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Simulated and low fat foods: A review

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Abstract
After the COVID-19 pandemic consumers have realised the importance of healthy diet and are more inclined into the consumption of low-fat products to decrease the risk of various chronic diseases and to maintain a healthy body. Fats play an important role in the acceptability of food by determining the texture, taste and flavour of foods. However, consumption and exposure to these diets have been proven to result in overconsumption of calories, leading to obesity and numerous health complications and human diseases, such as obesity, coronary heart disease, diabetes, hypertension and cancer. Due to these reasons food industries nowadays are leaning towards the production of low-fat products by using fat replacers to meet the consumer demands. Fat replacers can be divided into two categories, i.e., fat substitutes and fat mimetics. In general, the performance of a specific fat replacer is affected by its chemical nature and their properties are similar to those of conventional fats, allowing them to be used in replace frying oil, shortenings, and cocoa butter. This article provides information on types of fat replaces used and the benefits on its use in human health.

Keywords: Fat replacer, fat Mimetics, shortening, dietary fat

Introduction
Foods are a source of various substances that can control the physiological functions and modulate immune responses of the body (Kaminogawa1 and Nanno, 2014). Consumers in recent years have increasing concerns regarding ethical, environmental, and health issues associated with conventional food products and have resulted in consumers changing their preferences towards healthier food and beverage choices (Higgins and Llanos, 2015). The recent past year of the pandemic has made the consumers more conscious about their health and the food they consume.

Fats are composed mostly of the same three elements as carbohydrates - carbon, hydrogen and oxygen. Fats are made of a 3-carbon glycerol unit, which is sometimes referred to as the backbone of a fat. Each carbon on the glycerol can hold one fatty acid and supply 9 calories per gram of energy. Whereas, carbohydrates and protein supply 4 calories per gram. Fats are a source of energy for the body and supply essential fatty acids, such as linoleic and linolenic that is responsible for maintaining healthy skin and regulating cholesterol production levels. Fats carry fat-soluble vitamins A, D, E and K and aid in their absorption from the intestine. Fats play an important role in the acceptability of food by determining the texture, taste and flavour of foods (Rios *et al*., 2014) [13]. They are responsible for the smooth texture of salad dressing, the creamy feel of ice cream and chocolate, the moist, tender texture of cakes, the rich flavour of cheese and the juiciness of meats. Moreover, dietary fat plays an important role beyond basic nutrition and within food matrices. It is responsible for sensory and quality properties of a food including physical, textural and olfactory factors which influences the overall palatability. Many snack foods mostly rely on dietary fat for their palatable qualities in order to maintain consumer consumption and acceptance (Ovidiu, 2018) [11]. Emulsion-based foods contain high fat, which accounts for high amount of calories because fats have the highest number of calories per gram of the main food components. Due to recent consumer trends and health concerns, consumers want to decrease their calorie intake. However, it is challenging for the food industry to produce low-fat food products that satisfy customers expectations for fatty sensations while avoiding substantial changes in texture, organoleptic, and rheological qualities such as poor texture, taste, appearance, stability, and mouth feel (Keeton, 1994).

Human nature prefers to consume energy-rich foods, those high in fats, as an evolutionary mechanism for survival and maturation. However, consumption and exposure to these diets have been proven to result in overconsumption of calories, leading to obesity and numerous health complications and human diseases, such as obesity, coronary heart disease, diabetes, hypertension, and cancer. (Timper and Brüning, 2017; Di Feliceantonio and Small, 2019). The principal source of over 90 per cent of total fat in diets are from fats and oils, meats, dairy products, bakery products, confectionary and snack foods. Low fat ratios are highly recommended in food production since it aids in reduced risk of many syndromes including cardiovascular disease (CVD), hepatic steatosis, and obesity (Felisberto *et al.*, 2015).The food industry is countering this problem by developing reduced-calorie products that consumers can incorporate into their regular diet. Since, fat has higher caloric density than most nutrients in foods, reducing fat and cholesterol content is one of the primary trends currently in food product innovation (Ma and Boye, 2013) [7]. Therefore, a major need to develop low fat or reduced-calorie products that are convenient, affordable, and desirable to consumers is of utmost importance these days (McClements, 2015) [8].

Functional role of dietary fat

Dietary fat is a major energy source, essential for growth and development, and provides essential fatty acids needed for maintaining structure of cell membrane Also, fat aids in the absorption of fat-soluble vitamins and other phytochemicals. Fat in food has multiple functions during cooking process. Its heat transfer properties enable rapid heating and attainment of very high temperatures. High temperatures achieved by frying and deep-fat frying create many browning (Maillard Reaction) taste components that have positive sensory attributes. Fats absorb many flavour compounds and round the flavour by reducing the sharpness of acid ingredients. In meats, fat carries the flavour and contributes to the juiciness and tenderness, key to the difference in taste of the various kinds of meat and poultry (Min *et al*., 2010; Jones, 2014) [9, 5].

Functionally, fats affect the melting point, viscosity, crystallinity, and spreadability of many foods. Fat imparts a velvety mouth feel to products such as ice-creams, desserts, and cream soups. Smoothness in ice-creams and some candies is due to fat preventing the formation of large water or sugar crystals. Fats are responsible for the aroma and texture of many foods, thereby affecting the overall palatability of the diet (Rios *et al*., 2014) [13]. Although fat in food may increase acceptance, high-fat foods and diets are also high in calories, which may be problematic for the majority of individuals struggling with energy balance. In baked products, fat inhibits the formation of tough gluten strands, softens the crumb, and imparts tenderness and delays staling. Crispiness in cookies is due to fat in combination with some of the other ingredients. In flaky products such as croissants and pastries, fat's ability to pool in layer and coat gluten strands is crucial. Thus, fat replacers must be chosen with care to replicate the function of fat (Omayma *et al*., 2007) [10].

Fat replacers

Due to the growing rise in obesity and food-linked diseases, the replacement of calorie-dense fat has been a key focus of food industries in the last few decades with promising fat replacers.

A fat replacer is an ingredient that can be used to provide some or all of the functions of fat yielding fewer calories than fat. Moreover, the term of fat replacer may also imply to a substance that has certain desirable physical or organoleptic attributes of fats which it replaces without any of the undesirable properties of fats.

Fat replacers can be divided into two classifications i.e fat substitutes and fat mimetics on the basis of chemical natures and functionalities. Fat substitutes have a similar structure to that of triacylglycerols and they are used to substitute fats on a one-to-one basis, whereas in case of fat mimetics show functionalities comparable to the fat and they are not necessarily used on a one-to-one basis (Colla *et al*., 2018) [2].

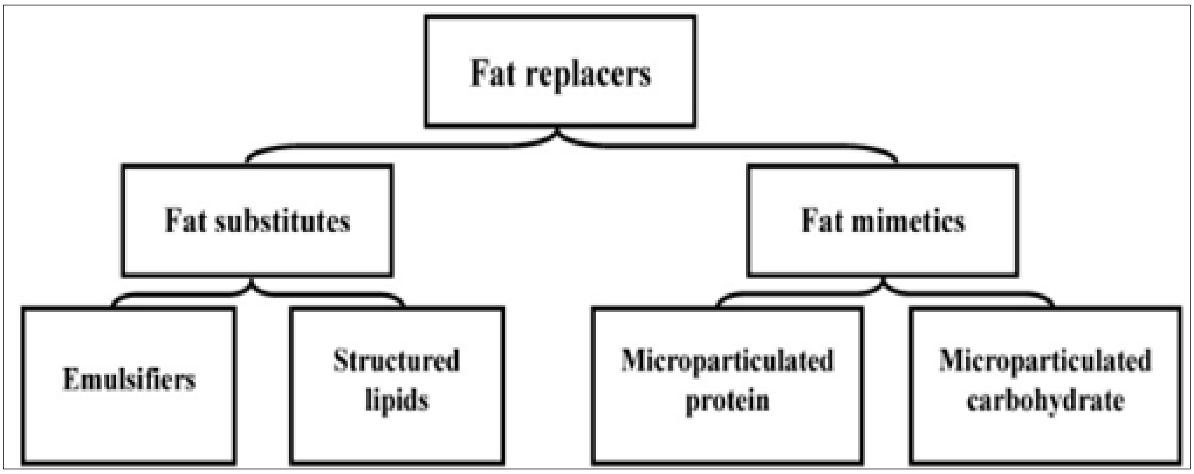
Various low-fat and fat-free foods have been developed using fat replacers. Claims have been made stating that most fat replacers have low-calorie or are non-digestible. Nevertheless, there are still considerable challenges in the industry for high-quality and cost-effective fat replacers to meet consumers' demands for high acceptability, low cost, and clean label for food products.

Digestibility

Fat replacers are not fully absorbed by the body. However, over consumption of fat-based and some carbohydrate-based replacement products may cause abdominal cramping, bloating, flatulence and loose stools (Sullivan, 2016) [17].

Classification of fat replacers

Fat replacers can be divided into two categories, i.e., fat substitutes and fat mimetics.



Fat substitutes

Fat substitutes are materials that simulate the chemical and physical properties of fats and oils and it can directly replace fat on a weight to weight basis. These materials can be produced by enzyme-modified oils and fats and can also be synthesized chemically can successfully maintain the palatability of foods as they can reproduce the texture and mouth feel of fat. They are typically synthetic molecules which provide no energy calories or structured lipid molecules which provide reduced energy calories (Sullivan, 2017) [16]. They are used for cooking and frying purposes due to their heat stable property and suitable for high temperature applications. They may not provide the taste properties of fat as fat itself provides flavour to foods and it is also a carrier of other fat-soluble flavour compounds in foods.

Fat mimetics

Fat mimetics are substances which have some organoleptic and physical properties which can mimic the conventional fat molecules. However, they cannot replace fat molecules in food on a weight-for-weight basis. Fat mimetics are typically protein- or carbohydrate or fiber-based molecules that may be modified to mimic some of the properties of conventional fats. Their energy contribution to the diet ranges from 0 to 4 kcal g (Sullivan, 2016) [17].

Fat mimetics are generally not suitable for frying application as they are susceptible to denaturation or caramelization. They are generally polar and water-soluble compounds in nature. Thus, they cannot replace some of the non-polar functional characteristics of fats, such as lipid-soluble flavour carrying capacity. However, their polar nature facilitates water binding which helps generate a sense of creaminess and lubricity in foods similar to that found in full-fat products (Henneberry *et al*., 2016) [4].

Fat replacers can also be categorized into three basic types

- **Carbohydrate-based replacers**: These are made from starchy foods, such as corn, cereals, and grains. Most fat replacers today are made from carbohydrate. Examples include cellulose, gelatin, dextrins, gums, and modified dietary fibers. Carbohydrates act as thickeners, moisturizers and stabilizers, but they cannot be used as a substitute for fats in frying. Carbohydrate based ingredients are used in lower-fat and fat-free baked goods, frozen desserts, gravies, processed meats, puddings, salad dressings, sour cream and yogurt. Fruits and fruit purees, such as applesauce and prunes, can be used as fat replacers. Baking Healthy® is a fruit based fat replacer. It is sold in the baking section of most grocery stores. Carbohydrate based ingredients provide 0 to 4 calories per gram, depending on the ingredient (Pang and Yao, 2017) [12].
- **Protein-based replacers:** These are made by modifying protein, using egg white or whey from milk. Examples include whey protein and microparticulated egg white and milk protein (such as Simplesse). Sources of protein based ingredients include soy, whey and egg white. Protein based fat substitutes may be found in cheese, butter, mayonnaise, salad dressings, frozen dairy desserts, sour cream and baked goods. Because protein based fat replacers break down when heated, they can be used only in uncooked foods. Protein based ingredients provide one to four calories per gram. Persons allergic to dairy or egg products will be unable to consume dairy or egg based fat replacers (Akbari *et al*., 2019) [1].
- **Microparticulated protein (MPP)** contains milk and/or egg or whey proteins (WPC) shaped into small round particles which are perceived by the mouth as creamy. It functions as a surrogate dispersed phase, replacing the fat droplets which conventionally provide dispersed phase functions which resemble systems as creams, mayonnaise, chocolate frankfurters and pasta. The (MPP) is digested as a protein with reduced calories and no cholesterol. One gram of (MPP) has approximately one-third of the calories of full calorie fats (McClement D, 2015; Akbari *et al*., 2019) [8, 1].
- Microparticulated proteins cannot be used in high-temperature frying, however, it may be used in most applications requiring heat, including canning, pasteurization and ultra-high temperature processing. It is used in dairy products and the production of cheeses, ice-cream, butter and sour cream as well as in oil-based products such as salad dressings and margarine. It has been designated as GRAS by the FDA for use in frozen desserts type products. The FDA has also agreed that whey-based microparticulated protein conforms to its definition of whey protein concentrate, as GRAS substance.
    a. Simpless® is made from whey protein or milk and egg protein. It produces from 1-4 kcal/g. The manufacturing process involves simultaneous heating and shearing to produce small particles of coagulated protein. It provides the mouth feel of fat. It is not suitable for frying but is stable for baking. It is considered GRAS by FDA and may be used in dairy products, salad dressing, margarine, mayonnaise-type products, baked goods, coffee creamer, soups and sauces (Owusu-apenten, 2005).
    b. Dairy Lo® is a protein-based ingredient which produces 4kcal/g. It is manufactured via thermal denaturation of proteins from sweet whey. It improves the texture, flavour stability of low-fat foods. It provides the mouth feel of fat and has GRAS status by FDA (Ovidiu, 2018) [11].
- **Fat-based replacers:** These are made by replacing **triglycerides** in vegetable oils. Examples includesalatrim (such as Benefat), and olestra (such as Olean).Fat based ingredients are made to contribute fewer calories or no calories. Fat based fat replacers are made in two ways:
    a. The structure is modified so that the fat is not absorbed as well
    b. The length of the fatty acid on the glycerol is shorter.

Because these replacers are made from fat, they provide the same physical properties as fats, including taste, texture and mouth feel. Fat based replacers can be used in a variety of foods, such as cheese, confections, sour cream and baked goods. One of the most recent fat replacers on the market is Olestra. This product is stable at high temperatures and can be used for frying. Olestra has been reported to decrease the absorption of vitamins A, D, E and K. For this reason, fat soluble vitamins be added to it (Drake *et al*., 2010) [3].

- Olestra is an emulsifier produced by reacting sucrose with 6-8 moles of C12–C22 fatty acids in the presence of a catalyst. The chemical configuration of Olestra accounts for its indigestibility and why it does not provide calories. It replaces the glycerol molecule with sucrose and has either 6- 8 fatty acids attached. With this many fatty acids, digestive enzymes can't get to the sucrose center in the time it takes for the molecule to move through the digestive tract. The sucrose center is where the breakdown of the substance for absorption into the body would take place.

- Olestra was approved in 1996 by FDA as a direct human food additive in salted snacks and crackers. It is also used to substitute 100 per cent of fats and oils in the preparation of savoury snacks (chips, crisps, extruded snacks and crackers). These uses include the substitution for fat for frying as well as sources of fat in dough conditioners, oil sprays and flavour (Yazici and Akgun, 2014).
- Sobestrin is produced by attaching a hydrophobic fatty acid to hydrophilic sugar alcohols mainly sorbitol. Other polyols used for sugar-fatty acid esters include tetrahalose, raffinose and stachyose.
- Salatrim, is a structured lipid (short and long acyl triacylglycerol rearranged molecules) produced from a mixture of short chain and a long chain fatty acid. The short chain acids are esterified at positions 1, 3 of the glycerol molecule. Whereas, the long chain acid is estrified at position 2.
- Salatrim is also called Benefat, provides approximate5 kcal/g because the short acids provide few calories whilst stearic acid is only partially absorbed in the body. It is usable at pH 3-7.5 and under cold conditions. The suitable product categories for salatrim include confectionery, cookies, cakes, brownies and pie crust
- Caprenin, the second product belonging to MCTs, the glycerol back bone is substituted by caprylic acid, capric acid and behenic acid. This fat replacer yields 5 kcal/g as compared to 9 kg/g for normal fat. The caloric reduction is apparently due to the less efficient metabolism of fatty acids within the body. The functional properties of Caprenin are similar to those of cocoa butter. The useable temperature for Caprenin is <132 ºC and is usually used in confectionary products (Saha and Bhattacharya 2010) [14].

Functions of fat replacers

In general, the performance of a specific fat replacer is affected by its chemical nature and roles in the food system. Lipid-based fat replacers are esters or polyesters that contain fatty acids; they usually provide few if any calories because of their low digestibility (Su *et al.*, 2010) [15]. Their chemical structures result in reduced digestibility, and their physicochemical properties are determined by the profiles of fatty acids. Their properties (e.g., crystallization-melting properties) are similar to those of conventional fats, allowing them to be used in replace frying oil, shortenings, and cocoa butter.

The chemical natures of protein- and carbohydrate-based fat replacers are completely different from those of triacylglycerols, thus, they cannot imitate fats at the molecular level. However, proteins and carbohydrates may bring their fat-replacing functionalities through two approaches (Ma and Boye 2013) [7].

- First, both proteins and carbohydrates are macromolecules that yield characteristic physicochemical and sensory properties (e.g., viscosity and thickness), which may provide a fat-depleted product with properties comparable to those of a full-fat product.
- Second, proteins and carbohydrates can naturally form or be processed to form micro particulates with sizes and shapes similar to those of fat globules and emulsion droplets, thus allowing them to mimic the fats

Commercially available protein-based fat replacers are Simpless R and Dairy-Lo R, which are derived from whey protein concentrates and are classified as GRAS (generally regarded as safe) (Yazici and Akgun, 2004) [18]. The spherical shape and uniform size of particulates can provide a creamy, smooth and rich texture that is desirable for frozen desserts and dairy products.

Unlike the limited available choices for lipid- and protein-based fat replacers, carbohydrate-based replacers include a large family of materials, including starches, gums, fibers and their derivatives.

Table 1: Functions of fat replacers (Sullivan, 2016; Sullivan, 2017; Kew *et al.*, 2020) [17, 16, 6]

Types	Functions
Carbohydrate based	Increasing viscosity, providing mouthfeel, texturizing, thickening, gelling, stabilizing, water holding, lubricity,retaining moisture, retarding staling, texturizing, aiding formulation of bakery products
Lipid based	Emulsifying, providing mouthfeel, holding flavourants, texturizing, stabilizing, increasing overrun, providing cohesiveness, tenderizing, carrying flavour, replacing shortening, preventing staling, preventing starch retrogradation, conditioning dough, texturizing, providing flavour and crispiness.
Protein based	Emulsifying, water holding, texturizing of the food products

Fiber based fat mimetics

Microcrystalline cellulose

It is colloidal products based on co-processing microcrystalline cellulose with sodium carboxymethyl cellulose. A recent addition to the colloidal microcrystalline cellulose products was based on co-processing with alginates or whey or maltodextrins. Usage levels of microcrystalline cellulose can range from 0.1 to 10 per cent, but standard use levels are from 0.4 to 3.0 per cent. The food products where microcrystalline cellulose is most frequently used as fat replacers include: salad dressings, bakery products, dairy products, ice-cream and frozen desserts, cheese spreads and processed meats. In most food systems, microcrystalline cellulose is used as part of an overall fat-mimetic system, which often includes soluble hydrocolloid starch, fat flavours and antimicrobial agents (Saha and Bhattacharya, 2010) [14].

Methylcellulose gums

Methylcellulose gums such as methylcellulose (MC) and hydroxypropylmethyl cellulose (HPMC) are commercially significant polymers used in a variety of food applications for more than 40 years. Like fats, MC and HPMC helps entrap air in food stuffs to improve structure, stabilize air or carbon dioxide bubbles to reduce volume loss and enhance moisture retention. The most important applications of MC and HPMC include: fried foods, liquid foods, baked products, frozen dairy products and low-fat whipped toppings. The main benefit from using MC and HPMC in fried food products is the reduction in fat uptake achievable during the frying step. This contributes to a lower caloric value and improved cooking economy from reduced oil losses (Colla *et al.*, 2018) [2]. Also, reduced fat-baked goods have benefited from their use as they compensate for fat removal by enhancing air entrainment, promoting uniform fine cell size in the crumb structure.

Pectin

Pectin is a hydrocolloid consisting of partial methyl esters of polygalacturonic acid. Pectin is found in all fruits and vegetables and is obtained by aqueous extraction of citrus peel and apple byproducts of juice manufacture. The peel or pomace may be blanched after juice extraction in order to inactivate the endogenously located pectin esterase followed by drying. There is a range of specially tailored pectins for fat replacement. Commercial pectins are divided into low methoxy (LM) pectins and high methoxy (HM) pectins according to the degree of estrification (DE) (Zoulias *et al.*, 2002) [19]. The DE is defined as the percentage of galacturonic acid units that are methyl estrified. Pectins with a DE below 50 per cent are designated as LM-pectins, whereas pectins with DE above 50 per cent are designated as HM pectins. The DE values for commercial LM-pectins typically range from 20 to 40 per cent and from 55 to 75 per cent for HM-pectins (Saha and Bhattacharya, 2010) [14].

Slendid covers a range of special pectin tailor-made for fat replacement. It offers a range of properties including: stability of heat, pH, shear and salt, neutral taste, fat-like dissipation, virtually no calories and relatively low usage levels i.e. 0.2 to 1.5 per cent. It may be used in a wide range of food applications such as: spreads, mayonnaise and salad dressings, processed meats, ice creams, processed cheeses, soups and sauces, desserts and bakery production, in which fat may be partly or fully replaced (Sullivan, 2016) [17].

Hydrocolloid gums

Hydrocolloid gums are long-chain biopolymer molecules that are obtained from plant materials such as seaweeds, seeds and tree exudates. They may also be produced by the chemical modification of polysaccharides or from microbial fermentation. They play a significant role in foodstuffs since ancient times on account of their texturizing and water-structuring properties. It is the high molecular weight of these ingredients, combined with the restrictions in flexibility between monomer units within the polymer chain that gives rise to their viscosifying properties. The most hydrocolloid gums that can be used as fat mimetics include galactomannan extracted from guar gum and locust bean gum. The role of hydrocolloid gums in fat replacement is not as a direct fat mimetic but as a tool for controlling viscosity and texture and binding excess water in their three dimensional network structure (Omayma *et al.*, 2007) [10].

Polydextrose is a complex carbohydrate formed by the random polymerization of glucose, sorbitol and citric acid, which has been used in human food as a low-caloric bulking agent (1 kcal/g). Polydextrose, being a multifunctional food ingredient can be also used as a humectants, texturizer, thickener, stabilizer and cryoprotectant. It is worth to mention that although polydextrose is not a fat-replacer, it has a relatively high viscosity in solution and can therefore contribute to the mouth feel and creaminess of fat-reduced formulations. Polydextrose can therefore be considered as a fat-mimetic in some applications such as reduced – fat pastry, soft chewy candies and spoonable and pourable dressing (Jones, 2014) [5].

Fat substitutes and fat Mimetics used in food industry

Table 2: Fat replacers used in different food products (Omayna *et al.*, 2007; Pang and Yao, 2017 and Colla *et al.*, 2018) [10, 12, 2]

	Fat substitutes	**Fat Mimetics**				
	Derived from fat	Protein based	Starch (Carbohydrate based)	Cellulose (Carbohydrate based)	Gums (Carbohydrate based)	Polysaccaharide (Carbohydrate based)
	Salatrim Acyl triglyceride molecule	Simplesse Whey protein or white egg protein	Starches corn, potato, tapioca, rice, maize, waxy maize	Methylcellulose	Guar, locust bean, xanthangum	Maltodextrin Hydrolyzedstarch
Energy density	:5 kcal/g	4 kcal/g	4 kcal/g	0 kcal/g	0 kcal/g	4 kcal/g
Functional properties	emulsify, stabilize, texturize, lubricate, flavor carrier	stabilize, texturize	texturizer, water holding, thickening, gelling	texturizer	retard staling in baked goods, retain moisture	water binding, imparts mouthfeel, body, viscosity
Application	cheese, dips, sauces, dairy desserts, confectionary	cheese, yogurt, dips, mayo, dairy spreads, desserts	processed meats, margarines, sauces, dressings, baked food	frozen desserts, powdered soups/sauces	bakery good	Application: processed meats, dairy spreads, salad dressings, baked foods, frozen desserts
	Caprenin Energy density: 5 kcal/g Functional properties: emulsify, stabilize, texturize, lubricate, flavor carrier Application: candy, confectionary	Trailblazer White egg protein and xanthan gum Energy density: 4 kcal /gFunctional properties: stabilize, texturize Application: dairy, soups, sauces, baked food		Microcrystalline cellulose Energy density: 0 kcal/g Functional properties: stabilizer, texturizer, imparts mouthfeel Application: dairy, salad dressing, sauces desserts	Carrageenan Energy density: 0 kcal/ g Functional properties: texturizer, imparts mouthfeel, viscosity Application: processed meats, yogurts, salad dressings, desserts, ice cream, chocolate	Polydextrose Energy density: 1 kcal/g Functional properties: texturizer, bulking agent Application: confectionary, spreads, salad dressings, baked foods, frozen desserts, sauces, toppings

	Olestra (Olean) Sucrose polyester Energy density: 0 kcal/gFunctional properties: texturize, lubricate, flavor carrier Application: reducedfat snacks, potato chip				Pectin Energy density: 0 kcal/gFunctional properties: texturizer, imparts mouthfeel, viscosity Application: sauces, bakery, dips etc.	β-Glucan Energy density: 1 kcal/ g Functional properties: texturizer Application: baked foods

Conclusion

Due to urbanization, the is change in diet plan and physical activity of human that enhance the serious health issues due to change in metabolic reactions. But nowdays consumer are concern and aware about the effect of food on their health. The excess consumption of fat leads to various chronic disease. Thus the rising trend in the consumers for consuming healthier food with low fat and calories has driven the food industry in development and production of such food products. This trend has been increased the use of fat replacers as the consumers want the sensations while avoiding substantial changes in texture, organoleptic, and rheological qualities such as poor texture, taste, appearance, stability, and mouthfeel. Thus, various products have been already developed using fat replacers keeping in mind the consumer's acceptability in terms of taste and lower health risks.

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