Chem. Senses 35: 91–100, 2010
doi:10.1093/chemse/bjp086
Advance Access publication December 14, 2009

Acute Effects of Complexity in Aroma Composition on Satiation and Food Intake

Rianne M.A.J. Ruijschop[1], Alexandra E.M. Boelrijk[2], Maurits J.M. Burgering[1], Cees de Graaf[3] and Margriet S. Westerterp-Plantenga[4]

[1]NIZO food research, Kernhemseweg 2, PO Box 20, 6710 BA Ede, The Netherlands, [2]Danone Research Medical Nutrition, Bosrandweg 20, PO Box 7005, 6700 CA, Wageningen, The Netherlands, [3]Division of Human Nutrition, Department of Agrotechnology and Food Sciences, Wageningen University, Bomenweg 2, PO Box 8129, 6700 EV, Wageningen, The Netherlands and [4]Department of Human Biology, Maastricht University, Universiteitssingel 50, PO Box 616, 6200 MD Maastricht, The Netherlands

Correspondence to be sent to: Rianne M.A.J. Ruijschop, NIZO food research, Kernhemseweg 2, PO Box 20, 6710 BA Ede, The Netherlands. e-mail: rianne.ruijschop@nizo.nl

Accepted November 2, 2009

Abstract

The acute effect of complexity in aroma composition on perceived satiation and food intake was investigated in 41 young, healthy, and normal weight subjects. Subjects consumed 2 different strawberry-aromatized sweetened yogurt products (i.e., test and placebo product) in either an olfactometer-aided or an ad libitum eating experimental design. The test product was aromatized with a multicomponent strawberry aroma, whereas the placebo product was aromatized with a single-component strawberry aroma.

Compared to placebo, subjects felt significantly more satiated during aroma stimulation with the multicomponent strawberry aroma in the olfactometer-aided setting. Additionally, perceived satiation was significantly increased 10–15 min after consumption of the multicomponent strawberry-aromatized sweetened yogurt product in the ad libitum eating setting. There was no effect on the amount of strawberry-aromatized sweetened yogurt product consumed ad libitum. Apart from the differences in timing of the appetite-regulating effects, both experimental settings demonstrated that the multicomponent strawberry aroma, which was perceived as being more complex, yet of similar aroma quality, intensity, and pleasantness compared with the single-component strawberry aroma, was able to enhance perceived satiation. The methodology of the olfactometer-aided aroma stimulation proved to be representative of a real-life setting with regard to aroma exposure and satiation.

Food products, which are perceived as being more complex, have been suggested to delay the development of sensory satiation as a result of implicitly cueing for variation. The present results may be explained by increased sensory stimulation, due to concurrent exposure to multiple aroma components cueing for sensorily similar strawberry perception.

Key words: appetite profile, arousal potential level, flavor, food intake, olfactometer, satiation

Introduction

Sensory perception during food consumption is a complex process in which olfaction, taste, mouthfeel, vision, the trigeminal system, and auditory signals contribute to the total appreciation of a food product (Shepherd 1995; Meiselman 1996; Visschers et al. 2006). Repeated consumption across time may affect appreciation, in either a positive or negative direction, depending on the so-called arousal level of a sensory stimulus (Dember and Earl 1957; Berlyne 1960, 1970; Köster 2003; Lévy et al. 2006; Weijzen et al. 2008). The arousal level of a sensory stimulus, which is a combination of intensity, complexity, and novelty, is an intrinsic factor of a sensory stimulus, which is subject-specific and reduced by learning and experience. A single-peaked inverted U-shape relationship exists between the preference and perceived arousal level of a sensory stimulus (Dember and Earl 1957; Berlyne 1960, 1970), which notably includes perceived complexity (Dember and Earl 1957). For each subject, there is an optimal arousal potential level below and above which sensory stimuli are less preferred (Dember and Earl 1957; Berlyne 1960, 1970; Lévy et al. 2006). Mere exposure to food

products, which are initially perceived on the right side of the optimum arousal potential level (i.e., perceived as being slightly more complex and consequently less preferred than the optimum), is able to shift perception toward the optimum upon learning and experience (longer term food appreciation). In contrast, repeated exposure to food products that are initially perceived at the optimum, or on the left side of the optimum arousal potential level, will only lead to diminished interest or even to boredom (Dember and Earl 1957; Berlyne 1960, 1970; Köster 2003; Lévy et al. 2006; Weijzen et al. 2008).

A number of studies have revealed that repeated consumption of food products, which were perceived as being more complex, delayed the development of sensory satiation (Johnson and Vickers 1992; Lévy et al. 2006; Weijzen et al. 2008). A possible explanation may be that perceived complexity implicitly cued for variation in sensory properties. Increasing the variation of sensorily distinct foods slows the decline in desire to eat the food and increases meal size (Hetherington et al. 2006; Romer et al. 2006; Harthoorn et al. 2008).

In the present study, the focus was on aroma. Recently, we were able to show that a retronasally delivered aroma (strawberry) was capable of inducing satiation (Ruijschop et al. 2008). The current study investigates whether 2 different strawberry aroma compositions, which are expected to vary only in the perceived level of complexity, are able to show a difference in resulting satiation. Assuming that the total amount of exposure to a food's sensory properties determines the total decline in desire to eat, we hypothesized that an enhancement of sensory properties by increased sensory stimulation from a more complex aroma would further reduce the desire to eat and enhance satiation. This is suggested to be due to concurrent exposure to multiple sensory attributes cueing for similar sensory perception.

In order to study this hypothesis, a single-blind, placebo-controlled, randomized crossover design was performed to investigate the acute effect of complexity in aroma composition on satiation and food intake in human subjects. Two different strawberry-aromatized sweetened yogurt products (i.e., aromatized with a multicomponent [test product, hypothesized to be perceived as being more complex] or single-component [placebo product, hypothesized to be perceived as less complex] strawberry aroma) were tested in both an olfactometer-aided and an ad libitum eating experimental design. The aim of this study was to determine whether effects of a single exposure to a multicomponent strawberry aroma may contribute to satiation and subsequently, to a decrease in food intake, because of increased sensory stimulation, due to concurrent exposure to multiple aroma components cueing for strawberry perception. In addition, the results served to validate the methodology of olfactometer-aided aroma stimulation as representative of a real-life setting.

Materials and methods

Subjects

Forty-one healthy subjects (21 women and 20 men) aged 20–40 years living in Ede, the Netherlands, and surroundings were recruited through advertisements in the local newspapers. The subjects included normal weight subjects, with a body mass index (BMI) of 20–25 kg/m^2. Subjects' mean age (±standard deviation) was 29 ± 7 years and mean BMI (±standard deviation) was 23 ± 3 kg/m^2.

Subjects with low scores (≤9) on dietary restraint were selected using the Dutch translation of the three-factor eating questionnaire (Westerterp-Plantenga et al. 1999). In addition, based on self-report, subjects were not allergic to, nor did they have an aversion to, any of the food ingredients used in the present study. Subjects also reported a normal sense of smell.

Subjects were fully informed about the course of the test day and gave their written, informed consent. To prevent response bias, the participants were given no information about the hypotheses and nature of the predictions of the experiment. They were only aware of the original nature of the study, that is, the contribution of aroma to satiety. The study was approved by the Medical Ethical Committee of Wageningen University.

Preparation of products

Sweetened yogurt products

Batches of nonaromatized skimmed (0.5% fat) pasteurized yogurt were produced in NIZO food research's food-grade pilot plant and contained 90% milk (Friesland Foods), 1.0% starch (Roquette), and 8.4% sugar (CSM). Microbiological safety was checked for each yogurt production. The viscosity of the produced yogurt products was 61 ± 14 s, as measured with a Posthumus funnel, and the pH was 4.03 ± 0.1.

Strawberry-aromatized sweetened yogurt products

In order to prepare the strawberry-aromatized sweetened yogurt products, 1.0-mL strawberry solution with a concentration of 100 g/kg was added to 1-L sweetened yogurt product (NIZO food research) following a standardized procedure of continuous stirring. The strawberry-aromatized sweetened yogurt products were left 1.5 days at 4 °C to allow a good equilibration of the aroma in the product. No color was added to the strawberry-aromatized sweetened yogurt products to prevent any unwanted cross-modal effect from a pink- or red-colored yogurt product with respect to the 2 different strawberry aroma compositions.

Strawberry aroma

Ethyl butyrate (Sigma-Aldrich Chemie GmbH) was used as single-component strawberry aroma. Ethyl butyrate is one of the key components of a generic strawberry aroma quality.

The sensory quality of ethyl butyrate can be described as ethereal, fruity, ripe fruit notes (Flavor Database 2004). The multicomponent strawberry aroma used was the standard aroma of the COST 921 action, designed and supplied by Givaudan, which contains 15 components, including ethyl butyrate (COST 921 action).

Prior to use in the olfactometer, the strawberry aroma was diluted 10 000-fold in propylene glycol (private label from a local pharmacy in Ede, the Netherlands).

Validation of aroma stimulation via olfactometer as representative of a real-life setting

Olfactometer-aided aroma stimulation

On the one hand, the contribution of strawberry aroma was investigated apart from other stimuli from the yogurt matrix (associated with other ingredients, textures, and tastes). For this, the strawberry aroma was decoupled from the taste and mouthfeel of the sweetened yogurt product and delivered separately to the subjects by means of a tailored computer-controlled 4-channel olfactometer based on air dilution olfactometry (OM4). Using atmospheric pressure chemical ionization–mass spectrometry (APcI-MS) in combination with olfactometer methodology, complete strawberry aroma release profiles were designed that mimic those obtained in vivo during the consumption of strawberry-aromatized sweetened yogurt product (cf. de Kok et al. 2006; Visschers et al. 2006; Ruijschop et al. 2008).

In the current setup, the airflow out of the olfactometer was kept constant at 8 L/min so as to be as close as possible to natural aroma release conditions during consumption. A complete aroma time-intensity release profile was administered by the olfactometer, consisting of multiple aroma pulses. The aroma release curve, resembling the consumption of the strawberry-aromatized sweetened yogurt product, was delivered as a profile of 10 consecutive pulses, each lasting 3 s, with interpulse intervals of 1 s (Figure 1).

The odorized dilution airflow ratios, that is, the amount of odor-enriched air versus the amount of odorless air for the 10 pulses within the profile were 1:7, 2:6, 4:4, 4:4, 4:4, 4:4, 4:4, 4:4, 2:6, 1:7, with a total odor + dilution airflow of 8 L/min. The aroma concentration in the delivered air corresponds linearly to the fraction of the total flow for flow rates up to 4 L/min in each aroma vessel. The aroma profile was designed in such a way that the envelope of the aroma pulses mimicked the reflux of air that occurs during and after swallowing. Each subject received both aroma compositions via the same aroma profile with the same concentration of the strawberry aroma in a fully randomized order. For retronasal aroma delivery, approximately 9 cm in length of a silicon tube (suction catheter CH 10, D-Care B.V.) was placed into the lower meatus of the right nasal cavity. Anterior rhinoscopy was performed to exclude major pathology. Introduction of the tubing to the nose was tolerated well by all subjects without causing congestion, epistaxis, or mucus discharge. Subjects waited for 15 min in which they could relax and become familiar with the tubing. The extent to which a subject felt comfortable was recorded. The silicon tube was connected to the olfactometer while the subject was sitting straight up in a chair, enabling concurrent consumption of sweetened yogurt product.

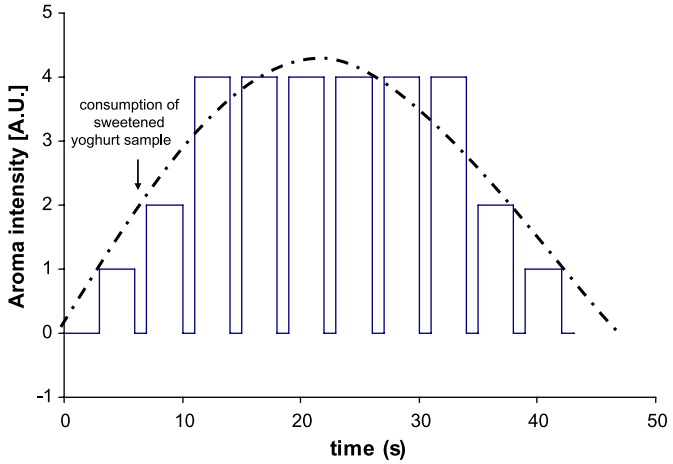

Figure 1 Aroma release profile delivered by olfactometer in both the single-component and multicomponent strawberry aroma stimulation. Because this study is comparison wise, expression of the flavor intensity in arbitrary units (AU) is sufficient to analyze differences (Taylor et al. 2000). The smoothed line indicates the perceived aroma intensity, which is a continuous envelope. Due to the length of the aroma profile, the start of the aroma delivery was 3 s before the instruction to consume the sweetened yogurt sample.

Subjects were connected to the olfactometer for 15 min. The aroma stimulation consisted of 15 aroma release profiles, starting every minute. All 15 aroma release profiles, which were retronasally delivered in the nose, were combined with the taste and mouthfeel sensation of the sweetened yogurt product (15 g) in the mouth. During one complete aroma stimulation experiment, every subject received 15 such sweetened yogurt samples (225 g in total), which were served at 7 ± 1 °C. A specific protocol was established for the timing of aroma delivery. As 15 g is a normal quantity to be consumed in one mouthful, subjects were instructed to consume the entire sweetened yogurt sample in one mouthful using a spoon. Due to the length of the aroma profile, the start of the aroma delivery was 3 s before the instruction to consume the sweetened yogurt sample, whereas the subjects were putting the spoon with the mouthful of sweetened yogurt sample into their mouth. No specific instruction with regard to breathing was given. With the exception of strong breath intake through the nose, the total airflow of 8 L/min from the olfactometer ensures delivery of the aroma to the olfactory epithelium. During the experiments, the subjects were closely observed in order to verify compliance with the protocol.

To prevent adaptation to the delivered aroma, the delay between the measurements amounted to a minimum of 17 s (i.e., the time interval between 2 successive aroma release profiles). Within this time interval, a continuous constant

flow of clean air was maintained. After aroma stimulation, the silicon tube was removed and subjects went to another room for the remaining part of the experiment.

Ad libitum consumption

Alternatively, in the more real-life setting, the contribution of strawberry aroma to satiation and food intake was investigated in an ad libitum eating experimental design. For this, the strawberry aroma was coupled to the taste and mouthfeel of the sweetened yogurt product. Subjects were simultaneously exposed to the strawberry aroma, taste, and mouthfeel of the yogurt product. Prior to consumption, the strawberry aroma was added to the sweetened yogurt product in a concentration comparable to the olfactometer-aided aroma stimulation, as measured in vivo using APcI-MS.

Experimental design

Separately, in order to prevent response bias, sensory data were obtained to investigate whether the difference in the 2 strawberry aroma compositions was large enough to be perceived as being different with respect to the level of complexity. Therefore, after the satiation experiments, a sensory evaluation was performed with the subjects who participated in this study. Based on these results, it could be checked whether the intervention was successful.

For the satiation experiments, each subject visited the test location 4 times in the morning, testing the 2 strawberry-aromatized sweetened yogurt products (i.e., aromatized with a multicomponent [test product] or single-component [placebo product] strawberry aroma) in either an olfactometer-aided or an ad libitum eating setting. Treatment order was counterbalanced across both test days and subjects. Between each visit there was a time interval of 1 week. Based on the results of the different technological approaches, it could be checked whether the olfactometer-aided aroma stimulation is representative of a real-life setting with regard to aroma exposure and satiation. Therefore, timings of the 2 experimental designs were kept the same as much as possible. However, due to practical feasibility, both experimental settings could not start at the same time of the morning. The olfactometer-aided setting only allowed one subject at the time.

To assure subjects visited the laboratory every time with comparable feelings of hunger and satiety, an individually standardized breakfast was included. Before starting the experiment, daily dietary energy requirements were calculated individually by multiplying the basal metabolic rate (BMR) by an activity index of 1.60. The BMR was calculated according to the equation of Harris and Benedict (1919). Subjects were asked to consume 10% of the daily dietary energy requirements for breakfast at home, which varied per person from 836 to 1463 kJ (from 200 to 350 kcal). In addition, the subjects were requested to consume the same type and amount of breakfast when visiting the laboratory the next times. A baseline measurement before the start of the olfactometer-aided aroma stimulation or ad libitum consumption of the strawberry-aromatized sweetened yogurt products recorded the initial hunger state.

In a single-blind, placebo-controlled, randomized crossover design, subjects were either administered 2 different strawberry aroma compositions using an olfactometer-aided setting as described above or served 2 different strawberry-aromatized sweetened yogurt products, from which they could eat ad libitum. Before, during and after the olfactometer-aided sensory stimulation and ad libitum consumption, appetite profile measurements were performed. The design of a test day is represented schematically in Figure 2A (olfactometer-aided setting) and Figure 2B (ad libitum eating setting).

Measurements

Sensory evaluation of the strawberry-aromatized sweetened yogurt products

Sensory attribute evaluation for the appearance, smell, taste, mouthfeel, and aftertaste of the different strawberry-aromatized sweetened yogurt products was performed by the subjects on a 100-mm visual analog scale (VAS; anchored for each with ''not at all attractive'' and ''very much attractive''; Aitken 1969). Intensities of smell, taste, and aftertaste were recorded on a 100-mm just-about-right (JAR) scale (anchored for each with ''much too weak'' and ''much too strong''; e.g., Shepherd et al. 1991).

Perceived levels of complexity, familiarity/novelty, and boredom were assessed for the different strawberry-aromatized sweetened yogurt products by questionnaire (cf. Weijzen et al. 2008). Subjects recorded ratings for the items ''difficulty to describe the taste,'' ''perceived number of ingredients,'' and ''perceived level of complexity'' (i.e., the dimension complexity); ''familiarity,'' ''perceived boredom,'' ''desire to eat,'' ''appropriateness to eat every day,'' and ''probability of personal choice'' (i.e., the dimension boredom; 100-mm VAS anchored for each with ''not at all'' and ''very much'').

Short-term appetite profile

The appetite profile, that is, ratings of hunger, fullness, satiation, desire to eat, and thirst were recorded on a 100-mm VAS (anchored for each with not at all and very much) repeatedly before, during, and after the olfactometer-aided sensory stimulation and ad libitum consumption of the strawberry-aromatized sweetened yogurt products (see VAS_{AP} Figure 2). In addition, at the same time points, desire to eat sweet products and desire to eat savory products were recorded on 100-mm VAS anchored with not at all and very much. All rating scales were provided on separate sheets that were collected after each rating.

Actual strawberry-aromatized sweetened yogurt product consumption

To measure the effect of the 2 different strawberry aroma compositions on actual yogurt product consumption,

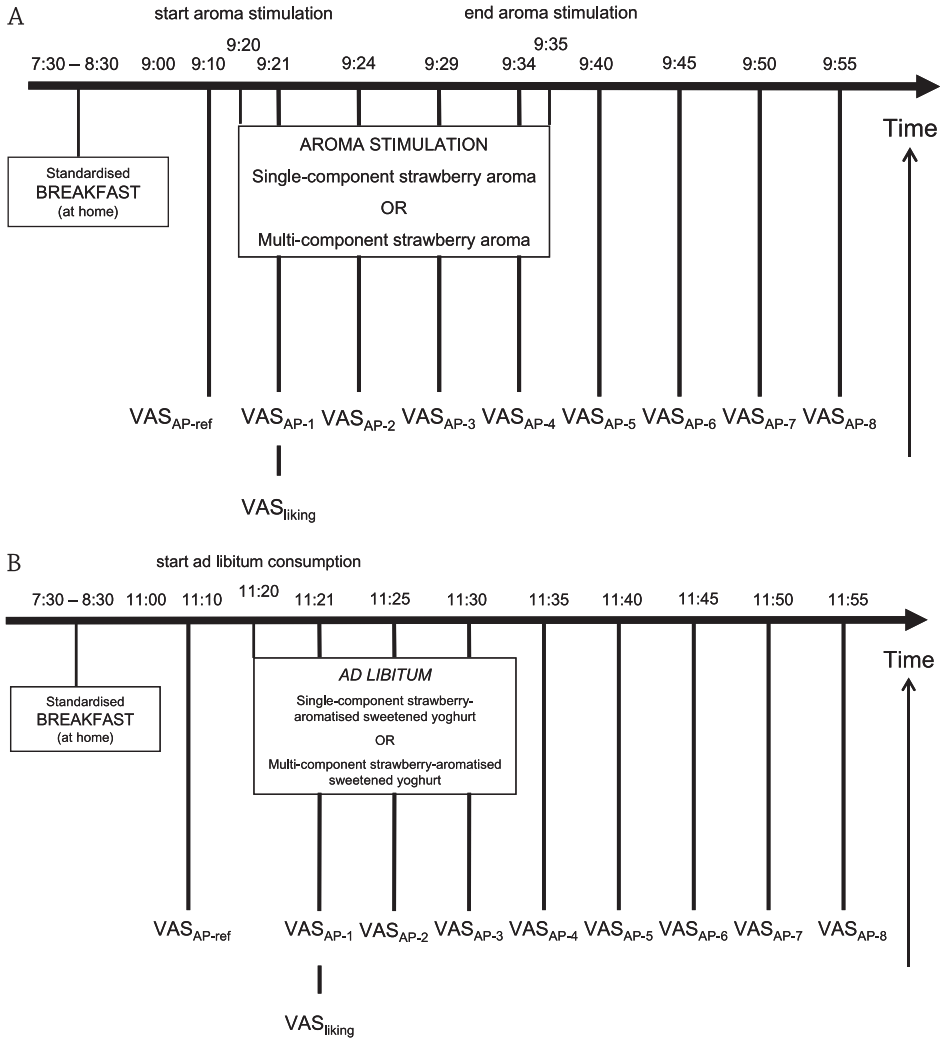

Figure 2 Overview of the test day protocol. Subjects came 4 times to the laboratory, a week apart, and received either the single-component or multicomponent strawberry olfactometer-aided aroma stimulation **(A)** or the single-component or multicomponent strawberry-aromatized sweetened yogurt product **(B)** in a fully randomized order. Appetite profiles were recorded on a 100-mm VAS repeatedly (**A** and **B**: $VAS_{AP\text{-}ref}$ to $VAS_{AP\text{-}8}$). Hedonic ratings were recorded for the strawberry-aromatized sweetened yogurt product on a 100-mm VAS (**A** and **B**: VAS_{liking}). In addition, the amount of strawberry-aromatized sweetened yogurt product consumed ad libitum was measured **(B)**.

subjects were offered 2 L of strawberry-aromatized sweetened yogurt product, served in an opaque bowl with a tablespoon at 7 ± 1 °C, from which they could eat ad libitum. The amount offered was such that there were always leftovers. After consumption, the amount of strawberry-aromatized sweetened yogurt product consumed was measured for each subject (Mettler-Toledo balance).

Pleasantness of flavor rating

Immediately after the start of the olfactometer-aided aroma stimulation or ad libitum strawberry-aromatized sweetened yogurt product consumption, pleasantness of taste of the consumed yogurt product was measured. Subjects were asked to scale their hedonic rating (100-mm VAS anchored with "not pleasant at all" and "very pleasant"; see VAS_{liking} Figure 2).

Data analysis

VAS and JAR ratings were measured in millimeters from the left (respectively, not at all and much too weak) end of the scale. The set of sensory data obtained was evaluated by regular statistical means (e.g., descriptive statistics), regular principal components analysis (FIZZ calculations, release 2.30c, Biosystemes), and a general linear model (GLM) procedure for repeated measures with participant and type of strawberry aroma as independent variables (SAS, release 9.1, SAS Institute Inc.).

Because there were no significant differences in VAS rating for the appetite profile at baseline measurement, delta VAS ratings, that is, changes in VAS ratings, were calculated by subtracting the ratings at the time point before olfactometer-aided aroma stimulation or ad libitum consumption

($VAS_{AP\text{-}ref}$ for appetite profile ratings) from the ratings at the different time points during and after olfactometer-aided aroma stimulation or ad libitum consumption ($VAS_{AP\text{-}1}$ to $VAS_{AP\text{-}8}$ for appetite profile ratings). Area under the curve (AUC) delta VAS ratings were determined using the trapezoidal method. As a composite measure for the appetite profile, hunger, and satiation scores were used, whereas desire to eat and fullness were scored similarly. All data are presented as means with their standard error of the mean (SEM). Actual strawberry-aromatized sweetened yogurt product consumption and the different AUC delta VAS ratings were compared between the 2 different strawberry aroma compositions, in either the olfactometer-aided or ad libitum eating setting, by using the GLM procedure for repeated measures, with participant and type of strawberry aroma as independent variables. Least squares means were used for post hoc comparisons. With the use of a mixed-model analysis of variance for repeated measures, differences in delta VAS appetite profile ratings were investigated per time point. Least squares means were used for post hoc comparisons.

Simple regression analyses ($f(x)$) were performed for actual strawberry-aromatized sweetened yogurt product consumption and short-term appetite profile (y), and pleasantness of taste and perceived levels of the dimensions complexity, familiarity, and boredom for the strawberry-aromatized sweetened yogurt products (x). For all data analyses, the statistical packages SAS (release 9.1, SAS Institute Inc.) were used. P values < 0.05 were considered statistically significant.

Results

Sensory evaluation of the strawberry-aromatized sweetened yogurt products

Subjects evaluated the appearance, (intensity of) smell, (intensity of) taste, mouthfeel, and (intensity of) aftertaste of both strawberry-aromatized sweetened yogurt products as acceptable attractive and JAR (Table 1). However, subjects rated the mouthfeel of the single-component strawberry-aromatized sweetened yogurt as more attractive compared with the multicomponent strawberry-aromatized sweetened yogurt ($F_{1,41} = 7.71$; $P = 0.01$). Apart from mouthfeel, sensory attribute evaluation did not differ significantly between the single-component and multicomponent strawberry-aromatized sweetened yogurt products.

The multicomponent strawberry-aromatized sweetened yogurt product yielded significantly higher scores compared with the single-component strawberry-aromatized sweetened yogurt product on the dimension complexity for the items difficulty to describe the taste (49.8 ± 3.3 mm and 62.9 ± 3.3 mm for the single-component and multicomponent strawberry-aromatized sweetened yogurt product, respectively; $F_{1,41} = 7.53$; $P = 0.01$) and perceived level of complexity (38.8 ± 2.6 mm and 47.3 ± 2.6 mm for the single-component and multicomponent strawberry-aromatized sweetened yogurt product, respectively; $F_{1,41} = 5.23$; $P = 0.03$) (Figure 3). Subjects evaluated the dimensions familiarity and boredom for both strawberry-aromatized sweetened yogurt products not significantly different.

Table 1 Sensory attribute evaluation of the different strawberry-aromatized sweetened yogurt products, as performed after the satiation experiments by the 41 subjects[a]

	Single-component strawberry aroma		Multicomponent strawberry aroma	
	Mean	SEM	Mean	SEM
Appearance (mm)[b]	60.4	1.6	61.9	1.6
Smell (mm)[b]	52.8	2.6	51.1	2.5
Intensity of smell (mm)[c]	48.4	2.5	49.1	2.5
Taste (mm)[b]	55.3	2.5	54.1	2.5
Intensity of taste (mm)[c]	56.5	1.4	55.2	1.4
Mouthfeel (mm)[b,d]	69.9	1.6	63.5	1.6
Aftertaste (mm)[b]	45.6	3.4	48.8	3.4
Intensity of aftertaste (mm)[c]	60.6	2.5	59.1	2.5

[a]Mean values and standard errors.
[b]100-mm VAS scale.
[c]100-mm JAR scale.
[d]Significantly different between the 2 yogurt products.

Pleasantness of taste of the strawberry-aromatized sweetened yogurt product

Subjects evaluated the pleasantness of taste for the single-component and multicomponent strawberry-aromatized sweetened yogurt product, as on average 59.4 ± 1.8 mm and 58.6 ± 1.9 mm, respectively. No significant differences in pleasantness of taste were observed between the strawberry-aromatized sweetened yogurt products in either the olfactometer-aided or the ad libitum eating setting ($F_{1,38} = 1.02$; $P = 0.32$ and $F_{1,40} = 3.12$; $P = 0.09$, respectively).

In general, it appeared that the amount of strawberry-aromatized sweetened yogurt product consumed ad libitum (y) was a function of personal pleasantness of taste of the strawberry-aromatized sweetened yogurt products (x) ($y = 3.1x + 175.8$; $R^2 = 0.07$; $P = 0.02$). Correspondingly, personal pleasantness of taste of the strawberry-aromatized sweetened yogurt products (x) was related to the appetite profile ratings (y); either positively for perceived satiation and perceived fullness or negatively for perceived hunger and desire to eat.

In addition, pleasantness of taste and perceived level of complexity for the 2 different strawberry-aromatized sweetened yogurt products were not linearly related but could be related to the theoretical inverted U-shape between pleasantness of taste and perceived level of complexity (Figure 4). The pleasantness of taste, as measured during ad libitum consumption, was equal for both strawberry-aromatized

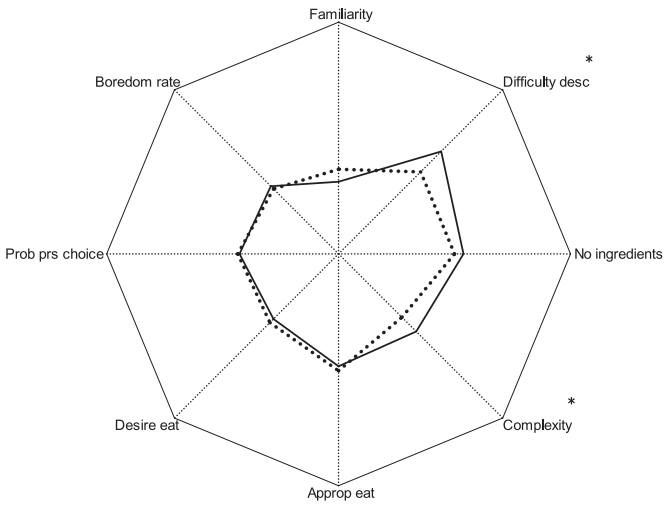

Figure 3 Star (spider) graph (100-mm scale) representing the ratings for the dimensions perceived complexity (i.e., the items difficulty to describe the taste [difficulty desc], perceived number of ingredients [no ingredients], and perceived level of complexity [complexity]), familiarity, and boredom (items perceived boredom [boredom rate], desire to eat [desire eat], appropriateness to eat every day [approp eat], and probability of personal choice [prob prs choice]) for the single-component (dot line) and multicomponent (solid line) strawberry-aromatized sweetened yogurt product. Parameters with a *denote that subjects evaluated the dimension complexity significantly higher for the multicomponent strawberry-aromatized sweetened yogurt product with respect to the items difficulty to describe the taste and perceived level of complexity.

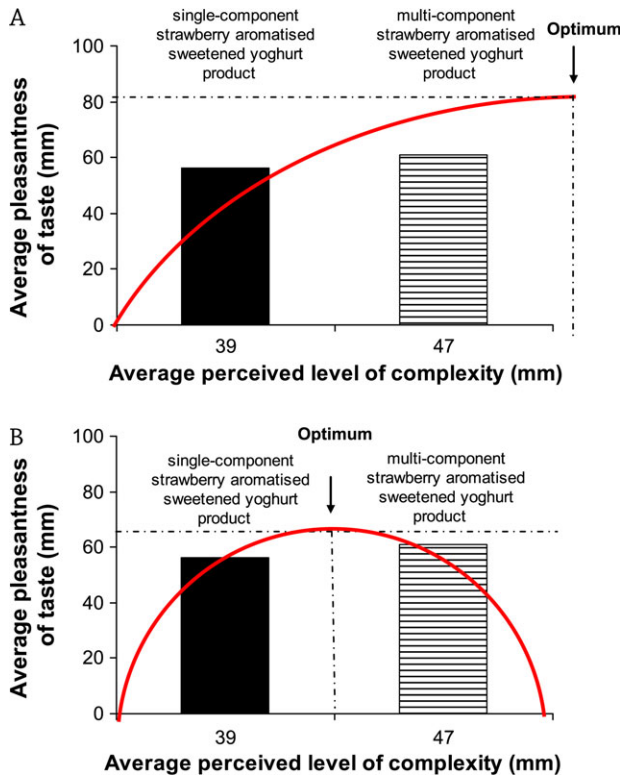

Figure 4 Illustration of the theoretical likely left side **(A)** or both left and right side **(B)** of the inverted U-shape relationship between pleasantness of taste and the arousal potential for the single-component (placebo product) and multicomponent (test product) strawberry-aromatized sweetened yogurt product. The pleasantness of taste, as measured during ad libitum consumption, was equal for both strawberry-aromatized sweetened yogurt products; however, subjects significantly perceived a higher level of complexity for the multicomponent strawberry-aromatized sweetened yogurt product.

sweetened yogurt products. However, subjects perceived a significantly higher level of complexity for the multicomponent strawberry-aromatized sweetened yogurt product compared with the single-component strawberry-aromatized sweetened yogurt product. Current strawberry-aromatized sweetened yogurt products are likely positioned either on the left side of the optimum arousal potential level (Figure 4A) or on both the left and right side of the optimum arousal potential level (Figure 4B) for the single-component (placebo product) and multicomponent (test product) strawberry-aromatized sweetened yogurt product, respectively.

Actual strawberry-aromatized sweetened yogurt product consumption

The amount of strawberry-aromatized sweetened yogurt product consumed ad libitum did not differ significantly between the 2 strawberry aroma compositions respectively, 347 ± 19 mL (range 51.4–1101.3 mL) for the single-component strawberry-aromatized sweetened yogurt product (placebo product) and 360 ± 19 mL (range 58.5–945.2 mL) for the multicomponent strawberry-aromatized sweetened yogurt product (test product) ($F_{1,40} = 0.24$; $P = 0.63$; data not shown).

In general, it appeared that the amount of strawberry-aromatized sweetened yogurt product consumed ad libitum (y) was a function of the perceived level of complexity for the strawberry-aromatized sweetened yogurt product (x) ($y = -4.1x + 528.1$; $R^2 = 0.10$; $P = 0.004$).

Short-term appetite profile

Because the amount of sweetened yogurt product consumed during olfactometer-aided sensory stimulation was fixed, no additional adjustments were made for the effect of amount consumed on recorded appetite profile ratings in the olfactometer-aided setting. Although the amount of strawberry-aromatized sweetened yogurt product consumed ad libitum was not equal for the 2 strawberry-aromatized sweetened yogurt products in the ad libitum eating setting, this difference was not significant between the 2 different strawberry aroma compositions. Also no additional adjustments were made for the effect of amount consumed on recorded appetite profile ratings in the ad libitum eating setting.

Figures 5 and 6 show the results of the 2 different strawberry-aromatized sweetened yogurt products, in either an olfactometer-aided or an ad libitum eating setting, on the change in VAS ratings of hunger and satiation, respectively. Compared with placebo, a significant difference was

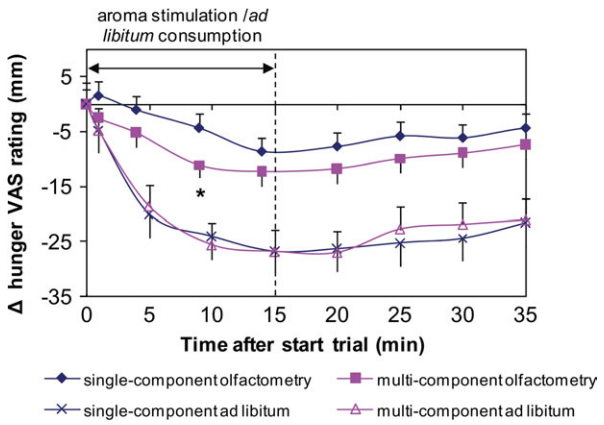

Figure 5 Change (Δ) in hunger VAS rating during and after the olfactometer-aided sensory stimulation (upper 2 data series; single-component and multicomponent olfactometer aided) and ad libitum consumption of the strawberry-aromatized sweetened yogurt products (lower 2 data series; single-component and multicomponent ad libitum), respectively. Values are means with their standard errors depicted by vertical bars. *denotes significant effect of type of strawberry aroma on change in hunger VAS rating at the designated time point with $P < 0.05$.

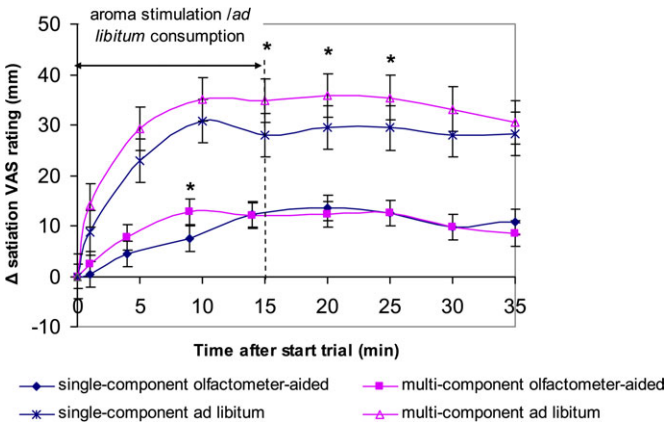

Figure 6 Change (Δ) in satiation VAS rating during and after the olfactometer-aided sensory stimulation (lower 2 data series; single-component and multicomponent olfactometer aided) and ad libitum consumption of the strawberry-aromatized sweetened yogurt products (upper 2 data series; single-component and multicomponent ad libitum), respectively. Values are means with their standard errors depicted by vertical bars. *denotes significant effect of type of strawberry aroma on change in satiation VAS rating at the designated time point with $P < 0.05$.

demonstrated in perceived hunger during olfactometer-aided sensory stimulation with the multicomponent strawberry aroma ($F_{1,342} = 5.31$; $P = 0.02$). Subjects felt less hungry during olfactometer-aided sensory stimulation with the multicomponent strawberry aroma (Figure 5; delta mean response at $VAS_{AP\text{-}3} \pm$ SEM: –11.1 ± 2.6 mm) than during olfactometer-aided sensory stimulation with the single-component strawberry aroma (Figure 5; delta mean response at $VAS_{AP\text{-}3} \pm$ SEM: –4.4 ± 2.6 mm).

In addition, subjects felt more satiated if they were aroma stimulated with the multicomponent strawberry aroma (Figure 6; delta mean response at $VAS_{AP\text{-}3} \pm$ SEM: 12.8 ± 2.5 mm) compared with the single-component strawberry aroma (Figure 6; delta mean response at $VAS_{AP\text{-}3} \pm$ SEM: 7.4 ± 2.5 mm; $F_{1,342} = 4.07$; $P = 0.05$). Furthermore, a significant difference in perceived fullness was found during olfactometer-aided aroma stimulation with the multicomponent strawberry aroma (delta mean response at $VAS_{AP\text{-}3} \pm$ SEM: 15.6 ± 2.7 mm) compared with the single-component strawberry aroma (delta mean response at $VAS_{AP\text{-}3} \pm$ SEM: 8.4 ± 2.7 mm) ($F_{1,342} = 5.78$; $P = 0.02$; data not shown, but similar to Figure 6).

In the ad libitum eating setting, a significant difference in perceived satiation was observed after consumption of the multicomponent strawberry-aromatized sweetened yogurt product (Figure 6; delta mean response at $VAS_{AP\text{-}4\text{–}6} \pm$ SEM: 35.2 ± 4.0 mm) compared with the single-component strawberry-aromatized sweetened yogurt product (Figure 6; delta mean response at $VAS_{AP\text{-}4\text{–}6} \pm$ SEM: 29.1 ± 4.0 mm). After consumption of the multicomponent strawberry-aromatized sweetened yogurt product, subjects felt more satiated than after consumption of the single-component strawberry-aromatized sweetened yogurt product ($5.03 \geq F_{1,359} > 3.90$; $0.03 \leq P < 0.05$). In contrast, a decrease in perceived hunger was not observed after ad libitum consumption of the multicomponent strawberry-aromatized sweetened yogurt product.

Discussion

The present study demonstrates that a multicomponent strawberry aroma, which was perceived as being more complex, yet of similar aroma quality, intensity, and pleasantness compared with a single-component strawberry aroma, is able to enhance satiation. There was no effect on the amount of strawberry-aromatized sweetened yogurt product consumed ad libitum. Satiation-enhancing effects may be explained by increased sensory stimulation. This is suggested to be due to concurrent exposure to multiple aroma components cueing for sensorily similar strawberry perception.

The subjects in the current study perceived no differences in appearance, (intensity of) smell, (intensity of) taste, and (intensity of) aftertaste between the single-component and multicomponent strawberry-aromatized sweetened yogurt products, apart from mouthfeel. There are no indications that the perceived difference in mouthfeel affected the present results. This unexpected distinction could not be related to batch differences in yogurt production or cross-modal sensory effects, such as differences in the perceived level of complexity. Based on the smell and taste ratings, it can be concluded that subjects were not consciously aware of the difference in strawberry aroma composition between the 2 different strawberry-aromatized sweetened yogurt products. However, subjects did perceive the multicomponent

strawberry-aromatized sweetened yogurt product as being more complex and more difficult to describe the taste compared with the single-component strawberry-aromatized sweetened yogurt product (Figure 3). Hence, the positioning of the single-component and multicomponent strawberry-aromatized sweetened yogurt product as placebo product and test product, respectively, turned out to be valid. This was the most unforeseeable part of the experimental design because it was not possible to define a priori the subjects' perceived level of complexity for the 2 different strawberry-aromatized sweetened yogurt products (cf. Weijzen et al. 2008).

Although differences in the perceived level of complexity between the 2 strawberry-aromatized sweetened yogurt products could be engineered, the average pleasantness of taste was equal for both yogurt products (Figure 4). The theoretical inverted U-shape relationship between pleasantness of taste and the arousal potential for the single-component (placebo product) and multicomponent (test product) strawberry-aromatized sweetened yogurt product is a result of a trade-off between the engineering of a maximum perceived level of complexity and preservation of a maximum pleasantness of taste. If strawberry-aromatized sweetened yogurt products, which would have been perceived as being more complex, had been used, pleasantness of taste might have been negatively affected, consequently leading to subjects who might stop eating, due to aversion instead of satiation. The positioning of the current strawberry-aromatized sweetened yogurt products on the theoretical inverted U-curve was successful for the present intervention with a single exposure (Figure 4). Thus, probably both yogurt products were perceived as a single "body/gestalt" without cueing for variation.

The result that the multicomponent strawberry aroma, which only varied in perceived level of complexity, was able to enhance satiation, was in line with our expectations (Figure 6). We hypothesized that the multicomponent strawberry aroma would lead to increased sensory stimulation due to concurrent exposure to multiple aroma components cueing for strawberry perception. To our knowledge, this result has not been shown before in the literature. Food products, which are perceived as being more complex, are usually reported to delay the development of sensory satiation (Johnson and Vickers 1992; Lévy et al. 2006; Weijzen et al. 2008). However, in those observations perceived complexity might implicitly cue for variation, leading to increased meal size (Hetherington et al. 2006; Romer et al. 2006; Harthoorn et al. 2008), whereas in the present study perceived complexity did not result in consciously perceived sensory differences between the 2 different strawberry-aromatized sweetened yogurt products. The absence of a significant effect on hunger ratings after ad libitum consumption of the multicomponent strawberry-aromatized sweetened yogurt product was not expected. Subjects likely interpreted hunger differently than the opposite of satiation.

In addition, the results served to validate the methodology of the olfactometer-aided aroma stimulation as representative of a real-life setting with regard to aroma exposure and satiation. Although timings of the 2 experimental designs were kept the same as much as possible, differences in timing of the appetite-regulating effects were nevertheless observed between the olfactometer-aided and ad libitum eating setting. However, both experimental settings demonstrated that the multicomponent strawberry aroma was able to enhance perceived satiation. Compared with the olfactometer-aided setting, appetite-regulating effects were observed later in the ad libitum eating setting. For example, compared with placebo, perceived satiation was significantly increased during aroma stimulation with the multicomponent strawberry aroma in the olfactometer-aided setting, whereas perceived satiation was significantly increased 10–15 min after consumption of the multicomponent strawberry-aromatized sweetened yogurt product in the ad libitum eating setting (Figure 6). These timing differences are likely to be ascribed to a controlled versus uncontrolled way of yogurt product consumption in the olfactometer-aided versus ad libitum eating setting, respectively. For example, eating rate and bite size are hypothesized to be different in the 2 experimental settings. In addition, the satiating power of food per kJ consumed is known to decrease slowly during the day (Schilstra 1981). By starting the ad libitum eating experiment in the beginning of the morning, satiating effects of the multicomponent strawberry-aromatized sweetened yogurt product even could have been observed during ad libitum consumption.

Although significant changes in appetite profile ratings were demonstrated between the 2 different strawberry aroma compositions, no significant difference between ad libitum consumption of the 2 different strawberry-aromatized sweetened yogurt products was observed. As discussed by Veldhorst et al. (2009), it is likely that the magnitude of the effect in perceived satiation was too small to have an effect on the amount consumed ad libitum. Veldhorst et al. (2009) showed that differences in appetite ratings in a preload–ad libitum meal design need to be at least larger than 15-mm VAS in order to have a significant effect on subsequent energy intake. Although in the present study no preload–ad libitum meal design was applied, differences in VAS between the 2 different strawberry aroma compositions in both the olfactometer-aided and ad libitum eating setting were rather small. The change in perceived satiation during olfactometer-aided aroma stimulation and after consumption of the yogurt products in the ad libitum eating setting was on average 73%, corresponding to 5.4-mm VAS and 22%, corresponding to 6.4-mm VAS, respectively. Alternatively, the magnitude of the appetite-regulating effect might have been bigger if the yogurt products had been pink colored. Although subjects were not told that they were going to consume a strawberry-aromatized yogurt product, addition of pink color to the yogurt products would likely have

been better to meet consumers' expectations toward the consumption of the strawberry-aromatized yogurt products.

The present study tested the acute effects on satiation and food intake of a single exposure to 2 different strawberry aroma compositions, which only varied in the perceived level of complexity. Because subjects were not able to make a distinction between the 2 strawberry aroma compositions based on sensory attribute evaluation, it would be interesting to investigate whether the present appetite-regulating effects are also observed after repeated exposure.

The concept that exposure to a more complex aroma stimulus is able to affect satiation may be valuable for the development of foods containing triggers that are able to induce or increase the feeling of satiation. A possible food application could be for instance, the engineering of multicomponent aroma compositions, which provide more body/gestalt to food products. Other specific food product applications might even strengthen the impact of the concept by the inclusion of other sensory attributes, such as texture complexity (e.g., cross-modal complexity interactions between aroma [perceived as complex in aroma composition] and texture [perceived as complex in aroma release profile due to longer oral processing as a result of texture]), as long as all those sensory attributes (e.g., texture maybe also color, taste) together add only to the complexity of a single body/gestalt of the food product and do not implicitly cue for variation.

Funding

This work was supported by DiOGenes. DiOGenes is the acronym of the project ''Diet, Obesity, and Genes'' supported by the European Community [Contract no. FOOD-CT-2005-513946].

The Parties of the project are listed on the web site of the project: http://www.diogenes-eu.org/. Special acknowledgment is made to the Dutch dairy organization for cofinancing this project.

Acknowledgements

We acknowledge Severine Bordet and Leonie Hermans for their skillful assistance with the preparations for this study.

References

Aitken RC. 1969. Measurement of feelings using visual analogue scales. Proc R Soc Med. 62:989–993.

Berlyne DE, editor. Conflict. Arousal and curiosity. New York: McGraw-Hill.

Berlyne DE. 1970. Novelty, complexity, and hedonic value. Percept Psychophys. 8:279–286.

COST 921 action. [Internet]. [cited 2008 October 31]. Available from: URL http://www.cost921.uni-wuppertal.de.

de Kok PMT, Boelrijk AEM, de Jong C, Burgering MJM, Jacobs MA. 2006. MS-nose flavor release profile mimic using an olfactometer. In: Bredie W, Petersen MA, editors. Developments in food science; Flavor science, recent advances and trends. London: Elsevier. 43. p. 585–599.

Dember WN, Earl RW. 1957. Analysis of exploratory, manipulatory and curiosity behaviors. Psychol Rev. 64:91–96.

Flavor Database by Leffingwell & Associates. 2004. [Internet]. [cited 2007 December 18]. Available from: URL http://www.leffingwell.com.

Harris JA, Benedict FG. 1919. A biometric study of basal metabolism in man (publication 279). Washington (DC): Carnegie Institute of Washington.

Harthoorn LF, Ruijschop RMAJ, Weinbreck F, Burgering MJM, de Wijk RA, Ponne CT, Bult JHF. 2008. Effects of aroma-texture congruency within dairy custard on satiation and food intake. Food Qual Pref. 19:644–650.

Hetherington MM, Foster R, Newman T, Anderson AS, Norton G. 2006. Understanding variety: tasting different foods delays satiation. Physiol Behav. 87:263–271.

Johnson J, Vickers Z. 1992. Factors influencing sensory-specific satiety. Appetite. 19:15–31.

Köster EP. 2003. The psychology of food choice: some often encountered fallacies. Food Qual Pref. 14:359–373.

Lévy CM, MacRae A, Köster EP. 2006. Perceived stimulus complexity and food preference development. Acta Psychol. 123:394–413.

Meiselman HL. 1996. The contextual basis for food acceptance, food choice and food intake: the food, the situation and the individual. In: Meiselman HL, MacFie HJH, editors. Food choice, acceptance and consumption. London: Blackie Academic & Professional. p. 239–263.

Romer M, Lehrner J, van Wymelbeke V, Jiang T, Deecke L, Brondel L. 2006. Does modification of olfacto-gustatory stimulation diminish sensory-specific satiety in humans? Physiol Behav. 87:469–477.

Ruijschop RMAJ, Boelrijk AEM, de Ru JA, de Graaf C, Westerterp-Plantenga MS. 2008. Effects of retro-nasal aroma release on satiation. Br J Nutr. 99:1140–1148.

Schilstra AJ. 1981. Meal-interval correlations: what can they tell us? Physiol Behav. 27:299–304.

Shepherd R. 1995. Psychological aspects of food choice. Food Sci Technol Today. 9:178–182.

Shepherd R, Farleigh CA, van Wharf SG. 1991. Effect of quantity consumed on measures of liking for salt concentrations in soup. J Sens Stud. 6:227–238.

Taylor AJ, Linforth RST, Harvey BA, Blake A. 2000. Atmospheric pressure chemical ionization mass spectroscopy for *in vivo* analysis of volatile flavor release. Food Chem. 71:327–338.

Veldhorst MAB, Nieuwenhuizen AG, Hochstenbach-Waelen A, Westerterp KR, Engelen MPKJ, Brummer RJM, Deutz NEP, Westerterp-Plantenga MS. 2009. Comparison of the effects of a high- and normal-casein breakfast on satiety, 'satiety' hormones, plasma amino acids and subsequent energy intake. Br J Nutr. 101:295–303.

Visschers RW, Jacobs MA, Frasnelli J, Hummel T, Burgering M, Boelrijk AEM. 2006. Cross-modality of texture and aroma perception is independent of orthonasal or retro-nasal stimulation. J Agric Food Chem. 54:5509–5515.

Weijzen PLG, Zandstra EH, Alfieri C, de Graaf C. 2008. Effects of complexity and intensity on sensory-specific satiety and food acceptance after repeated consumption. Food Qual Pref. 19:349–359.

Westerterp-Plantenga MS, Rolland V, Wilson SAJ, Westerterp KR. 1999. Satiety related to 24 h diet-induced thermogenesis during high protein/carbohydrate versus high fat diets, measured in a respiration chamber. Eur J Clin Nutr. 53:1–8.