Fat Substitutes, Fat Mimetics and Bulking Agents

Dennis T. Gordon University of Missouri, Columbia

Introduction

Everyone wants to consume fewer calories. Since excess weight is the principal and common factor associated with heart disease, cancer and high blood pressure, it is understandable why everyone is interested in reducing their caloric intake. Also, many people want to manage their weight for social, economic and other health reasons. Managing one's intake of calories is important! The first item listed on the new food label are calories per serving. Because of this almost general wish to manage one's weight and subsequent desire for fewer calories, the food industry is motivated to develop and market low calorie foods. Low calorie foods sell very well in the marketplace.

The design and manufacture of low calorie foods have required different strategies. These include using less fat and sugars, adding more water or more air and using some old and some new food ingredients. The subject of this review deals with these latter ingredients and they can be classified into two categories, fat replacers and bulking agents. These ingredients help the food manufacturer use less fat, albeit non digestible fat, and less sugar. The ultimate goal is to have fewer calories. Fat replacers can be further divided into two subcategories based on their chemical and physical properties, fat substitutes and fat mimetics. Many reviews on these food components are available.

In the spirit of this conference, it can be asked if these ingredients can be considered nutrients. Secondly, it can be asked if it is appropriate or necessary to have information on their amounts in foods and the food supply. The answer to both question is "yes". However, as will be discussed, these ingredients may best be described as non-conventional nutrients. Often they will be listed on the food label as "ingredients" immediately below the "Nutrition Facts" panel, but their use or function will not be shown. The total purpose of this review is to explain why the two questions starting this paragraph should be answered in the affirmative. Secondly, explain the significance of these ingredients in food systems and their influence on human physiology and potential health.

Possibly the best analogy to use in suggesting how fat substitutes, fat mimetics and primarily bulking agents can be classified as nutrients, would be to compare them with dietary fiber. Dietary fiber is believed to have very positive effects on human nutrition and health. It is required that the amount of dietary fiber in any food be included in the "Nutrition Facts" panel. There are strong recommendations from the nutrition community to increase our current dietary fiber intake form an estimated 11-24 g/day to 25-35 g/day. Complete information is being accumulated on the amount of dietary fiber in foods, to include its distribution into soluble and insoluble components. All this interest and work to inform the consumer about the amount of dietary fiber in their foods, recommendations to eat more, and all for a food component never found to be or classified as a [essential] nutrient! The author is of the strong opinion that dietary fiber should be considered an essential nutrient.

As the reader progresses through this review, the author would like him/her to continually think about the effects of these food ingredients in the intestine. It is through this entire organ that these low calorie ingredients may be exerting their unique and beneficial properties. Once ingested, they are on a unique journey in you and my intestine!

Fat Substitutes

Fat substitutes are similar to fats and can be defined as a compound that replaces triglycerides in cooking or in a food. Typical examples of fat substitutes are sucrose polyesters (i.e., Olestra, Proctor and Gamble Co.) and triglycerides containing specific fatty acids (i.e., Caprenin, Procter and Gamble Co.). Olestra is a mixture of the hexa-, hepta-, and octaesters (> 75%) of sucrose with fatty acids ranging in length from 8 to 22 carbon atoms. These sucrose polyesters cannot be digested in the small intestine and pass directly into the large intestine. Caprenin, a second type of fat substitute, contains caprylic (C8:0), and capric (C10:0) fatty acids in approximately equal amounts randomly esterified to two hydroxyl groups of a glycerol molecule and with behenic acid (C22:0) esterified to the remaining hydroxyl group. The melting point of Caprenin is approximately 32-35^{0}C compared to 80^{0}C for behenic acid. The ester bonds of the two medium-chain fatty acids are easily split with pancreatic lipase, but the ester linkage with behenic acid is not easily hydrolyzed. Any free behenic acid liberated or the monoglyceride containing behenic acid, monobehenen, cannot be liquefied at body temperatures and subsequently cannot be absorbed from the small intestine because of their high melting points. Caprenin is claimed to have 5 kcal/g compared to 9 kcal/g for conventional fats. Compared to sucrose polyesters that enter and leave the large intestine intact, less than one-half of the starting materials in Caprenin reach the large intestine. Other fat substitutes currently under development and safety testing are: esterified propoxylated glycerol; dialkyldihexadecyl malonate; dicarboxylic acid esters; jojoba oil; polysiloxanes; trialkoxycitrate; and trialkoxytricarballylates. These intact or partially digested fat substitutes (i.e., Caprenin) reaching the large intestine are not further acted upon by intestinal microflora.

Of all the fat substitutes available, only Caprenin has had limited application in foods. It was successfully used to reduce the caloric content by 25% in a new generation of Hershey and Milk Way II candy bars. All other fat substitutes still require approval for use from the Food and Drug Administration (FDA).

Fat Mimetics

Fat mimetics can be carbohydrates or proteins and are used to replace fat in foods because of their textural or organoleptic properties. Currently there is approximately 50 carbohydrate based fat mimetics available for use in foods and most can generally be described as modified starches or maltodextrins. Many of the gums or hydrocolloids used in food can also be described as fat mimetics and will be discussed later in this review. Fat mimetics derived from carbohydrates, with a few exceptions, are totally digestible and provide 4 kcal/g. Their usefulness resides in having the properties and mouth feel of fats, but with less caloric density. Because fat mimetics are digested and their repeating monosaccharide subunits are absorbed, these products do not reach the large intestine. Some of the common carbohydrate based fat mimetics are: N-Oil, derived from tapioca; N-Flate, from corn starch and; the N-Lite series of waxy maize maltodextrins. These products are produced by the National Starch and Chemical Corp. N-Flate is a composite material containing modified starch, nonfat milk solids, emulsifiers and guar gum. Others include: Maltrin M040, a corn maltodextrin (Grain Processing Corp., Muscatine, IA); Stellar, made from corn starch (A. E. Staley Co., Decatur, IL); Paselli SA-2, a potato starch product (AVEBE, Foxhol, Holland); and Nutrio P-Fibre, from pea fiber (Danish Sugar Factories, Braband, Denmark). This last product, Nutrio P-Fibre, is an example of a product designed to serve as a fat mimetic, but is nondigestible in the small intestine and will pass into the large intestine. Although listed as a fat mimetic, Nutrio P-Fibre can more accurately be considered as a type and source of dietary fiber.

Other additional carbohydrate based fat mimetics that deserve special mention are resistant starches (various manufactures), Fibersol-2 (Matsutani Chemical Ind. Co., Ltd, Japan) and polydextrose (Pfizer Chem. Co., Groton, CN). Resistant starch can simply be defined as starch resistant to digestion in the small intestine. The discovery of resistant starch in foods and its possible role in intestinal physiological is credited to Drs. John Cummings and Hans Englyst of the Dunn Nutrition Laboratories, Cambridge, United Kingdom. Both resistant starch and Fibersol-2 can be described as non-digestible dextrins, but Fibersol-2 may not be a true resistant starch because of its different chemical and physical properties. Resistant starch is insoluble and Fibersol-2 is soluble in water. Resistant starch is considered to have exclusively (1-4) glycosidic linkages. Different glycosidic linkages between glucose units are reported to be present in Fibersol-2. These compounds are not completely digested in the small intestine and a majority pass into the large intestine. During the heat processing of starch, especially high amylose starch, partial retrogradation occurs causing the resulting retrograded starch to have limited or resistant digestibility in the small intestine. Resistant starch is considered quantitatively fermented in the large intestine. Resistant starch products will vary depending on the starting material and processing conditions used to retrograde the starch. Besides the potential of adding resistant starch to foods as a food ingredient or fat replacer, it is estimated that conventional food processes contribute 10-30 grams of resistant starch to the diet per day and ultimately the large intestine. Crystalean (Opta Food Ingredients, Inc. Cambridge, MA) is a commercial resistant starch undergoing further development. Fibersol-2 can also be described as a product undergoing further development and testing. Polydextrose or Litesse (Pfizer Chem Co., Groton, CN) is a synthetic polymer consisting primarily of cross-linked glucose molecules and smaller amounts of sorbitol and citric acid. The molecular weight of the polydextrose polymer averages 1,500 and is water soluble. Because of its solubility, polydextrose is classified and used as a bulking agent. Only 25% of polydextrose is digested and therefore provides only one kcal per gram. There remains debate if it should be classified as a source of dietary fiber.

Protein based fat mimetics are not as many as the carbohydrate based fat mimetics, but they have received considerably more attention in the media. Their use in foods is based on their extremely small size, ranging from 0.1 to 3.0 μ (microns), and spherical shape. These two properties combine to result in smooth flowing layers of these particles mimicking the texture and mouth feel of fat. This textural property can be described as ball bearings rolling over each other. Three recently developed protein based fat mimetics are: Simplesse (The NutraSweet Co. Deerfield, IL) made from milk proteins and egg white; Trailblazer (Kraft-General Foods, Glenview, IL) derived from egg white, whey protein and xanthan gum; and LITA produced from corn zein (Opta Food Ingredients, Inc., Cambridge, MA). Because protein based fat mimetics are considered completely digested, very little reaches the large intestine. The xanthan gum in the Trailblazer product would be a non-digestible component, but the amount contained therein can be considered insignificant. The caloric content of Simplesse, Trailblazer and LITA are all 4 kcal/g.

Gums--Hydrocolloids

In discussing the use of fat mimetics in the design and manufacture of low calorie foods, it must be mentioned that many of these food ingredients do not function well unless used with gums (hydrocolloids). Gums are defined as non-digestible homo- and hetro-polysaccharides extracted from land and marine plants and microorganisms. Also, to be included in this category are the synthetic and modified edible polymers used for their hydrocolloid properties in foods. Martin Glicksman, formally with the General Foods Corp., has made continuous contributions in defining the chemistry and functionality of gums in food systems. There are many gums available for use in foods as fat replacers and these have been extensively reviewed by Mr. Glicksman. More correctly defined as hydrocolloids based on their functional properties in foods, these non-digestible carbohydrate polymers have made a recent reincarnation as soluble dietary fibers. Irrespective of the term used to describe these compounds, gums, hydrocolloids or soluble dietary fiber, they are extensively used with fat replacers or by themselves in foods. The important point to mention about gums is that they are not digested in the small intestine, but degraded to varying degrees by bacteria in the large intestine. Since gums are such as integral part of foods, and especially processed foods, they can play an important role in the in the general dynamics of the large intestine.

Bulking Agents

With the extensive use of high intensity sweeteners in foods (i.e., NutraSweet-aspartame, saccharin, and Acesulfame K), there is a need for non-caloric bulking agents. These bulking agents will provide for the body and texture in a food normally contributed by sugar. To accomplish their intended purpose of providing bulk without calories, bulking agents are non-digestible and non-absorbable and therefore pass into the large intestine. The ideal bulking agent would be as sweet as sugar and provide no calories, a model that currently does not exist! Polydextrose, previously mentioned, is the most widely used bulking agent in foods today. Other bulking agents that appear to have applicability in foods are briefly described. Isomalt or Palatinit (Palatinit USA, Elkhart, IN) consists of an approximately equal mixture of D-glucopyranosyl 1,6-mannitol and D-glucopyranosyl 1,6-sorbitol. Isomalt is reported to have 40-60 % of the sweetness of sucrose and is claimed to have one-half the calories. Raftiline (Tiense Suikerraffinaderij, Belgium) is derived from inulin and the oligofructan polymers can contain up to 60 fructose molecules (60 DP, degree of polymerization). Raftilose, also an oligofructose, is a mixture of glucofructosan and fructosan polymers containing two to nine sugar molecules (2-9 DP) and can be best described as the enzymatic hydrolysis products of raftiline or inulin. The caloric contents of Raftiline and Raftilose are reported to be 1.0 kcal/g and 1.5 kcal/g, respectively. Chemically and structurally similar to Raftilose are fructooligosaccharides or Neosugars. Fructooligosaccharides are naturally occurring in fruits, vegetables and grains and can be described as sucrose molecules to which have been added one (1-ketose), two (nystose) or three (1-ß-fructofuranosyl; nystose) fructose molecules linked in sequence. Each individual unit of fructooligosaccharide will contain a terminal glucose unit. Only a limited number of Raftiline or Raftilose subunits contain glucose at a terminal end of the molecule. Historically, Neosugars have been produced with the aid of microorganisms in limited quantities. With developments in genetic engineering, larger yields can now be obtained. ZeaGen, a subsidiary of Adolph Coors Co. (Broomfield, CO), produces and markets a fructooligosaccharide under the trade name Nutriflora. Fructooligosaccharides have about one-half the sweetness of sucrose and are claimed to have 1.5 kcal/g. Other potential bulking agents include the L-isomers of glucose, sucrose, gulose and rhamnose. Most ingested bulking agents will reach the large intestine.

Also, to be included in the category of bulking agents are small molecular weight compounds or oligosaccharides obtained from the hydrolysis of conventional plant or seaweed gums. Examples of this subclass of bulking agents are hydrolyzed guar gum (i.e., Sunfiber or Benefiber, Sandoz Nutrition Corp., Minneapolis, MN) and hydrolyzed carrageenan called policarren. Carrageenan, not hydrolyzed, has been used as the successful fat replacer in fat reduced hamburgers, although it was used as a fat-water-protein binder and not as a bulking agent. The potential to derive many bulking agents through the hydrolysis of plant and seaweed gums, and pectin, is unlimited. However, it is important to mention that hydrolyzed gums are currently not allowed as food additives by the FDA. Use of these hydrolyzed products may be limited because of the high costs to obtain generally recognized as safe (GRAS) status or approval as a food additive.

Dietary Fiber

Before going further, it is important to mention that dietary fiber is the classical non-digestible food ingredient reaching the large intestine. Dietary fiber has long been described as a bulking agent for use in foods, primarily to lower caloric content. The dietary fiber hypothesis implies that a high intake of foods rich in dietary fiber is associated with the lower incidence of many diseases, notably, chronic bowel diseases, diabetes, coronary heart disease and various types of cancers. By definition, dietary fiber is the remnants of plant cell wall material resistant to digestion by animals and humans. This includes: cellulose, hemicelluloses, pectins, gums and mucilages. Dietary fibers and bulking agents have some similar chemical and physical properties (i.e., solubility and carbohydrate composition) and all could result in similar physiological actions within the body.

Non-digestible Food Ingredients

When summing the total amount of potential fat substitutes and bulking agents to the non-digestible materials (i.e., dietary fiber, mucins, etc.) normally in the human diet, there can be a significant increase for non-fermentable and fermentable solids reaching the large intestine. The cumulative effects of these non-digestible fat substitutes, bulking agents and dietary fiber residues reaching the large intestine can represent a fascinating series of biochemical and physiological events. These widely varied and dynamic events are believed to have a major influence on functioning of the large intestine and ultimately the nutrition and health of this organ and the entire body.

The Large Intestine

For use in foods, we have three classes of compounds that can be used to help reduce caloric content. Having consumed these ingredients in different products, their importance now is to their influence on the body. In summary, fat replacers and bulking agents can be divided into three categories based on their potential reaction in the large intestine: 1) fat substitutes that are not further degraded nor used by the body or intestinal microflora and passed in the stool; 2) small molecular weight carbohydrate compounds (i.e., polydextrose) which are not completely fermented by the microflora and are passed in the stool and; 3) all other classes of carbohydrate compounds acted upon totally or partially by the intestinal microflora. This last group includes all dietary fibers, gums, bulking agents and similar compounds (i.e., polyols, lactose and glycoproteins) in foods and those produced throughout the alimentary tract.

Fat Substitutes

Since the fat substitutes are not degraded by bacteria in the colon, they retain their physical properties. Excess fat substitutes contribute an oily texture to fecal wastes and result in the problem of anal leakage or uncharacteristic oily stool composition. Now, this problem continues to plague fat substitutes from receiving FDA approval as food additives. The ultimate effects of fat substitutes on colonic functioning, their safety and interaction in the milieu of the large intestine are unknown and remain a challenging area for future research.

Carbohydrates

The second category of compounds reaching the large intestine are carbohydrates that will not be degraded or fermented to any further appreciable degree. These small molecular weight soluble compounds, such as polydextrose, will exert a bulking effect helping to retain additional water in the colon based on water-solute osmotic pressure equilibrium. The exact amount of polydextrose digestion occurring in the small intestine and/or fermentation in the large intestine is not known. It is not clearly known what other physiological effects this class of compounds can exert in and on the colon.

Dietary Fiber

Dietary fiber is substantially degraded in the colon, but its degradation is variable. Estimates as to the percent degradation of dietary fiber components are: 30-50% cellulose; 30-80% hemicelluloses; 85% pectins; 75% guar gum; 15% locust bean gum; and 10% carrageenan. The final remnants of soluble and insoluble dietary fiber components passed in the stool help retain water. The non-fermentable, non-soluble dietary fiber residues also serve as an anchor for bacteria in the colon. Stool frequency and ease of bowel movements and avoidance of constipation, are considered some of the most important physiological attributes of dietary fiber resulting from not being degraded. This attribute could also be extended to fat substitutes and bulking agents.

Fermentable Compounds

Having considered the food ingredients and the remnants of food not digested in the small intestine and not further degraded in the large intestine, what remains? The remaining food ingredients and compounds are those providing nutrients and energy for the intestinal microflora. This is a very large and diverse mixture of compounds. With appropriate substrates, the amount and types of microflora populating the large intestine can be dramatically changed. These changes in microflora can cause a cascade of events effecting: 1) the amount and types of enzymatic activity produced by these organisms; 2) the chemical composition of the colon's contents; and 3) changes in morphology of the intestine and the cytokinetics of intestinal cells.

Colonic Fermentation

With increased fermentation, comes increased production of short chain fatty acids (SCFA), hydrogen, methane and carbon dioxide and a fall in colonic pH. Bacteria are induced to use the gases as important sources of energy. These bacteria can be divided into two groups: 1) sulfur bacteria producing hydrogen sulfide and; 2) acetogenic bacteria that reduce both hydrogen and carbon dioxide to produce acetic acid. Increased fermentation lowers colonic pH. This physiological change is desirable. Lower pH in the ascending or right colon has been associated with a lower incidence of colon cancer. The high acid environment also promotes the growth of *lactobacillus* and *bifidobacterium* organisms, excluding the gram negative toxin-producing organisms. Thus, a beneficial relationship occurs. Colonic ammonia concentrations are also reduced, and this is considered advantageous because excess ammonia has been reported to increase cell turnover, especially in malignant cells.

Short Chain Fatty Acids

The three primary SCFA produced by fermentation in the large intestine are acetic, propionic and butyric. Acetic acid, produced through fermentation or through reduction of hydrogen with carbon dioxide by acetogenic bacteria, is used as an energy source by bacteria. This results in increased growth and metabolism. The anaerobic cycle is enhanced. Propionic acid is absorbed from the colon into the circulatory system and transported to the liver. The contribution of propionic acid to the intestinal microflora is not totally understood. Butyric acid is utilized by the colonic epithelial cells and has been implicated to be a potent cell regulator that exhibits antineoplastic activity. The incidence of colon cancer is retarded or reduced.

Intestinal Morphology and Cytokinetics

Food ingredients reaching the large intestine cause dynamic changes within this organ. Of these effects, possibly the most important are changes to the morphology and cytokinetics of the intestine. Morphology refers to the structural and physical characteristics of the intestine and the single layer of cells that line the intestine. Cytokinetics relates to the functioning and related aspects of the individual mucosal cell to include the rate at which cells migrate and are sloughed off the intestine, and the biological cycle that these cells undergo during replication and protein synthesis.

Current information suggests that dietary fiber, especially wheat bran, depresses total DNA and the rate of its replication within the intestinal mucosal cells. The synthesis of DNA and formation of new cells occurs within the cell cycle having 4 discrete phases. These phases are: M-phase or mitosis (cell division); G_0G_1-phase (resting); S-phase (DNA replication) and; G_2-phase (resting). The magnitude of the S-phase of the intestinal mucosal cell provides a quantitative measurement of cellular activity. By using bio-markers incorporated into the DNA and quantifying the number of cells that incorporate the bio-marker compared to the total number of crypt cells, an epithelial cell labeling index can be determined. This parameter is higher in individuals with colon or rectal cancers compared to normal subjects. It can only be speculated how certain dietary fibers and bulking agents can affect the intestinal cell's ability to be in S-phase and for how long a period. The more time cells spend in S-phase, the more time they spend in DNA replication and the greater the opportunity for a carcinogen to effect DNA replication and mutagenesis. It can only be speculated how changes to the diet will affect intestinal functioning and regulation. These answers will come with future research.

Conclusion

Although abstinence to excess food intake is possibly the best therapy for caloric restriction, it is difficult to practice. Low calorie foods produced with the aid of fat replacers and bulking agents offer the possibility to "have our cake and eat it too." It will be important for everyone associated with foods and the food industry to be aware of the functionality of fat replacers and bulking agents and the physiological changes they can produce in the intestine. As dietary fiber must still be proven to be a nutrient and shown to be "essential", similar research must be accomplished to understand the significance of these low calorie food ingredients in human bodily functioning and health. If for example, many different fat substitutes are approved for use in foods and food processing, data bank information will be important, so that individually or collectively, the amounts of these ingredients in the food supply can be determined.

Selected References

References, table and figures about the contents of this article can be obtained from the author. Portions of this article are contained in a manuscript submitted to the Institute of Food Technologist for publication *in Food Technology*.