



Successful Development of Satiety Enhancing Food Products: Towards a Multidisciplinary Agenda of Research Challenges

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In the context of increasing prevalence of overweight and obesity in societies worldwide, enhancing the satiating capacity of foods may help people control their energy intake and weight. This requires an integrated approach between various food-related disciplines. By structuring this approach around the new product development process, this paper aims to present the contours of such an integrative approach by going through the current state of the art around satiety enhancing foods. It portrays actual food choice as the end result of a complex interaction between internal satiety signals, other food benefits, and environmental cues. Three interrelated routes to satiating enhancement are to change the food composition to develop stronger physiological satiation and satiety signals, anticipate and build on smart external stimuli at the moment of purchase and consumption, and improve palatability and acceptance of satiety enhanced foods. Key research challenges in achieving these routes in the field of nutrition, food technology, consumer, marketing, and communication are outlined.

Keywords Satiety, satiation, obesity, behavior, appetite

INTRODUCTION

During the last decades, the prevalence of overweight and obesity (extreme overweight^a) in societies worldwide has increased dramatically, particularly among children (Lobstein and Baur, 2005). In Europe, the prevalence of obesity in men ranges from 4.0% to 28.3% and in women from 6.2% to 36.5% with considerable geographic variation. Prevalence rates in Central, Eastern, and Southern Europe are higher than those in Western and Northern Europe (Berghofer et al., 2008). Moreover, a large number of low- and moderate income countries experience similar problems (Popkin, 2005). Being overweight is a serious risk factor for many diseases such as Type 2 diabetes, coronary heart

diseases, hypertension (high blood pressure), and certain forms of cancer (Seidell, 2006; Visscher and Seidell, 2001). Obesity has additional negative effects, such as psychological suffering because of potential stigmatization and discrimination (Puhl and Heuer, 2009). Overweight and obesity are estimated to account for 8% of the overall burden of disease (Pomerleau et al., 2003). Obesity is therefore associated with enormous economic costs, being one of the leading public health problems in the western world. Muller-Riemenschneider et al. (2008) reported economic burdens ranging from 0.09% to 0.61% of a country's gross domestic product.

At the most basic level, the problem of developing overweight is one of an imbalance between energy intake and energy expenditure. In other words, the challenge to maintain a healthy weight requires that the amount of energy consumed matches (in the long run) the amount of energy expended. Although there is agreement at this abstract level of the thermodynamics, there is less agreement as to whether overconsumption or lack of exercise is tipping the balance. Recently, Westerterp and Speakman

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^aOverweight is typically defined as having a body mass index > 25 kg/m², obesity starts with a body mass index ≥ 30 kg/m²

(2008) argued that it is unlikely that decreased physical activity has fuelled the obesity epidemic. Rather, they held increased intake of calorie-rich foods high in saturated fats, sugar, and salts as primarily responsible. These foods are increasingly available everywhere and at any time in many societies worldwide. In this so-called “obesigenic environment,” people are continuously exposed to energy dense food, which is relatively cheap (Drewnowski and Specter, 2004). And although the fast rising obesity rates are difficult to explain by genes only, genetic factors making certain individuals more susceptible to overweight are increasingly being studied (Bell et al., 2005). Both routes, reduction of food intake and increase in physical exercise are valuable complementary routes in the battle against obesity. This paper focuses on one promising strategy to reduce energy intake; increasing the satiating properties of food products and the socio-economic context in which this strategy should operate.

Attempts to reduce food intake at any particular eating occasion (“satiating”) and across eating occasions (“satiety”) have taken a number of different routes. Educational approaches, although indispensable in their own, have had limited success so far in reducing the overweight and obesity problem (Jeffery and Utter, 2003). It has been suggested that this is because the internal signals to stop eating are weak, particularly in situations where the environment contains cues that stimulate eating (Wansink, 2004). Moreover, enjoying the abundance of food available is socially accepted and consumption in abundance is generally considered a stronger cue for social well-being than consumption in moderation. Providing information on food packages is an alternative route, essentially providing consumers cues in the external environment to help them regulate intake. However, such information is complex and many consumers do not actively use such information in their actual food choice decisions (Van Kleef et al., 2008). In this paper, we focus on a third possible route, namely that of enhancing the internal satiating power of food products. The hypothesis is that strengthening of internal physiological signals leads to reduced food intake, even in the presence of environmental cues. This does not rule out the two other routes though, it merely provides a different starting point. Such satiety-enhancing products need to be positioned convincingly in the market place, both through education and through product labelling. Legal developments regarding satiety-enhancement claims set increasingly stringent criteria for the development of such foods (see Blundell, 2010 for a review). European legislation now requires that the satiety enhancing claims are scientifically substantiated and positioned in a format that can be understood by the “average” European consumer (EU, 2007).

This already indicates that the development of satiety-enhancing foods could be an interesting “show case” for the need of integrative approaches between various food-related disciplines, ranging from human biology and physiology to food consumer sciences. The food industry could contribute to combating the overweight problem by exploiting the many opportunities in the development of satiety enhancing products. Industry experts suggest that these type of products offer a long

term growth perspective (Business Insights, September 2007). However, meeting such challenge is far-reaching, from a scientific, technical, and marketing and communication point of view. Scientifically, the key question is how to select the most promising ingredients and demonstrate the required evidence for their effect (Blundell, 2010). Technically, the challenge lies primarily in finding out how to put satiety enhancing food ingredients or compositions into the food matrix without negative consumer quality perceptions. For marketing and communication, the key challenge involves identifying the optimum positioning for a responsive target group. Taken as a whole, it is clear that developing and positioning products on “eat more of this and you will consume less” is not at all straightforward. This paper is not aimed to be a systematic review but rather to present the contours of such integrative research approach in light of the current state of the art around satiety enhancing foods. Crucial in the development of satiety enhancing food products is that they require an integrated multidisciplinary perspective at the problem, both in relation to public health governance, to corporate/marketing ambitions, and in its relationship to the nutritional, food technological, communication, and consumer sciences. We structure our paper along the stages of effective new product development.

DEVELOPING SATIETY ENHANCING FOOD PRODUCTS

New Product Development Process

To illustrate also the philosophy behind the research program, our review of the state of the art is structured around the new product development process, which involves the following critical stages (see Fig. 1):

Idea Generation

In the present context of satiety enhancing food products, new ideas are derived from human as well as animal biology/physiology, nutritional epidemiology, food technology, consumer learning, and consumer psychology in choice and consumption contexts (see section titled “Idea Generation: Three Routes to Enhanced Satiating and Satiety”).

Concept Development

A concept constitutes the outline of a product idea in terms of key product attributes: what are the functional benefits of the product to the consumer and would consumers buy the product based on those benefits (Moskowitz, 2007). In the present context, optimal product positions are derived from insight into message framing and communication effectiveness (see the section titled “Concept Development: How to Position, Develop and Communicate”). When functional benefits include weight

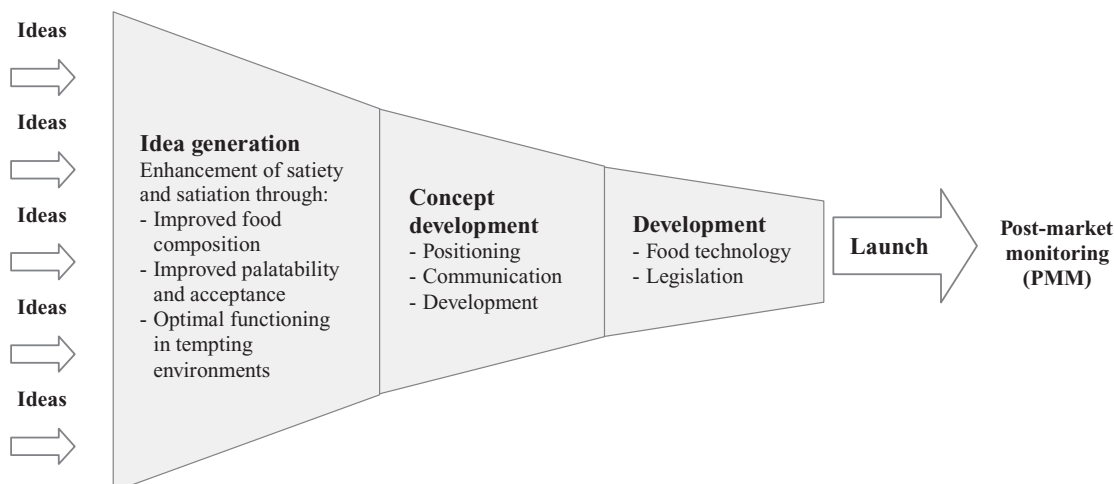


Figure 1 The new product development process to illustrate the development of satiety enhancing food products.

management or other health claims, the concept development stage includes building up scientific evidence to substantiate the claim.

Product Development

A crucial challenge in new product development is the extent to which the physical product can actually live up to its expectations in enhancing feelings of satiety and satiation. Novel ingredients and foods may require innovative food technology and processing methods. Moreover, can a compelling communication format be developed to put the products convincingly into the market place (see section titled “Product Development; Can the Product Develop against Promise?”)?

Launch and Post-Market Monitoring

Once the product is ready for market launch, the crucial question will arise for evidence that the product has been successful, both in terms of its commercial and public health ambitions. This requires (new) models for post-market monitoring (see section titled “Post Marketing Monitoring”).

Although the innovation funnel as illustrated in Fig. 1 may suggest a linear process, in today’s dynamic market places it is increasingly important that these steps are taken concurrently whenever possible and feasible to reduce time to market. For each of the steps, new methodologies and conceptual thinking may be required. In the next section we will discuss for each of the stages our analysis of the key challenges and how we have addressed them in this particular research program.

Idea Generation: Three Routes to Enhanced Satiation and Satiety

Reduction in food intake can be achieved through targeting two complementary processes: satiation and satiety. Satiation

concerns the satisfaction of appetite that develops during the course of eating and leads to meal termination. Satiety is the feeling of fullness after a meal, which decreases in time and ultimately leads to initiation of a new meal (De Graaf et al., 2004). Satiation and satiety are components of the appetite control system and are involved in limiting energy intake (Benelam, 2009). In addition, total intake may be reduced through substitution processes within the meal, whereby consumers learn to eat lower energy dense products (such as vegetables) as a substitute for foods with a higher energy density. Reduced caloric intake as a consequence of feeling satisfied during a meal (satiation) and feeling full after a meal (satiety) results from a complex interaction of factors. It is determined by internal satiety signals (Woods, 2005) as well as triggers in the external environment. Four questions guide the idea generation:

1. How do internal signals of satiety and satiation operate?
2. Which food products and food ingredients can trigger and enhance these internal signals and ultimately affect feelings of satiety, food intake, and bodyweight?
3. How do these internal signals impact on real life purchase and consumption situations which are full of environmental triggers that either stimulate or inhibit food consumption?
4. How can psychological food preference learning processes be exploited to induce a shift from high to low calorie dense foods?

Figure 2 summarizes the three main routes taken in the idea generation phase, building on the assumption that adequate regulation of food intake requires presence of both satiating physiological and psychological triggers. This implies that the development of satiety enhancing products requires an integrated multidisciplinary approach. Basically, enhancing the satiety of new or existing foods, and hence inhibiting food intake, can follow the routes as indicated in Fig. 2. (1) change food composition to develop stronger physiological satiation and satiety signals,

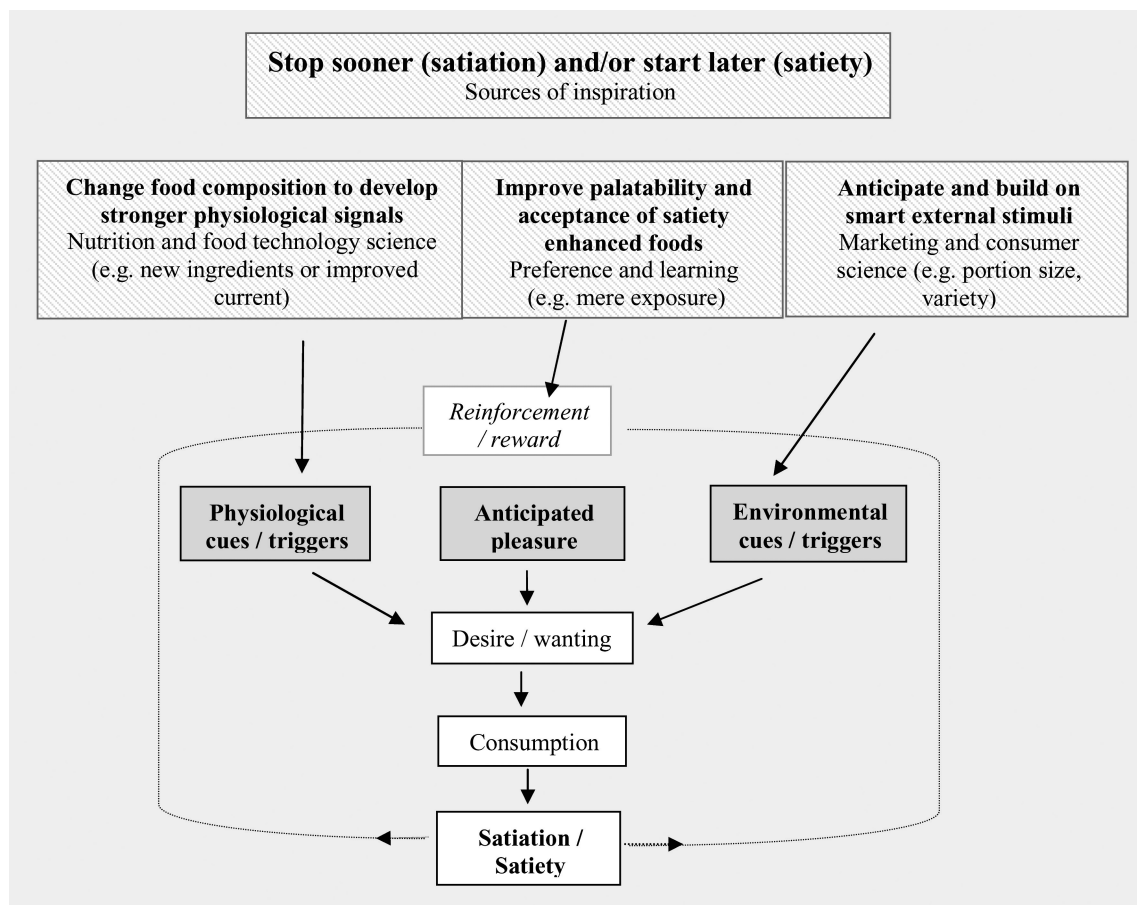


Figure 2 Schematic diagram of factors influencing satiety, inspired by and modified from Mela (2001; 2006).

(2) anticipate and build on smart external stimuli at moment of purchase (in store) and consumption (eating situation), and (3) improve palatability and acceptance of satiety-enhancing foods. Finally, the interaction between the three routes determines food preference and purchasing and consumption behavior.

Change Food Composition to Develop Stronger Physiological Signals

Understanding the Origin and Intensity of Internal Satiety Cues. Feeling satisfied results from various regulatory feedback mechanisms throughout the gastrointestinal tract. During the time a food moves through the entire gastrointestinal tract, secretion of various types of hormones send signals to the brain. The concept of the satiety cascade, originally developed by Blundell and co-workers (1987), describes the physiological mechanisms by which foods impact on satiety and satiety. This cascade gives a time resolved insight in the underlying mechanisms and their effects on the development of hunger and desire to eat. The first phase of the cascade includes sensory and cognitive effects that lead to feelings of satiety and short-term satiety. Those are mainly determined by pleasure, recognition, and the extent to which the sensation meets prior

beliefs and associations. A key sensory factor related to satiety in the cascade is dietary variety. Raynor and Epstein (2001) reviewed 39 studies examining dietary variety, energy intake, and body composition. Both animal and human studies showed that food consumption increases when there is more variety in a meal or a diet, even when the dietary composition of a meal is controlled for texture, energy density, and varying flavors. It is suggested that the responsible mechanism for this effect is sensory-specific satiety (Rolls, 1986; Hetherington, 1996), also called the “dessert effect” as people’s appetite tend to revive when confronted with a dessert after a meal (Remick et al., 2009). Sensory specific satiety refers to a drop in liking for a food after eating it, with little change of liking in foods not eaten (Redden, 2008). This implies that when a greater variety of food is available during a meal, biological satiety signals may be circumvented and it may take longer for satiety to occur for all foods, allowing for a greater intake (Raynor and Epstein, 2001). At a societal level, the increased accessibility to a large variety of food has been pointed at as one of the most dramatic changes in the past 30 years contributing to the obesity epidemic (Cohen, 2008). A cognitive factor is people’s “expected satiety” in decisions about what and how much to eat (Brunstrom et al., 2008). One study found that a 200 calorie portion of crackers is

expected to deliver the same satiety as a 721 calorie portion of M&M's (Brunstrom and Shakeshaft, 2009).

The second phase, associated with mid-term satiety, involves post-ingestive effects, including the release of a large variety of gastrointestinal hormones (GI hormones, also called gut hormones) in response to food quantity and quality. In the third phase, long-term satiety is mainly determined by post-absorptive effects, such as metabolite concentrations in peripheral blood (insulin, glucose, amino acids) and oxidation of nutrients (thermogenesis) in liver and other metabolically active tissues. The distinction between short- and long-term regulation of food intake is, however, not very sharp. Operating together and in interaction, the early and late phases of the satiety cascade determine the amount, duration and frequency of eating (Fig. 3). Their interaction determines the duration and strength of the satiety and satiation. For example, dietary fiber may induce satiety at a short-term due to increased viscosity, bulking, or water-binding in the proximal gastrointestinal tract (mouth, stomach, duodenum, jejunum). In addition, it may be fermented at a longer term in the ileum or colon and therefore result in the release of satiety hormones.

The mouth, stomach, and gut each play their role in regulating food intake, via a complex interplay of hormonal and neurological signaling pathways. Feeling satisfied results from various regulatory feedback mechanisms throughout the gastrointestinal tract. At the short-term, the following factors impact these feelings. Slow eating and intensive chewing may build up satiety and hence reduce meal size (Rolls and Rolls, 1997). The tastiness of food (the so-called palatability) is an important factor at the start of a meal, but its importance decreases during the course of eating (Bellisle et al., 2000). An early explanation for this effect was sought in an increased secretion of saliva and gastric juice which could subsequently expand the stomach (Heaton, 1973). A recent study indicates that the longer sensory exposure time in the mouth may be a key determinant of satiation (Zijlstra et al., 2009). In addition, a longer orosensory stimulation may facilitate the learned association between sensory signals and metabolic consequences (Mars et al., 2009). In the stomach, increased gastric volume induces satiation and satiety by activating stretch receptors in the smooth muscles (Marcianni et al.,

2001; Hoad et al., 2004). Lower motivations to continue eating may also result from increasing gastric viscosity (Marcianni et al., 2000; Juvonen et al., 2009) and delaying gastric emptying (Hellström and Näslund, 2001; Clegg and Shafat, 2009).

In the longer-term, satiety and satiation is regulated by various GI hormones that are secreted into the stomach (e.g., ghrelin, also called the "hunger hormone"), the small intestine and colon (e.g., cholecystokinin (CCK), and the glucagon-like peptide 1 (GLP-1)) and the pancreas (e.g., insulin). They are secreted into the blood where they have a variety of targets (e.g., liver, brain). The endocrine mechanisms by which these secreted gut hormones regulate appetite have been extensively reviewed during recent years (Ritter, 2004; Woods, 2005; Huda et al., 2006; Cummings and Overduin, 2007; Benelam, 2009). In general, the vast majority of the GI hormones induce satiety and therefore inhibit food intake. To date, ghrelin is the only GI hormone known to increase food intake. In addition, it is increasingly recognized that the adipose tissue itself plays a central role in the regulation of energy balance. That is because this tissue secretes hormones with profound effects on satiation mechanisms and energy balance. These hormones (e.g., leptin, insulin, adiponectin) make people less sensitive to GI satiety peptides (Havel, 2001), which implies that it may take longer before satiety signals are sensed by the brain. This may explain why obese men show different brain responses to satiation compared to lean men (Gautier et al., 2000) and this adds to the complexity of the mechanistic regulation of food intake.

The Role of Foods and Food Composition in Enhancing Internal Satiety Cues. Various nutritional studies have shown that variation in the food properties, such as energy density, content, texture, and taste experience are responsible for variation in both satiation and satiety. Numerous studies have examined the effect of certain food compositions on satiety (Table 1). Some authors even developed a satiety index (Holt, 1999; Holt et al., 1995) or satiety quotient (Green et al., 1997), demonstrating that foods provide different levels of satiety. In a typical satiety study in this research field, participants are given pre-loads with varying content. For a number of hours after consumption of the pre-load, participants are asked to indicate their hunger feeling, usually assisted by the visual analog scale (Flint et al., 2000).

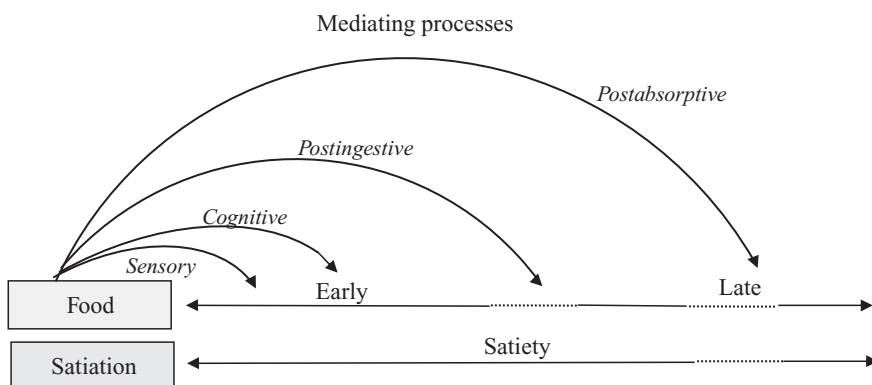


Figure 3 Satiety cascade (Blundell et al., 1987).

Table 1 Some illustrative effects of food composition on satiety: supposed underlying mechanisms and key references

Food composition	What is it doing?	Supposed underlying mechanisms	Key references
Fiber	Fiber-rich foods promote satiety	<ul style="list-style-type: none"> ○ Dilution of energy density of product ○ Require more chewing efforts resulting in slower eating ○ Expansion in stomach which slows down digestion. ○ Delay glucose absorption (lower glycemic index) ○ Affect gut hormones and fermentation processes in gut 	(Burton-Freeman, 2000; Papathanasopoulos and Camilleri, 2010; Slavin and Green, 2007)
Protein	High-protein foods promote satiety	<ul style="list-style-type: none"> ○ Thermogenic effect ○ Decreased energy efficiency ○ Effect on satiety hormones 	(Westerterp-Plantenga, 2008; Paddon-Jones et al., 2008)
Fat	High-fat foods promote satiety	<ul style="list-style-type: none"> ○ Delay stomach emptying ○ Ileal brake theory 	(Maljaars et al., 2008)
Carbohydrates	Complex carbohydrates increase satiety	<ul style="list-style-type: none"> ○ Modulating blood glucose levels 	(Ludwig et al., 1999)
Texture	A simple texture provides more satiety than a complex one.	<ul style="list-style-type: none"> ○ Closely related to strong and distinctive taste of certain products ○ Maximum sensory incentives in the mouth ○ Increased need for chewing promote satiety 	(De Graaf, 2005; Weijzen et al., 2008)
Novel ingredients	Functional ingredients: Commercial examples: Slendesta, Emulgold, Fabules	<ul style="list-style-type: none"> ○ Various mechanisms 	(Kovacs and Mela, 2006; Mela, 2007)

This section addresses the role of food composition in satiety, more specially macronutrients (protein, carbohydrates, and fat), energy density, texture, and novel ingredients.

Basically, there are three macro-nutrients that deliver energy to the body: fat, carbohydrates, and proteins. They are not providing the same amount of energy. A gram of proteins or carbohydrates provide 4 calories and a gram of fat 9 calories. The number of calories per gram food and the extent to which a product provides satiety are not linear. Protein generally increases satiety to a greater extent than carbohydrates or fat and in this way it may facilitate a reduction of food intake (Paddon-Jones et al., 2008; De Graaf, 2005). Halton and Hu (2004) reviewed the literature on the effects of high protein diets and foods on satiety and weight loss. They state that there is convincing evidence that meals high in protein are more satiating when compared to meals lower in protein, at least in the short-term. To a certain extent, this is due to increased thermogenesis. Thermogenesis can be explained as the increase in energy expenditure above the baseline following consumption. In relation to weight maintenance and even weight loss, research has shown that a relatively high-protein diet with low energy (offered *ad libitum*^b) has a positive effect, although at the long term this type of diet may have a negative effect on kidney function (Soenen and Westerterp-Plantenga, 2008). An additional advantage is that higher-protein diets have higher compliance (Paddon-Jones et al., 2008). However, research suggests that the type of protein matters in inducing satiety and that proteins should therefore not be considered generically (Paddon-Jones et al., 2008; Camire and Blackmore, 2007). For example, animal protein has been shown to produce a 2% higher energy expenditure than vegetable protein, resulting in reduced appetite (Westerterp-Plantenga, 2003).

^bA term used in nutrition research to indicate that study participants have free access to food or drinks thereby allowing the person to self-regulate intake according to his or her needs.

Although fat provides most energy on gram basis, it is not the most satiating macro-nutrient. Nonetheless, techniques that delay fat digestion could lead to satiety control (Camire and Blackmore, 2007). For example, fat typically delays the emptying of the stomach, which gives people a feeling of being full for a longer period of time. A significant part of the metabolic conversion of fatty acids is taking place at the distal part of the small intestines. Undigested fat gives a variety of signals that increase satiety and inhibit appetite. This theory is referred to as the “ileal brake theory” (Maljaars et al., 2008). Carbohydrates affect satiety more than fat, but this depends to a large extent on the type of carbohydrates. Carbohydrates involve both simple sugars and more complex carbohydrates. Simple sugars are digested quickly. The glycemic index indicates how foods change blood glucose levels, but the application of this index is controversial (van Bakel et al., 2009). However, blood glucose levels seem to play a role in relation to satiety. In particular, there is emerging evidence that high glycemic, refined carbohydrates decrease satiety and increase subsequent energy intake, as it pushes the body to refuel on carbohydrates (Ludwig et al., 1999; Anderson and Woodend, 2003).

One of the most important characteristics of a food that has a strong influence on satiety is its energy density (Benelam, 2009). Energy density is defined as the energy per unit weight of a ready to eat food (Whybrow, 2005). Water, air, and fiber are the main food constituents which can contribute to a lower energy density (Burton-Freeman, 2000). In essence, foods with high energy density have a lower satiating capacity, but are considered to be tastier. This is mirrored by low energy dense foods, such as vegetables and fruits, which are less palatable, but more satiating (De Graaf, 2005; Drewnowski, 2003). Rolls et al. (1999) found that water has a greater effect on satiety when it is consumed as part of a food rather than when consumed with a food.

Texture influences satiety as well. Foods with a chewier, denser structure (e.g., based on whole grains) have a higher

satiating capacity than less dense or liquid foods (Camire and Blackmore, 2007; De Graaf, 2005). For example, the consumption of soft drinks has increased substantially over the past decades. In the US, for instance, soft drinks represent the leading source of added sugars in the diet of adolescents (Guthrie and Morton, 2000). Sugar in liquid form has poor satiating power, and as a result, soft drinks tend to increase total energy intake without providing satiety (Popkin and Nielsen, 2003).

Based on increasing knowledge of how food composition affects food intake at the short-term and long-term, several novel ingredients have been developed that are supposed to suppress appetite and reduce food intake (Mela, 2007). Commercial examples are FabulesTM and PinnoThinTM derived from plant oils.

The Promising Role of Fibers. A promising and vast growing stream of research focuses on the role of fibers. Dietary fibers are defined by the Codex Alimentarius Commission as carbohydrate polymers with a degree of polymerization not lower than three^c, which are neither digested nor absorbed in the small intestine. In particular, dietary fiber consists of one or more of (1) edible carbohydrate polymers naturally occurring in the food as consumed, (2) carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic, or chemical means, or (3) synthetic carbohydrate polymers (Codex Alimentarius Commission, 2007). In general, inclusion of fiber in foods promotes satiation and prolongs satiety (Burton-Freeman, 2000). Fibers are primarily storage and cell wall substances of plants that cannot be digested by humans (Marlett et al., 2002). Natural fiber sources in the diet include fruits, vegetables, legumes, whole-grain products, nuts, and oat. The recommended intake of fiber is between 20 and 35 gram a day for adults. However, the majority of the population does not meet this recommended level of intake.

The mechanisms by which dietary fiber modulates energy intake are not yet clearly understood. Foods rich in fiber are usually less energy dense and larger in volume, which can directly reduce the intake of metabolizable energy (ME). In addition, increasing dietary fiber can decrease digestibility of macronutrients (Miles et al., 1988) and Atwater factors may overestimate energy availability from high-fiber diets (Zou et al., 2007). Apart from such direct effects, fiber-rich diets may also reduce ME intake by enhancing satiety via several routes. The mechanisms by which various types of fibers affect satiety have not yet been studied in detail. Fibers, including celluloses, fructans, pectins, galactomannans, beta-glucans, and resistant starches, are very diverse in their physical chemical characteristics (Potty, 1996). Functional fiber characteristics, such as water solubility, viscosity, gelling, water binding capacity, and fermentability, are expected to be pivotal in the regulation of satiety (e.g., Papathanasopoulos and Camilleri, 2010). Moreover, there are good reasons to assume that short-term satiety depends on other key characteristics (e.g., bulking due to high

water binding capacity or gelling) (Berthold et al., 2008; Hoad et al., 2004) than longer-term satiety (e.g., fermentability) (Cani et al., 2006; 2009). Hence, the effect of fiber differs according to the type of fiber used, but it should be realized that added fibers to food products do not always behave in a manner similar to naturally occurring fibers (Slavin and Green, 2007).

Potential advances in the field of fibers include the following. First of all, a key research challenge is to better understand the structure-function relationship of the numerous varieties of fibers in relation to specific satiety enhancing benefits. It may be more efficient to investigate few fiber types with specific physical characteristic like viscosity, solubility, gelling power, or fermentability than to investigate many individual branded fibers. Whether or not a fiber characteristic affects satiety is of interest, but also its mode and site of action remain to be identified. For example, Delzenne and Cani (2005) suggested that short chain fatty acids, which are produced during fermentation of fibers, may affect the release of gastrointestinal satiety hormones, such as peptide tyrosine tyrosine (PYY) and glucagon-like peptide 1 (GLP-1). Identification of the receptors that mediate this action of the short chain fatty acids on the production of satiety peptides (Tazoe et al., 2009; Ichimura et al., 2009) may then clarify underlying hormonal and neural pathways. In practice, such knowledge could be used for (technologically) modifying food ingredients, aiming at activating important physiological signaling pathways involved in satiety.

Animal research could identify the mechanisms by which dietary fibers affect satiety. A major advantage of using animal models is the accessibility of body tissues, which allows measurement of gene and protein expression in specific organs that may be involved in fiber-induced satiety. An additional advantage is that experimental factors, including the external stimuli, can be better standardized in animals. However, an appropriate animal model requires a good similarity of the gastrointestinal tract with that of human and it should be possible to obtain reliable outcomes which relate to satiety. The pig meets both requirements (D'eath et al., 2009; Rowan et al., 1994) and can therefore be considered as a good candidate. Importantly, obese pigs are similar to obese humans in that the major contribution to fat mass is the subcutaneous adipose tissue (Spurlock and Gabler, 2008), that is, the fat tissue just under the skin. The approach taken will allow categorization of fibers according to their physical-chemical properties, thereby circumventing the need to test each specific type of dietary fiber in humans. A better understanding of these mechanisms together with insight in dose-response relationships would help in selecting the most promising sources of dietary fiber to be used in satiety enhanced foods.

In addition to animal models, novel tools are increasingly being applied to study the functionality of dietary fibers. An example is a computer-controlled in vitro model of the gastro-intestinal tract to mimic the human digestive system. Such a model allows studying the underlying mechanisms of the processes that occur when fibers go through the gastro-intestinal tract. For example, it can be studied how

^cA degree of polymerization not lower than three is intended to exclude mono- and disaccharides.

quickly gastric emptying occurs for different types of fibers and what the effect of fibers is on the glycemic index (Venema et al., 2004). Results from these in vitro studies will have to be integrated with in vivo research to better understand the mechanisms of action of fibers in inducing satiety and satiety. Similarly, enteroendocrine cell lines may be used for studying the release of satiety peptides when exposed to dietary ingredients (Foltz et al., 2008; Reimann et al., 2004).

Knowledge from animal trials and in vitro experiments will need to be validated in human intervention trials. This can be done in short-term studies in which effects on satiety are assessed by means of visual analogue scales or an ad libitum meal after a fixed fiber-rich preload. However, short-term effects may differ from long-term effects of fiber. People may get used to the satiating effects of fiber after repeated exposure and also their microbiota will adapt. Apart from reported feelings of satiety, especially longer term changes in energy intake and bodyweight are of interest. This also holds for indicators of metabolic health, such as body fat distribution and parameters related to glucose and fat metabolism. It is increasingly acknowledged that research needs to be carried out in both healthy and overweight subjects. Obese persons may be more likely to reduce food intake as a result of increased fibers in their diet (Burton-Freeman, 2000), most likely because stomach responses to food are different in obese persons, who tend to have larger empty stomach volumes than normal-weight people. Ultimately, mechanistic concepts by which fiber characteristics affect appetite regulation can be applied for incorporating appropriate fiber sources in food products.

Improve Palatability and Acceptance Satiety Enhanced Foods

Food preferences are built on satiety. People have an innate tendency to like foods with a high energy density (Prentice and Jebb, 2003). Taste or liking is often believed to be the most important driver of food choice and consumption. However, it is commonly agreed that studying food rewards in eating behavior needs to distinguish between food liking and food wanting. Although intuitively liking and wanting seem similar, this distinction grew mainly out of research on drug addiction where stimuli that are often no longer liked are still intensely wanted (Berthoud and Morrison, 2008). Liking and wanting are different, both psychologically and neurobiologically. "Liking" refers to palatability (i.e., the pleasure of eating) and "wanting" refers to appetite (i.e., the motivation or desire to engage in eating) (Mela, 2006; Berridge et al., 2009). Based on advances in neurobiology it has become clear that different neurochemical pathways are associated with liking and wanting. Less is understood how liking and wanting components of reward might work together or separately to modulate appetite (Finlayson et al., 2007). The discussion is whether excessive food intake leading to obesity is the result of food wanting versus liking. The hedonic impact of increased palatability appears to be a key driver for stimulating appetite and consumption. It has been suggested that these highly palatable diets might over stimu-

late the reward systems in the brain (Berthoud and Morrison, 2008).

For food product development, Mela (2006) argues that it is increasingly clear that low product purchase frequency or changes in food preferences over time may not reflect a poor or loss of oro-sensory quality, but a sort of product boredom (a change in wanting) that can be distinguished from simple hedonics and liking. Relevant to note in relation to the distinction between food liking and wanting is that consumers often intuitively believe that unhealthy foods are inherently tastier. Raghunathan and colleagues (2006) showed that part of the attractiveness of food lies in its perceived unhealthiness. This consumer belief could work against the acceptance of foods being promoted as healthier since people might think they taste less good.

Lowering the energy density and/or adding fibers to a food typically have a strong effect on the structure, flavor, and texture, resulting in a less tasty food. A key example in this respect is the often low preference of children for the pure and intense taste of vegetables. Evidence from studies with children show the importance of early experience with various flavors and textures on developing food acceptance patterns (Birch, 1998). Hence, a major challenge is to focus on the psychological food preference learning processes to induce a shift from high to low calorie dense foods. One way to do this is by using different processing techniques and flavors to make low energy dense foods more palatable. For example, vegetables could be more suitable for children, by masking vegetable or diluting flavors to create a shift in liking in children (Zeinstra et al., 2009). Similar techniques could be applied to satiety-enhancing foods based on fiber.

Anticipate and Build on Smart External Stimuli

Beyond satiety and satiety signals felt physically by people, there are numerous other factors that determine food intake. Small environmental factors, such as visibility of foods, convenience, portion size, perceived dietary variety, and the presence of others have substantial influence on food consumption (Wansink, 2004). People are often not aware of the external influences on their food intake, but are nonetheless willing to provide explanations (Vartanian et al., 2008). When asked for the reason why people start or stop eating, they often state reasons related to taste, hunger, or satiety. However, hunger ratings are only weakly associated with actual eating (Mattes, 1990). Food providing enhanced satiety will have to function in the life of people surrounded by cues that stimulate excessive eating.

Earlier theories explaining obesity of Schachter (1968) built on the idea that obese people have the tendency to respond more to external cues (such as the time to eat) than normal-weight people who listen more closely to internal signals of hunger and satiety. An abundant literature has explored this hypothesis and found mixed results without convincing proof (Ruderman, 1986). In general, the internal signals of satiety and satiety are regularly overruled by environmental factors. Table 2 presents some illustrative effects of how cues in the environment impact the food intake of individuals.

Table 2 Some illustrative effects of environmental cues on satiety: supposed underlying mechanisms and key references

Cue/stimulus in environment	How does it work?	Underlying mechanisms	Key references
Portion and package size	People tend to consume more calories when eating large-sized foods than when eating smaller-sized foods.	<ul style="list-style-type: none"> ○ Portion distortion ○ Completion compulsion ○ Partitions draw attention to consumption by providing more decision making opportunities 	(Wansink and Kim, 2005; Cheema and Soman, 2008; Steenhuis and Vermeer, 2009)
Visibility and convenience of foods	Foods in sight and convenient foods increase consumption.	<ul style="list-style-type: none"> ○ Visibility stimulates salience and salient foods are consumed more frequently 	(Painter et al., 2002; Chandon and Wansink, 2002)
Watching television or listening to music	Distraction due to eating while watching television or listening to music increases consumption.	<ul style="list-style-type: none"> ○ Less attention for sensory and satiation signs leads to continuing eating 	(Harris et al., 2009; Stroebele and de Castro, 2004; 2006)
Social norms on appropriate quantity to consume	People model the intake level of their eating partners. Some people eat minimally or maximally to impress others.	<ul style="list-style-type: none"> ○ Norms have an inhibitory function if they are clear and unambiguous 	(Herman et al., 2003; Leone et al., 2007)
Time taken to eat	Slowing down eating (taking small bites, etc.) reduces calorie intake.	<ul style="list-style-type: none"> ○ More time for physiological satiety signals to develop ○ Brains may get more stimulation from small bites 	(Andrade et al., 2008)
Perceived variety	Repeating experiences, especially in terms of sensory characteristics, are less liked.	<ul style="list-style-type: none"> ○ <i>Sensory specific satiety</i>, often explained by “habituation” which is the psychological process whereby people respond less to a stimulus as they get exposed to it more 	(Raynor and Epstein, 2001; Redden, 2008)
Communication (e.g., labeling)	Information about the caloric and/or fat content of food increases food intake (‘health halo’).	<ul style="list-style-type: none"> ○ Claims can make consumers believe that the product is more healthful ○ Liberation effect (feeling less guilty after eating) 	(Wansink and Chandon, 2006; Geyskens et al., 2007)

A first group of these cues triggering overeating relate to consumption norms, which are gradually increasing. For example, the portion size presented to a consumer influences the amount eaten (Wansink and Kim, 2005). Average portion sizes have increased considerably over the past decades (Hill et al., 2003; Nielsen and Popkin, 2003) and larger portions have become the standard. These bigger portion sizes contribute to additional energy intake and presumably overweight. It is believed that particularly for children the increase in overweight is driven by a shift in eating patterns towards larger portion size of energy-dense foods (Lioret et al., 2007). An important mechanism explaining why larger portions lead to more consumption is the so-called “portion distortion” which is that larger portions are seen as an appropriate amount to consume at a single occasion (Steenhuis and Vermeer, 2009). Furthermore, they provide more value for money in the eyes of the consumer (Vermeer et al., 2010). Portion distortion also occurs when larger dishware, such as spoons and bowls, are used (Wansink and van Ittersum, 2006). For the food industry, offering a wider range of portion sizes or promoting and lowering prices of reasonable sized portions rather than oversized ones might be an appropriate strategy to address the negative influence of portion sizes (Ello-Martin et al., 2005).

On top of increasing consumption norms, the inability of people to monitor what they are eating influences food intake. This inability may occur because of distractions in the environment, such as watching television while eating (Harris et al., 2009) or listening to music (Stroebele and de Castro, 2006). It is believed that people eat more in such circumstances because they have

less attention to the sensory signs provided by the food. This could also be due to a mechanism called the “completion compulsion” (Siegel, 1957), or “plate cleaning” (Wansink, 2006). Moreover, while watching television, people are often exposed to food advertisements which stimulate appetite (Harris et al., 2009). Slow eating, which is related to consuming foods with a chewier, denser structure also has been found to be related to lower BMI, decreased energy intake, and more satiety after completion of a meal (Andrade et al., 2008; Sasaki et al., 2003).

The presence of other people has an impact on people’s eating behavior. People model the intake level of people present (Herman et al., 2003). This happens even under conditions of hunger or fullness. People typically follow one of the two possible norms for “appropriate” eating behavior; the norm to eat minimally, and the norm to avoid eating excessively. These social norms (i.e., the standard way of behaving that is representative of the group) have an inhibitory function, particularly when they are clear and unambiguous (Leone et al., 2007). If people cannot perceive the eating patterns and norms of others, they are likely to eat according to their own desire.

As indicated earlier, people eat more within a meal or across meals if a variety of foods is presented (Remick et al., 2009). But also visual effects of variety have impact. For example, Redden (2008) showed that satiation also depends on how much repetition people perceive. The author found that meals satiate less if people categorize the consumption episodes at lower abstraction levels. For instance, as people ate more jelly beans, their enjoyment declined less quickly when the candy was categorized specifically (e.g., cherry, orange) rather than generally

(e.g., jelly bean). This “sub categorization” made differences salient and increased the perceived variety, hence leading to less satiation and greater enjoyment.

These findings show that the positioning of satiety enhancing foods products is crucial if the purpose is to reduce total intake. It could be that the positioning of a food as “satiety enhancing” leads to the undesirable effect of overconsumption, closely related to the phenomenon of “health halo.” Wansink and Chandon (2006) found that labeling snacks as “low fat” increases food intake during a single consumption occasion by up to 50%. This was particularly the case for overweight people. Similarly, Geyskens et al. (2007) showed that exposure to health primes (e.g., words such as diet and fiber) increases the amount of low-fat chips consumed. This is because these primes led people to believe that the low-fat chips are healthier than they actually are. Furthermore, it led people to believe that they are closer to their ideal weight.

A key question, however, is whether there are any conditions under which individuals “listen” more or less to their feelings of hunger and satiety. It seems that some individuals are more responsive to these kinds of cues than others. For example, restrained eaters respond differently to cues in their environment, such as portion sizes (Scott et al., 2008). Restrained eaters tend to hold an all-or-nothing attitude after the perception of having over-eaten (Ruderman, 1986) while unrestrained eaters regulate their food consumption to a larger extent on appetite and satiety. Moreover, recent research shows that the trait of self-control influences consumption behavior (Baumeister, 2002). Impulses to eat indulgent foods occur automatically and overriding them requires self-control. Considering the impulsive influences on behavior is increasingly seen as of significant importance (Strack and Deutsch, 2004; Hofmann et al., 2008).

Evidently, the psychological state determines the extent to which people pay attention to internal signals in the competitive context of environmental cues. It is important to continue disentangling the bodily versus environmental signals in satiety and consumption research. More specifically, diverse lines of research seem to suggest that self awareness may somehow influence the awareness of internal states (Heatherston and Baumeister, 1991; Polivy et al., 1986). Hence, a key challenge is to gain insight into whether and how psychological states interact with physiological cues of hunger and satiety in determining food intake. Specifically, there is a need to assess whether responsiveness to physiological signals of hunger and satiety (i.e., adjusting food intake in response to these signals) can be influenced by psychological processes such as self awareness and goal activation. On a fundamental level, this insight will contribute to the body of knowledge on physiological cues of hunger and satiety. Also, it can give an indication as to what extent psychological processes of self awareness and goal setting influence not only cognition, emotions, or behavior, as has been extensively studied, but also extend to influence bodily processes. On a more applied level, insight into how individuals respond to hunger and satiety signals provides a knowledge base for the potential effectiveness of satiety enhancing food

products and allows for the formulation of boundary conditions under which satiety enhancing food products can and cannot be expected to lower food intake.

Concept Development: How to Position, Develop and Communicate?

Success of satiety enhancing foods, both commercially and in public health terms, depends among other factors on the degree to which the new proposition can be effectively and convincingly be communicated to the consumer as a competitive option (van Trijp and van Kleef, 2008; Siegrist, 2008). In other words, how can the benefit of satiety enhancement convincingly be communicated to the consumer? Positioning of satiety enhancing foods is not all that straightforward as it implies conveying the difficult message of “eat more so that you will eat less.” Effective development of satiety enhancing foods will need to consider potential positioning upfront in a creative, yet trustful manner (see section titled “New EU Legislation on Health Claims”). Existing knowledge in the areas of communication of health claims (Van Trijp, 2009) and psychological research on framing effects may inform appropriate strategies here. Previous research suggests that three issues are particularly important here: (a) how to define and articulate the consumer benefit, (b) how and in what detail to communicate the specifics, and (c) which products to use to deliver the benefit?

Consumers interpret specific communication messages (such as satiety enhancement) in more abstract terms to infer more abstract benefits of use (Gutman, 1997). In the case of satiety enhancement the more abstract benefits are likely related to weight control. Weight control is a common concern for many consumers nowadays. Among Americans, more than 50 percent of the adults claim that they are trying to lose or maintain weight. Eating less is a frequently reported strategy among those who are trying to control their weight (Weiss et al., 2006). Communication may follow different routes either focusing on the prolonged fullness or delayed feelings of hunger. Although these two benefits at first sight may be considered logically equivalent, psychological research on framing suggests that this is not necessarily the case. Consumer responses may differ depending on whether achievement of the positive end state (“keeping you full for longer”), or avoidance of the negative end state (“avoids feeling hungry for longer”) is being emphasized in the communication. In other words, different positioning may have different effects on consumer acceptance. This is particularly relevant for satiety-enhancing foods as they may be communicated in claims in terms of the active ingredients (e.g., “rich in fiber”), the underlying process (“keeping you satisfied for longer”), the behavioral outcome (“helps you eat less”), or even the health outcome (e.g., “helps you keep or regain a healthy weight”). Keeping in mind that within Europe these different claims verbalizations have become strictly regulated (see section titled “New EU Legislation on Health Claims”), an important research question concerns the level of detail that is desirable for communication to be

optimally appealing and persuasive to consumers. Van Trijp and Van der Lans (2007) compared consumer appeal of different claim formulations of added fibers in relation to the weight management benefit. The results show that the mentioning of the active ingredient (added fibers) adds to consumer appeal of the claim. Fiber in itself is a strong and familiar cue for satiation, and as a result the various claim formulations do not vary strongly in consumer appeal as consumers tend to “fill in” the missing information in terms of health impact (e.g., Roe et al., 1999).

Van Kleef et al. (2005) showed that the credibility of a nutrition and health claim not only depends on the claim but also on the interaction between the claim and the product (format) that carries the claim. Again, this is particularly relevant in the context of satiety-enhancing claims for at least two reasons. First, satiety-enhancing foods assume that eating one particular food influences the total intake of all other foods at some later occasion (Blundell, 2010). Two strategies are feasible depending in part on the distinction between satiation (within meal) and satiety (between meals). First is to develop satiety enhancing foods that are designed to replace existing products within the normal diet, but with lower energy density. To avoid caloric compensation later in the day, these products should either activate physiological mechanisms to prevent compensation or by mindful control over eating behavior (Blundell, 2010). Alternatively, satiety enhancing foods could replace existing products at the same volume, weight, and energy density level, but with an active ingredient to ensure prolonged feeling of fullness to delay the next eating occasion. A third strategy, but probably more appropriate as a supplement rather than a food, could be to develop innovative formats (e.g., mini-drinks) that are taken outside the meal occasions to specifically target the totality of food intake. At present there is little consumer evidence into how consumers would respond to these different positionings and to what extent this would align or contradict their lay knowledge on the processes of satiety and satiation.

Key questions in this respect are the following. What is the most effective way of positioning and communicating to the consumer the concept of enhanced-satiety value? How do consumers understand the satiety value and how can it best be communicated (e.g., as gain or avoidance of loss?) to consumers and labeled on pack (nutrition and health claims)?

Product Development; Can the Product Deliver against Promise?

For functional and health foods, this stage of the new product development process has a dual meaning. First of all, product efficacy can only be demonstrated if the satiety-enhancing product concepts can actually be technologically produced without compromising (too much) on taste, convenience, and price. This requires a stream of tests, including extensive testing with consumers (sensory and taste tests) (Tuorila and Monteleone, 2009). Fibers have several properties that are disadvantageous depending on the type of fiber and the processing conditions, such as discoloration, structure breaking, changing mouth feel, solidifi-

cation (i.e., the process of becoming solid), or gelation. Avoiding these potential problems is a major challenge for recipe development and food technological development (see the following section). Secondly, new product concepts need to conform to regulations in the field of health claims in terms of evidence provided on the product's efficacy (section titled “New EU Legislation on Health Claims”).

Food Technological Development

A promising route to satiety enhancement is to make foods less energy dense. This is typically achieved by replacing fat and/or carbohydrate components by water or air. It can also be achieved by adding extra fibers or changing the structure of foods. In most cases, this leads to a change in flavor release, color, texture, and mouth feel either immediately or after processing or during shelf life. To reduce this negative effect, food technologists need to pay attention to appropriate food microstructures (Palzer, 2009).

As fibers belong to the most promising satiety enhancing components, food technological research faces the challenges of improving the satiating capacity of fiber-rich foods by food processing or adapting food composition. Fibers can be derived from plant sources, such as cereal grains and fruits. Fibers add bulk and increase the viscosity. However, the type of processing applied influences the functionality of the fibers. In most cases, processing of foods containing fibers negatively affects their bioavailability and quality (Shahidi, 2009) and it may even affect its physiological effects on the human body (Rodríguez et al., 2006). In general, it may not even be possible to use certain ingredients in certain product formats, or a range of technologies (e.g., encapsulation, anti-oxidants, flavor masking agents) or process/recipe modifications may be required to overcome this (Day et al., 2009; Kovacs and Mela, 2006). A fruitful future research area is the development of fiber-rich vegetable matrices with high consumer likings, while preserving the bio-active components. In the development process of such products, extrusion plays a key role. Extrusion is the compression of food into a semi-solid mass, and then forcing it through a small opening to create new shapes and textures. An example of an extruded product is a breakfast cereal. This processing technique seems promising in creating foods with increased dietary fiber levels as it helps to minimize negative sensory effects of adding extra fiber.

Furthermore, effective monitoring of the amount and efficacy of components in raw material, after relevant food processing steps (e.g., high shear, temperature) and throughout the shelf life is necessary and include hydration properties, solubility, and interactions with other components of the product. It is important that the products stay stable and do not lose their quality or microbiological safety too quickly (Kovacs and Mela, 2006).

New EU Legislation on Health Claims

The new EU regulation on nutrition and health claims has come into force in 2007. There are two types of health

claims—risk reduction claims and functional claims. In the regulation (article 2), nutrition claims include any claim which implies that a food has a particular beneficial nutritional property. So, nutrition claims refer to what a product contains. A health claim is defined as “any claim that states, suggests or implies that a relationship exists between a food category, a food, or one of its constituents and health” (Aggett et al., 2005). Most claims related to satiety are considered to be health claims under the new EU regulation. In 2008, article 13 of the new EU regulation requested member states to submit a list of potential health claims to the European Commission. One category of claims qualified for consideration under article 13 is: “slimming, weight control, a reduction in the sense of hunger, an increase in the sense of satiety and the reduction of the available energy from the diet.” This new EU regulation is raising a number of issues concerning the accurate scientific substantiation of health claims, particularly in the field of satiety.

First of all, there is debate about what exactly constitutes sufficient scientific evidence although controlled clinical intervention studies are the “gold standard” for approval internationally (Hasler, 2008). To underpin the scientific substantiation of health claims, a set of criteria has been developed by the PASSCLAIM initiative, an EU funded project (Aggett et al., 2005). Health claims need to be based on the highest possible standards of scientific evidence (Richardson, 2005). In the US, the FDA has adopted four grades of evidence in the assessment of health claims (US Food and Drug Administration, 1999). In the EU, the concept of grades of evidence is not (yet) taken into account. It has been argued, however, that this grading of evidence has to be accommodated, to stimulate product innovation (Richardson, 2005). For example, the WHO (2004) states that there is convincing evidence that a high dietary fiber intake is leading to a reduction of obesity/weight gain (referred to in (Richardson, 2005). Extrapolation of laboratory studies to free-living people is complicated by difficulties in obtaining self-reported dietary intake data (Benelam, 2009).

Second, the EU regulation requires that when the true endpoint of a claimed benefit cannot be measured directly, studies should use markers. Markers should be biologically valid in that they have a known relationship to the final outcome and their variability with the target population is known. Markers should also be methodologically valid with respect to their analytical characteristics (Aggett et al., 2005; Richardson, 2005). De Graaf and colleagues (2004) presented an overview of physiological measures available that can serve as biomarker of satiation, satiety, or both. Although many studies report on beneficial effects of certain nutrients on satiety and satiation, rigorous longer-term studies are needed to investigate the effect on weight maintenance (e.g., Halton and Hu, 2004). For example, satiety effects may only have short-term impact, and at the long term the ability of a product to give additional satiety may fade out. There is a need for biomarkers measuring the effect of food intake on long-term satiety. As the beneficial effects of fiber depend on the type of fiber, it is particularly challenging.

Third, there are some methodological issues with regard to studies on satiety. As described in this paper, satiety is influenced by a wide variety of factors, such as energy density, food composition, and portion size. When using real foods, it is hard to control for all these influences at the same time (Halton and Hu, 2004). One challenge is to determine the time relations between sensory aspects, gastro-intestinal tract, possibly gut-microbiome, and food matrix in relation to lasting satiating effect.

Finally, an important objective for the development of the legislation is that nutrition and health claims do not mislead consumers and are understandable. Consumer understanding of the health claim is therefore, key to the success of new products. Nutrition and health claims can only be used if the average consumer can be expected to understand the beneficial effects expressed in the claim (Richardson, 2005). The “average consumer” is defined as someone who is reasonably well informed and circumspect. This will raise difficulties, as consumers differ between countries (Bech-Larsen and Grunert, 2003). Hence, national authorities and courts will be allowed to determine, on a case-by-case basis, whether the typical consumer is able to understand a claim.

Post-Market Monitoring

Many effects of new satiety enhancing foods can be seen only after the purchase and consumption of the product in the market place. Increasingly, there is a need to illustrate the (un-) intended effects of functional food introduction, both commercially and in public health terms. Post-market monitoring (PMM) is a relatively new approach in which a new product is observed and examined after introduction in the market place. The primary goal is to improve the safety of the new food product by better understanding (negative) effects on consumer consumption, nutrient intake levels, and health. Although in the field of medicine it is common to monitor the known and unknown effects since the 1960s (Van Puijenbroek et al., 2007), for foods it is relatively new. Given the large number of food products marketed on the basis of their additional health benefits, post-market monitoring will be increasingly important in the future. This is partly the result of growing doubts about effectiveness of current safety assessments, for example, in the field of genetically modified foods (Amanor-Boadu, 2004). It is to be expected that satiety enhancing foods based on novel ingredients will be subjected to PMM programs. The monitoring typically includes the following key questions (de Jong et al., 2007; Hepburn et al., 2008). First, is the use as predicted/recommended? It could be that some consumers run the risk of overconsumption of certain ingredients resulting in unintended negative health effects. Therefore, it is necessary to understand which consumers are using the product and in what amounts. Second, does the product cause unknown side effects, such allergic reactions or other negative health effects at the short or long-term? It could be that specific groups in society experience potential harmful

effects, for example, young children, the elderly, or people with a specific health condition. Negative health effects can also occur due to unexpected interactions of the ingredient with other food substances (de Jong et al., 2007).

Basically, PMM build on spontaneous reporting of health problems by consumers, for example, by contacting the toll-free call centers of a food company. Additional information is furthermore derived from food (household) purchase and consumption data, food supply data, clinical and epidemiological studies, and expert medical and literature reviews (Van Puijenbroek et al., 2007; Hepburn et al., 2008). The results of these studies are reported to regulatory agencies and can be used in regulatory decisions and future risk-benefit analyses. PMM is currently not an obligatory requirement for all new foods, but in the past legislative authorities have requested PMM programs as part of the approval of certain new food ingredients (Van Puijenbroek et al., 2007). For example, the US Food and Drug Administration (FDA) demanded a post-market monitoring program after the introduction of Aspartame (artificial sweetener) and the fat substitute Olestra (Allgood et al., 2001). The European Commission called for PMM after the introduction of a cholesterol lowering vegetable oil spread (Amanor-Boadu, 2004). The European Food Safety Authority (EFSA) proposes that PMM is performed for genetically modified foods (Hepburn et al., 2008). It is typically stressed that PMM is a complement to pre-market safety assessments and not a replacement (Amanor-Boadu, 2004; Hepburn et al., 2008).

Besides monitoring new food products in terms of their unintended health effects, it is also of crucial importance to understand the effect of the market introduction on total food purchase and consumption baskets at the level of effect on both the product substitution and overall nutrient (caloric) intake. For example, the purchase of the new product may help to establish a new food-choice behavior among consumers, so that one can observe more healthy purchase patterns in other food categories as well. Alternatively, consumers may substitute the new product for an incumbent healthy one, which results in a zero net effect. Finally, it is possible that consumers perceive the new healthy product as an antidote for unhealthy alternatives, so that they purchase more high-caloric food products, and neutralize (or even reverse) the health effect. Overall, major market interventions do not always have the impact one might expect (Pauwels and Srinivasan, 2004). Ideally, the effects of new satiety-enhancing foods would be assessed in terms of (reduced) levels of caloric intake within the individual's total diet. Measuring these effects is of key importance in terms of post-market monitoring; however, its application is severely restricted by the fact that the consumption of detailed food consumption data at the individual (within-household) level (as typically applied in Food Consumption Surveys) is very cumbersome and expensive. However, at the household food basket level such data are more or less routinely and continuously collected by market research agencies in terms of household panel data. Upon introduction of new satiety enhancing foods in the market place, the important research challenge here is twofold: (a) provide a

more detailed insight in substitution and complementarity effects within the food purchase basket at the household level (as analyzed from household panel data), and (b) to find innovative research methods to translate these changes into nutrient exposure at the level of specific target groups (e.g., children). Within the marketing science and econometrics literature, a diversity of modeling approaches has been developed to test market impacts of specific market introductions. However, these models have largely gone underexploited in the context of health impacts of new product introductions. Building on recent modeling approaches developed with econometric and marketing modeling, systematic testing frameworks to pinpoint the specific effects on the purchase and nutrient intake patterns of consumers as a result of the market introduction of new plant-derived satiety enhancing foods could be developed at the level of consumer-purchase baskets of households. Pinpointing these effects at the level of household-purchase data could then be linked to target group exposure levels by integrating a priori knowledge on the typical food distribution process within the household. Such a priori knowledge may be obtained from detailed analysis of available Food Consumption Surveys, which are typically collected at irregular periods in time. To our best knowledge, the methodology to extrapolate household purchase data to individual food consumption levels within the household is limited (Chesher, 1997; 1998), but could provide considerable potential.

CONCLUSION

In human history, it was more likely that people had too little to eat rather than too much, as is the case nowadays in many societies. The field of nutrition research has developed similarly from prevalent undernutrition and vitamin deficiencies into a period of food abundance and widespread overnutrition, in which the threat of overweight and obesity is increasing, particularly for children. The energy-dense and highly tasty foods available everywhere in the western society have been identified as a major factor contributing to the current overweight problem. Although it is generally accepted that no one solution will fix the obesity problem (King and Thomas, 2007), the study of satiety and the development of products that enhance satiety has been referred to as an extremely important area in need of more research (Ueland and Saris, 2006; Blundell, 2010). Structuring our review along the phases of the new product development process shows the multidisciplinary and extensive nature of such an undertaking.

Most work on satiety has been in the nutrition and sensory sciences and this work gives numerous opportunities for new satiety enhanced foods. So far, much research is being performed on ways in which food components, energy density, and food texture impact satiety and related aspects such as appetite, hunger, and weight management. The development of foods with high satiating capacity could build on the knowledge of how to feel full on fewer calories. As visually shown in the satiety cascade of Blundell (1987), satiation and satiety

are regulated by a variety of factors. Food composition and energy density have a strong impact on the sensation of fullness and satiety. Reduction of energy density may be accomplished by increasing the water and air content of foods resulting in bigger and hence more satisfying portions with less or equal caloric content. Fibers are particularly promising and research on how fibers affect satiation and satiety is very much needed as the relationship between physical-chemical characteristics of fibers and satiety is highly complex. This is because a variety of mechanisms is involved which may be responsible for the satiating effects, such as the increasing bulk weight and viscosity in the stomach, the decreasing speed in gastric emptying, and the higher gut transit time resulting in a lower glycemic index. Other suggested mechanisms work through an increased release of satiety hormones or the specific role of gut hormones and fermentation processes in the gastrointestinal tract. Overall, the specific mechanisms are incompletely understood and innovative research approaches, such as the ones making use of animal models are increasingly being applied. Longer term studies that examine the satiety process both in vivo and in vitro are considered necessary together with more attention for biomarkers to identify and measure the working mechanisms of fibers. This more elaborate understanding would help developing foods with enhanced satiation properties.

From a food technological perspective, it is not a matter of simply adding extra fibers, water, or air to a food to enhance satiety. The added bulk and weight to the food may make people feel full faster but at the same time these low energy dense foods are usually less appealing to consumers due to their taste and texture. Fibers have their specific challenges as they strongly impact the food matrix. By applying a variety of techniques (e.g., extrusion), a key challenge is to improve the taste and texture of fiber rich foods without changing the beneficial satiating aspects of fiber.

It is now generally agreed among researchers that satiety is a complex interaction of physiological and non-physiological mechanisms (Mela, 2005). Actual food choice is the end result of a complex interaction between internal satiety signals, other food benefits, and environmental cues such as health labels, portion size, and perceived variety. For many individuals the signals generated by the bodily system of appetite and satiety are simply overridden by these positive cues to eat. One possible intervention route in relation to external cues is to minimize or redirect external cues, for example, by restructuring the environment of the consumers by providing smaller portion sizes, decreasing the perceived variety, and carefully communicating about the satiety enhancing properties to prevent “health halo” effects. In addition, research at the crossroads of internal and external signals is currently being done to understand under which psychological and contextual conditions people have more attention for internal cues. Already in 1992, Booth (1992) argued that this integration is one of the main fundamental scientific problems for behavioral nutrition.

Satiety enhancing product features need to be convincingly and responsibly communicated to consumers. This requires a

careful selection of the types of benefits to communicate (e.g., prolonged fullness or delayed feelings of hunger), the level of detail provided to consumers, and the ascribed role of foods (e.g., replacing existing foods or introducing new supplement-type foods). At present, research is needed to understand consumer responses to these different positionings.

The new EU regulation requires convincing scientific evidence for any claim. Protecting consumers from false and misleading claims is an important objective of the current EU legislation on nutrition and health claims. Satiety enhancing foods may be successful in the short term, but little evidence currently supports their long term effectiveness. A major issue in the field of appetite control is the generalizability of research results, as the majority of studies are carried out in controlled environments. As still many studies do not include a focus on the context effects of an eating situation, future research will need to bridge the gap between different types of satiety research to get empirically supported understanding of the working mechanisms in real life. A potential difficulty could be that consumers compensate their lower energy intake by eating more later in the day after consuming satiety enhanced foods. As even small reductions in energy density of foods can have a big impact at the population level (Rolls et al., 2005), an area in need of future research is to investigate whether these products help to reduce the overall energy intake and population body weight (Bellisle, 2008). Post-market monitoring is a key element in this to obtain market and consumer behavior data about health effects and possible changes in consumer behavior.

Understanding a complex process as satiety, involving physiological processes of the entire metabolism as well as psychological and social processes is extremely challenging. Yet, it is clear that fundamental changes in the environment of consumers are greatly needed to bring the overweight epidemic to an end. Ultimately, the goal is not only to enhance the satiety capacity of single foods, but to make the environment less “toxic” by helping consumers to control their energy intake at the shorter and longer term.

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