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Review - Natural Food Extracts and Additives Section

FAT REPLACERS – REVIEW

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Abstract

Reducing dietary fat is the primary dietary goal for many consumers. Fat replacers are compounds incorporated into food products to provide them with some qualities of fat. Trends in dietary fat intake, classification by nutrient source, energy density, specific application and functional properties of fat replacers will be reviewed. Specific application and potential effects on health status of fat substitutes also will be reviewed.
Keywords: *fat replacers, fat substitutes, fat mimetics, low fat*

Dietary factors are implicated in the etiology of a number of chronic degenerative diseases (Harrigan, 1989; Haumann, 1986). Health-conscious consumers continue to look for ways to improve nutritional habits without sacrificing psychological satisfaction (Kostias, 1997; O'Brien, 2003; Plug, 1993). High fat intake is associated with increased risk for some types of cancer, and saturated fat intake is associated with high blood cholesterol and coronary heart disease (Krauss, 2001; Poppitt, 1995,). Also, consumption of a diet rich in fat has been identified as a risk factor for excess energy intake, positive energy balance, and the development of obesity (Thomas, 1992; Wylie-Rosett, 2002; Siggaard, 1996).

Current dietary guidelines recommend limiting total fat intake to <30% of calories and saturated fats to <10% of total energy intake for the population as a whole. The AHA (American Heart Association) recommends that those with elevated LDL cholesterol levels or cardiovascular disease restrict saturated fats to <7% of calories. To achieve a more healthful dietary pattern, current dietary guidelines recommend increasing intake of fruits, vegetables, and grains and modifying the type and amount of fat consumed (Krauss, 2000; Wylie-Rosett, 2002).

Consequently, health conscious individuals are modifying their dietary habits and eating less fat (Miller, 1996; Cengiz, 2005). Consumer acceptance of any food product depends upon taste—the most important sensory attribute. Although consumers want foods with minimal to no fat or calories, they also want the foods to taste good (Cáceres, 2004; Duflot, 1996). The development of reduced-fat foods with the same desirable attributes as the corresponding full-fat foods has created a distinct challenge to food manufacturers (Zoulias, 2002; Zalazar, 2002). Fat has functional properties that influence processing and the eating qualities of a food item, and these functions must be accounted for when lowering the fat in a product (Chronakis, 1997; Kavas, 2004; Koca, 2004).

As a food component, fat contributes key sensory and physiological benefits. Fat contributes to flavor, or the combined perception of mouthfeel, taste, and aroma/odor (Lucca, 1994; Mistry, 2001; Sampaio, 2004). Fat also contributes to creaminess, appearance, palatability, texture, and lubricity of foods and increases the feeling of satiety during meals (Romanchik-Cerpovicz, 2002; Sipahioglu, 1999). Fat can also carry lipophilic flavor compounds, act as a precursor for flavor development (e.g., by lipolysis or frying), and stabilize flavor (Romeih, 2002; Tamime, 1999). From a physiological standpoint, fat is a source of fat-soluble vitamins, essential fatty acids, precursors for prostaglandins, and is a carrier for lipophilic drugs (Trudell, 1996, Cooper, 1997, Harrigan, 1989). Fat is the most concentrated source of energy in the diet, providing 9 kcal/g compared to 4 kcal/g for proteins and carbohydrates.

Fat may be replaced in food products by traditional techniques such as substituting water (Chronakis, 1997) or air for fat, using lean meats in frozen entrées (Hsu, 2005), skim milk instead of whole milk (Zalazar, 2002) in frozen desserts (Specter, 1994), and baking instead of frying (Haumann, 1986) for manufacturing or preparing snack foods;

Some lipids may be replaced in foods by reformulating with selected ingredients that provide some fat-like attributes (Tarr, 1995; Sipahioglu, 1999). These fat replacers can be lipid, protein or carbohydrate-based (Table 1) and can be used alone or in unique combinations (Akoh, 1998; Costin, 1999; Lucca, 1994; Crehan, 2000; Sandrou, 2000).

Fat replacers are generally categorized into two groups: fat substitutes and fat mimetics. Fat substitutes are ingredients that have a chemical structure somewhat close to fats and have similar physiochemical properties (Lipp, 1998; Kosmark, 1996; Peters 1997). They are usually either indigestible or contribute lower calories on a per gram basis. Fat mimetics are ingredients that have distinctly different chemical structures from fat. They are usually carbohydrate and/or protein-based. They have diverse functional properties that mimic some of the characteristic physiochemical attributes and desirable eating qualities of fat: viscosity, mouthfeel and appearance (Johnson, 2000; Duflot, 1996; Harrigan, 1989).

Fat substitutes are macromolecules that physically and chemically resemble triglycerides (conventional fats and oils) and which can theoretically replace the fat in foods on a one-to-one, gram-for-gram basis. Often referred to as lipid- or fat-based fat replacers, fat substitutes are either chemically synthesized or derived from conventional fats and oils by enzymatic modification. Many fat substitutes are stable at cooking and frying temperatures (Cooper, 1997; Duflot, 1996; Harrigan, 1989; Kosmark, 1996).

Table 1. Classification of fat replacers by nutrient source, energy density, specific application and functional properties

Type of fat replacer				Nutrient source	Energy density	Specific application	Functional properties
Fat substitutes (derived from fat)	**Olestra/ Olean**			Sucrose polyester of 6-8 fatty acids	noncaloric (not absorbed)	Savory snacks	Texturize, provide flavor and crispiness, conduct heat
	Caprenin			Caprocaprylobehenic triacylglyceride	5 kcal/g	Soft candy, confectionary coatings	Simulating properties of cocoa butter (emulsify, texturize)
	Salatrim			Short and long acyl trigliceryde molecule	5 kcal/g	Chocolate-flavored coatings, deposited chips, caramels and toffees, fillings and inclusions for confectionary, peanut spread	range melting points, hardness, appearance
						baked goods, fillings and inclusions for baked goods;	Emulsify, provide cohesiveness, tenderize carry flavor, replace shortening, prevent staling, prevent starch retrogradation, condition dough
						savory dressings, dips, sauces	Emulsify, provide mouthfeel and lubricity, hold flavorants
						dairy desserts, cheese	provide flavor, body, mouthfeel, and texture, stabilize, increse overrun
Fat mimetics	Derived from protein	**Simplesse**		White egg protein, milk protein	4 kcal/g	Yogurt, cheese, sour cream	stabilize, emulsify
		Simplesse100		Whey protein		baked goods	texturize
						frozen dessert products	texturize stabilize
						frostings	provide mouthfeel, texturize
						salad dressing, dips, mayonnaise	Texturize, provide mouthfeel
						margarine	texturize
						Sauces, soups	texturize
		LITA		zein	1-4 kcal/g	baked goods	texturize
		Trailblazer		White egg protein, serum protein mixed with xanthan gum		dairy products	Stabilize, emulsify
						Soups, sauces	texturize
Fat mimetics	Derived from protein	**N-Flate**		Non fat milk, gums, emulsifiers and modified starch		salad dressing	Texturize, provide mouthfeel
						Icings, glazes, desserts, ice cream	Texturize, stabilize
						ground beef	Texturize, provide mouthfeel, water holding
	Derived from carbohydrate	**GUMS**	Guar	Galactomannan extracted from leguminous seed	noncaloric	baked goods	retain moisture, retard staling
			Xanthan	Microbial polisaccharide produced by aerobic fermentation of *Xantomonas campestris*			
			Locust bean	Extracted from seeds of the tree *Ceratonia silique*			
			Carrageenan	Sulphated polysaccharides extracted from red seaweed (marine algae of the class *Rhodophyta*)		salad dressings	increase viscosity, provide mouthfeel, texturize,
			Gum arabic	Dry exude from *Accacia* tree			
			Pectins	Cell wall polysaccharides extracted from apple pomace, citrus peel, sugar beet pulp, sunflowers heads		sauces	Thicken, provide mouthfeel, texturize

		Starch: native, modified by acid or enzymatic hydrolysis, oxidation, dextrinization, crosslinking, or mono-substitution; available in pregelatinized or instant forms		Common corn, high amylose corn, waxy maize, wheat, potato, tapioca, rice, waxy rice	4 kcal/g	Margarine, spreads, dressings, sauces, baked goods, frostings, fillings, meat emulsions	modifying texture, gelling, thickening, stabilizing, water holding
		CELLULOSE	**microcrystalline cellulose**	Obtained by mechanical grinding from various plant sources	noncaloric	salad dressings frozen desserts sauces dairy products	contributes body, consistency and mouthfeel, stabilizes emulsions and foams, controls syneresis, adds viscosity, gloss and opacity to foods
			powdered cellulose	Obtained by chemical depolymerization from various plant sources		frying	reducing the fat in fried batter coatings and fried cake donuts
						baked goods	increasing the volume of baked goods because it can stabilize air bubbles and minimize after baking shrinkage
			methyl cellulose	Obtained by chemical derivitization from various plant sources	noncaloric	baked goods frozen desserts dry mix sauces	impart creaminess, lubricity, air entrapment and moisture retention
			hydroxypropyl methyl cellulose	Obtained by chemical derivitization from various plant sources		Sauces, dressings	impart pouring and spooning qualities
		maltodextrins		Produced by partial hydrolysis of starch (corn, potato, oat, rice, wheat, tapioca,)	4 kcal/g	table spreads, margarine imitation sour cream, salad dressings, baked goods, frostings, fillings sauces, processed meat, frozen desserts	build solids and viscosity, bind/control water, contribute smooth mouthfeel
		polydextrose		Randomly-bonded polymer of glucose, sorbitol, and citric or phosphoric acid	1 kcal/g	baking goods and baking mixes, chewing gum, confections, frostings salad dressing, frozen dairy desserts and mixes gelatins, puddings and fillings, hard and soft candy, peanut spreads, fruit spreads, sweet sauces, toppings and syrups	bulking agent, formulation aid, humectant, texturizer smoothness in high-moisture formulation, fat-sparing effect
		β-glucan		Soluble fiber extracted from oats (sometime barley)	1-4 kcal/g	baked goods and a variety of other food products	adding body and texture

Fat Substitutes Available on the Market

*Olestra (Olean***,** Procter & Gamble, Cincinnati, OH) is a mixture of hexa-, hepta- and octaesters of sucrose prepared by chemical transesterification or interesterification of sucrose with six to eight long-chain fatty acids (saturated and unsaturated of chain length C12 and higher) isolated from edible fats and oils (Cooper, 1997; Peters, 1997). The physical properties of olestra are similar to those of a triglyceride with the same constituent fatty acids (Crites, 1997). Olestra made from highly unsaturated fatty acids is liquid at room temperature; olestra made from highly saturated fatty acids is solid (Harrigan, 1989). A schematic representation of the structure of olestra, is shown in Figure 1. Olestra has the organoleptic, and thermal properties of fat. Is not hydrolyzed by gastric or pancreatic enzymes because the large size and number of the nonpolar fatty acids constituents prevent olestra from being hydrolyzed by digestive lipases (O Hill, 1998; Peters, 1997; Cooper, 1997). Olestra passes through the gastrointestinal tract intact and is not absorbed. For this reason, olestra does not provide calories to the diet (Cooper, 1997, Haumann, 1986). Because of its unique properties, olestra can serve as a zero-calorie replacement (up to 100%) for conventional fat in a variety of foods. The U.S. Food and Drug Administration (FDA) has approved the use of olestra as a replacement for fats and oils currently used in the preparation of savory snacks (snacks that are salty or piquant but not sweet), such as potato and corn chips, cheese puffs and crackers and for frying of savory snacks (Akoh, 1998; Cooper, 1997; Peters, 1997).

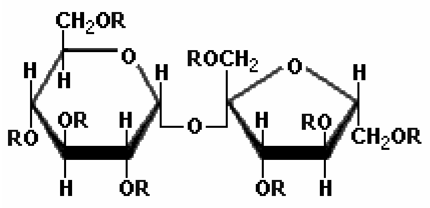

Fig. 1. General structure of Olestra (OLEAN)
R – acyl group of fatty acids

Because olestra is lipophilic, nondigestible and nonabsorbable, it has the potential to interfere with the absorption of other components of the diet, especially lipophilic ones, eaten at the same time as olestra. This interference occurs because a portion of those components may partition into the olestra in the gastrointestinal tract and be excreted with the olestra (O Hill, 1998; Peters, 1997; Cooper, 1997).

The dietary components that were assessed included macro-nutrients, essential vitamins and minerals, and other components of the diet such as phytochemicals (Cooper, 1997, Akoh, 1998).

The findings from the studies (Peters et al., 1997, O Hill, 1998) show that olestra can affect the absorption of other dietary components, especially highly lipophilic ones, when ingested at the same time. Olestra did not affect the availability of water-soluble micronutrients or the absorption and utilization of macronutrients. Olestra reduced the absorption of fat-soluble vitamins A, D, E and K; however, the effects can be offset by adding specified amounts of the vitamins to olestra foods. Olestra also reduced the absorption of carotenoids (Cooper, 1997; Peters 1997); Some people eating large amounts of olestra snacks may experience common gastrointestinal tract symptoms such as stomach discomfort or changes in stool consistency, similar to symptoms accompanying other dietary changes but these symptoms present no health risks (Akoh, 1998, Cooper, 1997).

As a result, the Food and Drug Administration (FDA) requires that food containing olestra be labeled with the statement: "This Product Contains Olestra. Olestra may cause abdominal cramping and loose stools. Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins A, D, E, and K have been added". The label statements is intended to inform consumers about potential gastrointestinal effects and the addition of vitamins to compensate for the effects of olestra on absorption of vitamins A, D, E, and K. The concentration of vitamins A, D, E, and K required for supplementation in olestra-containing foods are 0.34 X RDA (Recommended Dietary Allowance) for vitamin A/10g olestra, 0.3 X RDA for vitamin D/10g olestra, 0.94 X RDA for vitamin E/10g olestra, and 1.0 X RDA for vitamin K/10g olestra (Cooper, 1997). In approving olestra, the FDA concluded that olestra is not toxic, carcinogenic, genotoxic, or teratogenic; all safety issues were addressed; and there is reasonable certainty that no harm will result from the use of olestra in savory snacks (O Hill, 1998; Peters, 1997; Cooper, 1997).

Caprenin (caprocaprylobehenic triacylglyceride), (The Procter & Gamble Co.), is manufactured from glycerol by esterification with caprylic (C8:0), capric C10:0), and behenic (C22:0) fatty acids (Costin, 1999). Because behenic acid is only partially absorbed and capric and caprylic acids are more readily metabolized than other longer chain fatty acids, caprenin provides only 5 kcal/g (Akoh, 1998, Lucca, 1994). Caprenin's functional properties are similar to those of cocoa butter (Lipp, 1998). As a result, caprenin is suitable for use in soft candy and confectionery coatings (Lucca, 1994). The Procter & Gamble Co. filed a GRAS affirmation petition for use of caprenin as a confectionery fat in soft candy and confectionery coatings (CCC, 1996). Caprenin, in combination with polydextrose, was commercially available briefly in reduced-calorie and reduced- fat chocolate bars (Sandrou, 2000).

Salatrim (an acronym derived from **s**hort **a**nd **l**ong **a**cyl **t**riglyceride **m**olecule) is the generic name for a family of structured triglycerides comprised of a mixture containing at least one short chain fatty acid (primarily C2:0, C3:0, or C4:0 fatty acids) and at least one long chain fatty acid (predominantly C18:0, stearic acid) randomly attached to the glycerol backbone (Kosmark, 1996).

Structured lipids (Fig. 2) are triglycerides containing short chain fatty acids and/or medium chain fatty acids, and long chain fatty acids. Structured lipids are prepared by chemical and enzymatic synthesis or random transesterification (Akoh, 1998). Structured lipids are developed for specific purposes, such as reducing the amount of fat available for metabolism and, potentially, caloric value (Lucca, 1994).

Salatrim achieves a calorie reduction based on two principles: 1) short-chain fatty acids (e.g.,butyric) provide fewer calories per unit of weight than do longer chain fatty acids, and 2) stearic acid (the primary long-chain fatty acid of Salatrim) is only partially absorbed by the body. The net result is a triglyceride that has all of the physical properties of fat, but that contains only 5 cal/g instead of 9 cal/g for naturally occurring fat. The Food and Drug Administration has proposed to amend its food labeling regulation such that the total amount of fat declared on the label for a product containing Salatrim as the only fat source would be 5/9 of the total amount of fat of a traditionally made product (Costin, 1999; Akoh, 1998; Kosmark, 1996). Developed by Nabisco Foods Group, Salatrim is licensed to Cultor Food Science, which established the brand name Benefat™ for manufacture and marketing. FDA accepted for filing in 1994 a GRAS (Generally Recognize as Safe) affirmation petition submitted by Nabisco Foods Group (Akoh, 1998, Kosmark, 1996).

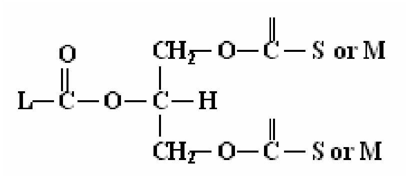

Fig. 2. General structure of structured lipids
S – short chain fatty acid
M – medium chain fatty acid
L – long chain fatty acid
The position of S, M or L is interchangeable

Salatrim compositions with differing amounts of short chain fatty acids and long chain fatty acids provide select functional and physical properties, e.g., a range of melting points, hardness, and appearance. Salatrim was designed for a variety of applications, including chocolate-flavored coatings, deposited chips, caramels and toffees, fillings and inclusions for confectionery and baked goods, peanut spreads, savory dressings, dips and sauces, and dairy products such as sour cream, frozen dairy desserts, and cheese (Lucca, 1994; Akoh, 1997; Kosmark, 1996). Salatrim, however, is not suitable for frying. The first Salatrim product, Benefat 1, was developed primarily to replace cocoa butter in confectionery applications (Lipp, 1998).

Emulsifiers, such as sucrose fatty acid esters, mono- and diglycerides, sodium stearoyl-2-lactylate, lecithin, and polyglycerol esters, contain both hydrophilic and lipophilic properties that enable the emulsifier to stabilize the interface between fat and water droplets through hydrogen bonding. By acting as surface active molecules, emulsifiers can replace up to 50% of the fat in a formulation (Costin, 1999, Akoh, 1998). They also provide and stabilize aeration, provide lubricity, complex with starch, interact with protein, modify the crystallization characteristics of other fats, promote and stabilize foam, control syneresis, carry flavors, and control rheology (Sipahioglu, 1999). Emulsifiers are most effective in replacing the functionality of fat when used in combination with other ingredients. Emulsifiers are useful in margarines, baked goods, frozen desserts, dairy products, spreads and shortenings, processed meats, whipped toppings, cake frostings and fillings, and confections (Lucca, 1994).

Fat Substitutes not Available on the Market

Sorbestrin (Cultor Food Science, Inc.,N.Y.), or sorbitol polyester for example, is a mixture of tri-, tetra-, and pentaesters of sorbitol and sorbitol anhydrides with fatty acids. The caloric value of Sorbestrin is 1.5 kcal/g. Sorbestrin is sufficiently heat stable to withstand frying temperatures. Sorbestrin, which is intended for replacement of fat in salad dressings, baked goods, and frying (Lucca, 1994). Other carbohydrate fatty acid esters and polyol fatty acid esters, hold potential for fat replacing systems. Polyol fatty acid esters are prepared by reacting one or more fatty acid esters with a polyol containing at least four hydroxy groups in the presence of a basic catalyst. Examples include sorbitol, trehalose, raffinose, and stachyose polyesters (Akoh, 1998).

Dialkyl dihexadecylmalonate (DDM) is a fatty alcohol dicarboxylic acid ester of malonic acid and alkylmalonic acid, synthesized by reacting a malonyl dihalide with a fatty alcohol. Frito-Lay, Inc. (Dallas, Texas) patented DDM for use in replacing oil in food formulations or in frying (Akoh, 1997; Fulcher, 1986). DDM is noncaloric because it is not digested or absorbed.

Esterified propoxylated glycerols (EPGs) comprise a family of derivatives of propylene oxide, synthesized by reacting glycerol with propylene oxide to form a polyether polyol that is subsequently esterified with fatty acids. EPGs differ from conventional triglycerides in the positioning of an oxypropylene group between the glycerol backbone and the fatty acids. EPGs are being developed by ARCO Chemical Co. and CPC International/Best Foods (Englewood Cliffs, N.J.) as a replacement for fats and oils in a variety of products including frozen desserts, salad dressings, baked goods, and spreads and for cooking and frying. EPGs can be tailored to produce specific functional properties (Akoh, 1997; Harrigan, 1989) and are expected to be low in caloric value due to their lipase resistance.

Trialkoxytricarballylate (TATCA), *trialkoxycitrate* (TAC), and *trialkoxyglyceryl ether* (TGE) are polycarboxylic acids with two to four carboxylic acid groups esterified with saturated or unsaturated alcohols having straight or branched chains of 8–30 carbon atoms. Because the ester units of the substances are reversed from the corresponding ester present in triglycerides, these compounds are not susceptible to complete hydrolysis by lipases (Akoh, 1997; Haumann, 1986).

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