◇◇◇ Review ◇◇◇

Response to Consumer Demand for Reduced-Fat Foods; Multi-Functional Fat Replacers

Jongbin LIM¹, George E. INGLET², and Suyong LEE^{1, †}

¹*Department of Food Science & Technology and Carbohydrate Bioproduct Research Center, Sejong University,
98 Kunja-dong, Kwangjin-gu, Seoul, 143-747, Korea*

²*Functional Food Research Unit, National Center for Agricultural Utilization Research, ARS, USDA,
1815 N. University Street, Peoria, IL 61604, USA*

The excessive dietary fat intake can result in health problems such as obesity and heart-related diseases, resulting in increased consumer demand for reduced fat foods. A number of food ingredients with fat-like functions have been developed as fat alternatives in the food industry. Especially, some fat replacers that belong to carbohydrate-based fat replacers, play multi-functional roles in foods beyond the reduction of fat and calories. They can provide beneficial physiological activity and control texture and rheology without quality loss. Also, they can promote the development of environment-friendly and natural products, make health claims on a label, and diversify the type of reduced-fat foods. Therefore, the use of multi-functional fat replacers can encourage the food industry to respond to current demand of health-conscious consumers for reduced-fat foods.

Key words: multi-functional fat replacer, low-fat, low-calorie, health claims

1. Introduction

As one of nutritional and functional components of diets, fat delivers pleasing taste and flavor as well as what food scientists call ‘mouth-feel’ in foods, thus providing positive sensory attributes. However, a number of studies have documented that excessive consumption of foods high in fat leads to health problems including obesity and heart disease. Thus, the food industry is facing the challenge of searching for new alternatives for fat in foods without any quality loss. Typically, fat can be replaced in foods by modifying the food formulation with carbohydrate-, protein-, and lipid-based ingredients. Even though a variety of fat replacers have been developed, there are unfortunately no ideal fat replacers which completely function like conventional fat. However, more recent development of food processing technology allows multi-functional fat replacers with unique qualities to be created and used in the most appropriated product applications. Consumers can therefore benefit from the use of multi-functional fat replacers

with health-enhancing effects and keep enjoying food products with reduced content of fat and calorie. There exist several review articles and books on fat replacers which summarize the properties and functions of various fat replacers [1-4]. However, most of them have been published in 1990s and more recent trends of fat replacers have not been reported yet. This article thus introduces recent studies on fat replacers which have been reported since 2000. Specially, a main focus in this article is placed on multi-functions of fat replacers (specifically, carbohydrate-based fat replacers) for commercial applications beyond reduced-fat and -calorie effects.

2. Classification of fat replacers

It is well recognized that fat plays critical functional roles in foods by providing tender texture, glossy appearance, good flavor, emulsifying property, and so on (Fig. 1). Thus, fat gives positive sensory and functional properties when incorporated into food formulations and its contribution to physiological benefits is also well-documented. Therefore, the removal of fat in food formulations can cause undesirable changes in food quality attributes.

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† Fax: 82-2-3408-4319, E-mail: suyonglee@sejong.ac.kr

Fig. 1 Functionality of fat in foods.

Fat replacers indicate food ingredients that can take the place of all or some of the fat in foods and yet give similar organoleptic properties to the foods [5]. In general, they serve two purposes which are the reduction of fat and calorie contents since fat has energy values of 9 kcal/g. Depending on their chemical structure, fat replacers are classified into lipid-, protein-, and carbohydrate-based fat replacers. Furthermore, another terms of fat replacers which are fat substitutes and fat mimetics

(also called analogs and mimics), have been widely used [2]. Fat substitutes indicate any ingredients of which chemical structure and physical property are similar to those of triglycerides. Therefore, most of fat substitutes indicates lipid-based fat replacers and can be used by replacing fat on an equal weight basis. On the other hand, carbohydrate- and protein-based fat replacers belong to fat mimetics which have similar organoleptic/physical characteristics to fat. Fat in foods may not be replaced with fat mimetics on a one-to-one basis. Recent applications of fat replacers since 2000 are presented in Table 1.

3. Multi-functions of fat replacers

For the successful development of fat replacers, there are fundamental factors which can be taken into account. First, fat replacers should be safe for the use in food applications. They also should have similar functional and organoleptic properties of fat in order to minimize

Table 1 Use of fat replacers in various foods from recent (2000~2010) literature.

Sources of fat replacers	Foods	Fat replacement up to (%)	References
Apple pomace	Cookie	~30	[13]
Barley	Sausage	45	[18]
	Cookie, Pumpkin pudding,	40~100	[19]
	Layer cake,		
	Fried pot crust and dip,		
	Taro custard,		
	Saute chicken curry		
Yeast β -glucan	Mayonnaise	~50	[20]
		~50	[21]
Buckwheat	Cake	~20	[22]
	Meat product	~20	[23]
Cannellini beans	Brownie	~50	[24]
Chestnut	Cookie	10~30	[25]
Cocoa	Muffin	25~70	[26]
Corn	Layer cake	~100	[27]
	Muffin	10~70	[28]
Hazelnut	Ice cream	1~3	[29]
Oat	Brownie	15~20	[30]
	Beef patty	13.45	[31]
	Cake	~20	[10]
		~40	[32]
	Chocolate	~10	[16]
	Cookie	~20	[33]
	Meat products	~20	[23]
Okra	Chocolate bar cookie	~100	[34]
Potato starch	Meat products	~20	[23]
Rice	Cookie	~50	[35]
Soy	Meat products	~20	[23]

the quality loss from fat replacement. Most of all, fat replacers should have significantly less fat and calories. Furthermore, it would be better to consider consumer dynamics for reduced-fat foods. The efforts to manage weight and chronic conditions have driven current health-conscious consumers to food-based solutions for reducing the risk of diseases and improving their health conditions. However, they do not want to change their current lifestyle by the sacrifice of their diet patterns. Therefore, there is a need to consider more various factors when replacing fat in foods, in order to satisfy the demand of current consumers for reduced-fat foods.

3.1 Reduction of fat and calorie

From a conceptual point of view, fat replacement is the reduction in fat-constituted calories by using food ingredients with less calories than conventional fat. Therefore, one of the strategies to develop fat replacers is to explore reduced-calorie compounds from non-lipid-based sources (such as carbohydrates and proteins) or manipulate the composition of fatty acids for lipid-based fat replacers (such as structured lipid). Since most of fat replacers from carbohydrate or protein sources have less energy (i.e. generally 4 kcal/g), the energy density of the foods can be readily reduced. As previously mentioned, a diet high in fat leads to undesirable health problems such as obesity, high blood pressure, and heart disease. Therefore, the World Health Organization recommends that the total fat intake should be less than 30% of the total calories and that the intake of saturated fat should not exceed 10% of the total calories [6]. Hence, the reduced content of fat and calorie derived from the use of fat replacers is a nutritional approach to prevent chronic diseases, thus providing beneficial health effects.

3.2 Physiological benefits

Healthy innovation is most widespread in the global food industry. Hence, when developing or discovering fat replacers, another factor to be considered is health-functional property derived from their physiological activities. In this aspect, carbohydrate-based fat replacers (especially from dietary fibers) impart various health benefits to the consumers when incorporated into food formulations at appropriate levels. Thus, fiber-based ingredients are becoming increasingly important as health-promoting functional materials. For example, microcrystalline cellulose, which is non-digestible and has zero-calories, has been used as a fat replacer for meat products, ice cream, salad dressing, and so on.

Also, food applications have benefited from the use of methylcellulose gums such as hydroxypropyl methylcellulose (HPMC) which is regarded as a soluble dietary fiber. Specially, the linkage of β -glucan and its physiological effects has been suggested by a number of in vitro and in vivo studies, demonstrating that β -glucan is effective in reducing cholesterol level, controlling blood glucose level, and reducing the risk of colon cancer [7–9]. Hence, a number of trials where β -glucan was used as a fat replacer, have been found in the literature. Even though health-enhancing effects from the use of carbohydrate-based fat replacers would hardly be claimed due to low level usage, it would be a right step in the right direction to healthy diets.

3.3 Textural and rheological control

Successful development of fat replacers has not only been confined to the reduction of fat and calorie contents by the use of a low-calorie ingredient. In addition, intensive efforts are needed to maintain or even improve the quality attributes of foods by replacing the functions of fat in foods. Most of fat replacers derived from carbohydrate-based fat replacers belong to hydrocolloids which are mainly hydrophilic biopolymers with high molecular weight with great water retention capacity. Thus, since carbohydrate-based fat replacers can bind substantial amount of water, their unique functionalities such as thickening, gelling, and emulsifying properties allow them to mimic the mouth-feel and flow properties similar to those of fat in aqueous systems. Hence, it is also critical to characterize the rheological properties of carbohydrate-based fat replacers prior to the food applications.

In general, carbohydrate-based fat replacers are dispersed/dissolved in water to form a viscous solution or a gel. The increased viscosity aids in incorporating more air bubbles and stabilizing the structure of a food matrix [10], demonstrating that the use of carbohydrate-based fat replacers can compensate for the volume and textural loss of reduced-fat foods. Also, most of fiber-based fat replacers in solutions exhibit shear-thinning flow behaviors which are known to provide a light and non-slimy mouthfeel to food products [11].

3.4 Green processing

A recent issue in the manufacturing industries is the 'Green' concept that promotes the development of environment- and human-friendly products. Moreover, with the recent well-being trend, natural products are so

increasing in prevalence that the growth rate of some natural categories in the food industry has begun to rise. Thus, fat replacers needs to be moved into natural realm by the use of natural ingredients and processing technology even though synthetic fat replacers (such as carbohydrate fatty acid polyesters) showed great potential for successful food applications. Although most of the natural applications are still in the early stage of development, Trim technology which stands for 'Technical Research Involving Metabolism' is approaching commercialization with C-trims (β -glucan-rich hydrocolloids from oat bran concentrates) [12]. Through the TRIM processing, a functional substance (specifically, β -glucan) from cereals such as oats and barley is extracted with the assistance of steam jet-cooking and physical fractionation steps. Thus, the combined use of thermo/mechanical treatments without any chemicals represents environment- and human-friendly technology. In case of natural ingredients, their functions in a body are so well-understood that the use in a food is on the rise when used at appropriate levels. Furthermore, the use of agricultural by-products as a source of fat replacers provides an opportunity for the food industry to move toward sustainable production. For example, apple pomace which is the major by-product of apple juice industry is generated approximately $3.0\sim 4.2\times 10^6$ Mton/year, causing serious economical and environmental problems for disposal. Thus, pectin-enriched materials from the apple pomace were prepared and evaluated as a fat replacer, producing baked goods with 30% less shortening [13].

3.5 Health claims on a label

US FDA initially authorized 7 health claims in 1993 and as of 2004, 12 health claims have been approved by the FDA. The intended purpose of health claims is to give

consumers the information on health-eating patterns which may lower the risk of heart disease, the level of blood cholesterol in a body, and so on. Since consumers can use health claims to make food choices, the food industry is very interested in using health claims on a food label to market their products.

Specially, the fat replacers based on β -glucan have been shown to be strong candidates for making health claims on a food label. The FDA authorized the use of a health claim for the role of β -glucan in reducing the risk of heart disease when 0.75 g of β -glucan/serving is included [14]. As a pioneer of fat replacers, Oatrim and Nu-trim which were developed by Dr. Inglett in USDA contains 5% and 10% β -glucan, respectively. Also, Calorie-control trim which is called C-trim for short, has high amounts of β -glucan ranging from 15% to 50% by weight. Therefore, the food products containing Trim products can be allowed to have a health claim on their labels [15].

3.6 Extension to diverse reduced-fat foods

As we think of the applications of fat replacers, they have been widely used in two food categories which are baked and dairy products. It would be because they belong to the representative groups containing high contents of fat and calories. Also, it is readily easy and convenient to modify their formulations without any significant quality loss. Thus, a number of studies on fat replacement in foods have been used mainly in baked or dairy products as a model system for fat replacement. However, the type of foods where fat is replaced has been recently diversified with increasing consumer demand for variety. For example, cocoa butter in chocolate was recently replaced with β -glucan-rich hydrocolloids and their rheological and tribological properties were characterized [16]. The cocoa butter replacement

Table 2 FDA-approved health claims.

Ingredients	Claimed diseases
Calcium	Osteoporosis
Sodium	Hypertension
Dietary fat	Cancer
Dietary saturated fat and cholesterol	Risk of coronary heart disease
Fiber-containing grain products, fruits, and vegetables	Cancer
Fruits, vegetables, and grain products that contain fiber, particularly soluble fiber	Risk of coronary heart disease
Fruits and vegetables	Cancer
Folate	Neural tube birth defects
Dietary noncariogenic carbohydrate sweeteners	Dental caries
Dietary soluble fiber, such as that found in whole oats and psyllium seed husk	Risk of coronary heart disease
Soy protein	Risk of coronary heart disease
Plant sterol/stanol esters	Risk of coronary heart disease

with β -glucan-rich hydrocolloids up to 10% produced soft chocolates with improved boundary lubrication properties. In addition, fried foods are one of the representative foods with high amount of oil and calorie which is thought to contribute to health problems like overweight and obesity. Even though fat replacement is not necessary in fried foods, the role of ingredients which reduce the oil uptake of fried foods is in good agreement with that of fat replacers in terms of reducing the content of fat (or oil) and calorie. Therefore, there existed a couple of preceding studies which reported the effect of carbohydrate-based ingredients on the reduction of oil uptake during frying. Specially, when β -glucan-rich flour from barley was evaluated as an oil barrier, it was found to absorb almost about half as much oil during frying than wheat batters [17].

4. Summary

Even though fat reduction in foods is not a novel concept in the food industry, there is still a dominant demand of health-conscious consumers for reduced-fat foods that can improve or enhance their health and lifestyle. Specially, carbohydrate-based fat replacers show great potentials for satisfying these consumer demands due to their multi-functions when incorporated into food formulations. Thus, without a doubt, the use of multi-functional fat replacers in foods can have various significant impacts on health as well as food qualities without serious concerns on the reduction of fat and calorie contents.

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