# Non-Meat Ingredients for Low-/No-Fat Processed Meats

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## Introduction

The growth and development of low/no-fat processed meat products at the retail level from 1990 to the present (1996) are strongly linked to consumer demands for a wide variety of reduced-fat processed foods that taste good and are "healthier." Most fat-free products average as much as 25% higher per-unit cost, but taste remains the most important factor influencing repeat customers for fat-free meats (Murphy 1995). Approximately half of the new red meat product introductions in 1995 (out of an estimated 168 total items) contained one of three reduced-fat claims (Krizner, 1995). In 1994, only 12.3% of product introductions made similar health claims. Part of the increased trend toward more low-fat/no-fat products may have been driven by mandatory nutritional labeling of food products and the growth of low-fat products in other market segments. Examples of new low/no-fat meat product introductions that were made in 1995 or before are shown in Table 1.

Based on a study by New York-based Packaged Facts entitled "The Market for Packaged and Canned Processed Meats," sales of processed meats are expected to increase in all processed meat segments throughout the rest of this decade. Key factors driving packaged processed meat sales will include: convenience, variety and value; the need for more low- and no-fat items, as well as full-fat products; a demand for new taste experiences; a growing desire for freshness in products; and a need for on-the-go products (Salvage, 1995). As shown in Table 2, the projected sales of traditional and low-fat cold cuts, sausages, frankfurters and bacon are expected to increase through 1999 by 7.2, 14.1, 11.2 and 12.4%, respectively. The composite increase of all these cuts is projected to be 10.8% in total retail sales.

Key Words: Low-Fat, Processed Meats, Fat Replacements, Fat Substitutes

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Other factors may impact the sale of low/no-fat processed meats. Busetti (1995) reports that by July 1, 1998, school lunch meals over the course of a week must provide 30% or less calories from fat and 10% or less calories from saturated fat. Frankfurters sold to schools are not specifically mandated to lower their fat content, but lower-fat franks will be more attractive to school lunch programs in order to meet these criteria. Thus, the impetus exists for establishing low/no-fat products in the food service market. At the present time, low-fat processed meats are not performing well in the fast food outlets, as evidenced by withdrawal of McDonald's McLean Delux hamburger in February 1996. The reason given for removing this low-fat (9%) item containing ground beef, water, carrageenan, flavorings and encapsulated salt was the "lack of consumer acceptance." Based on current consumer demand, low-fat items apparently do not fare as well in the fast food market because of the lack of fat flavor.

## Goals for Fat Reduction

Recent commitments by processed meat manufacturers to the development of low/no-fat products for retail has led to the evaluation of numerous fat substitutes and fat replacements. Fat substitutes are ingredients which have basically the same physical (and in some cases, chemical) properties of fat or lipids, while fat replacements are ingredients which mimic some aspects of fat's physical attributes. Ideally, substitutes or replacements are ingredients which contribute few or no calories to formulated foods without dramatically altering flavor, mouthfeel, viscosity or other organoleptic properties (Keeton, 1991).

The primary goals for utilizing fat substitutes/replacements in processed meats are to:

- Reduce total fat, calories and percent of calories from fat
- Meet consumers expectation for "healthier" foods
- Retain product palatability (flavor, texture, mouthfeel)
- Stabilize meat product moisture and appearance
- Provide low-fat products at or near the cost of traditional meat items and
- Optimize ingredients which mimic the functional and sensory properties of tissue lipids (fat).

**TABLE 1. Examples of Low-/No-Fat Processed Meat Products Introduction in 1995.**

| Brand/Variety | Product | Description |
|---|---|---|
| Hygrade | Ball Park Fat Free Classic | 40 Calories, 150 mg cholesterol, 560 mg sodium |
| Eckrich | Eckrich Fat Free Franks | Turkey, pork, beef, natural smoke flavor |
| Oscar Mayer* | Fat-free Hot Dogs & Bologna | 100% fat-free |
| | Lunchables | 96% fat-free ham slices, 10 g fat 4.5g of which is saturated |
| Tyson | Sliced Lunch Meats | 100% fat-free, replaces 95% fat-free |
| ConAgra Inc. | Healthy Choice | Seven new items — sandwich, breakfast sausage, smoked sausage, deli and frozen entrees |
| Nestle Food Co. | Lean Cuisine, Hearty Portions | Sirloin beef tips, rigatoni and meat balls |
| Bryan Foods Inc. | | 97% Fat-free, lunch meats, Southern-style baked ham, barbecue ham, Texas brand barbecue beef, brown sugar glazed ham |
| Bil Mar Foods | Mr. Turkey | Close trimmed chicken and turkey meat, 100% fat free, smoked turkey and chicken breasts (Rotisserie Flavor) |
| Hormel | Light & Lean | 97% Fat Free |

**First introduced Oscar Mayer Light line in 1990 (85% fat-free), Healthy Favorites followed in 1992 (97% fat-free) and Oscar Mayer Free in January 1995. Source: Meat Marketing & Technology, November 1995, pp. 40-41.*

## Categories of Fat Substitutes and Fat Replacements

Several review articles have summarized the types, characteristics, properties and potential problems of fat substitutes/replacements suitable for use in meat products (Claus, 1991; Dikeman, 1987; Giese, 1992; Huffman et al., 1991; Keeton, 1991; Keeton, 1994; McAuley and Mawson, 1994; Pearson et al., 1987; and Shand and Schmidt, 1990). This review will survey fat substitutes/replacements currently in use for coarse and emulsified sausages, ground meats and brine-injected whole-muscle or structured products as well as discuss emerging ingredients which might serve a similar role in processed meat products. Ingredients in use, or of potential use, to replace fat can be grouped into the following categories:

- Leaner raw meat materials and recovered tissues
- Added water
- Fat substitutes
  Structured lipids (Caprenin, Salatrim, Olestra)
- Fat replacements
  Protein-based (Soy, Gelatin, Milk, Whey, Egg, Wheat, Oats, Corn)
  Carbohydrate-based (Starches, Maltodextrins, Gum Hydrocolloids, Cellulose)

**TABLE 2. Projected Retail Dollar Sales of Packaged Processed Meats 1994-1999.**

| Category of Cuts | 1994 (Sales in Millions $) | 1999 (Sales in Millions $) | Total % Change 1994-1999 |
|---|---|---|---|
| Cold Cuts | 6,010 | 6,440 | + 7.2 |
| Sausages | 5,025 | 5,735 | +14.1 |
| Frankfurters | 2,600 | 2,890 | +11.2 |
| Bacon | 2,225 | 2,500 | +12.4 |
| All Categories | | | +10.8 |

*Source: Meat Marketing & Technology, December 1995, p. 16.*

### Lean Raw Materials and Recovered Tissues

Very lean, relatively expensive, raw materials will not be discussed, but are required as the primary formulation base to produce low-/no-fat products. These can include such items as bull meat, cow meat, picnic pork cushions, trimmed ham muscles, skinless turkey thighs, turkey drum meat, poultry lean, finely textured lean, recovered lean tissue, desinewed shanks and trimmings from deboned veterbral material.

### Added Water

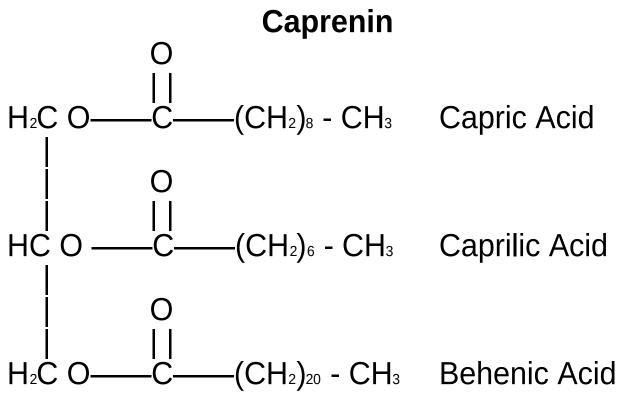
Added water is required in all low-/no-fat formulations as a partial replacement for fat and for adequate hydration of fat mimics to activate their functional, fat-like properties. The amount of added water is controlled by the Code of Federal Regulations for Animals and Animal Products, Sections 319 and 381, Title 9: Chapter III—Food Safety and Inspection Service, Meat and Poultry Inspection, Department of Agriculture. However, maximizing retention of added water and/or the water indigenous to muscle tissue allows for its interaction with other ingredients and contributes to the juiciness, flavor, texture and other sensory properties that are essential for acceptable and economically competitive low-/no-fat meat products.

## Fat Substitutes

### Structured Lipids

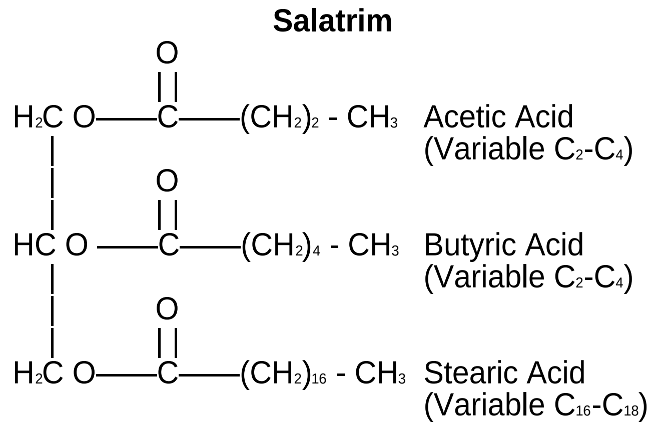
Structured lipids are glycerol based triglyceride molecules that have been structurally altered by rearranging short- and long-chained fatty acids into combinations that reduce their caloric value (5 Kcal/g), while retaining the functional characteristics of fat (Kevin, 1995). Because these molecules are digested but only partially absorbed, these chemical alterations are viewed by some as being a healthier alternative toward reducing fat calories while retaining fat properties.

**FIGURE 1.**




*Triglyceride structure of caprenin (structured lipid) which yields 5 Kcal/g due to partial absorption of behenic acid.*

**FIGURE 2.**




*Salatrim (structured lipid) triglyceride where R groups are at least one short-chained fatty acid (acetic, propionic and butyric), one long-chained fatty acid (stearic acid) and varying combinations of short or long-chained fatty acids for the third R group.*

*Caprenin* was originally developed by Procter and Gamble for the confectionery industry with functional properties similar to cocoa butter. It was intended for soft candy and confectionery coatings with reduced caloric value. Caprenin is manufactured from two medium-chain fatty acids, caprylic (C8) and capric (C10) and one long-chain fatty acid, behenic acid (C22), attached to a glycerol backbone (Figure 1). Rather than the 9 Kcal/g for triglycerides, Caprenin has only 5 Kcal/g since the behenic acid is only partially absorbed with the bulk of the compound passing through the body. By altering the fatty acid composition of the triglyceride, Caprenin can be altered to meet the functional needs of other foods and possibly meat products. Caprenin is currently used in M&M/Mars Milky Way Lite bar.

*Salatrim* was developed by Nabisco Foods Group and originally intended to replace fat (and reduce fat calories by 50%) in foods such as chocolate-flavored coatings, fillings, baked goods, peanut spreads, savory dressings and dairy products (sour cream, cheese and frozen dairy desserts). It has been licensed to Pfizer Food Science (now Cultor Food Science) for further development and commercialization. It was intended to provide a reduced-calorie ingredient that would function well in low-moisture food systems, while avoiding the disadvantages of other fat-based replacers (Kosmark, 1966).

Salatrim is a chemical contraction for short- and long-chain acyl triglyceride molecules that are composed of four basic structures containing combinations of short-chained (acetic, C2; propionic, C3; and butyric C4) acids in various combinations with long-chained fatty acids (Figure 2). The combinations of long- and short-chained fatty acids give the desired functionalities. The long-chained fatty acid, primarily stearic acid (C18), is obtained from complete hydrogenation of soy or canola oil to avoid formation of trans fatty acids (Kevin, 1995). Variations in salatrim are produced by replacing some of the long-chain fatty acids of highly hydrogenated vegetable oils (canola and soy) with specific ratios of short-chain (acetic, propionic or butyric) acids leaving a combination of at least one short-chain fatty acid and one long-chain fatty acid (predominantly stearic acid).

Salatrim triacylglycerides are hydrolyzed during digestion into fatty acid and glycerol components and the short-chain fatty acids that result produce less energy than the long chain fatty acids. In addition, stearic acid is only partially available to the body for energy utilization, thereby reducing salatrim's total caloric value. Although saturated, salatrim has been shown not to promote hypercholesterolemia.

In June 1994, FDA accepted Nabisco's GRAS affirmation petition for salatrim and its first application will be in Hershey's Reduced-fat Baking Chips under the trade name, Benefat®. Nabisco plans to launch a new line of granola bars containing Benefat® and these will be sold under the SnackWell brand. Because salatrim may vary from a liquid to a solid at room temperature, modified or newly-developed versions are being tested as full-calorie fat reduction ingredients for use in processed and cultured cheese, frozen dairy desserts, salad dressings, peanut spreads, dips and other spreads.

*Olestra* is not technically a structured lipid, but a sucrose polyester (SPE) with fat-like properties (Aylward, 1996; Giese, 1996). SPE was discovered in 1968, patented in 1971 (Procter and Gamble) and was designed to replace a portion of the oil (fat) in snack foods. It is comprised of a sucrose backbone with six to eight fatty acids attached and is made by reacting fatty acids with the eight available hydroxyl groups of sucrose in the presence of a catalyst (Figure 3). The fatty acids can be varied depending upon the specific functionality desired. Saturated and unsaturated fatty acids of chain length C12 to C20 and higher from soybean, corn, palm, coconut and cottonseed oil can be used to manufacture Olestra.

**TABLE 3. Functional Properties of Food Proteins.**

| Function | Application | Protein Type |
|---|---|---|
| Nutrition | Infant formulas, protein-enriched foods | Soy, Milk |
| Solubility | Beverages, liquid and moist foods | Whey, Soy |
| Viscosity | Soups, sauces, salad dressings, yogurt | Numerous |
| Water Holding | Meat, seafoods, baked goods, yogurt | Muscle, Egg, Milk, Soy |
| Gelation | Meats, baked goods, dairy products, gelatin desserts | Muscle, Egg, Soy, Milk |
| Adhesion/Cohesion | Meats, sausages, pasta, baked goods | Muscle, Egg, Whey |
| Emulsification | Sausages, salad dressings, sauces, baked goods | Muscle, Milk, Egg, Soy |
| Foaming/Whipping/ Film Formation | Confectionery, baked goods, whipped toppings, frozen desserts | Egg, Milk, Soy |

*Source: Food Technology. October 1994. p. 53, as adapted from Damodaran (1994) and Lawson (1993).*

SPE molecules are not broken down by digestive enzymes and thus not absorbed in the intestine. As a consequence, potential side effects may include loose bowels, flatulence, anal leakage and cramping depending upon the levels ingested. However, olestra has been demonstrated not to be toxic, carcinogenic, gentoxic or teratogenic and is neither absorbed or metabolized (0 Kcal/g). Of additional concern is decreased cartenoid absorption in the intestine by olestra, making these less available to the immune system to ward off disease (cancer) and a reduction in the absorption of fat-soluble vitamins A, D, E and K. As a precaution, these vitamins are added to olestra to compensate for any reductions in absorption. High use levels of up to 30 or 40% in products will also be monitored to determine olestra's effect in the diet.

Olestra was approved (January 1996) as a calorie-free replacement for up to 100% of the conventional fats and oils used in the preparation of savory snacks such as flavored and unflavored chips (Frito-Lay), crisps (Pringles), extruded snacks and crackers. These uses include the substitution for fat in frying as well as sources of fat in dough conditioners, oil sprays and flavors. Olean® is the Procter and Gamble brand name for olestra that is currently being test marketed on potato chips and crisps.

By varying the fatty acid chain length and degree of saturation, olestra may be used in baked and fried foods, dairy products, cooking oils, margarine, spreads and shortening. These have the same properties (flavor, texture, color, mouthfeel, satiety value and shelf-life) as do the triglycerides they replace, but without the calories. Olestra can be converted to solid form by using shorter-chain saturated fatty acids that are coupled to glucose or sucrose molecules, rather than longer-chain unsaturated fatty acids. Solid olestra might be given consideration for use in meat products, but labels would likely contain language that warns of the possibility of causing abdominal cramps and loose stools. FDA currently requires that products containing olestra have the statement, "This Product Contains Olestra."

## Fat Replacements

A recent survey of fat-free frankfurter products available at retail identified the following non-meat ingredients as fat replacements: Modified potato starch, soy protein concentrates, potato starch, modified food starch, sodium caseinate and gelatin (Murphy, 1995). Supplemental ingredients included: Alkaline sodium phosphates, hydrolyzed beef, sodium lactate, hydrolyzed milk protein and autolyzed yeast. Whole-muscle, brine-pumped items such as hams, poultry/turkey rolls and similar items often contain soy protein isolate, starch and carrageenan to control moisture, retain desirable textural characteristics and reduce the fat content.

### Protein-Based Replacements: Plant-Derived

The major commercially-derived animal proteins are obtained from a variety of sources including animal skins, eggs, milk and fish. Plant protein sources include soybeans, wheat, corn, peas, cottonseed and oats. Proteins used as fat replacements in meat products offer essential functional characteristics, such as increased emulsification capacity, product stabilization, increased viscosity, firmer texture and greater water-holding capacity (Rakosky, 1989). In addition, proteins can contribute to nutritional value by increasing the protein level, enhancing the essential amino acid profile and in some cases, increasing product economy (Giese, 1994). Examples of the functional properties of commercially-used proteins are given in Table 3.

*Soy proteins* are produced in the form of flours, grits, concentrates and isolates and texturized forms of these products (Giese, 1994). Soy flour or grits are the least refined (40% to 54% protein) form of soy proteins and are produced by grinding and screening soybean flakes, either before or after the oil is removed. Defatted flours (52% to 54% protein) are prepared by grinding defatted flakes through a No. 100 U.S. Standard screen size. Moist heat treatment is used to produce products with a Nitrogen Solubility Index of high (85-90), medium (20-60) or low (<20) grades. Defatted grits are the same as flour except that they are passed through a No. 10 and 80 screen size. This product has application in ground meat systems and bakery products.

Soy protein concentrates (>70% protein) are prepared from defatted soybean flakes by acid leaching (~pH 4.5) and extraction with aqueous alcohol (60 to 70%). Soy protein isolate (>90% protein), on the other hand, is extracted from the same starting material, defatted soybean flakes, by removing most of the non-protein components with a water or mild alkali wash at pH 8 to 9, followed by centrifugation

**TABLE 4. Milk Proteins for Application to Low-/No-Fat Meat Products.**

| Ingredient | Protein Content (%) | Properties | Applications |
|---|---|---|---|
| NFDM | 33.9-35.6 | Water binding, foam formation, emulsification | Meat and meat analogs |
| Caseinates | 89-94 | Superior emulsification water binding | Meat products and analogs |
| Dried Whey (Sweet or Acid) | 2.5-13.1 | Some foaming, texture formation, absorption media | Meat products |
| WPC | 70-80 | Excellent water-binding, gelation, foaming, emulsification | Meat products, surimi, fat substitutes |
| WPI | 90+ | Enhancement of WPC properties | |

*NFDM = Non-fat Dry Milk; WPC = Whey Protein Concentrate; WPI = Whey Protein Isolate*
*Source: Concentrated and Dried Dairy Products, VCH Publishers Inc. and Prepared Foods, May 1996, p. 91.*

to remove insoluble fibrous residue. The pH of the extract is adjusted to pH 4.5 to precipitate the protein curd. Soluble oligosaccharides are separated from the curd by centrifugation. The curd is then neutralized with sodium or potassium salts to make the protein more soluble and functional, followed by multiple washings and spray drying. Approximately one- third of the starting material is recovered as an isolate. Soy protein isolates and neutralized soy protein concentrates are often incorporated into finely ground meats such as bologna and frankfurters to retain moisture, bind fat and stabilize the emulsion.

Textured soy products (flours, concentrates and isolates) can be extruded to give texture and shape. Isolates may be extruded into an acid-salt bath that coagulates the protein into fibers that are combined with binders to form fiber bundles, but these textured isolates must be frozen to prevent spoilage. Textured soy proteins (flours and concentrates) are most often used in coarse chopped or ground meats such as pizza toppings, taco meats, meat balls, meat patties and Salisbury steaks to give structure, reduce cooking loss and extend freshness.

*Wheat proteins* are predominantly storage proteins found in wheat kernels that consist primarily of gluten. Gluten is separated from the wheat flour by a water wash to remove starch and other soluble components, leaving the insoluble gluten. Vital wheat gluten retains its viscoelastic properties and is used in many bakery goods and breakfast foods. It is suited for meat and fish products heated above 185°F because of the protein's ability to retain elasticity under high heat conditions.

*Corn protein isolate* is processed by a cold-filtration process (Pierce, 1994) to yield a cream-colored product containing 92% to 98% protein. Currently, it is being used to bind water and fat in ice cream, as a gel or whipping agent in toppings, or to increase viscosity in frozen aerated desserts.

*Pea protein flours and isolates* are both available commercially, but the isolate (83% protein) is more functional in terms of its ability to bind water, emulsify fat and contribute foaming and gelling characteristics. The isolate has been used mostly to formulate frozen non-dairy desserts and to replace albumen in sponge cakes (Giese, 1994).

**Protein-Based Replacements: Animal-Derived**

*Milk proteins* are derived from whole milk (87.5% water, 4.5% lactose, 3.5% fat, 1.0% ash and 3.5% protein) with the most primary product being *non-fat dry milk (NFDM).* NFDM is produced from pasteurized skim milk that is concentrated and spray-dried, resulting in a cream-colored powder. NFDM contains lactose, milk proteins and minerals in the same relative proportions as fresh milk. Examples of additional milk-derived proteins for use in low/no-fat meat products are shown in Table 4.

Milk contains two principal protein components, casein and whey proteins. *Casein* is extracted from milk through either isoelectric or enzymatic (lactic acid fermentation) precipitation. The caseinates are derived from lactic or acid (enzymatic) casein by rinsing, treating with various alkaline salts, heating and spray-drying. They are most often used in processed meats as fat emulsifiers and to improve moistness and smoothness (Giese, 1994). In emulsified meat products, caseinates compete with myofibrillar proteins and are preferentially absorbed onto fat globules over the meat proteins to stabilize the emulsion and reduce water loss during heating.

*Whey* is the by-product of cheese and casein manufacture and can be processed into a variety of protein forms, including concentrates and isolates. Lactalbumin (85% to 90% protein) is a special type of *whey protein concentrate (WPC)* that has been heat denatured (90°C) which in turn causes the whey proteins to self-aggregate and precipitate, making this protein less soluble than other whey proteins. The composition of various whey proteins is given in Table 5 (Huffman, 1996).

*Whey protein concentrates* are spray-dried white powders that serve as a good source of essential amino acids especially leucine, isoleucine and valine. The undenatured proteins are soluble below 70°C and above pH 3 to 5 with isoelectric points in the 4.5 to 5.3 range. Added sugar improves heat stability. When heated, WPCs increase in viscosity (slightly) and water-holding capacity due to a partial unfolding exposure of more hydrophilic groups for water retention. Whey proteins have both hydrophilic and hydrophobic regions and act as fat emulsifiers. When heated to approximately 65°C, gelation begins yielding smooth, strong,

**TABLE 5. Composition of Whey Proteins Used in Food Products.**

| Analytical Components (%) | Whey | Whey Protein Concentrate 30% | 50% | 80% | Whey Protein Isolate 90% |
|---|---|---|---|---|---|
| Ash | 10 | 8 | 7 | 4 | 3 |
| Fat | 1 | 4 | 5 | 3 | 4 |
| Lactose | 76 | 53 | 35 | 7 | 1 |
| Protein | 13 | 34-35 | 50 | 80 | 90 |

*Source: Food Technology. February 1996, pp. 49-52.*

elastic gels similar to egg white. In aqueous solutions, gelation begins at approximately 7% protein concentration, but in food systems, gelation may occur at 0.5 to 3.0% protein. This gelation is particularly important in meat and seafood products to stabilize the food matrix. Additionally, the adhesion properties of whey proteins increase batter retention to meat and fish products and can also serve to bind meat pieces to each other. Commercially, whey protein concentrates are used to prevent or minimize shrinkage during cooking, act as emulsifiers and/or retain juiciness. Product applications for WPCs include ham items, frankfurters and luncheon meats.

*Gelatin* is a widely used ingredient in meat products and is produced by partial hydrolysis of collagen (chief component of skins, hides and white connective tissues of animals). Two types of gelatin are produced, Type A and Type B. Type A is produced by acid processing of collagenous raw material and has an isoelectric point between pH 7 and 9. Type B collagen is alkaline (lime) processed and has an isoelectric point between pH 4.8 and 5.2. Gelatin is used in a variety of meat products, dairy products and confectionery for its ability to stabilize water, but its largest use is in making gelatin desserts.

*Egg proteins* are derived from the whole egg, yolk or whites. These products are valued for their foaming, binding and thickening ability, emulsifying power and ability to tenderize and retain moisture, but they are not widely used in meat products.

*Fish protein concentrate* is manufactured from deboned whole fish after fat and water extraction with a solvent such as isopropyl alcohol. The extracted material is then dried and serves as a binder. Surimi, a minced water-washed fish protein concentrate that has been treated with cryoprotectants and frozen, could be used in meats to increase the myofibrillar protein content, decrease fat and increase the gelling properties of lean meats (Lanier, 1994). However, many of the animal proteins may be too expensive to utilize fully in low/no-fat meat products.

### Microparticulation of Proteins

Milk, egg or whey proteins may be shaped into small round spheres (0.1 to 2.0μm) by heating under high shearing conditions. The resulting protein forms a microparticulate structure which is perceived in the mouth as fat-like and creamy (Miller, 1993). These fat mimics are used in applications requiring heating in the form of canning, pasteurization or ultra-high temperature (UHT) processing, but cannot be used under high-temperature frying conditions. Most product applications have been limited to reduced-fat ice cream, butter, sour cream, salad dressings and margarine. Simplesse® and Dairy-Lo® are two commercial microparticulate fat substitutes produced by heating WPC during shearing.

### Carbohydrate-Based Replacements: Starches

*Starches* are carbohydrate granules of glucose that usually contain amylose, a linear, straight chained alpha-1,4 glucopyranose polymer and amylopectin, a branched (tumble weed-like) alpha-1,4 glucopyranose polymer with branching components at l, 6 linkages (Shand and Schmidt, 1990). Granule size, shape and distribution and the amylose/amylopectin ratio of a starch varies with the plant source, the most common of which are corn, potato, wheat, tapioca and rice. Starches are extracted by wet or dry milling, followed by enzymatic hydrolysis to make smaller molecular weight starch polymers in the range of 5,000 to >1,000,000 daltons. The amylose component determines the gelling properties of a particular starch due to its ability to form hydrogen bonds with adjacent molecules to build a three-dimensional network. Gelatinization or granule swelling in the presence of water is critical for starch to emulate fat, reduce moisture loss and improve freeze-thaw stability in low-/no-fat meat products, but starches do not participate in the binding or emulsification process.

Food starch can be modified by hydrolysis (HCl treatment in a slurry or dry state), oxidation with sodium hypochlorite, cross-linking between hydroxyl groups (phosphorus oxychloride and adipic acid) and substitution of hydroxyl groups with monofunctional groups (acetic anhydride or propylene oxide) (Luallen, 1985). Modifications can alter viscosity, hydration capacity, solubility and gelatinization and starch properties. Most starches that are used as fat replacements are pregelatinized or modified to enhance their hydration capacity between 125° and 150°F, since this heat processing range is insufficient to gelatinize untreated starch.

Modified starches such as Oatrim® may be produced by enzymatic hydrolysis of oat starch while maltodextrins are manufactured by hydrolyzing potato or corn starch with acid or enzymes. Maltodextrins have a dextrose equivalent (DE) of ≤ 20 and are characterized by a bland flavor and smooth mouthfeel.

**TABLE 6. Major Edible Hydrocolloids Used for Fat Reduction in Foods.**

| Source | Product |
|---|---|
| Plant Exudates | Gum arabic, ghatti, karaya, tragacanth |
| Extracts | |
| Seaweed | Agar, alginates, carrageenans |
| Plant | Pectin, hemicelluloses |
| Cereal | ß-Glucans, pentosans |
| Animal | Gelatin |
| Flours | |
| Seed | Locust bean, guar, tara, tamarind, quince, psyllium, flax |
| Cereal Starch | Corn, wheat, rice, waxy maize |
| Root/tuber | Tapioca, potato, konjac |
| Microbial Fermentation | Xanthan, gellan |
| Modified Derivatives | |
| Cellulose Fibers | Carboxymethylcellulose, mehtylcellulose |
| Starch Derivatives | Hydroxypropyl starch |

*Source: Food Technology. April 1996, p. 81.*

**Resistant Starch**

Resistant starches are so named because they are resistant to digestive enzymes and act more like dietary fiber than starch (Kevin, 1995). These modified starch molecules are composed of retrograded amylose, known as RS3, that pass through the small intestine basically intact; but in the large intestine, they are partially fermented to produce short chain fatty acids (mostly butyric). There appears to be evidence that consuming resistant starch could provide a direct health benefit to the colon, since butyric acid has been shown to inhibit cancer cell growth.

The raw starting material for the starch is a hybrid variety of high amylose corn yielding a resistant starch with an effective total dietary fiber content of 30% and 2.8 Kcal/gm. The commercial product is a white crystalline powder with no odor or taste that could improve the processing and/or quality of fiber-fortified foods, overcoming flavor and textural problems associated with traditional fiber ingredients. These starches are biochemically modified corn starches that are GRAS and labeled as maltodextrins. Two commercial products currently available are Novelose® from National Starch and Chemical Company and CrystaLean® from Opta Food Ingredients, Inc.

**Carrageenan**

By definition, hydrocolloids are long-chain polymeric materials that thicken or gel in aqueous systems and include a broad classification of edible gums (Table 6) (Glicksman, 1991). Some of these ingredients have been applied to meat systems as fat substitutes because of their sensation of fattiness or oiliness that tends to mimic the mouthfeel of animal fat. Carrageenan has been the most utilized hydrocolloid for reducing the fat content of ground meats (McDonalds McLean Delux) as well as enhancing the texture of low-fat meat products such as deli-rolls, turkey breasts, turkey breakfast sausage, low-fat frankfurters, beef franks, poultry lunch meats and hams (Murphy, 1995).

Carrageenan is a high molecular weight polysaccharide extracted by a variety of methods from euchemuma, chondrus and gigartina seaweeds. The raw base material for carrageenan is harvested principally from coastal waters surrounding the Philippines, Indonesia, Ireland and parts of East Africa. Three types of refined carrageenan are derived from these raw materials:

- Kappa carrageenan produces a strong, rigid, slightly opaque thermo-reversible gel and forms a firm gel structure in the presence of potassium salts. It is synergistic with other gums and reduces syneresis in products.
- Iota carrageenan forms a clear, elastic gel in the presence of calcium salts, is syneresis-free under freeze-thaw conditions and resets after shearing. Both iota and kappa forms serve as gelling agents.
- Lambda carrageenan is used primarily to thicken liquids and has limited applications to meat products.

Specific carrageenan functionalities are also derived by blending different types of refined carrageenan to produce products with specific properties.

Carrageenan is available in three forms: refined, semi-refined or a blend of the two. Semi-refined is also known as Philippine Natural Grade (PNG) and has some cellulose fibers remaining in the gel matrix with the carrageenan. Natural Grade carrageenans cost less and differ in functionality from the refined form. Some suppliers have promoted the semi-refined as offering the following advantages in brined products:

- Better brine absorption prior to cooking
- Less sensitivity to temperature increases which cause premature swelling and clogging of injector needles and filter screens
- Less syneresis in sliced product, possibly due to the cellulose fibers
- Less "rubbery" texture than with refined carrageenans.

Neither refined nor Natural Grade carrageenans improve the functionally of meat proteins, but serve to form a separate hydrocolloid network which congeals and binds water in conjunction with the myofibrillar proteins in meat and poultry products. In addition, carrageenan maintains a higher pH in the product which enhances the water-holding capacity of myofibrillar proteins. Carrageenan is somewhat like fat in that it forms a thermally reversible gel that is stable at room temperature, melts upon cooking and recongeals with minimal loss of gel strength when cooled. For products such as low-fat bologna, this improves texture, firmness and sliceability. Carrageenan can be added as a dry powder directly to a meat block in a blender prior to tumbling; alternatively, some processors premix carragennan with the dry ingredients prior to tumbling. In chilled brines, carrageenan should be dispersed after the addition of alkaline phosphates and salt. Salt inhibits hydrocolloid swelling and prevents plugging of the injector needles. "Streaking" or veins of residual carrageenan within the interior of brine-pumped products such as hams can be caused by premature or partial gelation ("swelling") of the carrageenan at the time of injection. Ensuring complete solubilization prior to pumping can prevent this defect.

**Konjac**

Konjac is a polysaccharide powder classified as a glucomannan hydrocolloid that is composed of mannose and glucose units weighing approximately 1,000,000 daltons. Acetyl groups are randomly distributed on side chains and water solubility is controlled by the presence of these groups. Deacetylation of konjac with alkali and/or heat causes formation of a thermally irreversible gel while thermally reversible gels may be made by treatment of konjac with 1% KCl + 0.2% $CaCl_2$, mechanical agitation and heat (80°-85°C). Konjac powder hydrates rapidly and binds 80 to 100 times its weight in water. Combinations of carrageenan, xanthan gum or locust bean gum are synergistic with konjac and produce gels varying in strength and elasticity. For example, konjac/carrageenan blends have four times the gel strength of carrageenan alone. When starch is added to the combination, a heat-stable gel results with enhanced freeze/thaw stability.

Konjac and konjac/carrageenan/starch blends may be successfully incorporated into coarse ground pork sausage and emulsified low-/no-fat meats in pregelled forms to serve as a fat replacer and water binder (Osburn and Keeton, 1994; Becker, 1995). Conversely, konjac blends may also be added to emulsified products in dry or prehydrated forms, but some differences in water absorption properties may be noted. USDA-FSIS approval for konjac use in meats products was obtained in July 1996 with the same formula limitations as starch (a maximum of 3.5%).

**Pectin**

Pectin consists of partial methyl esters of polygalacturonic acid and is found in all fruits and vegetables. It is obtained by an aqueous extraction of citrus peels and apples and primarily used to replace fat in frozen desserts, baked goods, spreads and processed cheese. When used in meat products, it tends to have a softening effect on the texture of products.

**Cellulose**

Cellulose is a carbohydrate polymer of glucose units having beta-1,4 linkages unlike starch which has alpha-1,4 linkages. Cellulose is not digested by humans and thus does not contribute to the caloric value of food when used as an ingredient. Cellulose derivatives such as microcrystalline cellulose, carboxy methyl cellulose (CBMC), methyl cellulose and hydroxypropyl methyl cellulose are used as food stabilizers, thickeners and texture modifiers. When dispersed in water, cellulose derivatives produce a gel network that stabilizes foams and emulsions and increases viscosity and dietary fiber content.

CBMC, a synthetic, water-soluble gum (polymer) is primarily used as a stabilizing, thickening agent in such foods as ice cream, dairy substitutes, puddings, fruit concentrates, sauces and baked and frozen products. Different CBMCs have been tested in reduced-fat franks and been shown to soften the texture of the franks (Lin et al., 1988), but this may be a positive attribute for this category of products.

Microcrystalline cellulose or cellulose gel is partially depolymerized cellulose and is used as an anticaking agent, binding agent and a dispersing agent. As a fat replacer, it is used in combination with other hydrocolloids. When Todd et al. (1990) incorporated microcrystalline cellulose in ground pork at 3.5% and 7.0% levels, it produced a grainy texture.

Methyl cellulose and hydroxypropyl methyl cellulose form a viscous, colloidal suspension and serve as bulking agents, stabilizers and food binders. Hill and Prusa (1985) found these ingredients to increase patty gumminess, decrease Instron compression scores and decrease meat flavor when used at 0.5% or 1.0% in lean beef (5.4% fat). However, cellulose derivatives used in combination with other hydrocolloids, starches or proteins may provide synergistic effects to benefit textural attributes of low-/no-fat meat products.

## Regulatory Limits of Fat Replacements

Policy Memos 123 and 121B (USDA-FSIS, 1995) allow processors to reduce fat in cooked and fermented sausage and fresh pork sausage and ground beef products, respectively, yet still call them by their traditional names (in combination with reduced-fat qualifiers and if certain restrictions are followed). For example, this policy allows the use of terms defined in regulations such as "Lean," "Reduced-Fat," "Low-Fat," etc. when there is a reduction in fat content resulting from the use of fat replacers (carrageenan, isolate soy protein, etc.). These products must meet the criteria for use of the nutrient content claim associated with the fat reduction. Label examples may include: "Lean Ground Beef, Water and Carrageenan Product," or "Reduced-Fat Pork Sausage, Water and Binders Product," or "97% Fat-Free Kielbasa" or "Reduced-fat Pepperoni." Modifications from the standardized or traditional sausage products must be explained on the ingredients statement with an asterisk and language such as, "Ingredient(s) not in regular "_______" (name of the product). This will assist the consumer in differentiating standardized and fat modified products.

According to Kushner (1996), FSIS has submitted to Office of Management and Budget (OMB) two rule-making initiatives for approval that would permit deviations from Standard of Identity products for the production of lower fat alternatives to traditional foods. The second is an advance notice of proposed rule-making that would solicit comments of FSIS historical reliance of food standards to dictate the labeling and composition of food generally. The proposed rule is expected to follow FSIS approval of the production of "reduced-fat pepperoni," and issuance of a policy memo that specifically permits deviations from a food standard in order "to reduce the fat content [of the standardized product] to qualify for use of nutrient content claim." That policy specifically allows for the use of ingredients not otherwise permitted by a standard such that the modified food qualifies for a defined nutrient claim which is included in the product name. Although the policy memo is limited to modified breakfast sausage, cooked sausage and fermented sausage, the expected proposal will cover virtually all standardized foods. The proposal mirrors an existing FDA regulation that permits deviations from its standards when a modified food bears a nutrition claim as part of the product name. Currently, USDA-FSIS fat-free products must contain fewer than 0.5 g of fat per serving (100 g).

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