. The decrease in low-density-lipoprotein cholesterol is probably caused by a lower total energy intake together with a decrease in cholesterol absorption.

One of the main problems with the use of SPE in food is its reported unwanted laxative effects (Jandacek & Webb, 1978; Boggs, 1986). In an attempt to overcome this problem, Bernhardt (1987) has filed a patent that gives details of SPE that are effective against laxative side effects. These compounds contain a much higher proportion of saturated and monounsaturated fatty acids and, in addition, have a much higher viscosity than those associated with the laxative effects. It is considered that these solid polyol fatty acid polyesters, which have a melting point of approximately 37°, might exhibit a certain crystallinity in the gut, thereby increasing the solid:liquid ratio and consequently reducing this unpleasant side effect.

Further concern has been expressed on the effect of SPE consumption on fat-soluble vitamins. A long-term study on hypercholesterolaemic patients found that vitamin A levels were not consistent but that vitamin E levels were significantly lower in subjects consuming SPE than in the placebo group. There was no difference in vitamin D between groups and vitamin K concentrations remained unchanged (Mellies *et al.* 1985). Another study (Fallat *et al.* 1976) indicated that SPE consumption reduced the levels of the vitamins A and E.

It must be stated, however, that a much more recent report (Lawson, 1990) indicated the very great lengths that Procter and Gamble have gone to in order to establish the safety of SPE consumption. The toxicological tests have involved 100 animal studies and twenty-five human clinical trials. It is stated that the protocols and results of these studies have been reviewed by independent pathologists and toxicologists. It has been said by representatives of Procter and Gamble that consumption of SPE led to no gross or microscopic changes to the morphology of any gastrointestinal tissue. Further to this, human clinical trials have shown that SPE does not affect the status of vitamins A, D and K under the proposed conditions of use. It has been stated, however, that SPE would be supplemented with vitamin E to compensate for the amount normally found in vegetable oils.

Unlike the fat substitutes described earlier, the potential applications of SPE are extremely varied and apply to foods that will be exposed to elevated temperatures. It has, for example, been considered that SPE would be used in quantities of up to 350 g/kg in shortenings, salad and cooking oils intended for use in the home and the food service industry. In commercial settings, it has been suggested that SPE might be used as a 750 g/kg substitute for use in deep-fat frying (Karcek, 1988).

Clearly, SPE potentially have a vast number of applications and it will be of great interest to follow Procter and Gamble's petition of the FDA for the clearance of Olestra in a number of food products.

#### OTHER HEAT-STABLE FAT SUBSTITUTES

There exists a number of others that, like SPE, are stable at elevated temperatures. Two such compounds, trialkoxytricarballoyate (TATCA) and trialkoxycitrate (TAC), both have structures that resemble those of triacylglycerols. However, whereas triacylglycerols are formed via the esterification of glycerol and three fatty acids, TATCA and TAC are products of the reaction between tricarballoyic or citric acid and three fatty alcohols. The effect of this is that TATCA and TAC contain ester linkages that are sterically reversed in comparison with triacylglycerols and as a result are not hydrolysed by digestive enzymes (Hamm, 1984). In addition, the viscosity and surface tension of these chemicals are similar to those of vegetable oils but they have the advantage, in this context, that their susceptibility to enzymic hydrolysis is very low; consequently their energy value is expected to be negligible.

#### THE FUTURE

A number of very useful fat substitutes have already been used in a variety of products and this trend is likely to continue, particularly following the recent approval of Simplesse by the FDA.

What is clear at present, is that there exist few, if any, fat substitutes that have FDA approval and can successfully be exposed to elevated temperatures. It is for this reason that such intense interest exists in the production of SPE, its safety and applications.

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