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Review

Optimising foods for satiety

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Foods that generate strong satiety sensations have obvious benefits for weight management. This review builds on the understanding that a food's satiating power is dependent on the amount of protein, carbohydrate, fat and fibre it contains by examining evidence that the consumer's sensory and cognitive appraisal of the food is also important. It is concluded that numerous features of a food product can be manipulated to enhance the consumer's experience of satiety but the combination of these features will ultimately determine its effect on appetite control. Taking this integrated approach to satiety will optimise the development of high satiety foods.

Introduction

The alarming rise in global rates of overweight and obesity (Popkin, Adair, & Ng, 2012) does not only have profound implications for health and wellbeing (Dixon, 2010) but also for the environment (Hall, Guo, Dore, & Chow, 2009) and the economy (Yach, Stuckler, & Brownell, 2006). Many people live in an "obesogenic" environment that stimulates appetite and promotes an excessive consumption of calories. Influential factors include the advertising and availability of processed energy dense foods and beverages (Halford, Gillespie, Brown, Pontin, & Dovey, 2004; Hill & Peters, 1998), particularly those eaten outside a meal context (Rolls, Roe, Kral, Meengs, & Wall, 2004), shifts in serving size norms favouring larger portions (Nielsen, 2003; Wansink & Kim, 2005), and the relative cost (£/KJ) and accessibility of an unhealthy diet relative to recommended healthier diets (Drewnowski & Darmon, 2005). Changing the current food environment to be more "leanogenic" requires political and cultural reform, with considerable support from the food industry. There is no magic bullet. A pragmatic approach is to make numerous small changes to the food environment to help people eat more healthily. Enhanced satiety foods (those with an increased capacity to inhibit appetite in the period *after* consumption) could be part of this approach, because they directly promote reduced food intake and also aid compliance with healthy eating and weight management strategies, by lessening the effect of sensations of hunger on motivation and mood (Hetherington *et al.*, 2013).

In recent years the food market has seen a rise in the sale of enhanced satiety products (categorically different to reduced-energy diet foods), which claim to be effective at staving off hunger and seem to be well received by the public (Bilman, Kleef, Mela, Hulshof, & van Trijp, 2012; Hetherington *et al.*, 2013). In the UK these are required to abide by European Commission regulation that satiety claims should be substantiated by scientific evidence based on the nutritional profile of the food and not mislead the consumer (European Commission, 2007; 2012). Though there is continued debate about what constitutes a valid claim (Blundell, 2010; Booth & Nouwen, 2010; de Graaf, 2011a, 2011b; Griffioen-Roose, Wanders, & Bánáti, 2013), the vast majority of satiety claim submissions to the European Food Safety Authority (EFSA) fail to be approved because of a lack of evidence that satiety generated by the product leads to reductions in energy intake, and/or that the effect is sustained with repeat experience (Halford & Harrold, 2012).

Despite important scientific advances in understanding the relationship between specific nutrients and appetite control, with some success in the application of these findings to the manufacture of high satiety foods, non-nutrient contributors to the consumer's experience of satiety have received less attention. The purpose of this paper is to discuss what is known about the satiating constituents of food and build on this by examining evidence that contextual cues from cognitive and sensory signals generated at the time of consumption influence the consumer's experience of satiety and also, critically, moderate nutrient-based satiety. Taking this integrated approach to satiety will better inform the development of enhanced satiety

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food products by highlighting the numerous elements of a food that can be manipulated to optimise its affect on appetite, and by demonstrating that the combination of these elements will ultimately determine how effective it is at generating sensations of satiety.

Satiety as a multi-factor construct

The idea that the sensation of satiety is dependent on more than just the metabolic effects of nutrients in the gut and intestine was conceptualised by John Blundell, Rogers, and Hill (1987) over 25 years ago. Their satiety cascade model (Fig. 1), which has been well described in several other reviews (*e.g.* Halford & Harrold, 2012; Van Kleef, Van Trijp, Van Den Borne, & Zondervan, 2012), proposes that even before food arrives in the gut, cognitive and sensory signals generated by the sight and smell of food, and by the oro-sensory experience of food in the oral cavity will influence not only how much is eaten at that eating episode (satiation) but also in the period after consumption. These early satiety signals will integrate with post-ingestive and post-absorptive signals to determine satiety. Pre-ingestive sensory and cognitive signals signify the imminent arrival of a nutrient load, and the body's rapid response to this information is to physiologically prepare for the efficient digestion, absorption and metabolism of nutrients (Pavlov & Thompson, 1902). These cephalic phase responses, involving gastrointestinal hormones, acid secretions and changes to gastric and intestinal motility (see Power & Schulkin, 2008) are thought to heighten post-consumption sensations of satiety because they change how well nutrients are processed by the digestive system (Smeets, Erkner, & De Graaf, 2010). Another way that pre- and post-ingestive signals might interact is through the memory of food consumption; strong pre-ingestive cues might enhance eating encoding and this might impact on the way consumer's interpret physiologically derived satiety sensations, though this is yet to be empirically tested. Either way, it can be predicted that a nutritionally rich food will have maximal impact on appetite only when the experience of consuming it leads the consumer to anticipate its satiating effects. Equally, the same nutrient rich food may have weak effects on satiety if expectations are not in line with its nutrient content. Indeed, when food is ingested in the absence of cognitive and sensory pre-ingestive signalling, for example when delivered directly to the gut via a nasogastric tube, satiety responses to nutrients are weaker (Cecil, Castiglione, French, Francis, & Read, 1998a; Cecil, Francis, & Read, 1998b; Lavin, French, Ruxton, & Read, 2002).

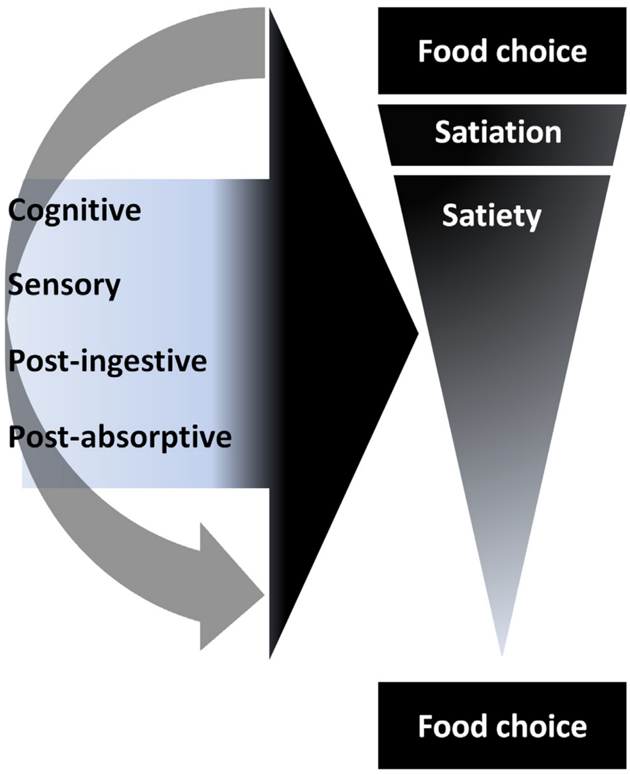

Fig. 1. The satiety cascade. Adapted from Blundell *et al.* (1987).

Food macronutrients and satiety

Classic satiety research has typically looked at the physiological effects of food ingredients in isolation while holding all other contributors to satiety constant. This important work has highlighted that two foods of equal energy may have distinct effects on satiety if their macronutrient compositions differ. For example, women whose diet was modified to be high in protein and carbohydrate for a day reported higher levels of satiety compared to another day when the principle energy source of their diet was fat, despite the diets being matched for energy content (Westerterp-Plantenga, Rolland, Wilson, & Westerterp, 1999). The idea of a hierarchy of satiating effects of macronutrients in the order of protein > carbohydrate > fat (Blundell & Macdiarmid, 1997) goes some way to explain why not all calories will have the same impact on satiety, and has been hugely influential in the development of enhanced satiety foods. Nowadays, for many people, "high protein" is synonymous with feeling full and is central to most satiety claims in the appetite management food market. Protein has taken centre stage as *the* high satiety food constitute because of considerable experimental and real-world research indicating that increasing the protein composition of the diet without changing net energy can lead to enhanced feelings of satiety (Paddon-Jones *et al.*, 2008). Possible physiological mechanisms underlying this effect include diet induced thermogenesis (Halton & Hu, 2004) and gastrointestinal hormonal signalling (Veldhorst *et al.*, 2008), while two recent studies indicated that the sensory experience of ingesting protein is also important (Bertenshaw, Lluch, & Yeomans, 2013; Masic & Yeomans, 2013). Randomized trials of high protein diets on weight management provide evidence that these types of eating plans can support longer-term weight loss (*e.g.*