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REVIEW PAPER

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THE MERITS OF FAT REPLACERS IN LOW-CALORIE FOOD

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ABSTRACT

Carbohydrate and protein replacers of fat are frequently used by food manufacturers in response to the increased risk of diseases, which are connected with oversupply of energy and lipids in the diet. Low-calorie replacers such as inulin can limit hunger and normalize blood cholesterol levels. Increases in the nutritional value of food products can be achieved by partially replacing fat by soy protein isolates. Amino acids and deficient minerals like calcium and iron can be provided by food containing protein-based fat substitutes. Some fat substitutes, like maltodextrin, can slightly reduce the bioavailability of the fat-soluble vitamins. As a result, food products containing maltodextrin should be fortified with the affected substances to reduce the risk of malnutrition. The long-term effects of carbohydrate and protein replacers on the human body have not been sufficiently explained, and so fat replacers should be limited in the daily diet.

Key words: fat substitutes, inulin, maltodextrin, protein isolates

INTRODUCTION AND PURPOSE

Fat needs to be present in the daily diet in order to maintain good health and the proper functioning of the human body. According to the recommendations of the World Health Organization (WHO) and the United Nations Food and Agriculture Organization (FAO), daily fat consumption should not be lower than 15–20% of energy demand per day and not higher than 30–35% [FAO 2008]. The 20–35% range is recommended by the European Food Safety Authority [EFSA 2010]. FAO/WHO experts recommend that monounsaturated fatty acids, such as olive oil and canola oil, should provide 13% of the daily energy intake. The consumption of saturated fatty acids, which originate from animals, should not exceed 7% of total lipids [Baylin 2013, Jarlenski and Barry 2013]. In recent years, particular attention has been paid to the supply of polyunsaturated fatty acids, the recommended consumption of which should constitute 6–10% of the daily energy intake. The dietary ratio of n-3 fatty acids to n-6 fatty acids is even more important for human health than their amount in the daily diet, due to the competition between these nutrients in many metabolic processes (the recommended ratio is 1:4) [Kalogeropoulos et al. 2010, Liu et al. 2013, McDaniel et al. 2013].

Lipids are essential compounds of the diet, as they are the primary source of energy for the human body. They also function as building blocks and have a thermoregulatory role. The successful absorption of the fat-soluble vitamins (A, D, E, and K) requires fat

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to be consumed in adequate amounts. Weight loss and abnormal metabolic processes can be reasons for the insufficient supply of lipids. However, the excessive consumption of fats, and especially of saturated and trans fatty acid isomers, is more frequently observed than the deficiency of these compounds in the daily diet. Lipids have a high energy density (9 kcal/g), which means that overconsumption of these nutrients leads to overweight, obesity, and diseases of the cardiovascular system – and in particular to atherosclerotic lesions [Niki and Traber 2012, Wakai et al. 2014]. The average daily intake of lipids in the European Union has exceeded the reference values at 36% of daily energy requirements, though a downward trend in the consumption of edible fats and oils has been observed in recent years in European countries [Bogumil et al. 2013].

Fat-reduced foods appeared as a result of market requirements and consumer expectations. The reduction in elimination of fatty acids was carried out by the introduction of specific food additives. Fat substitutes exhibit similar functional properties and sensory qualities similar to those of traditional lipids. Fat replacers have a considerably lower energy value than fat, so using lipid substitutes in low-calorie food is justified. However, the bioavailability of fat-soluble vitamins should not be reduced or limited by the addition of low-fat alternatives. There are two types of lipids replacers with different chemical structures: carbohydrate-based and protein-based fat substitutes [Sahan et al. 2008, Martin et al. 2011, Ng et al. 2011, Ebneter et al. 2013]. The aim of this study was to assess the positive and negative aspects of fat replacers (mainly plant replacers) and whether they have a place in the daily diet.

CARBOHYDRATE SUBSTITUTES OF FAT

Inulin

Inulins are polysaccharides that belong to the fructan group, composed of fructose molecules joined by a $\beta(2\rightarrow1)$ glycosidic bond. This compound has mimetic characteristics and its chemical structure allows it to serve as a carbohydrate-based fat replacer. Inulin is an important ingredient of low-calorie food as it can replace highly energetic nutrients, including both monocarbohydrates and lipids (and especially saturated fats). It is a natural substance that is mainly obtained from chicory root by extraction and desiccation. The addition of inulin to food products does not change their organoleptic features, but it is a good extender, which allows for the fat content of the final product to be reduced. Inulin has a number of qualities that make it popular in food manufacturing. It can mask the characteristic metal taste of sweeteners, which are often used in food with reduced nutritional value. Additionally, inulin intensifies the effect of sugar substitutes, allowing less of them to be used. Inulin is characterized by an approximately tenfold higher sweetening power than sucrose, and this is enhanced further in combination with artificial sweeteners. Inulin also improves the aroma and taste of low-calorie food. For these reasons, inulin can replace the fat that would otherwise result in various sensory qualities in products [Zahn et al. 2010, Arcia et al. 2011, Charalampopoulos and Rastall 2012]. Inulin also alters the hardness, viscosity, and adhesion of products, with the rheological properties of inulin-enhanced food products being dependent on the arrangement of the molecules in the system of proteins and fats occurring in a particular food [Salvatore et al. 2014].

Inulin has a documented, positive impact on the functioning of the human body, and products that contain it can be considered functional foods. This compound is a specific fraction of dietary fiber that does not undergo digestion or absorption in the human body. It is a natural prebiotic that stimulates the growth of intestinal microflora. Studies have shown that this saccharide reduces the number of colonies of *Clostridium* spp. and *Escherichia coli* bacteria, while at the same time stimulating the proliferation of saprophytic flora, including *Lactobacillus* spp. in the intestine [Kolida et al. 2002]. Inulin provides nutrients for bacteria in the large intestine, where it undergoes a fermentation process that produces short-chain fatty acids (for example, butyric acid), which are important in the regeneration of intestinal epithelial [Macfarlane and Macfarlane 2011]. Research has shown that the presence of inulin in the daily diet minimizes flatulence [Koecher et al. 2014]. The influence of this compound on human intestinal microflora prevents the development of certain types of cancer, particularly colon cancer. It is significant that inulin has the ability to bind large amounts of water, thus preventing constipation [Barclay et al. 2010, Meyer et al. 2011, Morris and Morris 2012].

Taking into account the fact that inulin is a low-calorie substance (with 1 kcal/g), it could be consumed by obese patients. Gargari et al. showed that the use of 10 g inulin per day by people with overweight or first-degree obesity caused a weight loss similar to that associated with a low-energy diet and reduced intake of highly calorific fats [Gargari et al. 2013]. Moreover, foods containing inulin tend to have low glycemic indices, which promotes weight loss, because (among other effects) the rapid growth of postprandial glycemia and insulin levels is not observed. The hunger and snacking related to this phenomenon are also limited [Hijova et al. 2013]. G-43 receptors (GPR-43) are activated by short-chain fatty acids (such as butyric, propionic, and acetic acid) being produced in larger quantities. The overexpression of GPR-43 in adipose tissue and in enteroendocrine cells secreting YY peptide occurs alongside the exaggerated secretion of leptin. Prolongation of intestinal transit time and the synthesis of this adipokine and of YY peptide are inhibited by knockout of the gene for the G-43 receptor [Ischimura et al. 2009].

The effect of inulin on glycemic control has not been clearly described, but it has been suggested that it is beneficial for patients with disorders of carbohydrate metabolism. A significant decrease in glucose and glycated hemoglobin has been observed in patients with both type-2 diabetes and overweight or obesity (body mass index in the 25–35 kg/m^2 range) consuming 10 g of inulin rich in oligofructose per day [Dehghan et al. 2014]. The metaanalysis conducted by Bonsu et al. [2011], which verified 13 randomized clinical trials in respect of the effect of fructans (including inulin) on glycemia, showed no interaction (for two-thirds of the studies) or a reduction in the plasma concentration of glucose (in the remaining third). Statically significant differences were demonstrated only in one study [Bonsu et al. 2011]. On the basis of nine randomized studies, it can be concluded that the consumption of approximately 17 g inulin per day can significantly reduce levels of total cholesterol and triglycerides in blood serum. This is safe, because it is being done only in people with abnormal lipid profile [Forcheron and Beylot 2007, Wu et al. 2010]. Adding inulin to the daily diet also inhibited inflammation, because of the reduction in the expression of proinflammatory cytokines such as IL-2, TNFα, and IL-10 [Hijova et al. 2013]. In randomized clinical studies in obese patients with type-2 diabetes, the application of 10 g inulin per day reduced the concentrations of markers of inflammation (IL-6 and TNFα) [Dehghan et al. 2014]. In women with type-2 diabetes and BMIs ranging from 25 to 35 kg/m^2, two months' supplementation with 10 g of inulin in two doses (5 g each) had an antioxidant effect (increasing the total antioxidant capacity, increasing the activity of superoxide dismutase and catalase, and decreasing the concentration of malondialdehyde) [Gargari et al. 2013].

Inulin, as a soluble dietary fiber fraction, has an influence on the bioavailability of minerals. The absorption of calcium in the small and large intestine is enhanced by inulin, due to the reduction in the pH of the intestinal contents and the change in the speciation and solubility of the element [Coxam 2007]. The results of animal studies suggest that a diet rich in inulin may reduce the bioavailability of copper, and an excessive supply of inulin could lead to a copper deficiency [Untea et al. 2013]. The recommended intake of inulin in the diet is from 3 to 6 g per meal, as a once-off intake of a larger amounts (20–30 g) can have a laxative effect. Inulin is especially used as a low-energy component of dairy products, sweets, and slimming supplements [Barclay et al. 2010, Meyer et al. 2011, Morris and Morris 2012, Kuntz et al. 2013].

Maltodextrin

Maltodextrin, like inulin, is a carbohydrate substitute for fat. The chemical structure of this natural compound is based on α(1→4) glycosidic bonds (and a smaller number of α(1→6) glycosidic bonds). Maltodextrin is obtained by partial enzymatic hydrolysis of starch. In considering the properties of maltodextrin, we take into account the dextrose equivalent (DE), which is the percentage of reducing sugars (glucose) contained on a dry weight basis. The DE value of maltodextrin does not exceed 20. Low-saccharification maltodextrin has a DE in the 7–10 range, mid-saccharification maltodextrin has a DE of 10–15, and high-saccharification maltodextrin has a DE of 15–20. The higher the dextrose equivalent, the greater the water solubility and sweetening strength. These features have a significant impact on the use of maltodextrin in the food industry [Takeiti et al. 2010, Soto et al. 2012, Hadnadev et al. 2014].

The attractiveness of foodstuffs can be enhanced by the addition of maltodextrin, which can function as a filler, a stabilizer, and a thickener. Maltodextrin forms emulsions with the capacity to bind water in conjunction with lipids. The formation of ice crystals at low temperature and the crystallization of sucrose can be further inhibited by the addition of maltodextrin. Maltodextrin is also a carrier of taste and smell. Changes in the organoleptic properties of food containing maltodextrin are not observed, because, unlike inulin, its sweetening strength is low. Using starch hydrolysates in low-calorie food has an influence on the consistency of the product, and maltodextrin has the ability to change its structure at different temperature. Thermoversible gels, with a consistency very similar to that of fats, can be formed by low-saccharification maltodextrins. Food products containing this ingredient demonstrate viscosity, lubricity, and softness. These polysaccharides maximize the sensation of taste and have an effect on food by giving gloss [Takeiti et al. 2010, Soto et al. 2012].

Maltodextrin has a natural origin and is safe for human health. In randomized studies in people with both type-2 diabetes and overweight or first-degree obesity who received two doses of 5 g of maltodextrin per day for 2 months, fasting glycemia, the level of insulin, and the concentration of glycated hemoglobin did not changed. Comparable values for HOMA-IR (homeostatic model assessment – insulin resistance) have been reported in patients before and after interventions using maltodextrin. No effects have been noted on the antioxidant capacity (total antioxidant capacity of plasma, activity of glutathione peroxidase, catalase, and superoxide dismutase, and the concentration of malondialdehyde) of patients taking 10 grams of maltodextrin per day for two months [Gargari et al. 2013].

These fat substitutes appear to be valuable food additives, because they affect the bioavailability of minerals, increasing absorption of calcium and magnesium (deficiencies of which are a common problem) [Miyazato et al. 2010]. The level of absorption of calcium and magnesium in rats and the increase in intestinal fermentation is augmented by the presence of resistant maltodextrin resulting from thermal or enzymatic degradation of starch (containing a mixture of oligo- and polyglucosides). The degree of bioavailability of these minerals, as well as of iron and zinc, in the animals was correlated with the level of short-chain fatty acids (the number of which depends on the anaerobic bacterial fermentation of dietary fiber) – especially of acetic acid and propionic acid, though not of butyric acid [Miyazato et al. 2010].

The energy value of maltodextrin is low and does not exceed 1 kcal/g [Sobolewska-Zielińska and Fortuna 2010]. Its physicochemical properties, described above, are used in the production of low-calorie margarines, additions to meat, dressings, sauces, mayonnaise, yoghurt, sweets, frozen desserts, and beverages [Chugh et al. 2013, Psimouli and Oreopoulou 2013, Udomrati et al. 2013]. Special caution is however needed with concomitant use of drug therapies, as studies have shown that the maltodextrin contained in food products can react with certain medicinal substances, such as ibuprofen, increasing its solubility and changing the metabolism of the drug in the human body [Garnero et al. 2013].

PROTEIN SUBSTITUTES OF FAT

Egg albumin

The protein albumin, on account of its emulsifying and filling properties, is one of the finest lipid substitutes. The chemical structure and organoleptic features of fatty acids can be imitated with this ingredient. Due to its capacity to bind large quantities of water, albumin is also good thickener. It also gives foods a pleasant consistency, spreadability, and a creamy flavor desired and expected by consumers. Significantly lower energy values (4 kcal/g) than those of traditional lipids can be achieved with the use of this fat replacer, which can thus play an important role in weight loss therapy. Egg albumin is rich in necessary nutrients, such as the exogenous amino acids needed for the proper functioning of the human body. The nutritional value of the final product is increased by the addition of lipid substitutes based on protein. The chemical score of egg protein, adjusted for actual protein digestibility, is much higher for than for plant peptides [Jing et al. 2011]. Ovalbumin exhibits antioxidant activity but, on the other hand, has a strong allergic effect on patients with inflammatory disorders [Yu et al. 2011]. In various in vivo and in vitro studies, egg proteins have demonstrated a number of valuable effects: for example, ovotransferrin is immunomodulating, lysozyme has anticancer effects, and ovalbumin, lysozyme, and ovotransferrin display antibacterial activity. These kinds of peptides have an impact on the functioning of the cardiovascular, nervous, and digestive systems [Yu et al. 2014].

Protein substitutes of lipids are mainly used as fillers in meat products with reduced fatty acid contents. These substances are not as popular as carbohydrate fat replacers, because egg albumin cannot be used to produce food requiring heat treatment, as at high temperatures, protein undergoes irreversible denaturation, permanently altering the structure and characteristics of the product to which it was added. Mimetics based on polypeptides have been used as ingredients in margarines, on account of the creamy consistency they impart. The addition of egg albumin to low-calorie food products also limits the usefulness of these products to vegans [Jing et al. 2011].

Soy protein isolates

Natural polypeptides such as soy protein can also serve as fat substitutes in low-calorie food. They have similar physicochemical properties to animal proteins – for example, their capacity to bind water, which allows them to be used as a filler. Soy protein is also an emulsifier, which greatly simplifies the manufacturing process. The appropriate structure and consistency are given by the addition of these proteins to products, without affecting other rheological properties [Chamba et al. 2014].

Soy proteins also possess a number of positive features, aside from the lower calorific value than fats. They are a source of endogenous amino acids – mainly of glycine but also of necessary exogenous compounds (tryptophan) and other important nutrients (lecithin). The antioxidant capacity of food is increased by glycosylation of soy proteins with other fat substitutes, such as maltodextrin, which effectively protects the human body from the harmful influence of free radicals [Zhang et al. 2014]. Furthermore, the digestibility of food is improved and significant amounts of minerals – particularly calcium, iron, and phosphorus – are provided by soy proteins. The changes in fat-free body mass in a group of people engaged in an intensive program of endurance exercise are not inhibited by supplementation with these ingredients, nor have decreases in the blood level of testosterone in these people been observed [Kalman et al. 2007]. Beneficial effects of soy protein have been noticed in terms of preventing diseases of the cardiovascular system, some cancers, and the symptoms of menopause (mainly in connection with the delivery of bioactive isoflavones, such as genistein and daidzein) [Pavese et al. 2010, Squadrito et al. 2013]. These compounds are anti-inflammatory, and thus associated with the inhibition of free radical reactions. Fasting glycemia, insulin level, HOMA-IR, and the lipid profile (decrease in the concentration of triglycerides, total and LDL cholesterol, and increase in HDL cholesterol level) were improved by using of genistein at a dose of 54 mg for 12 months, which was documented in a randomized study conducted on a group of postmenopausal women. Normal values of systolic and diastolic blood pressure, as well as appropriate levels of adiponectin and lower concentrations of homocysteine and visfatin, have been obtained through the consumption of soy protein [Squadrito et al. 2013]. The transduction of signals transmitted through the protein tyrosine kinase, is inhibited by genistein. Tumor processes are also limited by this isoflavone. Apoptosis of damaged cells is induced, while metastasis and angiogenesis are inhibited by genistein [Squadrito et al. 2013, Pavese et al. 2010].

Products containing soy protein have been consumed for many millennia by Asian populations (and, more recently, by many vegetarians in different nations) in much larger quantities than they are consumed by the general western population. These proteins are mainly used for the production of low-calorie bread, pasta, and meat and food concentrates [Siva et al. 2011]. Soy proteins are also used for obtaining lactose-free and gluten-free food when using sources of plant starch – for instance rice [Guardeno et al. 2013].

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