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Fat replacers: Definition, types, and uses in different food products-a review

Jagbir Rehal, Gurjot Kaur, Pragati Kaushal*
Department of Food Science and Technology, Punjab Agricultural University, Ludhiana, Punjab, India

Abstract
This review paper provides an in-depth analysis of fat replacers and their role in reducing calorie intake and addressing related health concerns. Fat replacers are categorized based on their source, functionality, and nutritional composition. Furthermore, this article encompasses a comprehensive exploration of trans fats. Various fat replacers employed in diverse food products are examined, highlighting their ability to emulate fat properties while reducing caloric content. The review delves into the functions and reactions of fats, underscores the necessity for fat replacers, discusses the different types of fat replacers, and presents research findings on the application of fat replacers in various food products.

Keywords: Fat replacers, fat substitutes, fat mimetics, trans fats, free fatty acids.

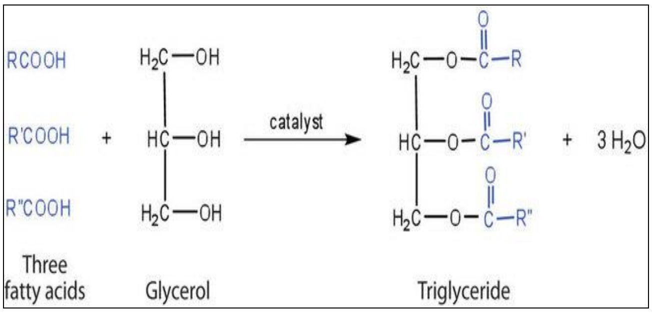
Introduction
The issue of obesity and its detrimental effects on health has experienced an upward trend in recent years. The alteration in dietary patterns and eating habits significantly contributes to this phenomenon. The primary concern lies in the transition towards fast food, which is high in calories but lacks proper nutrition. When considering health, the constituents of food play a crucial role. These constituents encompass proteins, carbohydrates, lipids, fats, vitamins, and minerals. Each of these components plays a vital role in the quality and processing of food products. Among them, fat garners greater attention, particularly from health-conscious individuals.

Fat plays a crucial role in food products, contributing to texture, flavor, mouthfeel, and overall sensory appeal. However, excessive fat consumption has been linked to various health concerns, including obesity, cardiovascular diseases, and metabolic disorders. As a result, there has been a growing demand for healthier alternatives that can reduce fat content in foods without compromising quality. This has led to the development of fat replacers, which are ingredients designed to mimic the functional and sensory properties of fats while lowering calorie intake.

Fat replacers are broadly categorized into carbohydrate-based, protein-based, and fat-based substitutes, each offering unique properties suitable for different food applications. These alternatives are widely utilized in processed foods such as dairy products, baked goods, meat products, and sauces to enhance health benefits while maintaining consumer acceptance. The effectiveness of fat replacers depends on factors such as food matrix compatibility, processing conditions, and desired product characteristics.

This review explores the definition, classification, and application of fat replacers across various food products. By understanding their functionality and potential, the food industry can develop healthier formulations that cater to the increasing consumer demand for low-fat and nutritious foods.

Role of fat in human body
Fats are esters of fatty acids and glycerol, known as triglycerides. The chemical reaction involved can be expressed as follows:



Fats serve as the powerhouse of energy within the body, providing a substantial 9 kcal of energy. Furthermore, they serve as the building blocks for prostaglandins, which play a vital role in the initiation of inflammatory responses. In addition to their energy-providing function, fats are also crucial as they serve as the primary source of several fat-soluble vitamins and free fatty acids. Overall, the scientific significance of fats lies in their role as both an energy source and a precursor for important biological molecules, making them indispensable for various physiological processes.

Role of fat in food
Fat plays a crucial role in the sensory attributes of food, including its mouthfeel, appearance, texture, and flavor. It is a primary component found in various foods such as butter, ghee, oil, and fatty fruits like avocado. Additionally, fats contribute to determining the shelf life of a product. The presence of free fatty acids and lipids can lead to chemical transformations such as oxidation, hydrolysis, and rancidity.

Fat is an essential macronutrient that plays a significant role in food systems, influencing sensory attributes, texture, stability, and nutritional value. It serves multiple functions in food products, impacting their overall quality and consumer acceptance.

1. **Sensory and Functional Properties**

- **Flavor Carrier:** Fat enhances the flavor profile of foods by dissolving and retaining fat-soluble compounds, providing richness and depth to taste.
- **Texture and Mouthfeel:** It contributes to creaminess, smoothness, and tenderness in various products such as dairy, baked goods, and confectionery.
- **Satiety:** Fat slows gastric emptying, promoting a feeling of fullness and reducing overall food intake.

2. Structural and Processing Functions

- **Emulsification:** In products like mayonnaise and dressings, fat aids in stabilizing emulsions, preventing separation.
- **Heat Transfer:** Fats facilitate uniform cooking and browning in fried and baked foods, contributing to desirable sensory attributes.
- **Aeration and Leavening:** In baking, fat incorporates air into batters and doughs, leading to a light and fluffy texture.

3. **Nutritional Significance**

- **Energy Source:** Fats provide a concentrated source of energy (9 kcal/g), essential for metabolic functions.
- **Nutrient Absorption:** They enable the absorption of fat-soluble vitamins (A, D, E, and K), supporting overall health.
- **Essential Fatty Acids:** Fats supply essential fatty acids, such as omega-3 and omega-6, which are crucial for brain function and cellular health.

In summary, fats are essential constituents in food and significantly impact its overall quality. Despite its vital role, excessive fat intake, particularly trans and saturated fats, has been linked to health risks such as obesity and cardiovascular diseases. Consequently, fat replacers and reformulation strategies are being explored to create healthier food products without compromising quality.

Reactions involving fats

As fats impart taste and odor to food, their stability plays a very important role. The stability of fats is related to saturation and unsaturation of the fatty acids. Lipids are the key elements for determining the stability of fats. The storage of any fat-rich food depends upon the stability of fats.

Rancidity: When there is a formation of undesirable odor and flavor due to a change in lipids is called rancidity.

Rancidity occurs in two ways

1. **Oxidation:** Fats when coming in contact with air react with oxygen resulting in undesirable characteristics. This is known as oxidative rancidity. There is a formation of a large number of intermediates in case of oxidation leading to rancidity. This rancidity is triggered by many factors like heat, light, radiation, and enzymes mainly lipoxygenases.

Initiation: $RH \rightarrow R^{\cdot} + H^{\cdot}$

Propagation: $R^{\cdot} + O_2 \rightarrow ROO^{\cdot}$

$ROO^{\cdot} + RH \rightarrow ROOH + R^{\cdot}$

Termination: $ROO^{\cdot} + R^{\cdot} \rightarrow ROOR$

2. **Hydrolysis:** The ester linkages of lipids are hydrolyzed to yield fatty acids. When the base is the hydrolyzing agent, the liberated fatty acids are converted into salts, or soaps which is known as saponification. When agents like acids or enzymes are involved, free fatty acids are released, known as lipolysis or hydrolytic rancidity.

Polymerization: Unsaturated fatty acids with double or triple bonds can undergo polymerization when exposed to heat, oxidation, and the presence of free radicals or polar catalysts. Polymerization leads to various alterations in the molecular weight, color, viscosity, and refractive index of fats and oils when heated. These polymers have an impact on the oil's quality and also reduce the efficiency of heat transfer, resulting in an undesirable modification of the product being fried in said oil.

Trans Fats

Trans fatty acids (TFAs) are a type of unsaturated fatty acids that possess a trans configuration, in contrast to the more favorable cis configuration. These TFAs are recognized as the primary culprits behind the development of cardiovascular diseases, elevated levels of detrimental cholesterol, and various other health-related concerns. Their consumption leads to an increase in low-density lipoproteins (LDL), triglycerides, and insulin, while simultaneously reducing the beneficial high-density lipoproteins (HDL) . The negative impact on health associated with TFAs is attributed to their isomeric properties, which arise during the process of hydrogenation of vegetable oils. The principal origin of trans fatty acids can be attributed to the industrial hydrogenation of oils. However, they can also be obtained through the bacterial conversion of unsaturated fatty acids in the rumen of ruminant animals. Naturally, animal-derived sources contain approximately 20% trans fatty acids, while processed foods and oils contain a significantly higher proportion, accounting for around 80%. Notably, trans fats are prominently present in baked goods such as cakes, biscuits, crackers, and bread, comprising nearly 40% of their composition. Animal products contribute to approximately 21% of trans fat intake, fried potatoes contribute 8%, and potato chips, corn chips, popcorn account for 5%. Additionally, shortening comprises 4% and breakfast cereals contain 5% trans fats (Dhaka *et al.* 2011) [1].

Fat replacers and their need

Fat replacers are chemical compounds that confer the attributes of fats to food items, thereby mimicking their functionality while reducing calorie consumption. They serve as substitutes for fats in various food industries in order to address the adverse effects associated with excessive fat consumption, particularly the elevated levels of saturated fats that can contribute to unhealthy cholesterol levels. By incorporating fat replacers into food products, the caloric intake can be reduced by approximately 4 kilocalories.

1. Types of fat replacers

In general, there are two main categories of fat replacers: fat substitutes and fat mimetics. Fat substitutes closely resemble fats in their chemical composition and physical properties, but they are typically indigestible. On the other hand, fat mimetics have different chemical structures compared to fats and are often derived from carbohydrates or proteins.

Fat substitutes share similarities with triglycerides both in terms of their physical appearance and chemical makeup. They can be either chemically synthesized or extracted from conventional oils and fats. Fat mimetics, on the other hand, are classified into different types based on their composition, including protein-based, carbohydrate or starch-based, and cellulose-based options. Examples of fat mimetics include maltodextrins and polydextrose. The difference between the fat substitutes and fat replacers is given in the Table 1 below (Ognean *et al.* 2006) [2]

Table 1: Difference between the fat substitutes and fat replacers

Fat substitutes	Fat mimetics
▪ Possess similar chemical structure to fats	▪ Possess different chemical structures from fats
▪ Extracted from conventional sources of fats	▪ Extracted from non-fat sources
▪ Sources- Oils and fats	▪ Sources- Protein, carbohydrates
▪ These are fat substances.	▪ These are non-fat substances.
▪ Examples: Olestra, salatrim, caprenin	▪ Examples: Simplesse100, LITA, N-Flate

Some fat substitutes like Sorbestrin, Dialkyldihexadecylmalonate (DDM), Trialkoxytricarballylate (TATCA), Trialkoxycitrate (TAC), Trialkoxyglyceryl ether (TGE), and Esterified propoxylatedglycerols (EPGs) are not available in the market (Ognean *et al.* 2006) [2]. The fat substitutes available in the market are olestra, caprenin, and salatrim and their details and applications are stated in the following Table 2.

Table 2: Different fat replacers available in the market

Sr. no	Name of fat replacer	Type of fat replacer	Source of fat replacer	Application	Made from
1.	Olestra	Fat substitute	Derived from fat	Savory snacks	Sucrose polyester blend
2.	Caprenin	Fat substitute	Derived from fat	Soft candy and confectionary coatings	Triglycerides containing caprylic, capric and behenic acids
3.	Salatrim	Fat substitute	Derived from fat	Baked goods, fillings	Short and long chain acyl triglyceride
4.	Simplesse	Fat mimetics	Derived from protein	Yogurt, cheese	Whey protein concentrate
5.	LITA	Fat mimetics	Derived from protein	Baked goods	Zein protein
6.	N-flat	Fat mimetics	Derived from protein	Salad dressings, ground beef, ice-cream	Gums, emulsifier and modified starch
7.	Gums (guar, xanthan, locust bean, pectins)	Fat mimetics	Derived from carbohydrates	Baked goods, salad dressings, sauces	Glactomannan
8.	Starch	Fat mimetics	Derived from carbohydrates	Margarine, spreads, sauces	Corn, wheat, rice

There are some other fat replacers other than fat substitutes and fat mimetics. These include fiber-based fat replacers, fat extenders, synthetic fat substitutes, and combination systems which include Bindtex, Carra flat, Fat-Tastic, etc.

2. Factors involved in using fat replacers

1. **Sensory factors:** The incorporation of fat replacers exerts an influence on sensory attributes such as gustatory, olfactory, textural, chromatic, and flavor characteristics. Nonetheless, fat replacers inadequately emulate the functionalities bestowed by fats in the product. For instance, in the context of reduced-fat meat products, the desirability is compromised since fat plays a pivotal role in determining the succulence and tenderness, vital attributes associated with meat and its derivatives.

2. **Nutritional Factors:** The role of nutrition is crucial in the transformation of food items. Fat serves as a vital energy source for the human organism, while also acting as a reservoir for fat-soluble vitamins (such as vitamins A, D, E, and K) and essential fatty acids. Moreover, it functions as a precursor for prostaglandins, which play a regulatory role in physiological processes. In meat products, fats contribute to over 50% of the total caloric content. The implementation of fat replacers is beneficial in reducing calorie consumption, consequently impacting the nutritional composition.

3. **Other Factors:** These include technical, safety, cost, specifications, and other important points for an improved product design.

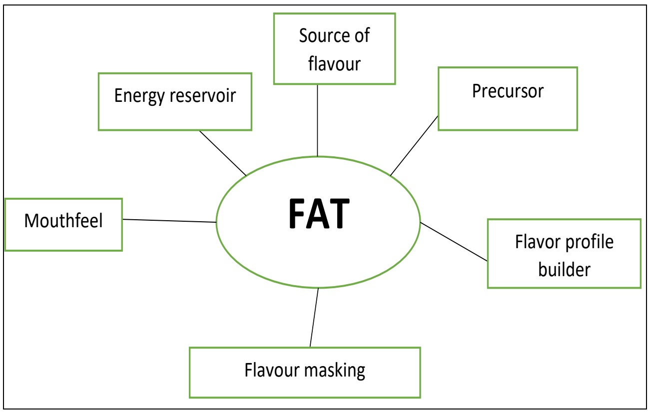


Fig 1: Various physio-chemical and sensory characteristics of fat

Advantages and disadvantages of fat replacers

Fat replacers are ingredients designed to mimic the functional properties of fats while reducing calorie content in food products. They are widely used in the food industry to develop healthier alternatives without compromising texture, flavor, and stability. However, their use comes with both benefits and challenges.

3. Advantages of Fat Replacers

- **Reduced Caloric Intake:** Fat replacers help lower the overall energy content of foods, aiding in weight management and reducing the risk of obesity.
- **Improved Heart Health:** By replacing saturated and trans fats, these alternatives can contribute to lower cholesterol levels and a reduced risk of cardiovascular diseases.
- **Enhanced Nutritional Profile:** Many fat replacers, especially carbohydrate- and protein-based ones, provide additional dietary fiber or protein, improving the nutritional quality of food products.
- **Maintains Sensory Properties:** Fat replacers are designed to replicate the mouthfeel, creaminess, and texture of fats, ensuring consumer acceptance in reduced-fat products.
- **Versatility in Food Processing:** They can be incorporated into a wide range of products, including dairy, baked goods, meats, and snacks, making them highly adaptable in food formulation.

Disadvantages of Fat Replacers

- **Altered Taste and Texture:** Some fat replacers may not fully replicate the sensory qualities of natural fats, leading to differences in flavor, mouthfeel, and overall consumer satisfaction.
- **Digestive Issues:** Certain fat substitutes, particularly fat-based replacers like olestra, can cause gastrointestinal discomfort, including bloating and diarrhea.
- **Nutrient Absorption Concerns:** Fat replacers may hinder the absorption of fat-soluble vitamins (A, D, E, and K), potentially leading to nutrient deficiencies if not properly balanced in the diet.
- **Processing and Stability Challenges:** Some fat replacers may not perform well under high-temperature processing or prolonged storage, affecting the stability and shelf life of food products.
- **Higher Costs and Formulation Complexity:** The use of fat replacers often increases production costs and requires reformulation efforts, making it challenging for manufacturers to maintain product affordability.

The excessive use of fat replacers is due to their ability to intimate the fat properties by preventing the consumers from the undesirable properties of fats. Fats contain approximately double the calories of other macronutrients of food. Fat intake leads to the production of fatty acids and lipids resulting in cholesterol which is a risk factor for cardiovascular diseases.

Properties for ideal fat replacer

- Safe for use
- Exhibit properties same as fats
- Physiologically inert
- Nutritionally equivalent to fats

Adequate testing criteria are implemented to ensure the safety of specific fat substitutes in food products. Testing of fat substitutes encompasses assessments of chemical composition, purity, absorption, toxicity, mutagenicity, carcinogenicity, and environmental impact. Metabolic studies have shown that sucrose polyesters can effectively lower plasma cholesterol levels. Evaluating the nutritional aspects of any type of fat substitute is also crucial. Some fat substitutes may impact digestibility, leading to gastrointestinal issues. The palatability and appearance of fat substitutes, particularly in meat products, pose significant challenges. Post-marketing surveillance (PMS) is necessary after the introduction of low-fat food products or fat substitutes. PMS helps in determining the actual consumption of the product and enables monitoring of any adverse effects resulting from the new fat substitutes or other ingredients. Low-fat products are recognized for their potential to assist in achieving desired macronutrient ratios and dietary recommendations.

Fat replacers used in different food products

The fat replacers used in different food products are tabulated in Table 3 as under:

Table 3: The fat replacers used in different food products

Sr.no	Food category	Name of food product	Name of fat replacer	Type of fat replacer	Reference
1.	Meat and Meat Products	Processed meats	Quaker Oatrim 5Q	Starch-derived	Ozlem and Kemal (2003) [3]
		Sausage and ground beef products	Slenderlean	Starch-derived	
		Pork sausages	Leanmaker	Fiber-based	
		Processed meat and fish products	Konjac-N	Gums/gels/thickeners	
		Ground meats	Nutricol Konjac flour	Gums/gels/thickeners	
		Burgers and sausages	Fat replacer 785, Fat replacer 786	Combination systems	
		Meat products with frying oil	Alkoxylated alkyl glucosides esterified and fatty acids	Synthetic Fat Substitutes	
2.	Milk Products	Yoghurt	Dairy Lo, Maltrin	Protein-based, carbohydrate-based	Ali et al. (2017) [7]
		Mozzarella cheese	Simplesse D100, Dairy Lo, Stellar 100X	Protein-derived, modified corn starch plus xanthan	McMahon et al. (1996) [11]

		Skim milk powder	Oatrim	Starch-based	Chen et al. (2020) [5]
		Cheese	Z-Trim	Starch-based	Chen et al. (2020) [5]
		Ice-cream	Wheat bran starch, potato starch	Starch-based	Chen et al. (2020) [5]
3.	Cereal and Cereal Products	Cereal	Oatrim	Starch-based	Chen et al. (2020) [5]
4.	Bakery Products	Legume cracker	Inulin, Maltodextrin	Carbohydrate-based	Colla et al. (2018) [10]
		Muffin	Rice starch, Inulin, Xanthan gum	Starch-based, Carbohydrate-based	
		Biscuit	Polydextrose, Kel-Lite BK, Resistant starch	Carbohydrate-based	
		Croissant	Maltodextrin	Carbohydrate-based	
		Cake	Inulin, Pectin, Oatrim, Oleogels	Carbohydrate-based, Starch-derived	

Conclusions

In conclusion, the utilization of fat replacers in high-fat food holds immense promise. These innovative ingredients offer a potential solution to mitigate the risks associated with excessive fat consumption, including obesity, cardiovascular diseases, diabetes, and digestive complications. The widespread adoption of fat replacers in contemporary high-fat products attests to their growing popularity and recognition among consumers and food manufacturers alike. With ongoing research and advancements in this field, fat replacers are poised to play a vital role in promoting healthier eating habits and improving overall public health.

While fat replacers offer significant health benefits and food industry applications, their effectiveness depends on the type used, the food matrix, and consumer preferences. Ongoing research and advancements in food technology continue to improve fat replacer formulations, aiming for better functional and nutritional outcomes in reduced-fat products.

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