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Do rye product structure, product perceptions and oral processing modulate satiety?

Saara Pentikäinen[a,*], Nesli Sozer[a], Johanna Närväinen[a], Kirsi Sipilä[b,c,d,e], Syed Ariful Alam[a], Raija-Liisa Heiniö[a], Jussi Paananen[f], Kaisa Poutanen[a], Marjukka Kolehmainen[g,a,h]

[a] VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland
[b] Institute of Dentistry, University of Eastern Finland, P.O. Box 1627, FI-70211 Kuopio, Finland
[c] Oral and Maxillofacial Department, Kuopio University Hospital, Kuopio, Finland
[d] Research Unit of Oral Health Sciences, Faculty of Medicine, University of Oulu, Oulu, Finland
[e] Oral and Maxillofacial Department, Medical Research Center Oulu, Oulu University Hospital, Oulu, Finland
[f] Bioinformatics Center/Institute of Biomedicine, University of Eastern Finland, P.O. Box 1627, FI-70211 Kuopio, Finland
[g] Institute of Public Health and Clinical Nutrition, University of Eastern Finland, P.O. Box 1627, FI-70211 Kuopio, Finland
[h] Kuopio University Hospital, Kuopio, Finland

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ABSTRACT

Food structure and cephalic phase factors are hypothesized to contribute to postprandial satiety in addition to established food properties such as energy content, energy density, and macronutrient and fibre composition of a preload. This study aimed to evaluate if the structure of rye products has an impact on subjective feelings of satiety, and whether cephalic phase factors including oral processing, satiety expectations and perceived pleasantness modulate the interaction. Four wholegrain rye based samples (extruded flakes and puffs, bread and smoothie) were studied in terms of texture characteristics, *in vivo* oral processing, and expected satiety (n = 26) and satiety as well as perceived pleasantness (n = 16) (ClinicalTrials.gov number: NCT02554162). The vast textural differences between products were reflected in mastication process, perceived pleasantness and satiety expectations. Extruded products required the most intensive mastication. Rye puffs and rye bread which were characterised by a solid and porous structure, and showed better satiety effect in the early postprandial phase compared to other products. Mastication effort interacted with satiety response. However, the products requiring the most intense mastication effort were not the most satiating ones. It seems that there are some food structure related factors that influence both mastication process and postprandial satiety, the mastication process itself not being the mediating factor. Higher palatability seems to weaken postprandial satiety response.

1. Introduction

The feeling of satiety has been proposed to support weight management through various routes such as greater food reward, reduced hunger and better control of energy intake (Hetherington et al., 2013). For instance, the amount and type of dietary fibre in food, macronutrient composition and energy density of food contribute to the modulation of satiety. In addition, cognitive and sensory signals generated before and during eating (cephalic phase) are proposed to influence satiation (intra-meal satiety) and satiety (inter-meal satiety) (Blundell et al., 2010). Cephalic phase responses such as stimulation of hormone and enzyme secretion are hypothesized to enhance nutrient processing and thus to enhance also satiety response (Smeets, Erkner, & De Graaf, 2010).

Signals that are generated already during oral processing are needed for optimal appetite regulation, in addition to signals originating from later phases of digestion (Smeets et al., 2010). The importance of oral phase for appetite regulation has been well established in studies where appetite suppression has been incomplete after infusing food directly to stomach. Hogenkamp and Schiöth recently reviewed studies on oral processing of food, satiation and satiety, and concluded that viscosity of food had consistent impact on *ad libitum* food intake (satiation) and that orosensory exposure was the mediating factor between viscosity and satiation (Hogenkamp & Schiöth, 2013). Later, Bolhuis et al. showed that hard foods which were eaten in smaller bites than soft foods and processed longer in mouth, reduced the energy intake during the meal,

* Corresponding author at: VTT Tietotie 2, P.O. Box 1000, 02044 VTT, Finland.
E-mail addresses: saara.pentikainen@vtt.fi (S. Pentikäinen), nesli.sozer@vtt.fi (N. Sozer), johanna.narvainen@vtt.fi (J. Närväinen), kirsi.sipila@uef.fi (K. Sipilä), ariful.alam@vtt.fi (S.A. Alam), raija-liisa.heinio@vtt.fi (R.-L. Heiniö), jussi.paananen@uef.fi (J. Paananen), kaisa.poutanen@vtt.fi (K. Poutanen), marjukka.kolehmainen@vtt.fi, marjukka.kolehmainen@uef.fi (M. Kolehmainen).

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Table 1
Nutrient content of the food samples and nutrient content and portion sizes of portions served in the satiety trial.

	Samples (/100 g)					Satiety trial portions (/portion)				
	WG sourdough rye bread	Extruded WG rye flakes	Extruded WG rye puffs	Refined wheat bread	Black-currant juice	WG sourdough rye bread + juice	Extruded WG rye flakes + juice	Extruded WG rye puffs + juice	WG rye smoothie	Refined wheat bread + juice
Nutrient content										
Energy (kcal)	200	322	330	253	38	382	382	382	382	382
Starch (g)	35.4	57.7	59.8	46.4	ns	33.7	34.1	34.5	34.1	34.8
Protein (g)	6.5	9.7	9.8	9.1	ns	6.2	5.7	5.6	5.7	6.8
Fat (g)	0.6	1.2	1.3	2.4	ns	0.6	0.7	0.7	0.7	1.8
Total dietary fibre (g)	13.3	20.7	19.8	4.7	ns	12.6	12.2	11.4	12.2	3.6
Soluble dietary fibre (g)	7.5	9.5	10.7	2.3	ns	7.2	5.6	6.2	5.6	1.7
Insoluble dietary fibre (g)	3.6	3.7	4.0	1.5	ns	3.4	2.2	2.3	2.2	1.1
Oligosaccharides (g)	2.2	7.6	5.2	1.0	ns	2.0	4.5	3.0	4.5	0.7
Sugar (g)	–	–	–	–	9.6	48	48	48	48	48
Portion sizes (g)										
Cereal product						95	59	58	58	75
Juice						500	500	500	500	500
Total						595	559	558	559	575

and that the effect was sustained over the following meal (Bolhuis et al., 2014). They also concluded that the differences in oral processing might mediate this effect. Mastication process has also shown to suppress gastric emptying rate (Ohmure et al., 2012).

The effects of preload texture and resulting oral processing on postprandial satiety have been investigated in several studies. Energy intake at next meal context is adjusted only partly after a liquid preload while it is fully adjusted after semi-solid or solid preload (Almiron-Roig et al., 2013). This leads to lower overall caloric intake (preload and *ad libitum* meal) after semi-solid or solid preloads compared to liquid preload. This indicates that food texture, at least when liquids are compared to solids or semi-solids, plays a role not only in satiation but also in satiety response. However, the results concerning food textures other than liquids, resulting in varying orosensory exposure, are somewhat inconsistent (Hogenkamp & Schiöth, 2013). Satiety effect of foods with either solid or heterogeneous texture, assumed to induce high orosensory exposure, or corresponding comminuted texture, assumed to induce low orosensory exposure, have been compared by various groups: Mattes et al. found that there were no differences in satiety responses between solid and semi-solid foods (apple vs. apple soup, peanut vs. peanut soup or chicken vs. chicken soup) (Mattes, 2005) whereas later (Flood-Obbagy & Rolls, 2009) a whole apple was concluded to induce more pronounced satiety than apple sauce and the whole apple also reduced energy intake in the following meal. Martens et al. showed that solid food (steamed chicken breast) resulted in enhanced satiety response compared to liquefied food (blended steamed chicken breast) (Martens, Lemmens, Born, & Westerterp-Plantenga, 2011) whereas Flood and Rolls showed that there was no difference in satiety response whether soup was offered as separate broth and vegetables versus pureed soup (Flood & Rolls, 2007). In addition heterogeneous and homogeneous yoghurts resulted in similar satiety response (Tsuchiya, Almiron-Roig, Lluch, Guyonnet, & Drewnowski, 2006). To summarize, the evidence regarding the importance of food texture and oral processing on satiety is inconsistent. Most of the studies do not report oral processing precisely. The influence of oral processing on appetite has been studied also in experimental settings where the same foods have been eaten varying the number of chews or mastication time as instructed by the researchers. The results of such studies have been inconsistent: some reports indicate that increasing number of chews or mastication time improves satiety but others show no connection (Hogenkamp & Schiöth, 2013).

Sensory characteristics of foods such as chewiness and saltiness (Forde, van Kuijk, Thaler, de Graaf, & Martin, 2013), anticipated creaminess (McCrickerd, Lensing, & Yeomans, 2015) and thickness and creaminess (Yeomans & Chambers, 2011) have been found to influence on expected satiety. Even expectations about the satiating capacity of foods evoked by visual and other sensory perceptible cues have shown to influence the actual satiety response: In the study of Brunstrom et al participants were shown either a large or a small portion of fruits prior to consuming an equal size fruit smoothie (Brunstrom, Brown, Hinton, Rogers, & Fay, 2011). The participants who saw the larger fruit portion reported higher expectations of satiety and in fact also experienced enhanced satiety for three hours. Liking of food has also been repeatedly shown to influence appetite reflected as an increased intake as palatability increases (Sørensen, Møller, Flint, Martens, & Raben, 2003). However, results concerning the importance of palatability on postprandial satiety remain inconclusive. To summarize, cephalic phase factors including oral processing, perception about pleasantness of food as well as expectations about its satiating capacity may all work together to modulate the satiety response.

The current study aimed to evaluate if the structure of rye products influences subjective feelings of satiety, and if cephalic phase factors including oral processing, satiety expectations and evaluated pleasantness are mediating the interaction. The use of rye products as model foods allowed the comparison of extreme food structures with only minor differences in chemical composition.

2. Materials and methods

2.1. Products and their nutrient contents

The test foods were wholegrain rye products representing various structures; wholegrain sourdough rye bread, extruded wholegrain rye flakes, extruded wholegrain rye puffs and wholegrain rye smoothie (Table 1 and Fig. 1). Wheat bread was included as a control product. Wholegrain sourdough rye bread (wholegrain rye flour, water, salt) and refined wheat bread (wheat flour, water, yeast, sugar, rapeseed oil, salt) were commercially available products by local bakery (Emil Halme). Wholegrain rye puffs and flakes were prepared at VTT using whole grain rye flour (Oy Karl Fazer AB/Fazer Mills and Mixes, Lahti, Finland) and salt (0.8%) as ingredients. A twin screw extruder (APV MPF 19/25, Baker Perkins Group Ltd, Peterborough, UK) was used to produce the extrudates with a constant feed rate of 60 g/min and temperature