Sensory and consumer-oriented studies on the effect of fat in different food matrices

A comparison between yoghurt, vanilla custard, Lyon-style and liver sausages

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„Jede Erkenntnis beginnt mit den Sinnen.“

Leonardo da Vinci

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Coauthors

Parts of this thesis were conducted in cooperation with other scientists. Prof. Dr. Mechthild Busch-Stockfisch supervised the thesis, whereas Prof. Dr. Jörg Hinrichs co-supervised the thesis. Both contributed significantly to its contents and structuring.

- CHAPTER 2: Ehrhard Köhn was involved in the statistical analyses of this chapter.

- CHAPTER 3: Alina Krzeminski prepared most parts of the written version of this chapter and provided the texture data. Ehrhard Köhn assisted with the statistical analyses. Jochen Weiss supported the discussion and supervised this chapter.

- CHAPTER 4: Regarding this chapter, Ehrhard Köhn supported the statistical analyses.

- CHAPTER 5: Ehrhard Köhn assisted in the statistical analyses, whereas Petra Bennwitz was involved in the studies which are presented in this chapter.

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List of publications

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Table of contents

SYMBOLS AND ABBREVIATIONS

Symbols	**Definition**	**Units**
c/w	casein-to-whey protein ratio	w/w [%]
C_F	fat content	w/w [%]
C_P	protein content	w/w [%]
$d_{3,2}$	sauter mean diameter	µm
$d_{75,3}$	particles of the 75th percentile	µm
$d_{90,3}$	particles of the 90th percentile	µm
η_{app}	apparent viscosity	Pas
$G'_{10\ rad\ s^{-1}}$	storage modulus at 10 rad s^{-1}	Pa
Loop Area	area of hysteresis loop	Pa/s
$\tau_{50\ s^{-1}}$	shear stress at 50 s^{-1}	Pa
$\tau_{100\ s^{-1}}$	shear stress at 100 s^{-1}	Pa

Abbreviations

A	appearance
AIC	Akaike's Information Criteria
ANOVA	analysis of variance
BIB	balanced incomplete block
CF	citrus fiber
CL	cluster
CRE	coefficient of the regression equation
DoD	Drivers of disliking
DoL	Drivers of liking
I	inulin
IC	information criteria
MFA	multiple factor analysis
n.s.	not significant
O	odor
PC	principal component
PCA	principal component analysis

QDA	quantitative descriptive analysis
Quadr.	quadratic
RS	rice starch
Ta	taste
Te	texture
UHT	ultra high temperature
vs	version

1 Introduction, scope and outline

1.1 Introduction

1.1.1 Overweight, obesity and consumers' attitudes towards fat and fat reduced foods

Since 1980, obesity has nearly doubled all over the world (WHO, 2013) and in at least 13 countries, more than half of the adult population is overweight (Sassi, 2010). Overweight and obesity promote the risk for cardiovascular diseases, diabetes, musculoskeletal disorders and cancer (WHO, 2013). Current data showed that 67% of men and 53% of women in Germany are overweight, with 23% of men and 24% of women being obese. This may result from an imbalance between energy intake and physical activity as well as partially from a high sugar consumption and an increased daily fat intake (35% of total calories instead of the recommended 30%), which may be caused by an increased consumption of meat and meat products as well as milk and dairy products (Heseker, 2012). Besides the responsibility of the individual for increasing the frequency of physical activity and for paying more intention to a healthier diet, the food industry can play an important role in promoting healthy diets by means of reducing sugar and fat in food (WHO, 2013). As dietary fats provide twice as much energy as proteins or carbohydrates, the reduction of fat in foods helps to reduce the total energy intake. However, the palatability of foods is often related to their fat content and consequently high-fat products are often preferred and their consumption is difficult to give up (Drewnowski, 1992; Drewnowski & Almiron-Roig, 2010), because fat contributes to appearance, texture, mouth feel and flavor properties of foods (Drewnowski, 1987). Nevertheless, consumers' interest for energy reduced food is increasing, but nonetheless they want the products to be palatable (Akoh, 1998; Drewnowski, 1992). Therefore a similar sensory quality is needed in reduced fat foods.

1.1.2 The role of fat in foods and the importance of the matrix

The perception of fat is food-specific or rather system-specific (Drewnowski, Shrager, Lipsky, Stellar, & Greenwood, 1989; Mela, 1990; Tepper, Shaffer, & Shearer, 1994) and the effect of fat reduction depends on the type and structure of the product as well as on the extent of fat reduction (Jones, 1996). There are differences in the perception of the fat content between solids and liquids, because fat can mainly be detected by texture and mouth feel attributes, which are easier to perceive in liquid foods; in solid foods, fat tends to be hidden (Cooper, 1987; Drewnowski et al., 1989; Tepper et al., 1994). Depending on the food matrix, fat imparts various textural properties such as hard, soft, oily, juicy, elastic, thick, flaky, heavy, viscous, smooth, crunchy, creamy, crispy and rich (Drewnowski, 1987; Miller & Rolls, 1996). Hence, different foods represent different matrices and in different matrices, fat exerts different effects on sensory properties, leading to different ways and options to reduce fat. Furthermore, different foods imply different consumer expectations concerning sensory properties.

What sensory properties does fat contribute to the full-fat variant? Which changes are caused due to the reduction of fat? Which food ingredients or methods are suitable to provide similar sensory properties to the full-fat counterparts? What do consumers' expect and what are their preferences?

1.2 Scope

Since fat perception is food-specific, a detailed approach, adjusted to a particular product, is needed to meet consumers' expectations of fat reduced foods. This study aimed to evaluate and to contrast the various effects of fat and fat reduction on sensory properties and consumer acceptance of popular meat and dairy products and to evaluate the suitability and acceptability of adapted innovative methods to reduce or rather to substitute fat. Furthermore, the drivers of liking and disliking for the different food variants were aimed to be determined.

For this purpose, a similar methodology was applied in the different surveys, illustrated in **Figure 1.1**: a) selection of different matrices, b) selection and application of innovative, adapted methodologies to reduce and substitute fat, c) evaluation of changes in sensory properties caused by fat reduction using descriptive analysis, d) evaluation of consumers' acceptability of products with varying fat contents by means of consumer testing, e) determination of drivers of liking and disliking by means of relating descriptive and consumer data, and f) examination of the acceptability/suitability of the applied adapted methods to reduce fat.

Selection of the food types for the current study based on general popularity of the products, their contribution to an increased daily fat intake (by means of being a meat or dairy product) as well as on differences in the structure between the foods:

Plain stirred yoghurt. Plain stirred yoghurt is a natural dairy product and is considered as a semi-solid. The semi-solid consistency appears due to the acid coagulation of casein at the isoelectric point. In the current study, variations in the fat content were achieved by adjusting the fat content of the used milk, ranging from 0.1% to 12.0%. Sensory changes caused by fat reduction were tried to be compensated by means of changing the protein content as well as by adding whey protein to the formulation, resulting in modified casein-to-whey protein ratios.

Starch-based vanilla custard. Starch-based vanilla custards are dairy dessert products and are considered as sweet jellified milk with a semi-solid consistency, which occurs due to the water binding capacity of the stabilizer. Because of their simple structure and the relatively small number of ingredients (milk, sucrose, thickeners, colorants and aroma), they are considered as useful model foods. The fat content of the model custards was modified by using milk with varying fat content as well as by adding dairy cream or a vegetable fat cream. The fat content ranged between 0.1% and 15.8%.

Lyon-style sausage. Lyon-style sausages are meat products and they are considered as soft-solids because they require chewing, but do not have "crispy" attributes (Foegeding et al., 2011). In our surveys, fat was substituted by substituting parts of back fat by lean meat as well as by adding combinations of dietary fibers (inulin and citrus fiber) as well as partially rice starch. The fat content of the sausages was varied between 3.0% and 25.0%.

Liver sausage. Liver sausage is a spreadable meat product. "A spreadable material is characterized by a more or less plastic rheology. Very loosely stated, a plastic material is a solid-like material" (Bot, Flöter, Lammers, & Pelan, 2003). In our examinations, fat was substituted by combinations of dietary fibers (inulin and citrus fiber) and partially rice starch. Fat contents of the liver sausage samples ranged between 3.0% and 30.0%.

It was hypothesized that (i) depending on the specific food, different sensory attributes are influenced by fat, (ii) that, depending on the food matrix, there are certain attributes which are affected by fat in different directions, (iii) that certain attributes are more important for consumers for some foods but less important for others, and (iv) that high-fat products are often preferred by consumers and therefore, the sensory profile of the fat reduced counterparts has to be adapted to the high-fat profile.

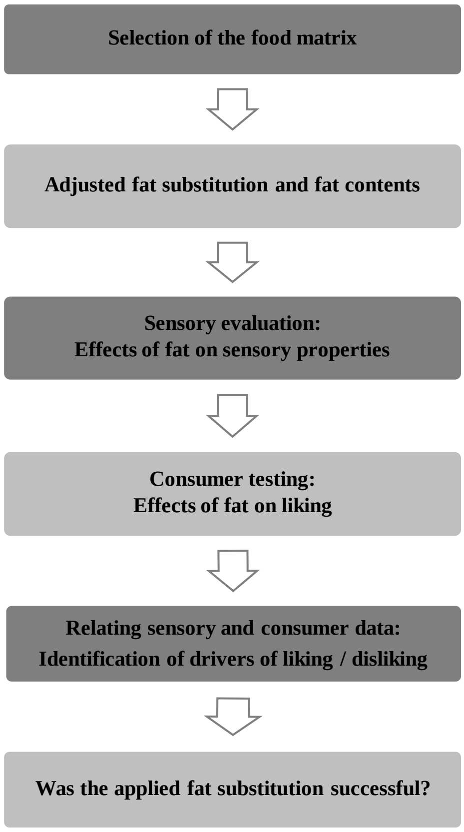

Figure 1.1: Illustration of the applied methodology to evaluate yoghurt, vanilla custard, Lyon-style and liver sausages.

1.3 Outline

This thesis focuses on the effects of fat on sensory properties and consumer acceptance of different food matrices.

CHAPTER 2

... evaluates the effects of variations in fat, protein and casein-to-whey protein ratio on sensory properties of stirred yoghurt. Additionally, it was evaluated whether fat-related properties may be imitated by variations in protein and whey protein addition.

CHAPTER 3

... presents the relationships between sensory mouth feel data and instrumental data of the stirred yoghurt systems evaluated in chapter 2.

CHAPTER 4

... studies the effects of variations in fat, protein and casein-to-whey protein ratio on consumers' acceptability of the stirred yoghurt systems evaluated in chapter 2. Furthermore, drivers of liking and disliking for plain stirred yoghurt are presented.

CHAPTER 5

... describes the influence of quantitative and qualitative variations in fat on sensory properties and consumer liking of model vanilla custard desserts. Drivers of liking and disliking for vanilla custard are additionally presented.

CHAPTER 6

... identifies the effects of fat and fat reduction and the addition of inulin, citrus fiber and partially rice starch as fat replacers on sensory properties and consumers' acceptability of Lyon-style and liver sausages. Additionally, drivers of liking and disliking for both sausage types are discussed.

CHAPTER 7

…contrasts the obtained results of the effects of fat in plain stirred yoghurt, starch-based vanilla custard as well as in Lyon-style and liver sausages and illustrates their practical applicability. Furthermore, an outlook for future research is given.

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2 Effects of casein-to-whey protein ratio, fat and protein content on sensory properties of stirred yoghurt

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Abstract

The effects of fat, protein and casein-to-whey protein ratio on sensory properties of stirred yoghurt and interactions between these three components were examined using descriptive analysis. Furthermore, the possible enhancement of fat-related sensory properties by variations in protein content and whey protein addition was studied. A study with 14 defined yoghurts was carried out. Variations in fat content (C_F = 0.1, 3.5, 6.0 and 12.0%), protein concentration (C_P = 3.5, 4.5 and 6.0%) and casein-to-whey protein ratio (*c/w* = 80/20, 60/40 and 40/60) were chosen to determine effects and relations of C_F, C_P and *c/w* for a wide product range. Results demonstrated decreasing effects concerning the attributes aromatic, sour and astringent, and increasing effects regarding graininess and yellow color, with decreasing *c/w* and increasing C_P. An increase in C_F reduced the effect of *c/w*. Creamy taste and texture, visual and textural viscosity, as well as fatty mouth feel, increased with increasing C_F, C_P and *c/w*. The effect of C_P decreased with increasing C_F. An increase in C_P enhanced fat-related sensory properties whereas whey protein addition resulted in the opposite effect.

2.1 Introduction

The production of reduced-fat products is a high priority issue for the food industry. However, fat in food exerts important influence on appearance, flavor and texture (Drewnowski, 1987). Therefore, it is important to understand how fat may influence sensory properties and how it can be replaced or imitated.

In recent years, the consumption of fermented dairy products, like yoghurt, increased due to their dietary benefits and flavor properties (Kaminarides, Stamou, & Masouras, 2007). Consumer acceptance of dairy products is strongly affected by textural properties (Frost & Janhoj, 2007), as well as the fat content (Folkenberg & Martens, 2003a). Folkenberg and Martens (2003b) showed a strong influence of fat on odor, flavor, taste and texture attributes in stirred yoghurts. Consequently, there is a need to know how to imitate fat in reduced-fat yoghurts.

The addition of milk ingredients such as whey proteins is an alternative to affect textural properties of dairy products. Textural and physical properties of yoghurts fortified with whey protein concentrate (WPC) were examined by a number of researchers (Aziznia, Khosrowshahi, Madadlou, & Rahimi, 2008; Guzmán-González, Morais, Ramos, & Amigo, 1999; Jelen, Buchheim, & Peters, 1987; Remeuf, Mohammed, Sodini, & Tissier, 2003; Sodini, Montella, & Tong, 2005). Effects of microparticulated whey proteins, WPC or whey protein isolate addition on sensory properties of yoghurt were also reported by several authors (Isleten & Karagul-Yuceer, 2006; Modler, Larmond, Lin, Froehlich, & Emmons, 1983; Torres, Janhoj, Mikkelsen, & Ipsen, 2011). Effects of variations in fat and/or protein contents on sensory properties in yoghurt have been examined as well (Janhoj, Petersen, Frost, & Ipsen, 2006; Mistry & Hassan, 1992). However, little is known about sensory effects of whey protein addition with simultaneous variation in fat and protein content.

Krzeminski, Großhable, and Hinrichs (2011) examined microstructural and physical properties of whey protein-enriched yoghurts at varying fat and protein contents. The present study analyzed these samples sensorially. Hence, including a wide range of milk composition variations, the objective of this study was to evaluate effects and interactions of fat, protein and casein-to-whey protein ratio and associated changes on sensory sensations in stirred yoghurts. Additionally, another aim was to evaluate if fat-related properties could be enhanced by means of variation in protein and whey protein addition.

2.2 Materials and methods

2.2.1 Samples

A total of 14 yoghurt samples with compositions as outlined in **Table 2.1**, were prepared as described by Krzeminski et al. (2011).

Table 2.1: Protein content (*C_P*), fat content (*C_F*) and casein-to-whey protein ratio (*c/w*) of the evaluated yoghurt samples.

Sample	C_P (%, w/w)	C_F (%, w/w)	*c/w*
A	3.5	6.0	80/20
B	6.0	6.0	80/20
C	4.5	0.1	80/20
D	4.5	3.5	80/20
E	3.5	0.1	60/40
F	6.0	0.1	60/40
G	3.5	6.0	40/60
H	6.0	6.0	40/60
I	4.5	6.0	60/40
J	4.5	12.0	80/20
K	4.5	0.1	40/60
L	4.5	12.0	40/60
M	3.5	12.0	60/40
N	6.0	12.0	60/40

Yoghurt was filled into 500 mL odorless plastic containers and stored at 10 °C. Samples were evaluated within one week after production.

2.2.2 Sensory evaluation

In order to receive a detailed description of sensory properties and differences between the samples, descriptive analysis according to international standards (ISO, 2003) was applied. A group of 22 trained panelists (4 males, 18 females, aged between 21 and 25 years, and selected on the basis of availability, previous training and liking of yoghurt) generated a list of terms with 14 appearance, taste and texture attributes, focusing on terms that discriminated among samples. Selected terms were verbally defined and trained with suitable references. Attributes and definitions are given in **Table 2.2**.

Table 2.2: List of the sensory attributes used for the evaluation of the yoghurts with definitions.

Property	Attribute [a]	Definition
Appearance	Color	Degree of white or rather yellow color
	A Viscous	Visible flow resistance, from thin to thick
	A Grainy	Visible amount of perceptible small particles
Taste	Sour	Basic taste stimulated by acids
	Aromatic	Typical flavor of yoghurt
	Off-flavor	A general, non-specific term, related to properties that are unpleasant
	Ta Creamy	Degree of perceived flavor associated with fresh dairy cream
Texture	Te Viscous	Flow resistance in the mouth, from thin to thick
	Te Creamy	Personal definition of creaminess in the mouth, associated with gloss, smoothness and a higher viscosity
	Astringent	Degree of contract of body tissue and checks secretion
	Fatty mouth feel	Amount of fat perceived in the mouth; fatty film that covers the mouth/ throat
	Te Grainy	Amount of perceptible small particles
	Furred tongue	Degree of a furred tongue
	Slimy	Degree of a slimy/sticky mouth feel, associated with gruel

[a] A, appearance; Ta, taste; Te, texture.

In order to familiarize the panelists with the attributes as well as with the scaling procedure, they were trained with pilot tests. To eliminate the influence of the impression of the first sample, for example strong sourness or astringency, a commercial warm-up yoghurt sample was provided to be tasted just prior to the evaluation of the samples. During the sensory evaluation, a commercial yoghurt (C_P = 4.4%, C_F = 3.5%, c/w = 75/25) was additionally evaluated in each session in order to study the panel performance, as well as to allow for a comparison of the high number of samples. Sensory analysis was carried out comparatively in triplicate for each sample, with three or four yoghurts being served per session, using an eleven-point categorical scale. The order of attributes among sessions and panelists was the same. Attribute definition sheets were provided, as well as filtered tap water and matzo for neutralization. From a wide range of commercially available yoghurts, panelists chose two reference samples to represent the lowest and the highest intensity (0 and 10) for each attribute, respectively, to clarify the diversity of the product space of the descriptors. Finally, as some of the yoghurts represented the lowest or highest intensity for several attributes, a total of ten different yoghurts were provided as references in each session.

All sensory assessments took place at the Sensory Laboratory at University of Applied Sciences, Hamburg, Germany, equipped with separate booths according to international standards for test rooms (ISO, 2007). At a sample temperature of 10 °C, yoghurt samples were analyzed at room temperature (21 °C ±2 °C). Panellists received 60 g of each sample in 100 mL odourless and transparent plastic vessels (Bunzl Verpackungen GmbH, Gelsenkirchen, Germany), coded with three-digit random numbers. Samples were presented in randomized order among panellists according to Williams Latin Square (MacFie, Bratchell, Greenhoff, & Vallis, 1989). Sensory data collection was conducted using FIZZ (vs. 2.31G, Biosystèmes, Couternon, France).

2.2.3 Statistical analysis

Data were analyzed by a one-factor analysis of variance (ANOVA) with interaction to examine the product effect. Multiple comparisons of means were performed using Tukey's test ($P < 0.05$). Cluster analysis was conducted to group samples with similar sensory properties. In order to reduce the sensory dimensions as well as to gain information about differences and similarities between samples, principal component analysis (PCA) with varimax rotation (Abdi, 2003) was applied. Statistical calculations were performed using XLSTAT (vs. 2011.2.04, Addinsoft, Andernach, Germany). In order to detect interactions and to quantify the influence of the three milk composition variables on sensory properties, ANOVA models were applied and compared using commercially available Design of Experiment Software. For the purpose of studying the panel performance, data of the commercial yoghurt sample were also analyzed by means of ANOVA and Tukey's test.

2.3 Results and discussion

Mean values of sensory profiling and significant differences for each attribute are shown in **Table 2.3**. Comparing the 14 samples, results revealed significant differences in all descriptors. Data of the commercial yoghurt sample were excluded from statistical analysis, as it only served to control the panel performance and to allow for a comparison between all samples (a reliable reproducibility of the data has been determined, data not shown).

Table 2.3: Results of ANOVA, showing means and significance for each attribute, categorized in groups obtained from Cluster Analysis.

	Cluster	1			2			3			4					
Property	Attribute	A	C	D	E	G	K	F	H	N	B	I	J	L	M	Sign.
Appearance	A Viscous	6.5	2.7	4.8	1.9	6.4	5.0	7.6	5.4	8.0	7.5	7.4	9.5	9.6	9.4	***
	A Grainy	1.2	2.0	1.2	7.9	9.4	9.7	8.9	9.1	6.6	4.7	6.6	1.9	8.3	7.5	***
	Colour	4.4	4.7	2.8	6.5	3.0	8.9	9.1	9.1	8.5	6.2	4.1	3.9	5.0	4.5	***
Taste	Sour	3.4	3.9	3.3	2.7	2.2	2.3	1.9	1.4	1.3	3.3	2.6	1.9	1.8	2.8	***
	Aromatic	4.8	4.3	5.4	3.3	3.0	1.6	3.6	3.2	3.1	5.3	3.8	3.8	3.2	3.6	***
	Off-flavour	1.8	4.6	2.7	4.7	2.1	1.7	6.4	4.5	3.7	3.4	1.7	3.8	1.9	1.9	***
	Ta Creamy	4.0	2.8	5.3	1.2	2.3	0.2	1.9	1.9	2.7	5.2	3.6	7.5	4.3	6.2	***
Texture	Te Viscous	4.8	3.0	4.8	1.6	4.3	2.8	5.4	5.5	6.7	6.7	5.9	8.9	8.1	7.9	***
	Te Creamy	5.1	3.3	5.8	0.7	1.9	0.2	2.3	1.6	2.9	6.4	4.4	8.7	4.6	5.3	***
	Astringent	3.5	3.2	3.0	2.1	1.5	1.2	1.8	1.2	1.5	3.1	2.6	1.7	1.9	2.0	***
	Fatty mouth feel	5.4	3.7	5.5	2.1	4.3	2.4	6.0	7.1	7.2	7.3	5.8	8.2	7.1	7.2	***
	Te Grainy	0.3	2.0	1.3	7.0	8.4	9.6	8.3	9.6	8.1	3.7	6.1	0.8	8.4	5.9	***
	Furred tongue	4.1	4.2	3.8	2.4	3.6	0.8	5.2	6.8	7.7	5.1	4.6	5.2	5.6	4.6	***
	Slimy	3.8	3.3	5.4	2.3	3.0	2.9	3.7	3.1	3.0	6.1	3.5	5.9	3.5	4.8	***

Intensities were scored on an eleven-point categorical scale. Identification of samples can be seen in Table 2.1. A, appearance; Ta, taste; Te, texture; Sign., significance; ***, $P < 0.001$.

2.3.1 Characterization of and similarities between samples

The 14 samples were clustered in four groups, each showing similarities in sensory properties. Cluster 1 (samples A, C and D) consisted of yoghurts with high *c/w* (80/20). Cluster 2 (samples E, G and K) and cluster 3 (samples F, H and N) grouped yoghurts with lower *c/w* (60/40 and 40/60), whereas samples of cluster 3 also had protein contents of 6.0%. In contrast, samples of cluster 4 (samples B, I, J, L and M) were characterized by high C_F (6.0% and 12.0%).

Figure 2.1 displays the PCA biplot with the first two principal components explaining 74.1% of the variance (principal component 1 (PC1) = 38.2%, principal component 2 (PC2) = 35.9%). Attributes correlating negatively with PC1 were grainy (appearance and texture) and color. Those correlating positively with PC1 were ‘typical yoghurt attributes’ (astringent, sour and aromatic). PC2 was characterized by ‘fat-related attributes’ (creamy (taste and texture), viscous (appearance and texture) and fatty mouth feel), which correlated positively with PC2.

Regarding **Figure 2.1** and **Table 2.3**, samples of cluster 1 (high *c/w*) showed the highest intensities in ‘typical yoghurt attributes’, the lowest scores in graininess and color and medium values in 'fat-related attributes'. In contrast, cluster 2 samples (lower *c/w*) and cluster 3 samples (lower *c/w*, high C_P) were characterized by an intensive graininess as well as strong yellow color and thus by a low 'typical yoghurt character'. However, here, cluster 3 samples showed higher intensities in 'fat-related attributes' than cluster 2 samples. Samples of cluster 4 (high C_F) were very high in 'fat-related attributes' and showed low to medium intensities in 'typical yoghurt attributes', graininess and color.

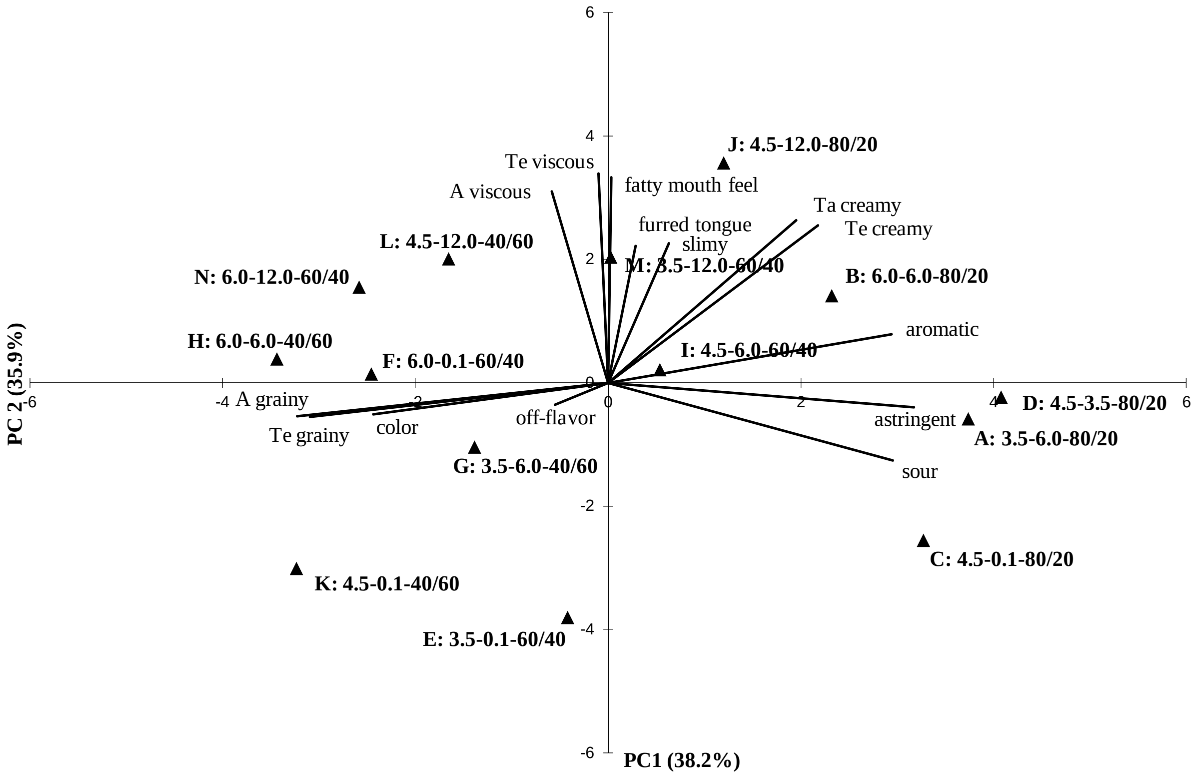

Figure 2.1: Principal component biplot with the first two principal components (PCs). showing the relation between the yoghurt samples and the accordant sensory attributes. Samples are presented in order of sample letter, protein content, fat content and casein-to-whey protein ratio. A, appearance; Ta, taste; Te, texture.

2.3.2 Effects of and interactions between C_F, C_P and c/w

Using C_F, C_P and *c/w* as independent variables, different ANOVA models were applied and compared, with factor scores PC1 and PC2 as dependent variables. **Table 2.4** is a summary of corresponding F-values, significances and coefficients of the regression equations (CRE) explaining extent and direction of influence.

Results indicated significant main effects of *c/w* and C_P, a quadratic relation of C_F (C_F^2) and an interaction between C_F and *c/w* concerning PC1 attributes. The influence of *c/w* was about twice as large as the effect of C_P, C_F^2 and the interaction between C_F and *c/w* (**Table 2.4**). An increase in protein and whey protein content generally increased graininess and color, and decreased 'typical yoghurt attributes'. Results concerning C_P can be compared to previous studies where increased graininess and/or flat flavor in yoghurt were found due to higher protein contents (Johansen, Laugesen, Janhoj, Ipsen, & Frost, 2008; Mistry & Hassan, 1992).

Table 2.4: Significance of the effects of protein (C_P), fat (C_F) and casein-to-whey protein ratio (*c/w*) on PC1 and PC2 attributes.[a]

Source	PC1 attributes [b]			PC2 attributes [c]		
	F-value	Significance [d]	CRE[e]	F-value	Significance [d]	CRE [e]
C_P	56.65	**	-0.40	25.65	**	0.42
C_F	0.03	n.s.	-0.01	164.38	***	1.08
c/w	398.98	***	1.03	9.70	*	0.25
$C_P \cdot C_F$	0.40	n.s.	-0.05	25.05	**	-0.59
$C_F \cdot c/w$	24.96	**	-0.38	0.96	n.s.	0.11
$C_P \cdot c/w$	0.98	n.s.	0.07	0.24	n.s.	0.06
C_P^2	6.31	n.s.	-0.25			
C_F^2	24.86	**	-0.49			
c/w^2	4.04	n.s.	0.20			

[a] ANOVA for PC1 was calculated by a quadratic model, whereas the one for PC2 was assessed by a linear model with interaction; [b] PC1 attributes: grainy (appearance and texture), color, 'typical yoghurt attributes' aromatic, sour, astringent; [c] PC2 attributes: 'fat-related attributes' viscous (appearance and texture), creamy (taste and texture), fatty mouth feel; [d] Significance: n.s., not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; [e] CRE, coefficient of the regression equation.

Due to a strong relation between larger particle size and sensory graininess (Cayot, Schenker, Houzé, Sulmont-Rossé, & Colas, 2008) our results concerning the effect of *c/w* on graininess are comparable to earlier studies, where increased particle sizes or graininess were found with increasing whey protein content (Beaulieu, Pouliot, & Pouliot, 1999; Kücükcetin, 2008; Lucey & Singh, 1997; Lucey, 2004; Puvanenthiran, Williams, & Augustin, 2002). Krzeminski et al. (2011) found larger particle diameters within the same samples with increasing whey protein and protein content, which complies with our findings.

It is a well known fact that flavor and texture interact with each other. As the attributes sour and aromatic decreased and graininess increased with increasing whey protein content, we assume a decrease in flavor attributes due to increasing particle amounts and sizes and an accordant change in flavor release and retention. Isleten and Karagul-Yuceer (2006) suggested flavor-binding properties of whey proteins as a reason for lower fermented flavor in yoghurts fortified with whey protein isolate.

Changes in color could be explained by different concentrations of skim milk powder and sweet whey ultra-filtration permeate when protein content was varied, as yellow color increased with increasing C_P and both were inherently yellowish. González-Martinez et al. (2002) determined higher scores in yellow color in yoghurt samples containing whey powder.

C_F exerted influence by means of the quadratic term and the interaction with *c/w*. The interaction implied a reduced effect of whey protein concerning PC1 attributes at simultaneous high C_F. Consequently, lowest graininess and yellow colour and highest scores in 'typical yoghurt attributes' could be found in yoghurts with high *c/w* and high C_F. The opposite effect could be seen for yoghurts with low *c/w* and low C_F. With reference to graininess, the findings agree with the results of Krzeminski et al. (2011), who ascertained the smallest particles in yoghurt based on high C_F and high *c/w* and the largest particles at low C_F and low *c/w*. In addition, Brauss, Linforth, Cayeux, Harvey, and Taylor (1999) determined decreasing particle sizes in yoghurt when fat content increased.

With respect to PC2 attributes results demonstrated significant main effects of C_F, C_P and *c/w*, in descending order of influence, as well as a significant interaction between C_P and C_F (**Table 2.4**). An increase of each factor led to increasing intensities in 'fat-related properties'. Consequently, samples with high C_F, C_P and *c/w* showed the highest intensities in creamy (taste and texture), viscous (appearance and texture) and fatty mouth feel.

Milk fat plays an important role concerning flavor and texture of dairy products (Kaminarides et al., 2007). Our results are consistent with the findings of other studies who found increasing viscosity, firmness, creamy flavor and mouth feel with increasing fat content (Brauss et al., 1999; Folkenberg & Martens, 2003b), low creaminess in low-fat samples as well as a correlation between creaminess, creamy flavor and fatty after mouth feel (Janhoj et al., 2006).

With regard to the effect of C_P, results are comparable to several studies where increased sensory firmness or viscosity of yoghurt was found due to increased protein contents (Janhoj et al. 2006; Johansen et al., 2008; Mistry & Hassan, 1992; Modler et al., 1983). Torres et al. (2011) showed that texture characteristics of low-fat yoghurts were more similar to those of full-fat samples when protein contents were high.

As 'fat-related properties' decreased with decreasing *c/w* and thus with increasing whey protein content, and graininess simultaneously increased, we conclude a negative correlation between 'fat-related properties' and graininess, comparable to Cayot et al. (2008).
The interaction found between C_F and C_P, led to the conclusion that the effect of C_P decreased with increasing C_F. Intensities in creamy taste and texture, visual and textural viscosity and fatty mouth feel at low to medium C_F could be increased by high C_P. However, really high intensities can only be achieved with high C_F.

2.4 Conclusions

Results showed, that 'typical yoghurt attributes' (aromatic, sour and astringent) decreased with decreasing *c/w* and increasing protein content, whereas graininess and yellow color were increased. However, high fat content reduced the effect of *c/w*. The effect of *c/w* was nearly twice as large as the effect of protein and its interaction with fat.
'Fat-related attributes' (creamy taste and texture, visual and textural viscosity as well as fatty mouth feel) increased with increasing fat content, protein content and *c/w*. However, the effect of protein decreased with increasing fat content. Fat was the most influential component, followed by its interaction with protein, the effect of protein and the effect of *c/w*.
The results showed that high intensities in 'typical yoghurt attributes' and low intensities in graininess and yellow color in a non-fat yoghurt could be achieved with increased *c/w* and decreased C_P. 'Fat-related properties' could be enhanced by increasing the *c/w* and C_P. Thus, the addition of the native whey protein isolate did not enhance fat-related sensory properties. Non-fat yoghurt enhanced in fat-related properties could be obtained by means of high *c/w* and C_P. However, as graininess increased with increasing C_P, a medium C_P is recommended.

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3 Relating creamy perception of whey protein enriched yoghurt systems to instrumental data by means of multivariate data analysis

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Abstract

Yoghurts differing in fat content, protein content and casein-to-whey protein ratio were produced, and structurally as well as sensorially examined. The objective of the current research was to evaluate the predictive value of rheological and particle size measurements concerning sensory appearance and texture attributes in 13 differently composed stirred yoghurt systems, with a focus on graininess, viscosity and creaminess. Structural and sensory analyses showed large differences in texture properties between the tested yoghurt systems. Both data sets were correlated by means of multivariate statistical methods. Sensory graininess was highly correlated with particle size-related parameters, sensory viscosity was highly correlated with destructive rheological parameters and creamy perception was highly correlated with particle size-related parameters and destructive rheological parameters, but was not as well described by any oscillatory parameter. Best predictive ability ($r^2 > 0.89$) was found for creaminess combining particle-size related and destructive rheological parameters tested within this study.

Practical application

Knowing the instrumental parameters describing sensory textural attributes provides important information for having a better understanding of the underlying processes during consumers' perception. Knowledge about the sensory behavior of a product and its oral processing imparts an opportunity to fasten the product development process. By means of yoghurt systems, instrumental parameters derived from particle size analysis and rheological measurements were correlated with sensory attributes in order to determine the main factors leading to the mouth feel sensations grainy, viscous and creamy of semisolid milk products.

3.1 Introduction

The description of creaminess by studying the relationship of sensory and instrumental texture data is a highly interesting and much debated topic. Creaminess is a complex sensation and is related to multiple food properties including textural attributes (Szczesniak, 1987), smoothness and thickness (Kokini, 1987), fattiness, flavor perception, and pleasantness (Tournier, Martin, Guichard, Issanchou, & Sulmont-Rossé, 2007) and overall liking (Richardson-Harman et al., 2000).

As reported by Janhøj, Petersen, Frøst, and Ipsen (2006), a moderate predictive ability of the sensory attribute creaminess was shown for a large set of rheological data and parameters derived from Posthumus funnel measurements for plain stirred yoghurts. However, it has been demonstrated that consumers' rated perception of creaminess is not only strongly correlated to bulk rheological parameters but also to the presence of particles (Kilcast & Clegg, 2002). For example, stirred low-fat yoghurt is perceived as creamy when small gel particles and high thickness are given as presented by Cayot, Schenker, Houzé, Sulmont-Rossé, and Colas (2008). It is a well-known fact that the incorporation of whey proteins into a yoghurt matrix leads to increased values of thickness (Britten & Giroux, 1991; Krzeminski, Großhable, & Hinrichs, 2011; Lucey & Singh 1997; Torres, Janhøj, Mikkelsen, & Ipsen, 2011) and to increased particle sizes (Beaulieu, Pouliot, & Pouliot, 1999; Krzeminski et al., 2011; Küçükçetin, 2008). Recently, structural properties of a set of 13 stirred yoghurts as a function of compositional parameters (fat and protein content, casein-to-whey protein ratio) were characterized by means of rheology and particle size analysis (Krzeminski et al., 2011). The structural data revealed different thickness properties (storage modulus G' = 0.18 – 2.95 kPa) and particle size classes ($d_{3,2}$ = 12 – 125 µm) for the studied yoghurt samples. Corresponding sensory results demonstrated that "fat-related attributes" (visual and textural viscosity, fatty mouth feel and creamy texture) increased with increasing fat content, protein content and casein-to-whey protein ratio (Tomaschunas, Hinrichs, Köhn, & Busch-Stockfisch, 2012) which is consistent with other findings (Brauss, Linforth, Cayeux, Harvey, & Taylor, 1999; Folkenberg & Martens 2003).

The intention of this study was to examine the predictive value of instrumental data derived from rheology and particle size measurements, with a particular view to the concept of creaminess. Thus, a wide range of differently composed yoghurt systems have been investigated texturally to examine which instrument or rather which combination of instruments will best predict relevant sensory attributes. The primary objective of the present study was to find structural and sensory differences from full-fat control results testing if the range of studied textural parameters was wide enough for response differences. The secondary objective was to correlate both data sets by means of PCA and multiple linear regressions in order to gain knowledge about the predictive ability of generated models to sensory attributes.

3.2 Materials and methods

3.2.1 Stirred yoghurt preparation

The production of stirred yoghurt systems differing in their composition was carried out at Dairy for Research and Training of University of Hohenheim as described by Krzeminski et al. (2011). Chosen response surface design (Box-Behnken-Design) is also described in detail by Krzeminski et al. (2011). Three factors were varied in each case at three levels: protein content (C_P = 3.5, 4.5 and 6.0%, w/w), casein-to-whey protein ratio (c/w = 80/20, 60/40 and 40/60) and fat content (C_F = 0.1, 6.0 and 12.0%, w/w), giving a total of 13 differently composed samples.

Table 3.1: Protein content (*C_P*), fat content (*C_F*) and casein-to-whey protein ratio (*c/w*) of the evaluated yoghurt samples, order of experiments was fully randomized.

Sample	C_P (%, w/w)	C_F (%, w/w)	*c/w*
A	3.5	6.0	80/20
B	6.0	6.0	80/20
C	4.5	0.1	80/20
E	3.5	0.1	60/40
F	6.0	0.1	60/40
G	3.5	6.0	40/60
H	6.0	6.0	40/60
I	4.5	6.0	60/40
J	4.5	12.0	80/20
K	4.5	0.1	40/60
L	4.5	12.0	40/60
M	3.5	12.0	60/40
N	6.0	12.0	60/40
Reference D	4.5	3.5	80/20

The factors and levels were selected in order to generate a wide range of structural and sensory properties in the stirred yoghurt systems. One of the yoghurts was selected as a control formulation (central point of the experimental design) which has been produced in triplicate to test the reproducibility of the manufacturing conditions. Representing a yoghurt texture that is desired by customers, yoghurt with 3.5%, w/w, fat and 4.5%, w/w, protein with casein-to-whey protein ratio of 80/20 was produced additionally and regarded as reference yoghurt sample. **Table 3.1** outlines the composition of the yoghurt samples which were used within the present study.

3.2.2 Structural analysis

Particle size distribution of microgel particles in stirred yoghurts was determined by laser light scattering using a Beckman Coulter LS230 (Beckmann Coulter, Small Volume Mode, Fullerton, USA), modified according to Ciron, Gee, Kelly, and Auty (2010). Rheological measurements (small and large deformation testing) of stirred yoghurt systems were carried out using a stress-controlled AR2000 rheometer (TA instruments, Eschborn, Germany) with a searle-type coaxial cylinder measuring system. Full description of applied analysis methods and structural data of the evaluated yoghurt samples can be found in Krzeminski et al. (2011). Prior to structural analysis, yoghurt systems were maintained at 10 °C for 24 h. All measurements were performed at 10 °C. Particle size analysis has been replicated three times, rheological assessment twice.

Representative parameters from instrumental data were identified for further analysis and correlations with sensory attributes. Sauter mean diameter (d3,2) corresponding to fine microgel particles, particles of the 75th percentile (d75,3) and particles of the 90th percentile (d90,3) corresponding to coarse gel particles, were identified from particle size analysis. Small deformation test provided the representative parameter storage modulus at an angular frequency of 10 rad s-1 ($G'_{10\ \mathrm{rad\ s^{-1}}}$). Large deformation test revealed the representative parameters shear stress at a shear rate of 50 s-1 ($\tau_{50\ \mathrm{s^{-1}}}$) or rather at 100 s-1 ($\tau_{100\ \mathrm{s^{-1}}}$). According to Skriver, Holstborg, and Qvist (1999) and Shama and Sherman (1973) this shear rate regime reflects the best correlation to describe oral perception during the consumption of semisolid milk products, e.g. yoghurt. In addition, the apparent viscosity (η_{app}) and the area of hysteresis loop (Loop Area) between the upwards and downwards flow curve (0 to 500 s^{-1}, peak hold step at 500 s^{-1}, 500 to 0 s^{-1}, 3 min per step) were evaluated.

3.2.3 Sensory evaluation

Sensory descriptive analysis was performed by a group of 22 trained panelists (4 males and 18 females, mean age: 23 yrs) to evaluate sensory characteristics of differently composed stirred yoghurt samples. Panelists were selected based on availability, previous basic training according to DIN 10961 (German Institute for Standardization, 1996) as well as liking of plain yoghurt.

Descriptive analysis was carried out comparatively as defined in ISO 13299 (ISO, 2003) using an 11-point categorical scale. To prevent an influence of the impression of the first sample, a warm-up sample was tasted first. Sensory assessments were carried out at the Sensory Laboratory at University of Applied Sciences, Hamburg, Germany, in separate booths in accordance with ISO 8589 (ISO, 2007). An amount of 60 g of each yoghurt sample was served in 100 mL odorless and transparent plastic cups (Bunzl Verpackungen GmbH, Gelsenkirchen, Germany) at 10 °C, coded with 3-digit random numbers. Samples were presented in randomized order according to Williams Latin Square (MacFie, Bratchell, Greenhoff, & Vallis, 1989). In total, 14 sensory descriptors concerning appearance, taste and texture were determined by the sensory panel to characterize stirred plain yoghurt.

The focus of this work is on sensory attributes in respect to appearance and texture. **Table 3.2** outlines the sensory data set with the corresponding definitions and abbreviations used in tests and graphs.

Sensory evaluation was carried out comparatively in triplicate for each sample, with three to five yoghurts being served per session, whereas the length of one session was at most one hour. During each sensory evaluation session, attribute definition sheets, filtered matzo and tap water for neutralization were provided. The inter-stimulus interval was defined by each panelist. Repeated measures were performed on different days. Reproducibility was tested with ANOVA (not shown). The panel quality was controlled using a commercial full-fat sample that was analyzed in each session. Sensory data collection was carried out using FIZZ Data Acquisition System (Biosystèmes, Couternon, France, vs. 2.31 G). As the commercial full-fat sample results analyzed by ANOVA showed a good reproducibility of the sensory data, it was excluded from further statistical analyses.

Table 3.2: Sensory descriptors and their definitions.

Property	Attribute	Definition
Appearance	A grainy	Visible amount of perceptible small particles
	A viscous	Visible flow resistance, from thin to thick
Texture	Te grainy	Amount of perceptible small particles
	Te viscous	Flow resistance in the mouth, from thin to thick
	Te fatty mouth feel	Amount of fat perceived in the mouth; fatty film that covers the mouth/throat
	Te slimy	Degree of a slimy/sticky mouth feel, associated with gruel
	Te creamy	Personal definition of creaminess in the mouth, associated with gloss, smoothness and a higher viscosity

A, Appearance; Te, Texture.

3.2.4 Data analysis

Statistical calculations were performed on raw data by means of the statistical analysis software XLSTAT (Addinsoft, Andernach, Germany, vs. 2011.2.04). Structural and sensory differences among the yoghurt systems were analyzed by Principal Component Analysis (PCA, $P < 0.05$) and displayed using a PCA biplot. The relationship between instrumental and sensory data was studied using PCA with sensory descriptors as dependent *Y*-variables and instrumental parameters as independent *X*-variables. Correlations between instrumental and sensory data were determined using Pearson's correlation coefficient ($P < 0.05$). Finally, the relation between the latent sensory variables and instrumental data was further investigated by means of backward multiple linear regression. P-values for taking a variable into the model were set to 0.05 and to 0.1 for removing it from the model. The values for the latent sensory variables were calculated as means of their respective manifest variables.

3.3 Results and Discussion

Sensory data and instrumental data derived from particle size analysis and rheological measurements were analyzed separately before being correlated among each other.

3.3.1 Structural difference from control results

Principal component analysis (PCA) was used to display the relative "locations" of the 13 different yoghurt samples in respect to the reference sample as a function of structural parameters derived from particle size analysis and rheological measurements. Two principal components were extracted that together explained 87.21% of the total variance, with the first principal component (PC1) accounting for 49.69% of the variance and the second principal component (PC2) for additional 37.52%. The corresponding biplot of the PCA is presented in **Figure 3.1**.

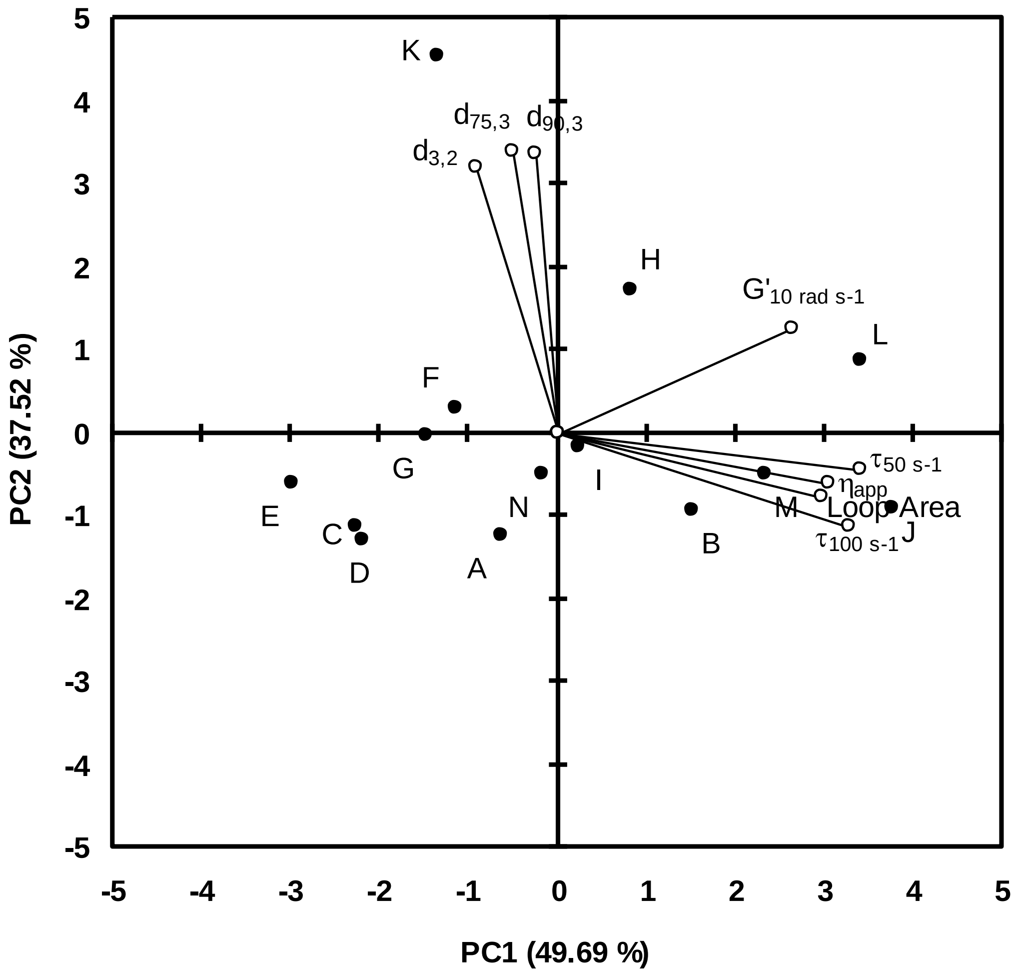

Figure 3.1: Principal component biplot (P < 0.05) after VARIMAX rotation between structural parameters (○) and yoghurt systems (●) with regard to the reference sample (D). $d_{3,2}$, sauter mean diameter; $d_{75,3}$, particles of the 75th percentile; $d_{90,3}$, particles of the 90th percentile; $G'_{10\ rad\ s^{-1}}$, storage modulus at 10 rad s^{-1}; $\tau_{50\ s^{-1}}$, shear stress at 50 s^{-1}; $\tau_{100\ s^{-1}}$, shear stress at 100 s^{-1}; η_{app}, apparent viscosity; Loop Area, area of hysteresis loop.

PC1 was characterized by rheological parameters ($\tau_{50\ s^{-1}}$, $\tau_{100\ s^{-1}}$, η_{app}, Loop Area and $G'_{10\ rad\ s^{-1}}$), correlating positively with it. In contrast, PC2 was described by particle size-related parameters ($d_{3,2}$, $d_{75,3}$ and $d_{90,3}$), correlating positively with it. PCA revealed a negative correlation between particle size-related parameters and large deformation parameters, whereas oscillatory parameters were positively correlated with the particle size.

The biplot shows that the yoghurt samples are projected in all quadrants revealing a wide spectrum of various structural properties of the investigated yoghurt systems compared to the reference sample as affected by compositional variables. All yoghurts were evaluated by a sensory panel in respect to appearance and texture.

3.3.2 Sensory differences from control results

The PCA groups the tested sensory attributes and the compositional variables for 13 different yoghurt samples with regard to the reference sample and is displayed in **Figure 3.2**. PC1 explained 50.14% of the variance and PC2 an additional 42.94% giving a total of 93.08% of the variation of the data represented in the biplot. The biplot also shows the distribution of the tested yoghurt systems.

The grouping of the sensory descriptors revealed that PC1 was defined by *viscous* attributes (*A* and *Te*) as well as with *Te fatty mouth feel*, correlating positively with it. PC2 was characterized by *grainy* attributes (*A* and *Te*) and slimy and creamy texture, correlating positively with it. The attributes *A grainy* and *Te grainy* as well as *A viscous* and *Te viscous* were, however, closely related.

Among the compositional variables, C_P and C_F were positively loaded on PC1, whereas *c/w* was negatively correlated with PC2. Further, C_F was significantly positively correlated with the *viscous* attributes (*A* and *Te*), *Te fatty mouth feel* and *Te creamy*. *Grainy* attributes (*A* and *Te*) were significantly negatively correlated with *c/w*, whereas *Te slimy* and *Te creamy* were significantly positively correlated. The compositional variable C_P revealed no significant correlation to tested sensory attributes. Detailed analyses of the sensory results as a function of compositional variables for the investigated range of yoghurt samples are presented in Tomaschunas et al. (2012).

Tested yoghurt systems showed a wide range of structural properties (**Figure 3.1**) as well as various sensations concerning appearance and texture evaluated by the sensory panel (**Figure 3.2**). Thus, all manufactured yoghurt systems were used for performing the correlation analysis by means of PCA between structural and sensory attributes.

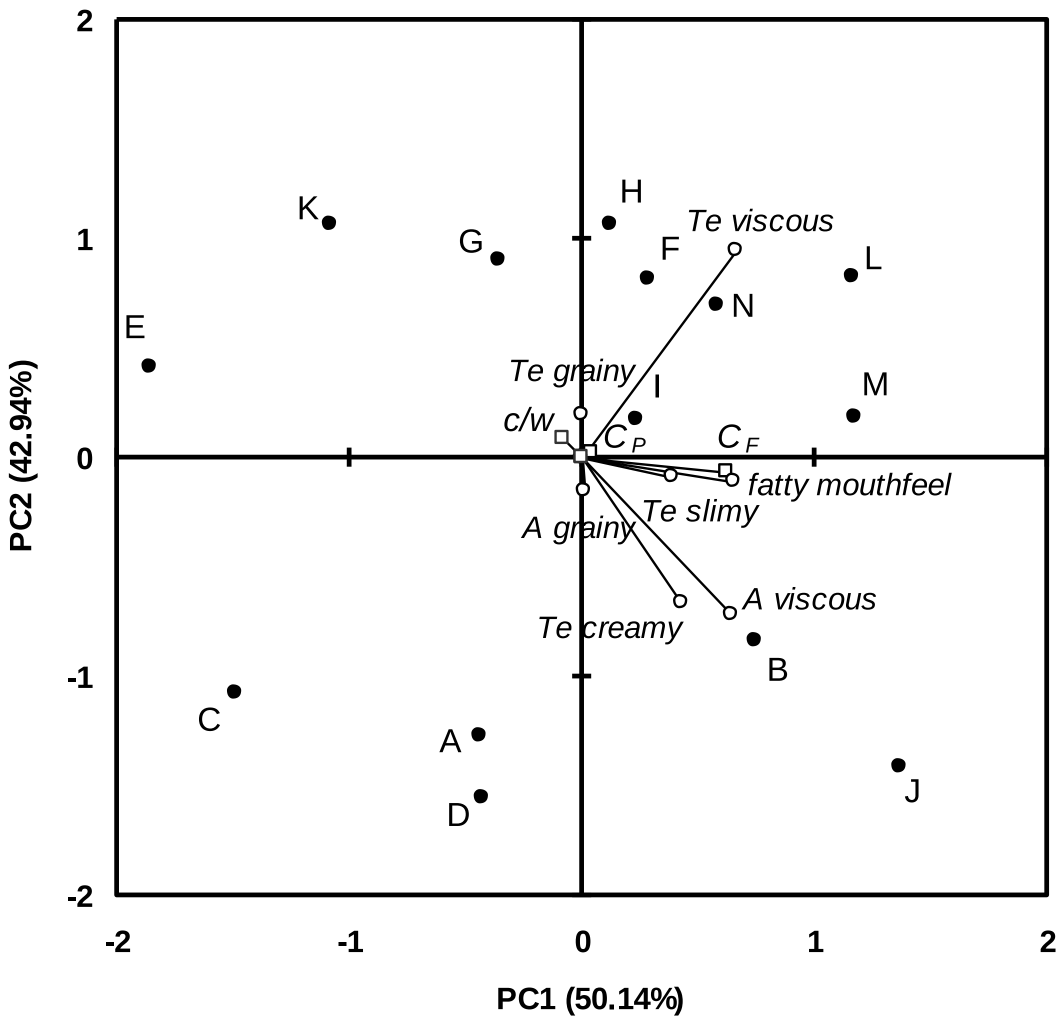

Figure 3.2: Principal component biplot ($P < 0.05$) after VARIMAX rotation between sensory attributes (○), compositional variables (□) and yoghurt systems (●) with regard to the reference sample (D). A, Appearance; Te, Texture; C_P, protein content; C_F, fat content; c/w, casein-to-whey protein ratio.

3.3.3 Correlations between instrumental and sensory data

PCA was applied to correlate instrumental parameters derived from particle size analysis and rheological assessments with sensory attributes. **Figure 3.3** shows the corresponding loading plot of the first two principal components after VARIMAX rotation. Results revealed that the first two factors with an eigenvalue higher than 1 explained 93.68 % of the total variance, with the first factor accounting for 48.24 % and the second for 45.44 %.

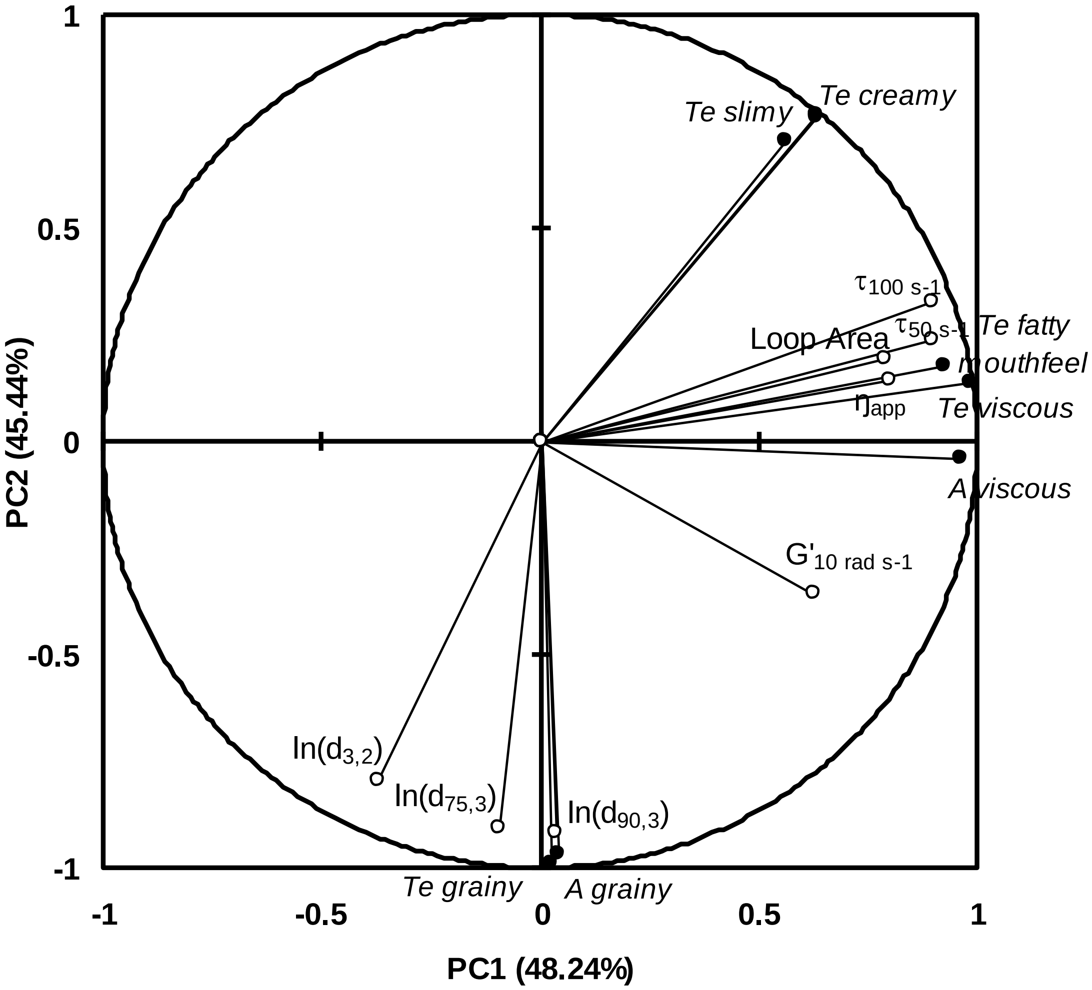

Figure 3.3: Principle component variable biplot (P < 0.05) after VARIMAX rotation with instrumental variables (○) as supplementary and sensory attributes (●) as active variables. $d_{3,2}$, sauter mean diameter; $d_{75,3}$, particles of the 75th percentile; $d_{90,3}$, particles of the 90th percentile; $G'_{10\ rad\ s^{-1}}$, storage modulus at 10 rad s^{-1}; $\tau_{50\ s^{-1}}$, shear stress at 50 s^{-1}; $\tau_{100\ s^{-1}}$, shear stress at 100 s^{-1}; η_{app}, apparent viscosity; Loop Area, area of hysteresis loop; A, Appearance; Te, Texture.

All rheological parameters ($\tau_{50\ s^{-1}}$, $\tau_{100\ s^{-1}}$, η_{app} and Loop Area, $G'_{10\ rad\ s^{-1}}$) as well as the sensory attributes *viscous* (A and Te) and *Te fatty mouth feel* were positively loaded on the first component PC1. The second factor (PC2) was negatively correlated with particle size-related parameters ($d_{3,2}$, $d_{75,3}$ and $d_{90,3}$) and *grainy* attributes (A and Te). The sensory attributes *Te slimy* and *Te creamy* were correlated positively with PC2.

As indicated by the PCA variable plot (**Figure 3.3**), three groups of latent sensory variables were detected. These latent sensory variables and their respective manifest variables are:

- Graininess: texture grainy, appearance grainy
- Viscosity: texture viscous, appearance viscous, fatty mouth feel
- Creaminess: texture creamy, appearance creamy, texture slimy

To ascertain significant relationships between the instrumental and the latent sensory variables graininess, viscosity and creaminess Pearson's correlation coefficients were used.

Table 3.3: Pearson correlation coefficients from PCA between sensory variables and instrumental parameters from particle size analysis and rheological measurements for a wide range of yoghurt systems.

	Particle size parameter			Rheological parameter				
				Large deformation test				Small deformation test
Sensory variables	$\ln(d_{3,2})$	$\ln(d_{75,3})$	$\ln(d_{90,3})$	$\tau_{50\ s^{-1}}$	$\tau_{100\ s^{-1}}$	η_{app}	Loop Area	$G'_{10\ rad\ s^{-1}}$
Graininess								
A grainy	**0.78**	**0.90**	**0.91**	-0.17	-0.26	-0.06	-0.16	0.34
Te grainy	**0.80**	**0.92**	**0.93**	-0.22	-0.31	-0.12	-0.20	0.38
Viscosity								
A viscous	-0.37	-0.04	0.10	**0.85**	**0.84**	**0.78**	**0.74**	0.52
Te viscous	-0.49	-0.23	-0.10	**0.93**	**0.95**	**0.83**	**0.82**	**0.61**
Te fatty mouth feel	-0.47	-0.31	-0.21	**0.83**	**0.86**	**0.66**	**0.79**	**0.60**
Creaminess								
Te creamy	**-0.86**	**-0.75**	**-0.66**	**0.76**	**0.84**	**0.67**	**0.65**	0.12
Te slimy	**-0.66**	**-0.62**	**-0.58**	**0.66**	**0.69**	0.51	0.53	0.04

Correlation coefficients in bold are significant at $P < 0.05$.

$d_{3,2}$, sauter mean diameter; $d_{75,3}$, particles of the 75th percentile; $d_{90,3}$, particles of the 90th percentile; $G'_{10\ rad\ s^{-1}}$, storage modulus at 10 rad s^{-1}; $\tau_{50\ s^{-1}}$, shear stress at 50 s^{-1}; $\tau_{100\ s^{-1}}$, shear stress at 100 s^{-1}; η_{app}, apparent viscosity; Loop Area, area of hysteresis loop; A, Appearance; Te, Texture.

The corresponding correlation matrix is given in **Table 3.3**. Results showed a positive significant correlation between graininess and particle size-related parameters indicated by $d_{3,2}$, $d_{75,3}$ and $d_{90,3}$. This result is in line with findings from Cayot et al. (2008) and Hahn et al. (2012) showing that the level of perceived graininess raises with increasing particle sizes. Own structural analysis of yoghurt systems (Krzeminski et al. 2011; Küçükçetin, 2008) revealed that large particle sizes were generated by increased whey protein ratio in protein content in heated milk systems, respectively. The same finding has been previously reported by Torres et al. (2011). Additionally, positive significant correlations were found between viscosity and rheological parameters. Selected shear rates showed high correlations ($r^2 > 0.7$) for oral viscosity which is consistent with results shown by Skriver et al. (1999), whereas obtained coefficients were slightly higher for $\tau_{100\ s^{-1}}$ than for $\tau_{50\ s^{-1}}$. The latent variable creaminess was negatively significantly correlated with particle size derived parameters and positively significantly with rheological parameters. However, creaminess was best correlated with $d_{3,2}$ and $\tau_{100\ s^{-1}}$. The non-destructive rheological parameter $G'_{10\ rad\ s^{-1}}$ was poorly correlated with the tested latent sensory variables. In terms of the manifest variables, *Te viscous* and *Te fatty mouth feel* revealed a positive significant correlation with $G'_{10\ rad\ s^{-1}}$.

Whereas graininess and viscosity are uncorrelated, creaminess is correlated with both viscosity and graininess. This result is in line with other findings (de Wijk, Terpstra, Janssen, & Prinz, 2006; Janssen, Terpstra, de Wijk & Prinz, 2007) and indicates that high creaminess is related with high viscosity and low graininess and *vice versa*. Regarding the instrumental measurements there is a rather high correlation between the large deformation rheological variables and viscosity as well as between the logarithms of the particle size measurements and graininess (**Table 3.3**).

3.3.4 Prediction of sensory attributes from instrumental data

The selection of the independent variables based on the following theoretical considerations of the authors:

- Graininess: different particle sizes should cause differences in the graininess perception. Since the empirical relations are not linear, the logarithm of the measurement was used.
- Viscosity: rheological properties of the yoghurt systems are expected to cause sensory perception of viscosity. Due to the empirical distribution a linear relation was chosen.
- Creaminess: since creaminess perception is influenced by both graininess and viscosity, particle size and rheological properties will determine creaminess. Alternatively, only those variables which will be selected for modeling graininess and viscosity will be used to model creaminess.

Figure 3.4 illustrates the quality of the multiple regression models for the prediction of the latent sensory variables graininess, viscosity and creaminess, plotting the measured values versus their predicted values. For graininess the chosen model contained only the $\ln(d_{90,3})$-variable as the most influencing one. A similarly simple model was chosen for the latent sensory variable viscosity, with $\tau_{100\ s^{-1}}$ as the only dependent variable.

Reasons for choosing the 2-variables model for creaminess are as follows:

- The other model does not contain any particle size variable. However, the assumption that creaminess perception depends on both perceived graininess and viscosity does require at least one predictor for graininess in the equation.
- Cook's distances are a bit more homogeneous compared to the other model.

The goodness of fit statistics for the graininess model provided good predictive values with $r^2 = 0.86$. A similar fit ($r^2 = 0.83$) was found for the latent sensory variable viscosity. The fitting of the two variables $\ln(d_{90,3})$ and $\tau_{100\ s^{-1}}$ with the creamy sensation resulted in $r^2 = 0.89$. The corresponding regression equations for the three latent sensory variables are as follows:

$$\text{Graininess} = -8.988 + 2.883 \times \ln(d_{90,3}) \qquad \text{(Eq. 1)}$$

$$\text{Viscosity} = 2.273 + 3.453\,\text{E}-02 \times \tau_{100\,\text{s}^{-1}} \qquad \text{(Eq. 2)}$$

$$\text{Creaminess} = 5.682 - 0.866 \times \ln(d_{90,3}) + 2.492\,\text{E}-02 \times \tau_{100\,\text{s}^{-1}} \qquad \text{(Eq. 3)}$$

Although, a wide range of yoghurt systems have been examined within this work, the obtained regression models cannot be extrapolated to other yoghurt textures without any limitations. Presented relationships between instrumental and sensory data suggested in this paper are only valid within the studied but wide product range (C_F = 0.1, 6.0 and 12.0%, (w/w); C_P = 3.5, 4.5 and 6.0%, (w/w), and *c/w* = 80/20, 60/40 and 40/60). However, as oral processing underlies thin-film tribological behavior, the presence of friction is known for simulating in-mouth processes (Bourne, 2002; de Wijk & Prinz 2005; Janhøj, Frøst, Prinz, & Ipsen, 2009; Lucas, Prinz, Agrawal, & Bruce, 2004).

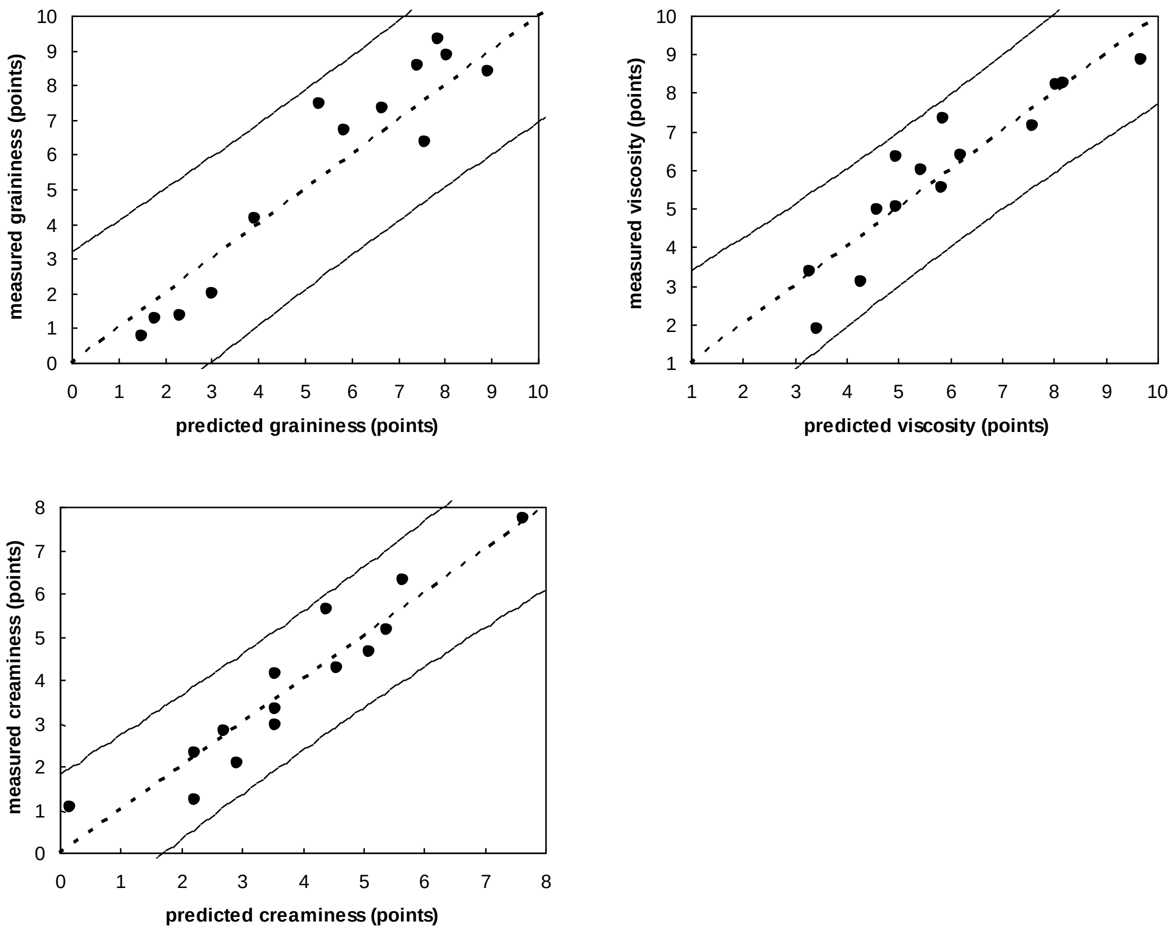

Figure 3.4: Multiple linear regression plots for the latent sensory variables graininess, viscosity and creaminess, measured versus predicted, by means of particle size and rheological derived parameters as a function of confidence interval limits (P < 0.05).

Lubrication in mouth is formed by the interaction between oral mucosa and food product as well as between tongue and palate, even in the presence of lubricants. Friction was reported by some authors to correlate with sensory attributes of food products (de Wijk & Prinz 2005; Malone, Appelqvist, & Norton, 2003). Furthermore, the work of Baier et al. (2009) showed that the perceived creaminess is more sensitive to friction data than to rheological data. For instrumental prediction of sensory attributes, we suggest the development of a method that enables to study the presence of friction occurring during oral processing. Further studies are directed to frictional measurements to this topic in order to enhance the predictive ability and therefore to improve the model for the sensory variables graininess and thus creaminess.

3.4 Conclusions

An understanding of a general aspect of sensory sensations such as viscosity, graininess and in particular creaminess by means of instrumental assessment would be beneficial and desirable for reasons of assessing textural behavior of yoghurt systems already in the phase of product development. In this context, the present study examined the relation between instrumental parameters derived from particle size analysis and rheological measurements and sensory attributes in respect to appearance and texture of whey protein enriched stirred yoghurt systems differing in fat and protein content. Particle size-related parameters were best-correlated with sensory graininess, whereas destructive rheological parameters were best-correlated with oral viscosity. Regression models for textural attributes graininess and viscosity revealed a good predictive ability. Reasons can be referred to the lack of description of tribological properties of the yoghurt systems taking place at a later stage of in-mouth processing. However, the regression model for the metadescriptor creaminess was the one that most accurately predicted the attribute ($r^2 > 0.89$) combining particle size-related parameters as well as destructive rheological parameters. To improve the model for creaminess, a further step could be taken and surface properties of the yoghurt systems could be added to the model. However, the outcomes of this study provide valuable information for the dairy industry in describing mouth feel attributes graininess, viscosity and creaminess by applying particle size analysis and rheological measurement that will enhance the yoghurt product development process.

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4 Consumer acceptance and its relationship to sensory properties of model yoghurt systems with various casein-to-whey protein ratios, fat and protein contents

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Abstract

The effects of fat (C_F), protein (C_P) and casein-to-whey protein ratio (*c/w*) on consumers' acceptability of plain stirred model yoghurts were evaluated. Using external preference mapping to relate hedonic to previously obtained descriptive data, preference driving factors were established. Additionally, it was examined whether liking of reduced fat yoghurt may be enhanced by changes in C_P and *c/w*. In order to determine effects and relations of C_F, C_P and *c/w* on liking for a wide product range (n =13), large variations in fat (C_F = 0.1, 3.5, 6.0 and 12.0%), protein (C_P = 3.5, 4.5 and 6.0%) and casein-to-whey protein ratio (*c/w* = 80/20, 60/40 and 40/60) were selected. In summary, overall liking was enhanced at medium C_F and C_P as well as high *c/w*. 'Typical yoghurt attributes' (sour, astringent and aromatic) as well as 'fat-related attributes' (creamy taste and texture, visual and textural viscosity and fatty mouth feel) were found to drive liking, whereas graininess and yellow color drove disliking. Liking of reduced fat yoghurt may be increased by high *c/w* and medium C_P.

4.1 Introduction

Consumers' interest for energy or rather fat reduced products increases. But with fat affecting appearance, flavor and texture attributes (Drewnowski, 1987), and with the importance of the sensory quality of foods on consumers' acceptability, it is crucial to substitute fat without changing the sensory quality and palatability of reduced fat food.

Yoghurt is a popular fermented dairy product which is widely consumed around the world, mainly because of its nutritional value and its sensory properties (Jaworska, Waszkiewicz-Robak, Kolanowski, & Swiderski, 2005; Saint-Eve, Juteau, Atlan, Martin, & Souchon, 2006). The acceptability of dairy products is strongly influenced by flavor, texture and also fat (Folkenberg & Martens, 2003; Frost & Janhoj, 2007; Saint-Eve et al., 2006) and fat reduced dairy products are often perceived as less palatable than the high-fat counterparts (Tuorila, Cardello, & Lesher, 1994). But which sensory attributes are responsible for bad or good liking scores? And how does fat affect liking? The examination of specific drivers of liking and disliking by means of relating descriptive data to hedonic data can give useful information. Consumers' opinions have to be incorporated already from the beginning of the development of a product (Van Kleef, Van Trijp, & Luning, 2005) and it is important to examine the degree of changes in liking due to changes in sensory properties. Relations between sensory properties and consumers' acceptability were in the past established for dairy products such as yoghurt drinks (Allgeyer, Miller, & Lee, 2010) and flavored yoghurts (Barnes, Harper, Bodyfelt, & McDaniel, 1991; Brennan, Setser, & Schmidt, 2002; Grygorczyk, Lesschaeve, Corredig, & Duizer, 2013). Commercial and model plain yoghurts ranging in fat from 0.1 to 5.3% were already examined by several researchers in terms of sensory properties, liking and relationships between both (Bayarri, Carbonell, Barrios, & Costell, 2011; Folkenberg & Martens, 2003; Harper, Barnes, Bodyfelt, & McDaniel, 1991; Jaworska et al., 2005), but larger variations in fat were not examined previously.

In order to affect textural properties of dairy products, milk ingredients such as whey proteins can be added to the formulation. Changes in the protein content also affect sensory properties of yoghurt (Janhoj, Petersen, Frost, & Ipsen, 2006; Mistry & Hassan, 1992; Tomaschunas, Hinrichs, Köhn, & Busch-Stockfisch, 2012). But how do changes in composition affect consumers' opinions? And how is it possible to reduce changes in liking caused by changes in the fat content? Isleten and Karagul-Yuceer (2006) evaluated the effect of adding whey protein isolate on liking of yoghurt and found a negative effect on sensory properties and liking. However, effects of reducing fat at simultaneous changes in protein and whey protein addition on consumers' acceptability have yet not been analyzed. The microstructural and physical properties of whey protein-enriched yoghurts with different fat and protein contents were already examined by Krzeminski, Großhable, and Hinrichs (2011), whereas the accordant sensory properties were evaluated by Tomaschunas et al. (2012). Based on these studies, the aim of the current study was to evaluate the effects of fat, protein and casein-to-whey protein ratio on consumers' acceptability of plain stirred model yoghurts (1), to establish the drivers of liking and disliking for yoghurts using a wide range of milk composition variations (2) and to examine whether liking of reduced fat yoghurt may be enhanced by varying the protein content and by adding whey protein (3).

4.2 Materials and methods

4.2.1 Samples

A total of 14 yoghurt samples with variations in fat (C_F), protein (C_P) and casein-to-whey protein ratio (*c/w*) as shown in **Table 4.1** were prepared according to Krzeminski et al. (2011).

Table 4.1: Protein content (C_P), fat content (C_F) and casein-to-whey protein ratio (*c/w*) of the evaluated yoghurt samples.

Sample	C_P (%, w/w)	C_F (%, w/w)	*c/w*
A	3.5	6.0	80/20
B	6.0	6.0	80/20
C	4.5	0.1	80/20
D	4.5	3.5	80/20
E	3.5	0.1	60/40
F	6.0	0.1	60/40
G	3.5	6.0	40/60
H	6.0	6.0	40/60
I	4.5	6.0	60/40
J	4.5	12.0	80/20
K*	4.5	0.1	40/60
L	4.5	12.0	40/60
M	3.5	12.0	60/40
N	6.0	12.0	60/40

* This sample was excluded from consumer testing.

Yoghurt samples were filled into 500 mL odorless plastic containers and were stored at 10 °C. Samples were evaluated within one week after production. Due to an undesirable grainy appearance and texture (Tomaschunas et al., 2012), sample K was excluded from consumer testing to avoid a general aversion against the yoghurt samples.

4.2.2 Consumer testing

The consumer acceptability test took place at the Sensory Laboratory of University of Applied Sciences, Hamburg, Germany, which is equipped with twelve separate booths according to international standards for test rooms (ISO, 2007). Data collection was carried out by means of FIZZ (vs. 2.31G, Biosystèmes, Couternon, France).

The 13 yoghurt samples were evaluated by a total of 74 consumers (52 females, 22 males, with a mean age of 24, range 18-61), consisting of students and employees from Hamburg University of Applied Sciences, Germany. Being inexperienced in sensory descriptive analysis but partially experienced in participating different consumer tests, consumers were selected based on liking and regular consumption of plain stirred yoghurt.

Using a completely randomized plan, each consumer participated in four sessions to evaluate all samples. Three or rather four samples were evaluated per session. A seven-point hedonic scale was used to determine color, appearance, odor, flavor, texture and overall liking, ranging from “dislike extremely” (1) to “like extremely” (7). Consumers individually chose the time interval between the different yoghurt samples. They received 30 g per sample in 100 mL odorless and transparent plastic vessels (Bunzl Verpackungen GmbH, Gelsenkirchen, Germany), with a sample temperature of 10 °C. Filtered tap water and matzo were provided as palate cleansers. Samples were coded with three-digit random numbers and were analyzed at room temperature (21 °C +/- 2 °C).

4.2.3 Statistical analysis

All statistical calculations were performed by means of XLSTAT (vs. 2011.2.04, Addinsoft, Andernach, Germany). Mean values and differences in liking were obtained by a one-factor analysis of variance (ANOVA), followed by multiple comparisons of means using Tukey’s test ($P < 0.05$). Cluster analysis was applied to overall liking data using Ward’s agglomerative hierarchical clustering with Euclidean distances, in order to group the model yoghurts in terms of liking.

In order to establish relationships between previously obtained descriptive data (Tomaschunas et al., 2012) and the hedonic data, external preference mapping was applied. It is common to cluster consumers based on their liking by means of applying a cluster analysis previous to external preference mapping and to use the obtained ratings of the obtained clusters. But as previous cluster analysis (data not shown) did not reveal significant differences in liking between the clusters, individual preferences (overall liking) of consumers were used as preference data (Y), whereas factor scores of the first two principal components from previous principal component analysis (PCA) with varimax rotation (Tomaschunas et al., 2012) were used as X configuration.

4.3 Results and discussion

4.3.1 Effects of C_F, C_P and c/w on liking

ANOVA results (**Table 4.2**) revealed significant differences between the 13 samples in all liking categories. Differences in odor liking were very small between the samples. Regarding color, appearance, flavor and texture liking, results in summary showed best liking results for samples A, B, C, D and J, whereas the remaining samples were predominantly liked less.

Table 4.2: ANOVA results showing means and significance for color, appearance, odor, flavor texture and overall liking for the 13 yoghurt samples.

Sample	A	B	C	D	E	F	G	H	I	J	L	M	N
Color liking	6.1^{f}	5.5^{def}	5.0^{cde}	5.7^{ef}	3.7^{a}	3.3^{a}	4.6^{bc}	3.6^{a}	4.7^{bc}	5.7^{ef}	3.9^{ab}	4.5^{bc}	4.7^{cd}
Appearance liking	5.7^{g}	4.9^{f}	4.6^{ef}	5.4^{fg}	2.6^{bc}	2.5^{abc}	3.2^{cd}	2.5^{bc}	3.1^{bc}	4.0^{de}	1.7^{a}	2.5^{ab}	4.1^{e}
Odor liking	5.7^{c}	5.4^{bc}	5.1^{abc}	5.5^{bc}	4.8^{ab}	4.4^{a}	5.3^{bc}	4.7^{ab}	4.9^{ab}	5.1^{abc}	5.0^{ab}	5.3^{bc}	5.3^{bc}
Flavor liking	5.0^{fg}	4.4^{de}	3.9^{cde}	5.3^{g}	3.3^{bc}	2.2^{a}	3.9^{cde}	2.0^{a}	4.1^{cde}	4.7^{efg}	3.7^{cd}	4.6^{defg}	2.5^{ab}
Texture liking	5.8^{f}	4.6^{e}	4.6^{e}	5.7^{f}	2.4^{bc}	2.2^{ab}	2.9^{cd}	1.4^{a}	3.2^{d}	4.9^{e}	2.1^{ab}	3.6^{d}	2.2^{bc}
Overall liking	5.2^{f}	4.3^{de}	3.9^{cd}	5.2^{f}	2.5^{b}	1.9^{ab}	3.3^{c}	1.5^{a}	3.5^{c}	4.7^{ef}	2.5^{b}	3.7^{cd}	2.2^{ab}

$^{a\text{-}g}$ Means followed by the same letters within a row did not differ significantly ($P < 0.05$). Intensities were scored on a seven-point hedonic scale. Identification of samples can be seen in Table 4.1.

Cluster analysis for overall liking data, which was applied to group samples with similar liking results, revealed three product clusters, with the best liked samples A, D and J, followed by yoghurts B, C, I and M. Samples E, F, G, H, L and N were liked the least. Regarding the best liked samples, it is remarkable that all the samples had a *c/w* of 80/20, whereas C_F (3.5 to 12.0%) and C_P (3.5 or 4.5%) varied between the samples. The medium liked yoghurt samples had a *c/w* of 80/20 or 60/40, fat contents of 0.1 or 6.0% and protein contents of 4.5 or 6.0%. The least liked samples had low casein-to-whey protein ratios (60/40 or 40/60), independent of the fat and protein content. Here, it is conspicuous that at a *c/w* of 60/40, either fat was low (0.1%) or protein high (6.0%). At a *c/w* of 40/60, fat varied between 6.0 and 12.0%, whereas protein contents varied between 3.5 and 6.0%.

As fat contents varied between the best-liked samples (3.5 to 12.0%), no clear effect of fat can be stated. However, non-fat yoghurts seemed to be rejected the most. Furthermore, it can be concluded that the proportion of casein-to-whey protein significantly affected liking. High whey protein concentrations decreased liking, whereas low concentrations led to an increase in liking. Furthermore, at low *c/w*, high protein content and low fat content strengthened the negative effect of whey protein on liking.

4.3.2 Relation between sensory attributes and liking

Sensory properties and the effect of C_F, C_P and *c/w* on sensory properties of the 13 or rather 14 yoghurt samples were already described in previous studies (Tomaschunas et al., 2012). The previously established data were related to the overall liking data of the current study. The results are visualized in the external preference map shown in **Figure 4.1**. It clearly illustrates the preferences of the 74 consumers and furthermore visualizes, that the preference driving factors for the consumers were mainly in the positive principal component (PC) 1 axis and also in the positive PC 2 axis. Drivers of disliking can be found in the negative PC 1 axis. Consequently, ‘typical yoghurt attributes’ (sour, astringent and aromatic) were the most relevant factors that drove liking, followed by ‘fat-related attributes’ (viscous appearance and texture, creamy taste and texture as well as fatty mouth feel). In contrast, disliking was driven by grainy appearance and texture as well as by yellow color.

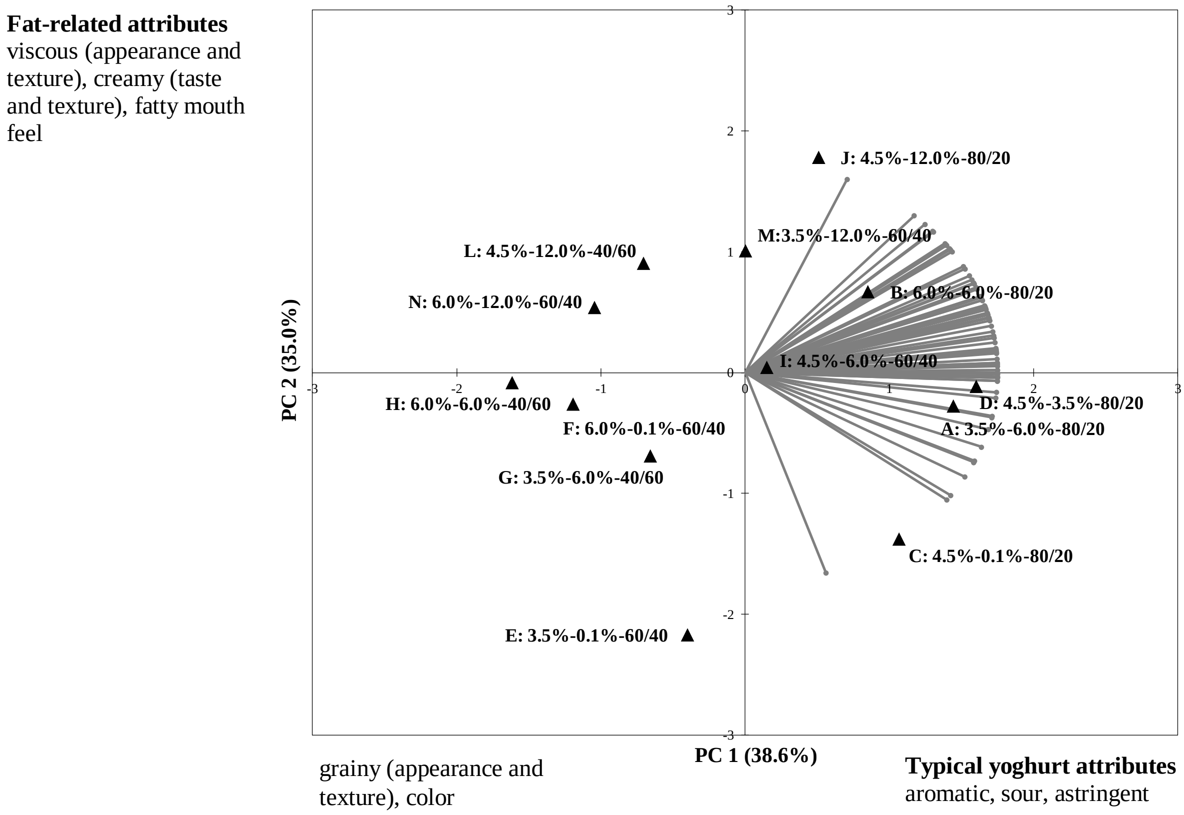

Figure 4.1: External preference map for principal component (PC) 1 and PC 2, representing the relation between sensory attributes, the 13 model yoghurts and consumers' liking. The vectors of the consumers represent their direction of liking. Samples are presented in order of sample letter, protein content, fat content and casein-to-whey protein ratio.

Drivers of liking for yoghurt were already examined by several researchers, such as sweetness, acetaldehyde flavor, milkiness and cooked milk descriptors (Bayarri et al., 2011; Folkenberg & Martens 2003; Harper et al., 1991). Contrariwise, a runny texture, graininess, chunkiness, saltiness, acidity, bitterness, astringency, fermented flavor, cooked-milk odor, off-flavor and acetaldehyde were found to drive disliking (Bayarri et al., 2011; Folkenberg & Martens 2003; Grygorczyk et al., 2013; Harper et al., 1991; Isleten & Karagul-Yuceer, 2006; Jaworska et al., 2005). Jaworska et al. (2005) furthermore did not find a significant relation between acceptability and attributes thickness and smoothness. Differences between the current study and previous studies in the determined drivers of liking and disliking presumably occurred due to variations in the tested yoghurt products as well as in the applied study designs, and consequently due to variations in the requested attributes and their intensities.

Creaminess is considered as an intrinsic sensory driver of liking (Frost & Janhoj, 2007). Folkenberg and Martens (2003) previously found creaminess as well as mouth feel and firmness to increase liking of plain yoghurts, which agrees with our findings. Folkenberg and Martens (2003) furthermore stated that liking of yoghurt increased with increasing fat content. This is only partially consistent with our findings because the fat content of the best-liked samples varied between 3.5% and 12.0% whereas the one of the least-liked samples varied between 0.1% and 12.0%. Differences between our results and the results obtained by Folkenberg and Martens (2003) are assumed to appear due to differences in the range of fat chosen as well as due to the additional variations in protein and the casein-to-whey protein ratio, which had a large effect on sensory properties (Tomaschunas et al., 2012). Differences concerning attributes acidity and astringency, which were found to drive disliking in the above mentioned studies but drove liking in the current study, presumably resulted from much higher acidity and astringency intensities regarding the yoghurt samples of those studies, because the intensities in 'typical yoghurt attributes' regarding the best-liked yoghurt samples in our study mainly varied between 3.0 and 5.4 on an eleven-point scale. Preferences for yoghurts with perceivable intensities in attributes sour, aromatic and astringent could be interpreted by consumers' expectations concerning plain yoghurt. As plain yoghurts belong to cultured dairy products (Tribby, 2009), they are presumably expected to possess perceivable intensities in 'typical yoghurt attributes' sour, aromatic and astringent, in contrast to flavored yoghurts which are probably expected to taste sweet and less sour. Same occurred to white color, which drove liking, because plain yoghurt presumably is expected to possess a pure white color. Graininess, ascertained as a driver of disliking, is known to be a common textural defect in dairy products with a negative effect on consumers' opinions (Rasmussen, Janhoj, & Ipsen, 2007; Tribby, 2009).

As 'typical yoghurt attributes' were decreased by high protein and whey protein content, whereas graininess and yellow color were increased (Tomaschunas et al., 2012), high protein and whey protein contents are supposed to drive disliking. And as the casein-to-whey protein ratio had the largest effect concerning the mentioned attributes (Tomaschunas et al., 2012), it is the whey protein content that exerted largest influence on consumer liking in terms of 'typical yoghurt attributes' in this study. Fat increased 'fat-related attributes' the most, followed by the casein-to-whey protein ratio and protein (Tomaschunas et al., 2012). The preference for yoghurts with medium to high intensities in 'fat-related attributes' shows that medium to high fat contents, casein-to-whey protein ratios and protein concentrations drove liking in terms of attributes viscous (appearance and texture), creamy (taste and texture) and fatty mouth feel.

Combining the effects of the three compositional factors on 'typical yoghurt' and 'fat-related' attributes as well as on graininess and yellow color, we conclude that samples with medium to high C_F, medium C_P and high *c/w* might be liked best. Best liking scores for non-fat (0.1%) yoghurt were achieved by high *c/w* and medium C_P.

4.4 Conclusions

Liking of plain stirred yoghurt was affected by fat, protein and casein-to-whey protein ratio. Being increased by high casein-to-whey protein ratios and low protein contents, the 'typical yoghurt attributes' (sour, aromatic and astringent) have been shown to drive liking. Medium to high intensities in 'fat related properties' (viscous appearance and texture, creamy taste and texture as well as fatty mouth feel) also drove liking and were shown to be primarily enhanced by fat but also by protein and a high casein-to-whey protein ratio. Furthermore, protein and a low casein-to-whey protein ratio increased graininess and yellow color, which were determined to drive disliking. Consequently, facing the challenge to produce acceptable reduced fat yoghurts, high casein-to-whey protein ratio and medium protein contents are needed to get accepted non-fat yoghurt. The addition of native whey protein isolate did not enhance liking of reduced fat yoghurts.

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5 Quantitative and qualitative variation of fat in model vanilla custard desserts: Effects on sensory properties and consumer acceptance

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Abstract

The effects of variation in fat content (0.1-15.8%) and type of fat, using different types of milk, dairy cream or vegetable fat cream, on sensory characteristics and consumer acceptance of starch-based vanilla model custards were studied. Descriptive analysis with trained panelists and consumer testing with untrained assessors were applied. Descriptive data were related to hedonic data using principal component analysis to determine drivers of liking and disliking. Results demonstrated an increasing effect of fat concerning visual and oral thickness, creamy flavor and fat-related texture properties, as well as a decreasing effect concerning yellow color and surface shine. A lack of fat caused moderate intensities in pudding-like flavor attributes and an intensive jelly texture. Adding a vegetable fat cream led to lower intensities in attributes yellow color, cooked flavor, thick and jelly texture, whereas intensities in vegetable fat flavor and fat-related texture properties increased. All consumers favored custards with medium fat contents, being high in pudding-like and vegetable fat flavor as well as in fat-related texture attributes. Non-fat custards were rejected due to jelly texture and moderate intensities in pudding-like flavor attributes. High-fat samples were liked by some consumers, but their high intensities in thickness, white color and creamy flavor also drove disliking for others.

Practical application

Consumers' concerns about obesity, diseases and fat in foods changes and the demand for fat reduced food increases. Therefore, the food industry is facing a challenge to produce fat reduced products with comparable characteristics to the full-fat counterparts. With the intention of reducing fat in food, it is important to evaluate its effect on sensory properties. Furthermore, it has to be examined, how fat affects consumer liking and which sensory properties are responsible for the results. Representing a semi-solid model food, the effects of fat were studied in model vanilla custard.

5.1 Introduction

Due to the increasing consumer interest for energy or rather fat reduced products, it is necessary to replace fat in food without decreasing the food quality and eating pleasure and this is one of the leading priorities of researchers in today's food industry. But fat affects appearance, flavor and texture and many desired attributes are linked to the fat content of a food product (Drewnowski, 1987). For instance, if the expected appearance of a food changes due to fat reduction such as lack of gloss or opacity, the consumer might suppose a less rich and less creamy texture (Civille, 1990). Moreover, changing the amount of fat changes the fullness of texture or the perceived creamy texture as well as the flavor strength and the duration of flavor perception (de Roos, 1997; Frost & Janhoj, 2007; Shamil, Wyeth, & Kilcast, 1991/92). However, the perception of fat is food-specific (Drewnowski, Shrager, Lipsky, Stellar, & Greenwood, 1989; Mela & Sacchetti, 1991) and therefore an illustration of the impact of fat in a certain food matrix and how it can be replaced is required.

Vanilla flavored dairy desserts are widely consumed in Europe such as "Natillas" in Spain, "Vanilla vla" in The Netherlands and "Crème dessert" in France and they are favored by the consumer due to their sensory properties but also due to their nutritional value (Tárrega & Costell, 2007). In Germany, vanilla custards are known as "Vanillepudding". Custards are useful model foods representing semi-solid dairy products due to their simple structure and the relatively small number of ingredients (milk, sucrose, thickeners, colorants and aroma).

Numerous studies have been published dealing with the sensory and/or rheological evaluation of commercially available vanilla custards (de Wijk, van Gemert, Terpstra, & Wilkinson, 2003a; de Wijk & Prinz, 2007; González-Tomás & Costell, 2006; Tárrega, Durán, & Costell, 2004; Tárrega, Durán, & Costell, 2005; Weenen, Jellema, & de Wijk, 2005) or model vanilla custard desserts (de Wijk, Rasing, & Wilkinson, 2003b; de Wijk, Prinz, & Janssen, 2006; Tárrega & Costell 2006; Vélez-Ruiz, González-Tomás, & Costell, 2005), amongst others studying the effect of fat. Elmore, Heymann, Johnson, and Hewett (1999) evaluated the sensory characteristics as well as the liking of creamy texture of vanilla puddings with varying amounts of milk fat and sodium salts, and variations in the amount and type of starch. But little or no research was conducted about the effects of variation in fat content and type of fat in model custard desserts regarding both, the sensory properties and consumer acceptance as well as relations between both data sets.

The objectives of the present study were to examine the influence of qualitative and quantitative variation in fat on sensory properties of starch-based vanilla model custard desserts (1), to evaluate associated effects on consumers' acceptability (2) as well as to determine accordant drivers of liking and disliking (3).

5.2 Materials and methods

5.2.1 Samples

Vanilla custard samples were prepared on the basis of a starch-based vanilla custard powder that requires cooking, kindly provided by Dr. August Oetker Nahrungsmittel KG, Bielefeld, Germany. The custard powder, from the same batch, consisted of starch, salt, aroma and colorant β-carotene. The prepared samples differed in fat content (0.1 to 15.8%) due to the fat content of the used milk, the addition of dairy cream or the addition of a commercially available vegetable fat cream (an alternative mix of milk, vegetable fats and stabilizers).
Table 5.1 shows the liquid phase compositions and the total fat contents of the six sample variants.

Table 5.1: Composition of the liquid phase, total fat content and sample identification of the evaluated six custard variants.

Liquid phase composition	Total fat content in %	Sample identification
100% UHT milk (0.1% fat)	0.1	0.1% (only milk)
100% UHT milk (1.5% fat)	1.5	1.5% (only milk)
75% UHT milk (1.5% fat), 25% vegetable fat cream (7.0% fat)	2.9	2.9% (with vegetable fat)
100% UHT milk (3.5% fat)	3.5	3.5% (only milk)
75% UHT milk (1.5% fat), 25% UHT dairy cream (30.0% fat)	8.6	8.6% (with dairy cream)
50% UHT milk (1.5% fat), 50% UHT dairy cream (30.0% fat)	15.8	15.8% (with dairy cream)

UHT, ultra high temperature.

Additionally, **Table 5.2** demonstrates the particular ingredients of those liquid phase components consisting of more than one ingredient.

Table 5.2: Ingredient list of the liquid phase components which consisted of more than one ingredient.

Liquid phase components	Ingredients
UHT dairy cream (30.0% fat)	Cream, carrageenan
Vegetable fat cream (7.0% fat)	Water, skim milk (20%), buttermilk (12%), vegetable fat (3.5%), vegetable oil (3.5%), modified starch, milk sugar, stabilizers (methyl cellulose, xanthan gum, carrageenan), sugar, emulsifier E 435, aroma, colorant carotene

UHT, ultra high temperature.

Each sample batch was prepared from 111 g custard powder, 120 g sucrose and 1500 g of the required liquids, resulting in 23 portions of respectively 65-75 g for the panelists or 34 portions of respectively 40-50 g for the consumers. Consequently, samples for panelists were respectively prepared from one batch, whereas samples for consumers needed the preparation of two batches. The custard powder was sifted and then mixed manually with the sugar using a whisk in a stainless steel bowl. Subsequently 150 g of the wet ingredients or rather 300 g, when containing cream or vegetable fat cream (due to a higher viscosity), were gradually added to the dry ingredients and mixed manually with a whisk, free from lumps. The remaining wet ingredients were heated in a cooking pot on a mobile ceramic glass cooktop at maximum capacity up to endpoint cooking temperature (98 °C). Frequent manual stirring with a whisk during heating was necessary to avoid scorching. After turning the cooktop off, the cooking pot was first removed, then the dry solid-liquid phase mix was stirred to the heated liquid phase with a whisk. Afterwards, it was heated on the cooktop for 60 s using the residual heat. Custards were filled in 100 mL transparent plastic cups, coded with three-digit random numbers. Samples cooled down at room temperature for 1 h, were capped, and refrigerated at 8 °C for approximately 24 h up to 90 min prior to the evaluation.

5.2.2 Sensory analysis

Sensory descriptive analysis adapted from quantitative descriptive analysis (QDA®) procedure (Stone & Sidel, 1985) was applied to evaluate sensory properties and to identify differences and similarities between the custard samples. Descriptive analysis was carried out at the Sensory Laboratory at Hamburg University of Applied Sciences, Hamburg, Germany. Consumer acceptability testing was conducted at the Sensory Laboratory of Dr. August

Oetker Nahrungsmittel KG, Bielefeld, Germany. Both, descriptive analysis and consumer testing were carried out in June 2010, in a standard room equipped with twelve separate booths according to international standards for test rooms (ISO, 2007) at room temperature (21 °C ± 2 °C). Panelists and consumers evaluated the six samples, being served with filtered tap water, cucumber pieces and matzo for neutralization between attributes and samples. Custards were positioned in randomized order among panelists and consumers corresponding to Williams Latin Square (MacFie, Bratchell, Greenhoff, & Vallis, 1989) and were evaluated semi-monadically. Data collection was carried out using FIZZ software (Biosystèmes, Couternon, France, vs. 2.31 G), at which each attribute appeared on a monitor. Using a mouse, panelists and consumers rated the different properties on the accordant scale.

5.2.2.1 Sensory descriptive analysis

A group of 22 panelists (4 males and 18 females, aged between 18 and 24), which were students from Hamburg University of Applied Sciences, was selected based on motivation, availability, ability to discriminate between samples and liking of vanilla custard. They were previously trained according to ISO guidelines (ISO, 1993) and were experienced (1 year) in sensory evaluation of dairy products and various food systems varying in fat content.

Term generation was carried out using commercial and differently prepared model custards representing a large product space. After three 1-h training sessions, including generation, discussion and reduction of sensory attributes, 16 descriptors concerning appearance (4), odor (1), flavor/taste (6) and texture/mouth feel (5) were found to describe the sensory properties and to discriminate among starch-based vanilla custards. Attributes in order of perception and their descriptions, which were verbally defined by the panel, are given in **Table 5.3**.

Providing various commercial and model custards as well as further suitable food samples as references for the selected descriptors, panelists were trained during four additional 1-h sessions to share a similar understanding of the properties. Assessors who showed different rating tendency were given additional training. Being familiar with the attributes' definitions, pilot tests were carried out over two sessions in order to familiarize the assessors with the scaling procedure as well as to test the panel consonance (training was continued until results showed good reproducibility, data not shown). Results and difficulties were discussed after each training session in consensus.

The six custard samples were evaluated in duplicate over two sessions using an eleven-point categorical scale, ranging from "very little" (0) to "very much" (10). Attribute definition sheets were provided in order to avoid uncertainty. The order of attributes among panelists and sessions was the same, starting with odor and continuing with appearance, flavor/taste and texture/mouth feel attributes. Time intervals between attributes and samples were chosen individually.

Table 5.3: Sensory attributes with definitions describing model vanilla custards.

Property	Attribute	Definition
Odor	Vanilla	Intensity of vanilla aroma
Appearance	Color	Color intensity, from pale/white to yellow
	Skin formation	Thickness of skin at the surface
	Surface shine	Degree of shine on the surface/reflected light from the surface
	Thick	Visual thickness
Flavor/ taste	Sweet	Intensity of sweetness
	Vanilla	Intensity of vanilla flavor
	Cooked	Intensity of cooked milk flavor
	Vegetable fat	Intensity of vegetable oil/fat flavor
	Creamy	Intensity of perceived flavor associated with fresh dairy cream
	Harmonious	Intensity of a harmonious taste sensation, absence of any off-flavors and too intensive flavors
Texture/ mouth feel	Thick	Perceived thickness in the mouth
	Jelly	Intensity of jelly texture, reminding of gelatin
	Sticky	Sticky/adhesive feeling in the mouth/difficult to swallow and to remove
	Creamy	Personal definition of creaminess in the mouth, associated with a velvety and smooth mouth feel
	Fatty	Fatty/oily consistency and layer, reminding of mayonnaise

Anchors: very little - very much.

5.2.2.2 Consumer acceptability test

The consumer panel included 66 consumers (50 females and 16 males, aged between 18 and 71) without previous experience in sensory descriptive analysis but partially with experience in different consumer tests. They were selected at random from an in-house Database of Dr. August Oetker Nahrungsmittel KG, Bielefeld, Germany, consisting of private person. However, selection was based on liking as well as on regular usage of vanilla custards.

Consumers were first instructed on the evaluation procedure. The hedonic test started with questions about demographics (age, gender) and product usage information (frequency of usage, data not shown). Afterwards, consumers evaluated the samples for appearance, flavor, texture and overall liking using a nine-point hedonic scale that was ranged from ”dislike extremely" (1) to "like extremely" (9). The six custard samples were evaluated over 1 session. Consumers individually chose the time interval between the different custards.

5.2.3 Statistical analysis

All statistical calculations were performed using the statistical analysis software XLSTAT (Addinsoft, Andernach, Germany, vs. 2012.1.01).
In order to identify sensory attributes that discriminated between the custard samples, a one-factor analysis of variance (ANOVA) was performed on each sensory descriptor. Tukey's test ($P < 0.05$) was exerted to determine significant differences between the custards. Furthermore, principal component analysis (PCA) was applied on the mean attribute scores of attributes that discriminated significantly between the custards to reduce the sensory dimensions and to visualize relations between samples and attributes. For sake of clarity, PCA was applied separately for properties appearance, flavor/taste and texture/mouth feel. Trained panel data of the first and second repetition were compared by means of ANOVA to control the panel performance and showed a reliable reproducibility of the data (data not shown).
Hedonic judgments concerning appearance, flavor, texture and overall liking were also analyzed by means of a one-factor ANOVA and Tukey's test ($P < 0.05$) to identify the best and least liked samples. Additionally, using Ward's agglomerative hierarchical clustering with Euclidean distances, cluster analysis was performed on the overall liking data, followed by a one-factor ANOVA and Tukey's test on the liking scores of the obtained clusters.
PCA was also applied to relate overall liking data to sensory descriptive data and to identify the drivers of liking and disliking. For this purpose, the product overall liking means of the obtained clusters were used as supplementary variables.

5.3 Results and discussion

5.3.1 Sensory descriptive analysis

Mean values of descriptive analysis, averaged across subjects and replicates, are given in **Table 5.4**. ANOVA results revealed significant differences among the samples in each attribute with the exception of odor attribute vanilla and flavor attribute sweet. Therefore, these attributes were excluded from further analysis. Relations between custard samples and sensory attributes are displayed in the PCA biplots shown in **Figure 5.1**, **Figure 5.2** and

Figure 5.3, separated into properties appearance, flavor/taste and texture/mouth feel. The accordant factor loadings of the attributes are given in **Table 5.5**.

Table 5.4: Mean values of sensory attributes with Tukey's significant differences for the six custard samples.

	Attributes	0.1% (only milk)	1.5% (only milk)	2.9% (with vegetable fat)	3.5% (only milk)	8.6% (with dairy cream)	15.8% (with dairy cream)
Odor	Vanilla	4.3^{a}	5.2^{a}	5.3^{a}	5.0^{a}	4.8^{a}	4.6^{a}
Appearance	Color	6.6^{d}	4.1^{c}	3.1^{b}	2.9^{b}	1.8^{a}	2.0^{ab}
	Skin formation	4.3^{ab}	4.5^{ab}	3.8^{ab}	5.3^{b}	5.3^{b}	3.3^{a}
	Surface shine	5.1^{bc}	5.4^{bc}	6.0^{c}	4.5^{b}	2.4^{a}	1.1^{a}
	Thick	6.9^{bc}	6.2^{b}	4.1^{a}	6.6^{b}	7.7^{cd}	8.6^{d}
Flavor/ taste	Sweet	5.7^{a}	6.5^{a}	6.8^{a}	6.1^{a}	5.7^{a}	6.2^{a}
	Vanilla	3.6^{a}	5.9^{b}	5.6^{b}	5.5^{b}	5.2^{b}	4.8^{ab}
	Cooked	2.4^{a}	4.7^{cd}	2.4^{ab}	5.2^{d}	4.6^{bcd}	3.1^{abc}
	Vegetable fat	0.6^{a}	1.1^{ab}	6.2^{c}	1.2^{ab}	1.9^{ab}	2.5^{b}
	Creamy	0.7^{a}	2.0^{ab}	1.7^{ab}	3.3^{bc}	5.0^{cd}	6.3^{d}
	Harmonious	2.8^{a}	6.1^{c}	5.1^{bc}	5.1^{bc}	5.1^{bc}	4.6^{b}
Texture/ mouth feel	Thick	4.4^{b}	4.7^{b}	2.5^{a}	4.7^{b}	6.5^{c}	7.2^{c}
	Jelly	5.6^{c}	4.1^{b}	1.2^{a}	3.7^{b}	3.8^{b}	3.4^{b}
	Sticky	3.3^{a}	4.0^{ab}	5.5^{bc}	4.0^{abc}	5.1^{bc}	5.5^{c}
	Creamy	2.0^{a}	4.6^{b}	7.3^{c}	5.4^{bc}	5.3^{bc}	5.1^{b}
	Fatty	2.7^{a}	4.3^{b}	7.1^{d}	5.1^{bc}	5.7^{cd}	7.0^{d}

$^{a\text{-}d}$ Means followed by the same letters within a row did not differ significantly ($P < 0.05$). Intensities were scored on an eleven-point categorical scale. Identification of samples can be seen in Table 5.1.

The reduction or elimination of fat in dairy products leads to changes in color, flavor and particularly in texture properties due to changes in composition, structure as well as interactions among components (González-Tomás, Bayarri, Taylor, & Costell, 2007; Guinard et al., 1997). Comparing the UHT samples as well as the samples containing dairy cream, conclusions concerning the effect of fat can be drawn. In general, the comparison of the UHT custard samples showed that differences between fat contents 1.5% and 3.5% were marginal, whereas the sample with 0.1% fat differed largely from samples with 1.5% and 3.5% fat. This is comparable with the findings of Frost, Dijksterhuis, and Martens (2001), who observed that the influence of fat on sensory properties of milk was not linear. Larger sensory differences were detected between milk with 0.1% and 1.3% fat than between milk with 1.3% and 3.5% fat.

Table 5.5: Factor loadings for the first three principal components of the separate PCAs for appearance, flavor/taste and texture/mouth feel for the sensory attributes, which differed significantly between the samples.

Property	Attributes	PC 1	PC 2	PC 3
Appearance	Color	0.715	-0.156	0.681
	Skin formation	0.076	0.993	0.094
	Surface shine	0.991	0.071	-0.066
	Thick	-0.865	0.046	0.495
Flavor/ taste	Vanilla	0.939	0.302	-0.160
	Cooked	0.781	-0.573	-0.166
	Vegetable fat	0.102	0.968	0.185
	Creamy	0.393	-0.237	0.888
	Harmonious	0.972	0.163	-0.091
Texture/ mouth feel	Thick	-0.103	0.989	0.102
	Jelly	-0.956	0.290	0.029
	Sticky	0.920	0.332	-0.194
	Creamy	0.954	-0.164	0.247
	Fatty	0.966	0.237	-0.020

Abbreviations are: PC, principal component.

5.3.1.1 Effect of fat on appearance

Regarding the PCA on appearance, results indicated that the first two components explained 80.4% of the variance (**Figure 5.1**). Principal component (PC) 1 (55.0% of the variance) ran from thick, correlating negatively with it, to color/surface shine, correlating positively with it. Consequently, thicker samples were more matt and less yellow, whereas visually softer samples were more yellow with a shiny surface. PC2 (25.4% of the variance) described the presence or absence of a skin. Being associated with the color/surface shine end and therefore being lower in thickness, samples with 0.1% and 1.5% fat were relatively similar, with the non-fat sample being more yellow and shiny. Additionally, these samples showed medium to moderate intensities in skin formation. The sample with 3.5% fat was associated with the skin formation end and showed medium intensities in PC1 attributes. Both cream samples were related to the thickness end and were whiter as well as less shiny than the other custards, but the custard with 8.6% fat had a thicker skin.

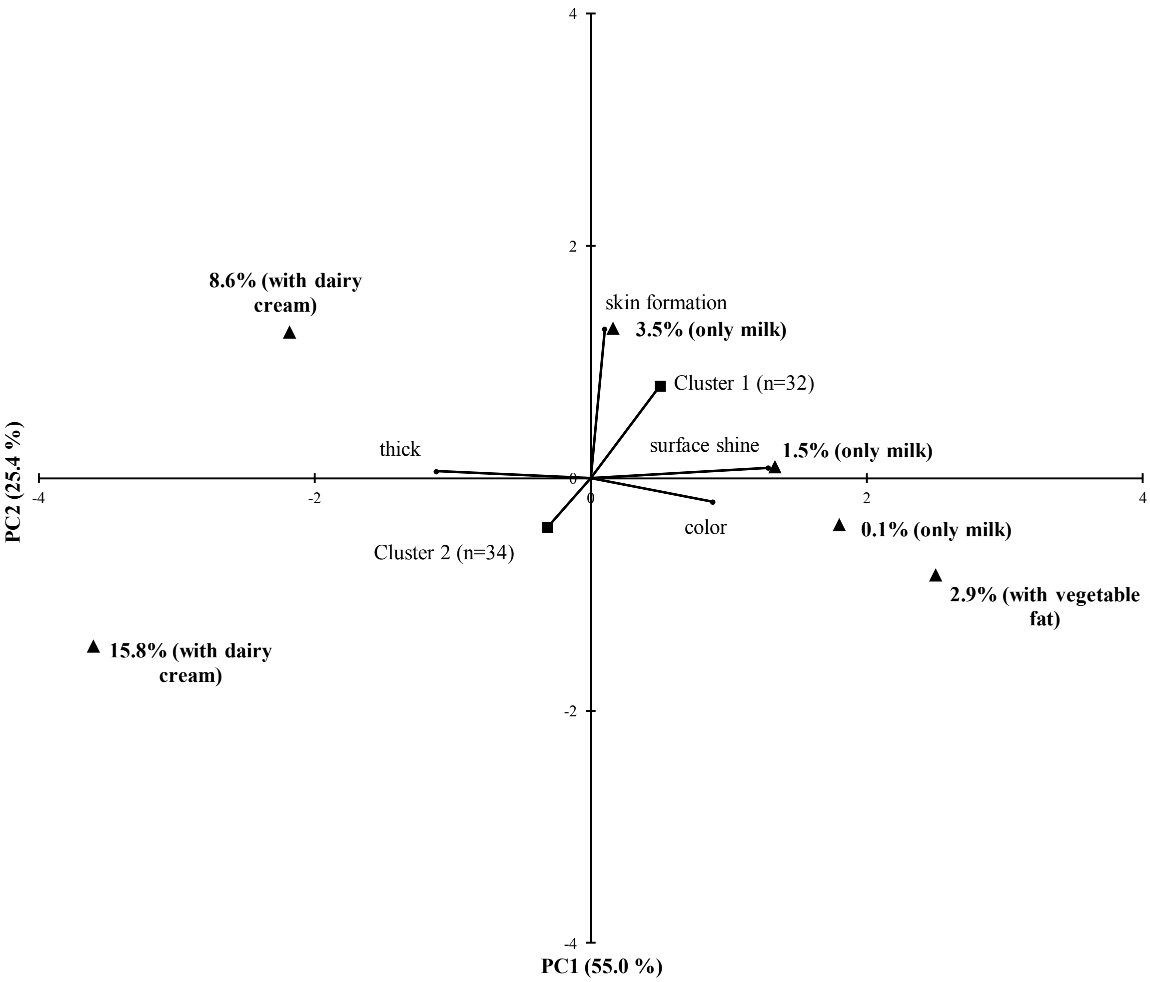

Figure 5.1: Parameter loadings and factor scores for principal component 1 (PC1) and principal component 2 (PC2), representing the relation between appearance attributes, the six custard samples and consumer clusters obtained from cluster analysis. The vectors of the clusters represent their direction of liking. Identification of samples can be seen in Table 5.1. Identification of clusters can be seen in Table 5.7.

Regarding ANOVA (**Table 5.4**) and PCA results (**Figure 5.1**), decreased yellowness and therefore increased whiteness are assumed with increasing fat content, but without a significant difference between the cream samples. Similar results were found by Elmore et al. (1999) who found fat to be responsible for a less yellow color. The increasing yellowness of the custards with decreasing fat content and the associated decreasing whiteness could be explained by color changes of milk with varying fat content. Phillips, McGiff, Barbano, and Lawless (1995) found out that milk samples became whiter with increasing fat content. Furthermore, fat posseses a whitening property, especially when products are homogenized (Dunkley, 1982).

The reduced whiteness or rather lightness with fat reduction could also be explained by reduced light scattering due to the light scattering properties of fat droplets (Chung, Degner, & McClements, 2013). Fat also affected the surface shine and visual thickness but differences were merely significant when comparing the UHT samples to the cream samples. Samples became matter and thicker when fat increased but this effect only related to larger differences in fat content or rather when dairy cream was added to the formulation. Differences in skin formation were merely significant between the high-fat (15.8%) sample and custards with 3.5% and 8.6% fat, with the high-fat sample having a thicker skin. Hence, no clear effect of fat on the skin formation could be detected.

5.3.1.2 Effect of fat on flavor/taste

PCA on flavor/taste revealed three meaningful dimensions. The PCA biplot (**Figure 5.2**) indicated that the first two components explained 80.8% of the total variance. PC1, describing 52.0% of the variance, was characterized by pudding-like flavor attributes (cooked flavor, vanilla flavor and harmonious), which correlated positively with it. Whereas PC2 (28.8% of the variance) showed, whether a vegetable fat flavor occurred or not. PC3 accounted for further 17.7% of the variance and loaded heavily with creamy flavor. The non-fat sample (0.1%) was separated from the other samples and showed moderate intensities in all flavor attributes. Samples with 1.5%, 3.5% and 8.6% fat were similar and high in pudding-like flavor attributes, but 8.6% fat caused a higher creamy flavor. The sample with 15.8% fat showed medium intensities in pudding-like flavor attributes and the most intensive creamy flavor.

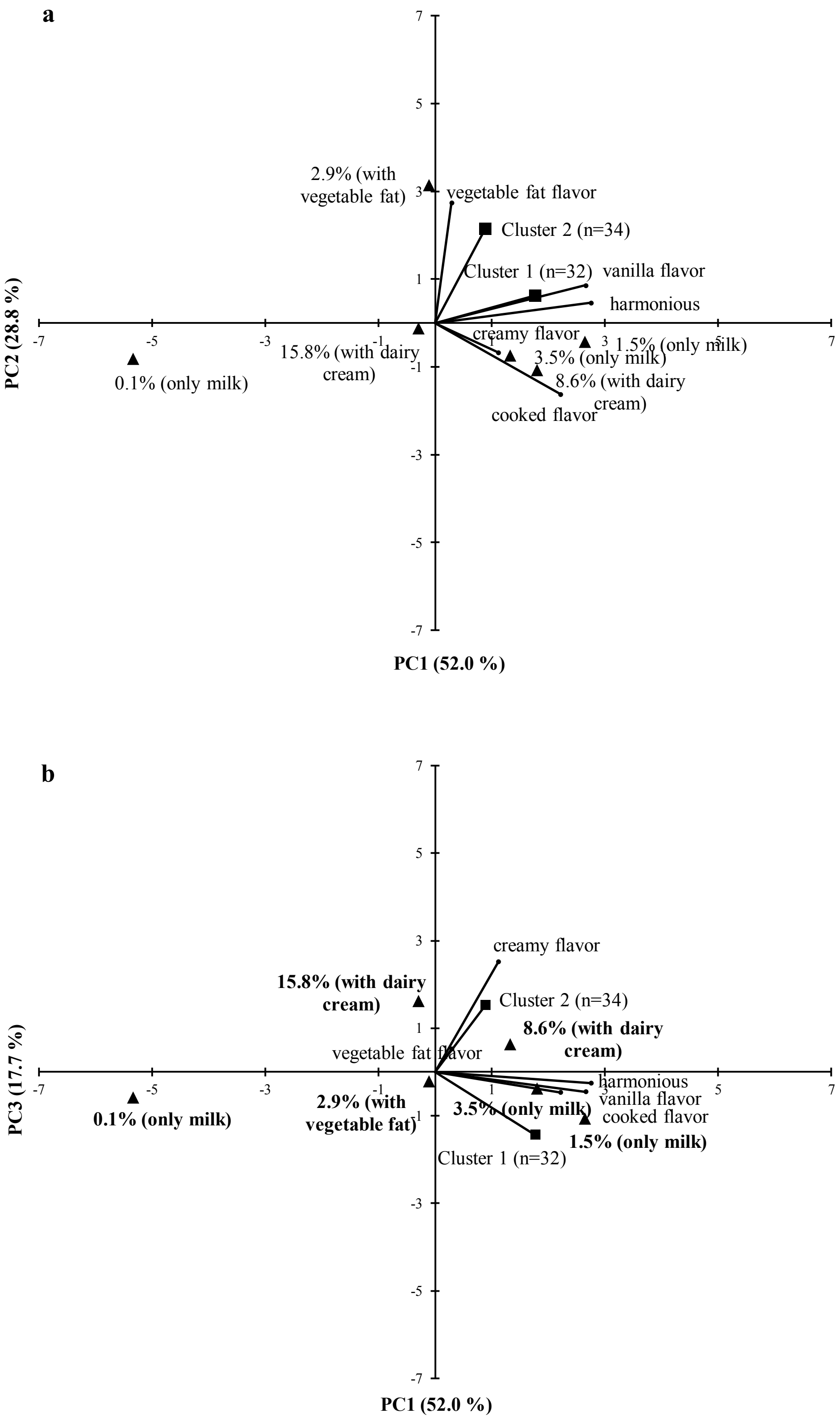

Figure 5.2: Parameter loadings and factor scores for principal component 1 (PC1) and principal component 2 (PC2) (a) as well as principal component 1 (PC1) and principal component 3 (PC3) (b), representing the relation between flavor/taste attributes, the six custard samples and consumer clusters obtained from cluster analysis. The vectors of the clusters represent their direction of liking. Identification of samples can be seen in Table 5.1. Identification of clusters can be seen in Table 5.7.

If cream was added to the formulation, creamy flavor increased significantly with increasing amount, which is self-explanatory. But creamy flavor was also significantly higher at 3.5% fat than at 0.1% fat. Comparable results were found by Elmore et al. (1999) who determined a stronger dairy flavor in custards with higher fat contents. Dunkley (1982) reported that milk flavor is apparent in products containing higher amounts of fat such as cream, particularly when it is used warm. Compared to the other samples which contained more milk fat, the pudding-like flavor was significantly lower at 0.1% fat. Hence, a lack of milk fat caused moderate sensations in flavor attributes vanilla, cooked and harmonious, presumably due to the effect of fat to act as the main solvent for various aroma compounds (Frost & Janhoj, 2007). De Wijk et al. (2003a) also found custards with high fat contents to produce more flavors and suggested a relation to the flavor-releasing properties of fat. Due to the effect of fat to slow flavor-release, it exerts influence concerning the intensity, the duration and balance of other flavors (Lucca & Tepper, 1994). Kersiene, Adams, Dubra, de Kimpe, and Leskauskaite (2008) showed a crucial influence of milk fat in model custards on the release of flavor compounds, retaining the flavor compounds due to hydrophobic interactions. Differences in pudding-like flavor attributes between the remaining UHT and both cream samples were not significant with the exception of the custard with 15.8% fat, being less harmonious and having a lower cooked flavor. Presumably, its creamy flavor predominated and covered the intensity of the other flavor attributes.

5.3.1.3 Effect of fat on texture/mouth feel

The first two components of the PCA describing the texture/mouth feel properties explained 97.4% of the total variance with PC1 (72.3%), running from jelly on the negative side to fat-related texture properties (sticky, creamy and fatty) on the positive side (**Figure 5.3**). ANOVA (**Table 5.4**) and PCA results (**Figure 5.3**) for texture/mouth feel indicated that jelly texture was significantly higher in the non-fat custard (0.1%) than in custards containing higher amounts of fat. Intensities in fat-related texture properties fatty, sticky and creamy increased with increasing fat content. Largest differences occurred between the non-fat custard and the other samples. The thickness of the model custards significantly increased at larger differences in fat content or rather when the fat content was raised with dairy cream.

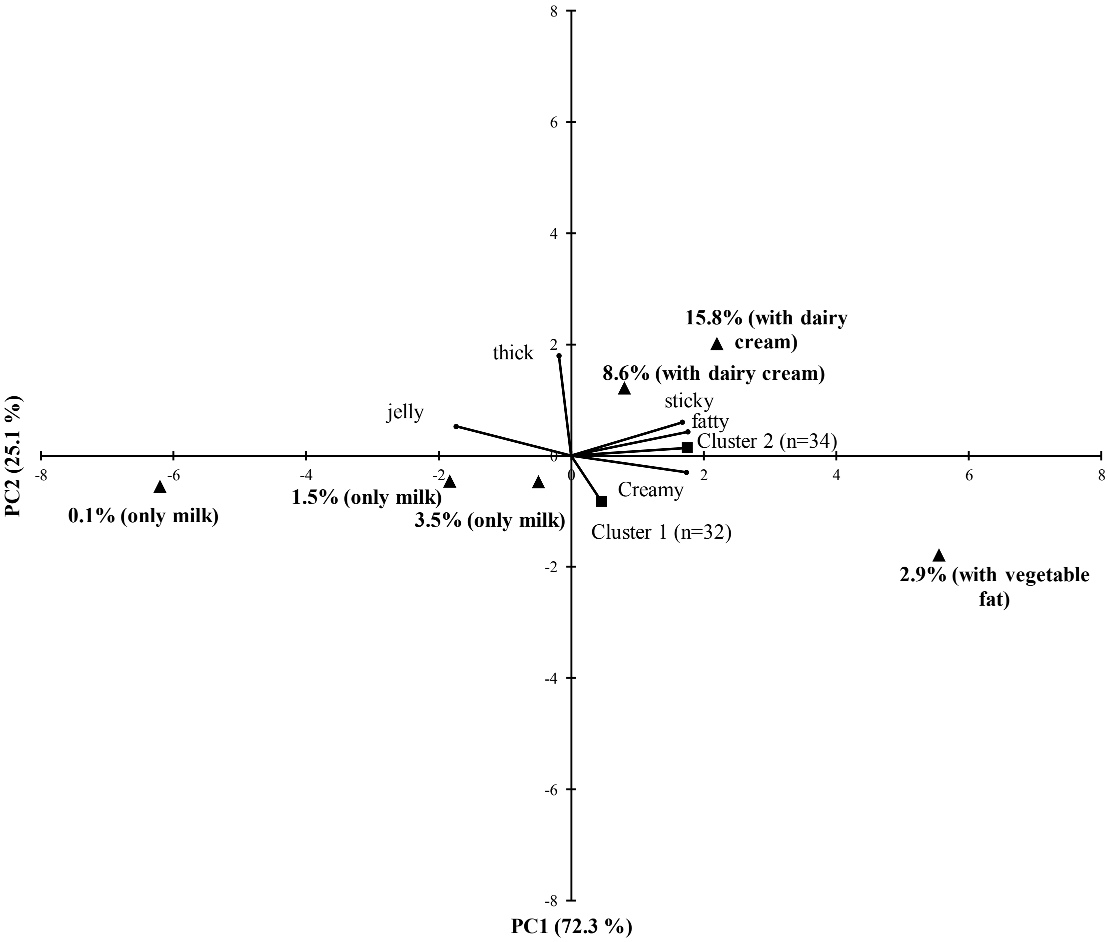

Figure 5.3: Parameter loadings and factor scores for principal component 1 (PC1) and principal component 2 (PC2), representing the relation between texture/mouth feel attributes, the 6 custard samples and consumer clusters obtained from cluster analysis. The vectors of the clusters represent their direction of liking. Identification of samples can be seen in Table 5.1. Identification of clusters can be seen in Table 5.7.

Other studies dealing with the effect of fat in model or commercially available vanilla custards also showed positive relations between the fat content and attributes creamy, fattiness, fatty mouth feel, fatty after feel and thick, and supposed these effects to occur due the lubricating and coating properties of fat (de Wijk et al., 2003a; de Wijk et al., 2003b; de Wijk et al., 2006; de Wijk & Prinz, 2007). Creaminess in dairy products is often connected to milk fat globules and consequently high creaminess is connected to a high fat content (Frost & Janhoj, 2007).

5.3.1.4 Effect of the addition of a vegetable fat cream

As the vegetable fat cream contained plenty of further ingredients such as fats, oils, modified starch, stabilizers and an emulsifier, no assumptions can be made concerning the effect of fat. But comparing custards with 2.9% and 1.5% fat, as they only differed in the presence of the vegetable fat cream, it is noticeable that the addition of vegetable fat cream caused a less yellow or rather a whiter color and a visually softer texture. Additionally, an intensive and dominant vegetable fat flavor occurred and cooked flavor decreased. Furthermore, the vegetable fat cream caused a creamier, fattier, stickier, softer and less jelly texture, presumably caused by the textural properties of starch and hydrocolloids and their interactions (Williams & Phillips, 2000). No significant differences occurred concerning the attributes skin formation, surface shine, vanilla, creamy flavor, harmonious and sticky. It is remarkable that the fat-related texture properties were highest in the custard containing vegetable fat, although the fat content was medium.

5.3.2 Consumer acceptability test

Appearance, flavor, texture and overall liking scores and the accordant results of ANOVA and Tukey's test are listed in **Table 5.6**. No significant differences among consumers were found in appearance liking (6.3 - 6.9). But ANOVA indicated significant differences for flavor and texture liking. Mean acceptance of flavor ranged between 5.3 and 6.3, with the non-fat (0.1%) and high-fat (15.8%) samples being significantly least-liked and the other samples being best-liked. Acceptability scores for texture liking ranged between 4.5 and 7.3, where the custard with 2.9% fat was liked the most, followed by the sample with 8.6% fat and then samples with 1.5% and 3.5% fat. The non-fat and high-fat samples were again least-liked for texture properties. As no significant differences were found for overall liking (5.6 - 6.4), cluster analysis on the overall liking data was applied to separate consumers according to their liking, resulting in 2 subgroups.

Table 5.6: Mean liking scores for the evaluated six custard samples for properties appearance, flavor, texture and overall liking.

Sample	0.1% (only milk)	1.5% (only milk)	2.9% (with vegetable fat)	3.5% (only milk)	8.6% (with dairy cream)	15.8% (with dairy cream)
Appearance liking	6.5[a]	6.5[a]	6.8[a]	6.3[a]	6.9[a]	6.6[a]
Flavor liking	5.3[a]	6.2[b]	6.3[b]	6.3[b]	6.3[b]	5.8[ab]
Texture liking	5.3[ab]	5.5[bc]	7.3[d]	5.9[bc]	6.2[c]	4.5[a]
Overall liking	5.6[a]	6.3[a]	6.4[a]	6.1[a]	6.4[a]	5.7[a]

[a-d] Means followed by the same letters within a row did not differ significantly ($P < 0.05$). Intensities were scored on a nine-point hedonic scale. Identification of samples can be seen in Table 5.1.

Table 5.7 shows the mean overall liking scores from the identified clusters. The 1st cluster included 32 consumers with mean values ranging from 4.1 to 5.7, preferring custards with 1.5%, 2.9%, 3.5% and 8.6% fat and rejecting custards with 0.1% and 15.8% fat. The 2nd cluster represented 34 assessors showing mean values between 6.7 and 7.3, and did not differentiated significantly between the samples, with the exception of the best-liked sample (2.9% fat) and the least-liked sample (0.1% fat).

Table 5.7: Overall mean liking scores for the evaluated six custard samples derived from cluster analysis.

Overall liking	0.1% (only milk)	1.5% (only milk)	2.9% (with vegetable fat)	3.5% (only milk)	8.6% (with dairy cream)	15.8% (with dairy cream)
Cluster 1 (n=32)	4.5[ab]	5.7[c]	5.6[c]	5.3[bc]	5.7[c]	4.1[a]
Cluster 2 (n=34)	6.7[a]	6.8[ab]	7.3[b]	6.8[ab]	7.1[ab]	7.1[ab]

[a-c] Means followed by the same letters within a row did not differ significantly ($P < 0.05$). Intensities were scored on a nine-point hedonic scale. Identification of samples can be seen in Table 5.1.
n, number of consumers.

5.3.3 Relationships between sensory attributes and consumer ratings and the effect of fat on consumers' acceptability

Descriptive data were related to overall liking data obtained from cluster analysis to determine drivers of liking and disliking. **Figure 5.1**, **Figure 5.2** and **Figure 5.3** display the relation between clusters' overall liking and the accordant sensory attributes of the custard samples. Cluster 1 preferred custards high in pudding-like flavor attributes and medium to high in fat-related texture properties. A stronger thickness, white color and creamy flavor up to certain intensity (8.6% fat) as well as vegetable fat flavor were also liked. Contrariwise, as custards with 0.1% and 15.8% fat were rejected, neither flavorless custards, nor custards with a too intensive creamy flavor, jelly and thick texture and a too white color were liked. Pudding-like flavor attributes, vegetable fat flavor as well as fat-related texture properties drove liking of the 2nd cluster, whereas a jelly texture drove disliking.

Results showed an effect of fat on consumers' preferences as high-fat custards and especially non-fat custards were least liked. No significant differences in liking were found between custards with medium fat contents (1.5% and 8.6%), which were best-liked. Consequently, too low and too high fat contents predominantly led to a rejection of vanilla custards. Contrariwise, Elmore et al. (1999) observed higher acceptance ratings for custards with higher amounts of fat. They determined consumer preferences for thicker, creamier and slower melting custards, which were more mouth coating and dense.

Due to the fact that the consumer sample size in our study was relatively low, further studies are needed to prove our findings, using a larger sample size.

5.4 Conclusions

Sensory profiles of model vanilla custards varying in fat content and type of fat were established in our study. Our results demonstrated that fat increased the intensities of visual and oral thickness, creamy flavor and fat-related texture properties (fatty, creamy and sticky) and decreased yellowness and surface shine. In non-fat custards, pudding-like flavor (vanilla, cooked and harmonious) was low and jelly texture high. The addition of a vegetable fat cream increased intensities in vegetable fat flavor and fat-related texture properties, whereas yellowness, cooked flavor intensity, jelly texture and visual and oral thickness were reduced. An effect of fat on consumers' preferences can be concluded, as consumers' overall liking results indicated that non-fat custards (all consumers) and high-fat custards (some consumers) were least liked. Mean values for flavor and texture liking showed lowest scores for both products. Custards with medium fat contents (1.5 - 8.6%) showed best acceptability results. Pudding-like flavor attributes, vegetable fat flavor and fat-related properties were intrinsic factors that drove liking of all consumers. Too high intensities in attributes thick, creamy flavor and white color drove disliking of some consumers, whereas a too jelly texture drove disliking of all consumers. The addition of vegetable fat cream demonstrated a good alternative for well accepted medium-fat vanilla custards.

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6 Changes in sensory properties and consumer acceptance of reduced fat pork Lyon-style and liver sausages containing inulin and citrus fiber as fat replacers

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Abstract

The effects of fat reduction in Lyon-style (25% fat) and liver sausages (30% fat) using inulin, citrus fiber and partially rice starch were studied in terms of sensory properties and consumer acceptance. Fat reduced Lyon-style sausages (3 to 17% fat) and liver sausages (3 to 20% fat) were respectively compared to the full-fat control. Reducing fat in Lyon-style sausages decreased meat flavor, aftertaste meat flavor, greasiness and juiciness, and enhanced color intensity, spiciness, spicy aftertaste, raspy throat, coarseness and firmness scores. But adding inulin and citrus fiber led to sensory characteristics similar to the full-fat reference. Regarding liver sausages, attribute scores in greasiness, creaminess, lumpiness and foamy were decreased with fat reduction and simultaneous addition of fibers. Color intensity, spiciness, firmness and attribute furred tongue were increased. Consumer tests revealed acceptable fat reduced (32 to 90% less than control) and fiber enriched (1.0 to 5.6%) sausages. Drivers of liking were found to relate to high-fat but also to low-fat samples.

6.1 Introduction

Lyon-style sausages (in Germany "Lyoner") are ready to eat cooked sausages similar to mortadella or rather bologna-type sausages. In Germany they are usually consumed in salads, on a piece of bread or typically pure. Liver sausages, also known as "liverwurst" (in Germany "Leberwurst"), are spreadable cooked sausages mainly consisting of liver, meat, fat, salt and spices. Both types of sausage are very popular in Germany and in many other countries.

Meat products can play an important role in human health, being low-carbohydrate, protein rich and an important source of some micronutrients (Biesalski, 2005). However, immoderate consumption of meat and meat products is proposed to promote the risk for chronic diseases such as obesity, amongst others due to their high fat content (Biesalski, 2005; Weiss, Gibis, Schuh, & Salminen, 2010).

Due to changing concerns about the relationship between dietary fats, obesity and related diseases, extensive research on low-fat foods such as meat products has been conducted in recent years (Carrapiso, 2007; García, Dominguez, Galvez, Casas, & Selgas, 2002; Jiménez-Colmenero, 2000; Kumar & Sharma, 2004; Yang, Choi, Jeon, Park, & Joo, 2007; Yoo, Kook, Park, Shim, & Chin, 2007). However, with fat playing a decisive role concerning the product properties and consumer acceptance, the reduction of fat in meat products poses a challenge to the food industry. Fat stabilizes the meat emulsion, reduces cooking loss, improves water holding capacity and provides juiciness and hardness (Carballo, Barreto, & Jiménez-Colmenero, 1995; Hughes, Cofrades, & Troy, 1997; Pietrasik & Duda, 2000; Yoo et al., 2007). Furthermore, fat plays an important role in affecting sensory characteristics (appearance, flavor and texture) and consumer acceptance (Homer, Matthews, & Warkup, 2000; Keeton, 1994; Tokusoglu & Unal, 2003; Weiss et al., 2010).

In order to achieve liking scores for fat reduced sausages similar to those of their full-fat counterparts, it is necessary to produce samples with similar sensory profiles (Solheim, 1992). Reducing fat in meat products can be carried out by using leaner meat parts, increasing the amount of water and/or using other substances such as fat replacers being either protein- or carbohydrate-based (Akoh, 1998; Jiménez-Colmenero, 1996; Keeton, 1994; Weiss et al., 2010). Solely reducing fat in the meat formulation may cause firm, mealy, more rubbery products with lower juiciness and higher redness values compared to the full-fat counterparts (Cáceres, García, Toro, & Selgas, 2004; Keeton, 1994; Weiss et al., 2010). As a common strategy, carbohydrate-based fiber rich fat replacers and starches are widely used in processed meat products, supporting water binding and revealing more stable products with improved texture properties (Bloukas & Paneras, 1996; Claus & Hunt, 1991; Grigelmo-Miguel, Abadías-Serós, & Martín-Belloso, 1999; Keeton, 1994; Shand, 2000; Thebaudin, Lefebvre, Harrington, & Bourgeois, 1997). Additionally, cooking yield is improved and formulation costs may be reduced (Jiménez-Colmenero, 1996; Keeton, 1994). Inulin for instance is ascribed to account for acceptable fat reduced foods and to provide fat-related texture properties in reduced fat meat products, such as a creamy and juicy mouth feel (Devereux, Jones, McCormack, & Hunter, 2003; Franck, 2002; Janvary, 2006; Nitsch, 2007). It provides technological benefits such as gelling characteristics and the ability to improve the physical stability of foods due to water immobilization (Franck, 2002). Fruit fibers were also found to be suitable to replace fat in meat products (García, Cáceres, & Selgas, 2007; Grigelmo-Miguel et al., 1999). The incorporation of fruit fibers into foods can enhance hardness, consistency, viscosity and juiciness (Fernández-Ginés, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Alvarez, 2003; Fischer, 2000). Rice starch, especially waxy rice starch, provides excellent flavor profiles in foods, as well as excellent mouth feel properties or rather fat-like mouth feel properties (Mitchell, 2009).

Moreover, fibers such as inulin and fruit fibers provide beneficial health effects and their consumption is recommended, as dietary fiber intake is related to a reduced risk of chronic diseases such as colorectal cancer (Aleson-Carbonell, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Alvarez, 2003; Beylot, 2005; Cherbut, 2002; Eastwood, 1992; Fernández-Ginés, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Álvarez, 2004; Kruse, Kleessen, & Blaut, 1999). Hence, the production of fiber enriched meat products fits well with today's increasingly health concerned consumers without altering their eating habits.

Several authors studied the effects of different types of fibers as fat replacer in cooked pork meat products on sensory properties or liking (Cáceres et al., 2004; Claus & Hunt, 1991; García, Cáceres, & Selgas, 2006; García et al., 2007; Krickmeier & Schnäckel, 2008; Selgas, Cáceres, & García, 2005; Shand, 2000). Sensory evaluations of full-fat and low-fat German bologna-type or rather Lyon-style sausages with added inulin were already carried out in terms of consumer acceptance or sensory analysis (Brauer, 2005; Hadorn, Piccinali, & Suter, 2007; Nitsch, 2007; Nowak, Von Mueffling, Grotheer, Klein, & Watkinson, 2007) but without revealing detailed descriptions of the effect of fat and the addition of fibers on sensory properties or relations between descriptive and hedonic data. Liver sausages were amongst others evaluated in terms of the effect of fat content (Chyr, Sebranek, & Walker, 1980) and fat reduction using inulin (Nitsch, 2007). However, little research has been targeted at fat reduction in Lyon-style and liver sausages using combinations of inulin and citrus fiber. The objectives of this work were to study the effects of reducing fat in Lyon-style (up to 88%

fat reduction) and liver sausages (up to 90% fat reduction) on sensory properties (1) and consumer acceptance (2), to evaluate whether sensory properties of fat reduced Lyon-style and liver sausages may be improved by adding combinations of carbohydrate-based fat replacers (3) and to elaborate the drivers of liking for both types of sausage (4).

6.2 Materials and methods

6.2.1 Products

Lyon-style and liver sausage samples with varying fat contents were produced and kindly provided by Herbafood Ingredients GmbH (Werder, Germany). To replace fat, citrus fiber (Herbacel AQ Plus Citrus, Herbafood Ingredients GmbH) or combinations of citrus fiber and granulated inulin (Orafti® GR, BENEO-Orafti) were added to the sausage formulation as fibers. Furthermore, native waxy rice starch (Remyline XS, BENEO-Remy) was partly used as an additional carbohydrate, not being a fiber.
Regarding both sausage types, respectively one production trial for each sample variant was done during one day for a preselection of samples (see Section 6.2.2.1 and 6.2.2.2). To ensure shelf life, a second production trial for each of the selected sample variants was carried out on another day for the subsequent sensory evaluations. In both cases, respectively the same raw material was used for the different sausage variants, where meat and fat were mixed for all batches prior to the sausage production in order to account for inter-individual variability between animals.

6.2.1.1 Lyon-style sausages

In addition to a full-fat (25%) reference sample, Lyon-style sausages with 17%, 10% and 3% fat were produced. Variation in fat was achieved by changing the relation between lean meat (pork leg) and back fat, following two approaches. In approach 1, parts of back fat were substituted by the same amount of lean meat. Due to expected technological problems for sausages with 3% fat, this approach was only applied to sausages with 10% and 17% fat. In approach 2, fat replacers in different combinations (inulin, citrus fiber and/or rice starch) were added to the formulation. In this approach water (ice) was increased and the meat protein level was adjusted to be comparable to that of the reference. Variations in the dosage and combination of the fat replacers were chosen with regard to adapt the firmness as much as possible to the full-fat reference.

Table 6.1: Lyon-style sausage formulations with the accordant fat content, meat protein content and ingredient proportions of the 18 sample variants.

	Nutrition facts (%)		Ingredient proportions (%)							
Sample	Total fat content	Total meat protein content	Pork lean meat	Pork back fat	Ice	Citrus fiber	Inulin	Rice starch	Pickling salt, phosphate, citrate, ascorbate, spices, sugar	Water
R	25	9.7	52.0	25.0	20.0	-	-	-	3.0	-
17%_LM	17	11.7	61.5	15.5	20.0	-	-	-	3.0	-
17%_ I_CF_1	17	10.3	54.0	16.0	26.0	0.200	0.800	-	3.0	-
17%_ I_CF_2	17	10.3	54.0	16.0	26.0	0.800	0.200	-	3.0	-
17%_ I_CF_3	17	10.3	54.0	16.0	26.0	0.500	0.500	-	3.0	-
10%_LM	10	13.3	70.0	7.0	20.0	-	-	-	3.0	-
10%_ I_CF_1	10	9.8	52.0	8.0	34.0	0.500	2.500	-	3.0	-
10%_ I_CF_2	10	9.8	52.0	8.0	34.0	1.500	1.500	-	3.0	-
10%_I_CF_3	10	9.8	52.0	8.0	12.0	0.750	3.000	-	3.0	21.25
10%_I_CF_4	10	9.8	52.0	8.0	12.0	1.000	1.000	-	3.0	23.00
10%_ I_CF_RS	10	9.8	52.0	8.0	34.0	0.500	1.500	1.0	3.0	-
10%_CF	10	9.8	52.0	8.0	12.0	1.500	-	-	3.0	23.50
3%_ I_CF_RS	3	11.3	60.0	-	33.0	1.500	1.500	1.0	3.0	-
3%_ I_CF_1	3	11.3	60.0	-	12.0	0.875	2.375	-	3.0	21.75
3%_I_CF_2	3	11.3	60.0	-	34.0	1.000	2.000	-	3.0	-
3%_I_CF_3	3	11.3	60.0	-	34.0	2.000	1.000	-	3.0	-
3%_I_CF_4	3	11.3	60.0	-	12.0	1.000	1.000	-	3.0	23.00
3%_CF	3	11.3	60.0	-	12.0	1.500	-	-	3.0	23.50

R, reference; LM, lean meat; I, inulin; CF, citrus fiber; RS, rice starch.

Firmness was measured in pretests (unpublished data) using a Texture Analyzer (TA.XT *plus*, Stable Micro Systems, Surrey, England). For this purpose, uniform sample portions from the middle of the sausages with a height of 10 mm and a diameter of 70 mm were used for analysis. Samples with a sample temperature of 8 °C were compressed to 60% of their original height using a cylindrical probe of 15 mm diameter at a cross-head speed for 1 mm/s. In approach 1, an adjustment of firmness and meat protein level was not possible due to the fact that fat was substituted merely by substituting back fat by the same amount of lean meat.

Sausages were produced in a classical way using a bowl chopper. Lean meat and back fat were grinded through a 5 mm plate. Meat, salt and chopping aids were placed into the chopper and run a few rounds before 50% of the total amount of ice was added. After achieving a temperature of 1-2 °C, back fat was added and chopped until having 8 °C. Finally, the remaining amount of ice, spices and fat replacers were added and chopped up to 12 °C. The meat emulsion was stuffed into casings and cooked up to a core temperature of 72 °C. Samples were stored at 5 °C and were evaluated within one week after production.

In addition to the full-fat reference, a total of 17 fat reduced Lyon-style sausages were produced, resulting in four 17% fat sausages, seven 10% fat samples and six samples with 3% fat. The 17% and 10% fat samples respectively included one sample with an increased amount of lean meat parts without fat substitutes (approach 1) and three samples (17% fat) or rather six samples (10% fat) with varying combinations of the above mentioned fat replacers (approach 2). Furthermore, six low-fat sausages (3% fat) with varying amounts of the fat substitutes were produced. Samples with the accordant fat and meat protein contents as well as ingredient proportions are given in **Table 6.1.**

6.2.1.2 Liver sausages

Fat contents of the liver sausages were varied similarly to approach 2 regarding the Lyon-style sausages (see Section 6.2.1.1). Hence, fat belly was substituted by leaner meat parts and various combinations of the fat replacers inulin, citrus fiber and/or rice starch to achieve fat contents of 20%, 10% or 3%. Lean meat and belly fat were cooked for about 90 min to get a soft texture. The cooking loss was determined to adjust the water content. The fat substitute was prepared by dispersing the fat replacers in hot broth. Samples were produced using a bowl chopper. Liver and salt were chopped to a homogenous emulsion. Cooked meat and belly fat were grinded though a 5 mm plate and placed into the chopper. Subsequently, the hot broth containing the fat replacers was added. After adding the liver emulsion to the chopper at a temperature of 45 °C, all the ingredients were chopped to the desired fineness. The meat emulsion was stuffed into casings and cooked up to a core temperature of 72 °C. Samples were stored at 5 °C and were evaluated within one week after production. As pretests showed an undesirably increased perceived spiciness with decreasing fat content (unpublished data), the amount of spices was reduced with decreasing fat content.

In addition to the full-fat reference, seven fat reduced liver sausages with varying amounts of inulin, citrus fiber and/or rice starch were produced, including two samples with 20% fat, three samples with 10% fat and two samples containing 3% fat. Samples with the accordant fat content and ingredient proportions are given in **Table 6.2.**

Table 6.2: Liver sausage formulations with the accordant fat content and ingredient proportions of the eight sample variants.

		Ingredient proportions (%)								
Sample	Total fat content	Pork liver	Pork shoulder	Pork lean belly	Fat belly	Broth	Citrus fiber	Inulin	Rice starch	Spices, onions, honey, ascorbate
R	30	25.0	-	20.0	30.0	19.5	0.1	0.4	-	5.0
20%_ I_CF	20	25.0	-	28.0	11.0	28.6	0.5	1.9	-	5.0
20%_ I_CF_RS	20	25.0	-	30.0	10.0	26.2	0.4	1.4	2.0	5.0
10%_ I_CF	10	25.0	16.0	17.0	-	33.9	0.7	2.6	-	4.8
10%_ I_CF_RS _1	10	25.0	10.0	21.0	-	33.9	0.7	2.6	2.0	4.8
10%_ I_CF_RS_2	10	25.0	16.0	17.0	-	32.2	0.6	2.4	2.0	4.8
3%_ I_CF_RS	3	25.0	25.0	-	-	37.5	1.1	4.5	3.0	3.9
3%_ I_CF	3	25.0	30.0	-	-	35.7	1.1	4.3	-	3.9

R, reference; I, inulin; CF, citrus fiber; RS, rice starch.

6.2.2 Sensory evaluation

Sensory evaluations and consumer testing were carried out at the Sensory Laboratory at Hamburg University of Applied Sciences, Germany. The laboratory is equipped with twelve separate booths according to international standards for test rooms (ISO, 2007). Data collection was conducted using FIZZ software (Biosystèmes, Couternon, France). Sausage samples were analyzed at room temperature (21 +/- 2 °C) under white fluorescent lighting and were coded with three-digit random numbers.

Based on availability, previous training and liking of Lyon-style and liver sausages, a total of eleven trained panelists (one male, ten females, aged between 22 and 30) were selected to participate in the discriminating and descriptive evaluations. During all evaluations, trained panelists were provided with toast bread, wheat-rye bread, cucumber and apple pieces as well as filtered cold and warm tap water (30 °C) as palate cleansers between samples.

6.2.2.1 Projective Mapping (Lyon-style sausages)

Projective Mapping (Pagès, 2005; Risvik, McEwan, Colwill, Rogers, & Lyon, 1994) was applied in order to get a first overview about differences between the full-fat reference and the fat reduced Lyon-style sausage samples as well as to preselect those fat-reduced samples for further sensory evaluations and consumer testing in the space of a fat content, which were most similar to the full-fat reference. It was conducted separately for the different fat contents as well as separately for flavor and texture, respectively in comparison to the reference. Projective Mapping is a simple and quick technique to obtain product similarities and differences, especially for large sets of products.

Lyon-style sausages were cut into slices (3 mm thick, 70 mm diameter) and were stored at 8 °C. Panelists received one slice per sample in 100 mL odorless, transparent plastic vessels (Bunzl Verpackungen GmbH, Gelsenkirchen, Germany). They were provided with a sheet of white paper (A4) and were asked to place the samples on it according to how they perceived them to be related to each other. Similar samples had to be located close to each other, whereas different samples should be placed far apart. Each of the eleven panelists participated in a total of six Projective Mapping sessions.

6.2.2.2 Triangle tests (Liver sausages)

In order to exclude similar samples with the same fat content for further sensory evaluations and consumer testing, Triangle tests according to ISO standards (ISO, 2004) were applied, respectively comparing samples with the same amount of fat. Panelists were asked to identify the sample that is differing in a triangle, which consisted of two identical and one differing sample. 10 g per liver sausage sample were filled in 30 mL odorless, transparent plastic vessels and were stored at 8 °C. Seven of the eleven trained panelists participated in the triangle tests and attended a total of five triangle test sessions.

6.2.2.3 Descriptive analysis

Descriptive analysis according to ISO standards (ISO, 2003) was carried out in order to examine the effects of fat and the addition of fat replacers on the sensory properties of the sausages. According to the procedure of descriptive analysis, panelists first generated a list of sensory terms to describe the samples, using the already selected sausage samples, during one (Lyon-style sausages) or rather four (liver sausages) panel sessions. In each case, selected descriptors were defined in consensus and trained using commercially available as well as the already selected Lyon-style and liver sausage samples during two training sessions. Two pilot tests were respectively applied to familiarize the panelists with the descriptors and the scaling procedure, followed by an additional training session, at which problems with descriptors were discussed in consensus.

Afterwards, panelists defined the intensities of the full-fat Lyon-style sausage and liver sausage sample in consensus in respectively one session, to use this data later as an open reference during the sensory evaluation. However, in order to study the panel quality, the reference sample for both sausage types was additionally tested encoded during all descriptive analysis sessions together with the other samples. Samples were evaluated semi-monadically, using a six-point categorical scale (0 to 5) with the same order of attributes among panelists and sessions. Attribute definition sheets were given for a better understanding, as well as a form with the defined intensities of the full-fat control, being marked on the accordant scales.

6.2.2.3.1 Lyon-style sausages

Panelists generated a list of terms with a total of eleven attributes concerning appearance (1), flavor/taste (4) and texture/mouth feel (6) to describe the sensory properties of Lyon-style sausages. Attributes, definitions and scale anchors are given in **Table 6.3**. As panelists were not able to evaluate the previously selected seven Lyon-style sausages at once, samples were presented according to a four out of seven Balanced Incomplete Block (BIB) Design (ISO, 2011). To ensure a four out of seven BIB design, 14 Blocks are required, which were distributed to the eleven panelists, so that in total at least 30 judgments were obtained for each product per attribute. A minimum of 30 judgments per sample was determined based on three replication measurements as well as an optimum panel size of ten assessors, which was assumed as a mean because descriptive panels usually have eight to twelve assessors (ISO, 2003). Accordingly, each trained panelist participated in five sessions. Panelists received one slice (3 mm thick, 70 mm diameter) per sample in 100 mL odorless, transparent plastic vessels.

Table 6.3: List of the sensory attributes used for the sensory evaluation of Lyon-style sausages with definitions and scale anchors generated by the panel.

Property	Attribute	Definition	Scale anchors
Appearance	Color intensity	Red color intensity	Light red/dark red
Flavor / taste	Meat flavor	Intensity of meat flavor	Absent/very intensive
	Spiciness	Intensity of overall spiciness	Absent/very intensive
	Aftertaste meat flavor	Intensity of meat flavor aftertaste after swallowing	Absent/very intensive
	Aftertaste spiciness	Intensity of spiciness aftertaste after swallowing	Absent/very intensive
Texture / mouth feel	Firmness	Perceived firmness during chewing	Soft/firm
	Juiciness	Perceived water content during chewing	Dry/juicy
	Coarseness	Degree of perceived fine granularity during chewing	Not much/very
	Greasiness	Fatty/greasy texture and layer	Not much/very
	Raspy throat	A raspy / scratchy feeling after swallowing	Not much/very
	Lumpiness	Amount of perceptible firm and irregular particles	Not much/very

6.2.2.3.2 Liver sausages

To discriminate between the liver sausages, panelists found a total of 26 attributes, describing appearance (5), odor (4), flavor/taste (11) and texture/mouth feel (6) properties. Liver sausages are usually not consumed pure but on a piece of bread. Therefore, consumer tests were conducted with liver sausages on a piece of bread and consequently, descriptive analysis was carried out with pure samples but also on a piece of bread to enable a correlation between panel and consumer data. **Table 6.4** summarizes the attributes with accordant definitions and scale anchors for the description of liver sausages. Odor and texture attributes as well as attributes porous and foamy were not evaluated on a piece of bread, as differences between samples could not be found by the panelists during the training sessions.

Table 6.4: List of the sensory attributes used for the sensory evaluation of liver sausages (pure and on a piece of bread) with definitions and scale anchors generated by the panel.

Property	Attribute	Definition	Scale anchors
Appearance	Color intensity*[a]	Red color intensity	Light red/dark red
	Porous	Visible amount of pores on the surface	Not much/very
	Spreadability*[a]	Degree of spreadability	Easy to spread/hard to spread
	Foamy	Foamy/airy appearance	Not much/very
	A Lumpiness*[a]	Visible amount of large particles	Not much/very
Odor	Odor of liver	Odor of animal liver	Absent/very intensive
	O Spiciness	Odor of overall spiciness	Absent/very intensive
	O Metallic	Odor of iron	Absent/very intensive
	Off-odor	A general, non-specific odor, related to unpleasant properties, untypical for the product	Absent/very intensive
Flavor / taste	Liver flavor*	Intensity of liver flavor	Absent/very intensive
	Meat flavor*	Intensity of meat flavor	Absent/very intensive
	Aftertaste*	Intensity of sum of all aftertastes after swallowing	Absent/very intensive
	Off-flavor*[b]	A general, non-specific flavor, related to unpleasant properties, untypical for the product	Absent/very intensive
	Ta Spiciness*	Intensity of overall spiciness	Absent/very intensive
	Peppery*	Intensity of peppery flavor	Absent/very intensive
	Saltiness*	Intensity of saltiness	Absent/very intensive
	Sourness*	Intensity of sour flavor	Absent/very intensive
	Sweetness*	Intensity of sweet flavor	Absent/very intensive
	Bitterness*	Intensity of bitter flavor	Absent/very intensive
	Ta Metallic*	Intensity of ferrous sulphate	Absent/very intensive
Texture / mouth feel	Furred tongue	Degree of a furred tongue after swallowing	Not much/very
	Firmness	Perceived firmness in the mouth	Soft/firm
	Creaminess	Individual definition of creaminess in the mouth, associated with smoothness, not rough	Not much/very
	Greasiness	Fatty/greasy texture and layer	Dry/very greasy
	Te Lumpiness	Amount of perceptible firm and irregular particles	Not much/very
	Graininess	Amount of perceptible small particles	Not much/very

*Attributes that were evaluated on a piece of bread. [a] Attributes that were analyzed after spreading a small amount of a sample ten times on a piece of grease-proof paper using a butter knife. [b] Attribute off-flavor was mainly described by a cinnamon and cardamom flavor.

A, appearance; O, odor; Ta, taste; Te, texture.

During the evaluation, panelists received several pieces of grease-proof paper and a butter knife for the evaluation of the appearance attributes color intensity, spreadability and lumpiness, as these attributes were easier to evaluate by this procedure. Referring to this, panelists spread a defined amount of a sample ten times on the piece of grease-proof paper using the butter knife and rated the intensities of the mentioned attributes while looking at the grease-proof paper.

Liver sausages were evaluated using a completely balanced plan, being presented in randomized order among panelists according to Williams Latin Square (Macfie, Bratchell, Greenhoff, & Vallis, 1989). Due to the large number of attributes and the evaluation of the pure sausages as well as the sausages on bread, panelists evaluated only two or rather three of the previously selected five different samples per session. By taking part in a total of six sessions, each sample was analyzed in triplicate by each panelist. Liver sausages were filled in 30 mL odorless, transparent plastic vessels and were stored at 8 °C. Panelists received vessels with 10 g per liver sausage to evaluate them pure. Additionally, they received vessels with 5 g of the liver sausage samples, served in 100 mL vessels, to spread the whole amount on a standardized piece of wheat-rye bread (50 mm diameter).

6.2.2.4 Consumer test

Based on regular usage as well as liking of Lyon-style or liver sausages, students and employees from Hamburg University of Applied Sciences, Germany, were selected to participate in the evaluation. They were inexperienced in sensory descriptive analysis but some of them were experienced in different consumer tests. Consumers were naïve with sausage production and were paid for their participation. Besides questions about demographic information (age, gender), consumers rated degree of overall liking semi-monadically, using a nine-point hedonic scale ranging from ”dislike extremely” (1) to “like extremely” (9). To neutralize between attributes and samples, toast bread, cucumber pieces as well as filtered tap water were provided during the evaluations of both sausage types.

6.2.2.4.1 Lyon-style sausages

Based on the BIB-Design (see Section 6.2.2.3.1), 140 consumers (62 females and 78 males with a mean age of 25, range 19-62) participated in the evaluation of the Lyon-style sausages, evaluating four of the previously selected seven samples in one session. A total of 140 consumers ensured that each sample was evaluated 80 times. Consumers received one slice (3 mm thick, 70 mm diameter) per Lyon-style sausage in 100 mL odorless, transparent plastic vessels.

6.2.2.4.2 Liver sausages

Using a completely randomized plan, liver sausages were evaluated by 80 consumers (36 females and 44 males with a mean age of 25, range 19-55) (see Section 6.2.2.3.2), evaluating each of the previously selected five samples in one session. Regarding liver sausages, an amount of 5 g per sample was spread on a standardized piece of wheat-rye bread (50 mm diameter), served in 100 mL vessels.

6.2.3 Statistical analysis

Projective mapping data of the Lyon-style sausages for flavor and texture were analyzed by calculating the Euclidean distances between the samples based on previous multiple factor analysis (MFA), using the X-co-ordinates and Y-co-ordinates on the A4 sheets for each product.

Data obtained from triangle tests of the liver sausages were analyzed using a table with the minimum number of correct responses that are needed to conclude that a perceptible difference between samples exists (ISO, 2004).

A one-factor analysis of variance (ANOVA) followed by multiple comparisons using Tukey's Test ($P < 0.05$) was applied to determine those sensory descriptors which differed significantly between the products. Attributes that did not discriminate significantly between the products were excluded from subsequent principal component analysis (PCA).

Consumer test data were first analyzed for homogeneity of the sample. Due to the fact that the Lyon-style sausages were tested according to a BIB-design, whereas a completely randomized plan was used for analyzing the liver sausages, different segmentation methods were applied. Consumer test data of the liver sausages were analyzed by agglomerative hierarchical clustering using Wards's Method with Euclidean distances. Since this method does not accept data matrices with missing values, latent class segmentation was chosen for segmenting consumers of the Lyon-style sausages consumer test, using overall liking scores as dependent variables and the products as independent variables. One advantage of latent class analysis is the possibility of using statistics for deciding how many segments should be chosen by comparing information criteria (IC) of models with differing number of classes. According to the AIC (Akaike's Information Criteria), the optimal number of classes or rather consumer groups was chosen regarding the one model, which delivered the lowest IC value.

Overall liking data of both product categories for the obtained consumer groups/clusters were furthermore analyzed by a one-factor ANOVA followed by multiple comparisons using Tukey's Test ($P < 0.05$) to test for significant liking differences between the products.

In order to identify drivers of liking and dislike, consumer data were related to panel data by means of PCA. The overall liking means of the determined consumer groups (Lyon-style sausages) or rather clusters (liver sausages on a piece of bread) were treated as supplementary data for the PCA on the descriptive data.

With the purpose of controlling the panel quality, the previously defined intensities of the open full-fat reference (Lyon-style and liver sausages) were compared to the intensities of the same but encoded sample obtained from descriptive analysis by applying a one-factor ANOVA and subsequent multiple comparisons using Tukey's Test ($P < 0.05$). A good panel quality was stated if the number of significant differences between the open reference and the encoded reference, regarding the total number of attributes, was not much higher than it was expected to occur at random.

All statistical calculations were conducted by means of XLSTAT software (Addinsoft, Andernach, Germany), with the exception of the latent class segmentation for the Lyon-style sausages, which was calculated by Latent Gold ® 4.0 (Statistical Innovations, Belmont, USA) and with the exception of the analysis of the overall liking data of the obtained consumer groups for the Lyon-style sausages, which was analyzed using SPSS (IBM Deutschland GmbH, Ehningen, Germany), because Latent Gold® converts the consumers' class segmentation data with the accordant liking data into an SPSS system file.

6.3 Results and discussion

6.3.1 Selected samples for descriptive analysis and consumer testing

6.3.1.1 Lyon-style sausages

The results of the separate Projective Mappings for flavor and texture for the different fat contents are summarized in **Table 6.5**, showing the Euclidean distances between the reference and the fat reduced samples which were calculated on the basis of a previously established MFA. Selection of samples for further sensory evaluations first of all resulted in respectively one sample per fat content with the smallest Euclidean distance by reason of being most similar to the full-fat reference (samples 17%_ I_CF_1, 10%_ I_CF_1 and 3%_ I_CF_RS).

Table 6.5. Euclidean distances between the full-fat and the fat reduced Lyon-style sausage samples.

Sample	Euclidean distance to the full-fat reference Lyon-style sausage (R)
17%_LM *	7.0
17%_ I_CF_1 *	6.2
17%_ I_CF_2	6.6
17%_ I_CF_3	7.7
10%_LM *	10.5
10%_ I_CF_1 *	5.9
10%_ I_CF_2	8.5
10%_I_CF_3	6.8
10%_I_CF_4	7.6
10%_ I_CF_RS	6.2
10%_CF	6.9
3%_ I_CF_RS *	7.4
3%_ I_CF_1 *	8.7
3%_I_CF_2	7.9
3%_I_CF_3	8.3
3%_I_CF_4	7.9
3%_CF	8.5

* Samples, which were selected for sensory descriptive analysis and consumer testing. Calculation of the Euclidean distances based on previous multiple factor analysis (MFA) data. Identification of samples can be seen in Table 6.1.

Concerning fat contents 10% and 17%, the samples without fat replacers (approach 1) were in any case selected for descriptive analysis and consumer testing. Regarding the 3% fat samples, a second sample was intended to be selected, choosing the sample with the largest Euclidean distance to the reference (3%_ I_CF_1), because samples were in general quite similar and variance was aimed to be increased. Consequently, Projective Mapping of the Lyon-style sausages resulted in the selection of six fat reduced samples for descriptive analysis and consumer testing.

6.3.1.2 Liver sausages

Triangle test results (**Table 6.6**) demonstrated no significant differences between both 20% fat samples as well as between both 3% fat samples. As a result, respectively one of the samples with 3% fat and with 20% fat was selected at random for subsequent sensory evaluation and consumer testing.

Table 6.6. Results of the triangle tests used to select significantly different liver sausage samples for descriptive analysis and consumer testing.

Sample comparisons		Number of correct observations [a]	P-value [b]
20%_I_CF *	20%_I_CF_RS	2	n.s.
10%_I_CF *	10%_I_CF_RS_1	7	0.001
10%_I_CF	10%_I_CF_RS_2	5	0.05
10%_I_CF_RS_1*	10%_I_CF_RS_2	3	n.s.
3%_I_CF_RS *	3%_I_CF	3	n.s.

* Samples, which were selected for sensory descriptive analysis and consumer testing. [a] Referring to the number of occasions at which the different sample in a triangle test was correctly identified, out of a possible maximum of 7 assessors. [b] Significant differences determined using the critical number (minimum) of correct answers (ISO, 2004). Identification of samples can be seen in Table 6.1.
n.s., not significant.

Triangle tests with the three liver sausage samples containing 10% fat resulted in a significant difference between sample 10%_I_CF and both samples containing rice starch. However, the samples containing rice starch were not found to differ significantly between each other. With sample 10%_I_CF_RS_2 being less significantly different to sample 10%_I_CF than sample 10%_I_CF_RS_1, sample 10%_I_CF_RS_2 was excluded from further investigations. Consequently, four fat reduced liver sausage samples were selected to be compared to the full-fat reference in the subsequent evaluations.

6.3.2 Panel quality

The previously established intensities of the open full-fat reference for each sensory descriptor, the ascertained mean values for the encoded reference obtained from ANOVA and the accordant results of Tukey’s test are shown in **Table 6.7** (Lyon-style sausages) and **Table 6.8** (liver sausages). Regarding Lyon-style sausages, a significant difference between the open reference and the encoded reference was only found in attribute greasiness. Concerning pure liver sausages mean values were found to differ slightly in four out of 26 attributes (off-flavor, sweetness, creaminess and greasiness). Regarding liver sausages on bread, significant differences were found in two out of 14 attributes (spiciness and sweetness). Hence, it can be stated that the panel delivered reproducible data, because the number of significant differences was not higher than it was expected to occur at random.

6.3.3 Sensory profiles

6.3.3.1 Lyon-style sausages

ANOVA results demonstrated significant differences ($P < 0.05$) between the seven selected Lyon-style sausages in each sensory descriptor (**Table 6.7**). **Figure 6.1** shows the PCA map, which first of all displays the Lyon-style sausage samples in relation to the accordant sensory attributes and explained 98.8% of the total variance. Attribute lumpiness was excluded from further analysis because of its low communality (0.09).

Attributes firmness, coarseness, raspy throat, spiciness, aftertaste spiciness as well as color intensity correlated negatively with principal component 1 (PC 1) (91.8%), whereas meat flavor, aftertaste meat flavor, greasiness and juiciness correlated positively with it. Both samples with 3% fat, one containing inulin and citrus fiber, and the other one containing additionally rice starch, were similar and were characterized by high intensities in the attributes that correlated negatively with PC 1. Contrariwise, the full-fat sample was described by the attributes that correlated positively with it. Samples containing inulin and citrus fiber with 10% and 17% fat were most similar to the reference sample. Hence, the chosen combination of inulin (2.5%) and citrus fiber (0.5%) for the 10% fat sample, and inulin (0.8%) and citrus fiber (0.2%) for the 17% fat sample, appeared to induce sensory properties similar to the full-fat reference, although fat was reduced by 32% or rather 60%. The fat reduced samples formulated with fat contents 10% and 17% without fat replacers (approach 1) were also relatively similar to each other. But with their medium intensities in all sensory descriptors, they are located between the 3% fat samples and the remaining three samples.

It can be concluded that fat reduction caused a decrease in meat flavor, aftertaste meat flavor, greasiness and juiciness. Contrariwise, fat reduction increased intensities in attributes firmness, coarseness, raspy throat, spiciness, spicy aftertaste and red color intensity.

Table 6.7: Defined intensities of the full-fat control and results from ANOVA and Tukey's test of the Lyon-style sausages, showing means and significance for each attribute.

		Sample							
Property	Attribute	Control	R	17%_LM	17%_I_CF_1	10%_LM	10%_I_CF_1	3%_I_CF_RS	3%_I_CF_1
Appearance	Color intensity	0.0^{a}	0.3^{a}	1.6^{b}	1.8^{b}	2.3^{c}	1.9^{bc}	4.6^{d}	4.7^{d}
Flavor / taste	Meat flavor	4.0^{c}	3.8^{c}	2.6^{b}	2.9^{b}	2.3^{b}	2.7^{b}	1.2^{a}	1.1^{a}
	Spiciness	1.0^{a}	1.1^{a}	2.3^{b}	2.3^{b}	2.3^{b}	2.4^{b}	3.8^{c}	3.8^{c}
	Aftertaste meat flavor	2.0^{de}	2.2^{e}	1.2^{c}	1.5^{cd}	1.2^{bc}	1.6^{cde}	0.6^{a}	0.6^{ab}
	Aftertaste spiciness	0.0^{a}	0.4^{a}	1.8^{b}	1.7^{b}	1.9^{b}	1.9^{b}	3.0^{c}	3.1^{c}
Texture / mouth feel	Firmness	1.0^{a}	1.1^{a}	3.0^{c}	2.0^{b}	3.3^{cd}	1.0^{a}	4.2^{e}	3.6^{d}
	Juiciness	4.0^{d}	3.9^{d}	2.3^{b}	3.3^{c}	2.2^{ab}	3.9^{d}	1.6^{a}	2.2^{ab}
	Coarseness	1.0^{a}	0.8^{a}	1.8^{bc}	1.3^{ab}	1.7^{bc}	0.8^{a}	2.7^{d}	2.2^{cd}
	Greasiness	5.0^{e}	4.3^{d}	2.5^{b}	3.4^{c}	2.4^{b}	3.9^{cd}	1.4^{a}	1.7^{a}
	Raspy throat	0.0^{a}	0.3^{ab}	1.6^{cd}	1.0^{bc}	1.5^{cd}	1.0^{bc}	2.4^{e}	1.9^{de}
	Lumpiness	1.0^{abc}	1.3^{cd}	1.8^{d}	1.2^{bc}	1.5^{cd}	0.9^{abc}	0.5^{a}	0.5^{ab}

$^{a-e}$ Means followed by the same letters within a row did not differ significantly ($P < 0.05$) (Tukey's test). Intensities were scored on a six-point categorical scale. Identification of samples can be seen in Table 6.1.

Several authors also found lower fat sausages to be darker, darker red or rather more intensive in color (Claus & Hunt, 1991; Grigelmo-Miguel et al., 1999; Nowak et al., 2007; Solheim, 1992; Ventanas, Puolanne, & Tuorila, 2010). The darker red color presumably resulted from the increased lean meat content, the lack of fat due to its whitening property (Dunkley, 1982) and partially due to higher water/ice contents (Jiménez-Colmenero, 1996). It could also be explained by a reduction in the overall light scattering due to the scattering properties of fat (Pietrasik & Duda, 2000).

Fat is known to affect juiciness (Pearson, Asghar, Gray, & Booren, 1987) and an increasing effect of fat on juiciness in meat products has already been reported (Ruusunen et al., 2003; Ventanas et al., 2010). Higher greasiness scores in higher-fat sausages were expected and were also found by Solheim (1992). Higher intensities in attributes coarseness and raspy throat in the lower fat sausages probably occurred as a result of lower juiciness and greasiness scores due to a drier mouth feel.

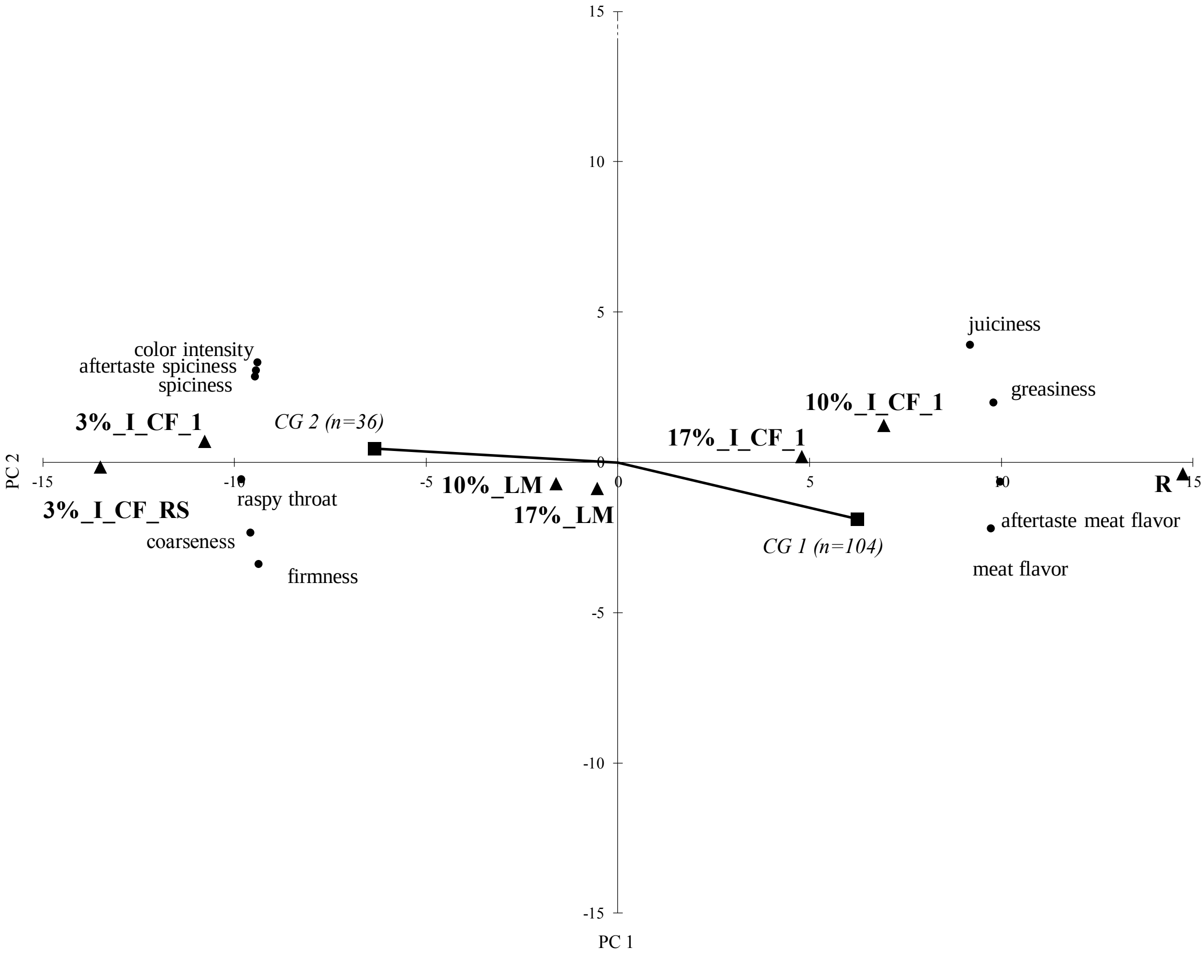

Figure 6.1: Parameter loadings and factor scores for principal component 1 (PC 1) (91.8%) and principal component 2 (PC 2) (7.0%) showing the relation between descriptive data and overall liking for the seven selected Lyon-style sausages. Samples and sensory descriptors, as well as consumer classes obtained from latent class segmentation, which were treated as supplementary data, are displayed. Identification of samples can be seen in Table 6.1. Attribute definitions can be seen in Table 6.3. CG, consumer group; n, number of consumers.

Firmness increases when fat is reduced with concomitant increases in the meat content (Weiss et al., 2010). Our results concerning firmness are consistent with the findings of other researchers (Barbut & Mittal, 1996; Keeton, 1994; Mendoza, García, Casas, & Selgas, 2001;

Nowak et al., 2007; Selgas et al., 2005; Solheim, 1992). However, contradictory results were found by several authors, assuming a decrease in firmness or hardness, following from higher water contents or rather moisture levels (Claus & Hunt, 1991; Claus, Hunt, & Kastner, 1990; Cofrades, Guerra, Carballo, Fernández-Martín, & Colmenero, 2000; García et al., 2007; Gregg, Claus, Hackney, & Marriott, 1993; Jimenez-Colmenero, Barreto, Mota, & Carballo, 1995).

The intensity of meat flavor and meat flavor aftertaste decreased with decreasing fat, but on the opposite, spicy flavor increased. There are studies with oppositional results, showing decreased sensory flavor intensities in meat products at reduced fat content such as meat flavor and aftertaste (Jiménez-Colmenero, 2000; Krickmeier & Schnäckel, 2008; Ventanas et al., 2010) or increased sensory scores such as attributes smoky, spicy, salty and overall flavor intensity (Chevance & Farmer, 1998; Crehan, Hughes, Troy, & Buckley, 2000; Hughes et al., 1997; Hughes, Mullen, & Troy, 1998; Solheim, 1992), which is consistent with our findings. Changes in the flavor strength and the duration of flavor perception are amongst others associated with the amount of the flavor carrier fat, with variations in the water/fat ratio due to the physico-chemical properties of flavorants and their distribution in the aqueous/lipid phase of a food, as well as due to changes in the concentration of odor and taste active compounds (Carrapiso, 2007; De Roos, 1997; Shamil, Wyeth, & Kilcast, 1991/1992). The effect of fat on the release of aroma compounds depends strongly on polarity, because greater effects of fat were found on lipophilic compounds than on hydrophilic compounds (Arancibia, Jublot, Costell, & Bayarri, 2011; Guinard, Wee, McSunas, & Fritter, 2002; Ventanas et al., 2010). With fat acting as a solvent for lipophilic volatile flavor compounds, the release of the accordant flavors is delayed in high fat foods and lipophilic compounds are released faster and more intensive with decreasing fat content (Brauss, Linforth, Cayeux, Harvey, & Taylor, 1999; Chevance & Farmer, 1999a; Frank, Appelqvist, Piyasiri, & Delahunty, 2012; Miettinen, Hyvönen, Linforth, Taylor, & Tuorila, 2004; Roberts, Pollien, Antille, Lindinger, & Yeretzian, 2003). Chevance and Farmer (1999a) found fat mainly affecting monoterpene and sesquiterpene hydrocarbons, terpenes containing oxygen, cyclopentenones, phenyl propanoids and phenols, which were earlier found to be derived from spices or smoke (Chevance & Farmer, 1999b). Furthermore, higher intensities in the descriptors spiciness, peppery and smoky were found for low-fat frankfurters, explained by a more rapid release of lipophilic terpenes, phenols and other compounds with fat reduction (Chevance & Farmer, 1998), which therefore could explain the increasing spiciness in the reduced fat Lyon-style sausages. Contrariwise, those flavor compounds, which are responsible for the meat flavor, are assumed to be hydrophilic, because meat flavor and meat flavor aftertaste were lower with fat reduction.

Moreover, changes in the fat content affect or rather fat reduction reduces emulsion stability (Jiménez-Colmenero, 1996; Marquez, Ahmed, West, & Johnson, 1989) and this effect could change interactions among components that are involved in emulsion stability and odorants (Carrapiso, 2007). Ventanas et al. (2010) furthermore assumed a coating effect of high amounts of fat in the mouth, which hinders flavor perception. Flavor strength and the duration of flavor perception are also known to be affected by texture properties. Guinard et al. (2002) explained lower garlic flavor intensities of higher fat salad dressings by a thicker and more viscous texture, because it takes more time to fully break down the fat matrix and therefore to release all the oil-soluble garlic flavor. Another explanation for a diminished flavor release could be mass transport, which is affected by a higher viscosity and would inhibit flavor release (De Roos, 1997).

The addition of inulin and citrus fiber seemed to reduce the changes in sensory properties caused by fat reduction. Inulin for instance is able to give meat products a creamier and juicier mouth feel (Franck, 2002). Other researchers found a softening effect of fibers or rather fruit fibers (García et al., 2007; Grigelmo-Miguel et al., 1999) and inulin (Selgas et al., 2005). An explanation for this could be that dietary fibers probably disrupt the protein-water or protein-protein gel network, resulting in decreased gel strength (Lin, Keeton, Gilchrist, & Cross, 1988).

However, samples containing fibers were still less juicy and greasy, weaker in meat flavor as well as stronger in color intensity, spiciness, coarseness, raspy throat and firmness. As coarseness is comparable to graininess, our results are comparable to the findings of Claus and Hunt (1991), who found fiber-containing bolognas to be grainier and less juicy than the high-fat counterparts, and explained lower juiciness intensities by increased graininess, because a drier sausage could cause less hydrated fiber which is more detectable. Regarding flavor, studies already indicated that flavor qualities of low-fat meat products could be assisted by carbohydrate-based fat replacers in terms of delaying the release of odor compounds (Chevance et al., 2000).

6.3.3.2 Liver sausages

Results from ANOVA (**Table 6.8**) revealed significant differences between the pure liver sausage samples in all the attributes with the exception of attributes porous, off-odor, meat flavor, spiciness (taste), saltiness, sourness and graininess, which were as a results excluded from PCA. **Figure 6.2** displays the PCA plot, showing the pure liver sausages and their descriptive attributes. It explained 93.6% of the total variance. PC 1 (84.2%) was represented by attributes greasiness, creaminess, lumpiness (appearance and texture), sweetness, foamy and off-flavor, which correlated negatively with it. The odor attributes as well as attributes color intensity, firmness, furred tongue and the remaining flavor attributes correlated positively with PC 1. PC 2 (9.4%) was described by attribute spreadability and correlated negatively with it. **Figure 6.2** shows that fat reduced samples differed strongly from the full-fat reference, which was characterized by attributes correlating negatively with PC 1. The low-fat sample (3%) and both 10% fat samples were relatively similar and they were mainly described by attributes correlating positively with PC 1. The sample with a fat content of 20% is displayed between the reference and the other samples and was most similar to the reference. It was characterized by spreadability as well as by medium intensities in attributes correlating with PC 1, but more intensive by those attributes correlating negatively with it.

As the amount of spices in the liver sausage samples was reduced with decreasing fat content, no evident effects of fat on flavor and odor attributes can be assumed, because it is not clear, how the reduction of spices affected other flavor and odor properties. Therefore, it is supposed that fat reduction in liver sausages at simultaneous addition of fibers merely decreased intensities in attributes greasiness, creaminess, lumpiness (appearance and texture) and foamy. On the opposite, intensities in red color intensity, firmness and furred tongue were enhanced. Attributes porous and graininess were unaffected by fat.

Table 6.8: Defined intensities of the full-fat control and results from ANOVA and Tukey's test of the liver sausages, showing means and significance for each attribute.

		Sample					
Property	Attribute	Control	R	20%_I_CF	10%_I_CF	10%_I_CF_RS_1	3%_I_CF_RS
Appearance	Color intensity	0.0^{a}	0.5^{a}	1.9^{b}	3.3^{c}	3.3^{c}	3.5^{c}
	Color intensity*	1.0^{a}	1.1^{a}	2.1^{b}	3.2^{c}	3.1^{c}	3.6^{c}
	Porous	2.0^{a}	2.3^{a}	2.1^{a}	2.1^{a}	1.8^{a}	2.1^{a}
	Spreadability	4.0^{b}	3.5^{ab}	4.1^{b}	3.1^{a}	3.8^{ab}	3.2^{a}
	Spreadability*	5.0^{c}	4.5^{bc}	4.2^{b}	3.5^{a}	3.9^{ab}	3.3^{a}
	Foamy	2.0^{c}	2.3^{c}	2.0^{c}	1.1^{a}	1.8^{bc}	1.3^{ab}
	A Lumpiness	3.0^{b}	3.4^{b}	1.6^{a}	1.7^{a}	1.2^{a}	1.5^{a}
	A Lumpiness *	2.0^{b}	2.6^{b}	1.0^{a}	0.8^{a}	0.9^{a}	0.5^{a}
Odor	Odor of liver	3.0^{ab}	3.0^{ab}	2.9^{a}	3.4^{ab}	3.6^{b}	3.5^{ab}
	O Spiciness	2.0^{a}	2.1^{ab}	2.5^{bc}	2.8^{cd}	2.8^{cd}	3.1^{d}
	O Metallic	1.0^{a}	1.2^{ab}	1.5^{abc}	1.8^{bc}	1.9^{c}	1.8^{bc}
	Off-odor	0.0^{a}	0.4^{ab}	0.2^{ab}	0.4^{ab}	0.2^{ab}	0.6^{b}
Flavor / taste	Liver flavor	3.0^{ab}	2.7^{a}	2.7^{a}	3.2^{ab}	3.3^{b}	3.3^{b}
	Liver flavor*	2.0^{a}	2.0^{a}	2.4^{ab}	2.6^{b}	2.8^{b}	2.6^{b}
	Meat flavor	3.0^{b}	2.3^{ab}	2.3^{ab}	2.2^{a}	2.5^{ab}	2.0^{a}
	Meat flavor*	1.0^{a}	1.3^{ab}	1.7^{bc}	1.7^{bc}	1.9^{c}	1.5^{abc}
	Aftertaste	2.0^{a}	1.8^{a}	2.0^{a}	2.4^{ab}	2.2^{ab}	2.7^{b}
	Aftertaste*	2.0^{a}	1.5^{a}	1.7^{a}	1.9^{a}	1.8^{a}	2.0^{a}
	Off-flavor	3.0^{c}	1.9^{b}	1.3^{ab}	1.0^{a}	1.1^{a}	1.4^{ab}
	Off-flavor*	2.0^{b}	1.4^{ab}	1.2^{a}	0.9^{a}	1.1^{a}	1.0^{a}
	Ta Spiciness	3.0^{a}	2.7^{a}	2.9^{a}	3.0^{a}	3.1^{a}	3.2^{a}
	Ta Spiciness*	1.0^{a}	1.6^{b}	2.6^{c}	2.8^{c}	2.6^{c}	2.9^{c}
	Peppery	2.0^{a}	2.0^{a}	2.7^{ab}	2.8^{b}	2.8^{b}	2.9^{b}
	Peppery*	2.0^{a}	1.9^{a}	2.5^{ab}	2.4^{ab}	2.5^{ab}	2.8^{b}
	Saltiness	2.0^{a}	1.8^{a}	1.9^{a}	2.2^{a}	2.2^{a}	2.0^{a}
	Saltiness*	1.0^{a}	1.3^{ab}	1.5^{abc}	1.8^{c}	1.9^{c}	1.8^{bc}
	Sourness	1.0^{a}	0.9^{a}	0.9^{a}	1.2^{a}	1.2^{a}	1.4^{a}
	Sourness*	1.0^{a}	1.2^{a}	1.2^{a}	1.4^{a}	1.3^{a}	1.4^{a}
	Sweetness	2.0^{c}	1.5^{b}	1.2^{ab}	0.9^{a}	1.1^{ab}	1.0^{ab}
	Sweetness*	3.0^{b}	1.8^{a}	1.4^{a}	1.1^{a}	1.3^{a}	1.3^{a}
	Bitterness	0.0^{a}	0.3^{ab}	0.6^{bc}	0.8^{bc}	0.9^{c}	0.9^{c}
	Bitterness*	0.0^{a}	0.4^{ab}	0.7^{bc}	0.8^{bc}	1.0^{c}	0.9^{bc}
	Ta Metallic	1.0^{a}	0.9^{a}	1.2^{ab}	1.4^{ab}	1.6^{ab}	1.7^{b}
	Ta Metallic	0.0^{a}	0.4^{ab}	0.8^{bc}	1.1^{bc}	1.3^{c}	1.2^{c}
Texture / mouth feel	Furred tongue	1.0^{a}	1.3^{ab}	1.5^{abc}	1.7^{bc}	1.8^{c}	1.8^{c}
	Firmness	1.0^{a}	1.3^{a}	2.1^{b}	3.0^{c}	3.0^{c}	3.3^{c}
	Creaminess	5.0^{d}	4.3^{c}	3.5^{b}	2.5^{a}	2.2^{a}	2.0^{a}
	Greasiness	5.0^{d}	4.3^{c}	3.4^{b}	2.3^{a}	2.3^{a}	2.0^{a}
	Te Lumpiness	3.0^{b}	2.9^{b}	1.1^{a}	0.8^{a}	1.0^{a}	0.5^{a}
	Graininess	3.0^{b}	2.8^{ab}	2.3^{a}	2.6^{ab}	2.3^{a}	2.4^{a}

[a-d] Means followed by the same letters within a row did not differ significantly ($P < 0.05$) (Tukey's test). *Attributes that were evaluated on a piece of bread. Intensities were scored on a six-point categorical scale. Identification of samples can be seen in Table 6.2.

A, appearance; O, odor; Ta, taste; Te, texture.

Little research has been reported concerning the effect of fat in liver sausages. However, Chyr et al. (1980) already described that the color of liver sausages was lightened with increasing fat content. Reasons for increased red color intensity as well as decreased greasiness and increased firmness, caused by fat reduction, were already discussed concerning the Lyon-style sausages (see Section 6.3.3.1). Fat is known to contribute to creaminess (Frøst & Janhøj, 2007) and therefore decreased creaminess scores with fat reduction were expected. Lower lumpiness scores may result from lower pork fat contents because the visual and perceived lumps presumably concerned to fat lumps. Enhanced scores in attribute furred tongue in the fat reduced samples possibly arose due to lower creaminess and greasiness scores, caused by a drier mouth feel.

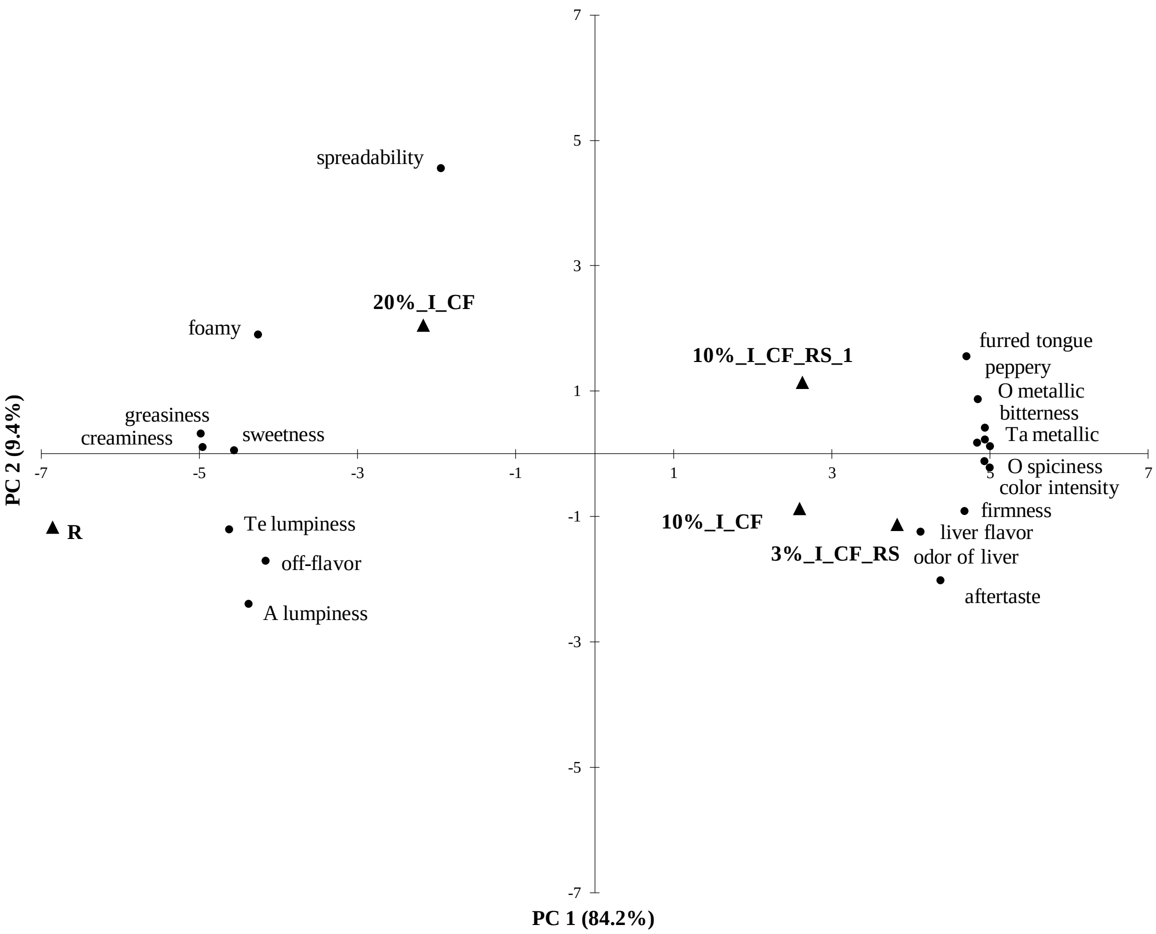

Figure 6.2: Parameter loadings and factor scores for principal component 1 (PC 1) and principal component 2 (PC 2) showing the relation between the five selected liver sausage samples and the accordant sensory attributes for the evaluation of pure liver sausages. Identification of samples can be seen in Table 6.2. Attribute definitions can be seen in Table 6.4. A, appearance; O, odor; Ta, taste; Te, texture.

Although no clear effects of fat on flavor and odor can be stated due to changes in the amount of spices with fat reduction, potential effects of fat on flavor and odor are discussed. As no significant effect arose in spicy taste, and as spiciness (odor) was significantly higher in the fat reduced liver sausages, although the amount of spices was reduced with decreasing fat content, an increasing effect of fat reduction on spiciness is supposed. Spicy odors were previously found to be more intensive in low-fat than in full-fat frankfurters (Chevance & Farmer, 1999a), which is consistent with our findings. They assumed that the release of aroma compounds was related to the solvation in the lipid phase.

With decreasing fat and quantity of spices, intensities in attributes sweetness and off-flavor decreased, whereas attributes metallic (odor) and odor of liver as well as flavor descriptors peppery, bitterness, metallic, liver flavor and aftertaste were enhanced. The effect of fat on the perception of flavors, such as spiciness, was already discussed for the Lyon-style sausages (see Section 6.3.3.1). Shamil et al. (1991/1992) furthermore supposed higher perceived bitterness with fat reduction due to the tendency of bitter compounds to be hydrophobic and to reside in a lipophilic environment. This effect is also supposed to be related to attributes peppery and saltiness. The off-flavor, which was higher in high-fat liver sausages, was described by the panel as a cinnamon/cardamom flavor. The higher scores probably occurred due to the higher amount of spices in samples with higher amounts of fat, because the spice mix contained cinnamon. Furthermore, a relation between this cinnamon/cardamom off-flavor and sweetness is assumed, because cinnamon is suggested to exhibit sweetness properties (Blank & Mattes, 1990).

ANOVA results of the evaluation of liver sausage on a piece of bread indicated that samples did not differ significantly concerning the attributes aftertaste, off-flavor, sourness, sweetness and bitterness (**Table 6.8**), which may be attributed to a neutralization effect caused by the wheat-rye bread. Consequently, further statistical analyses were conducted without these descriptors.

Figure 6.3 visualizes the relation between the evaluated liver sausage samples on a piece of bread and the accordant sensory descriptors. The PCA plot explained 94.9% of the total variance. Attributes lumpiness (appearance) and spreadability correlated negatively with the first dimension (86.5%), while flavor attributes metallic, saltiness, liver flavor, spiciness, peppery and meat flavor, as well as color intensity, correlated positively with it.

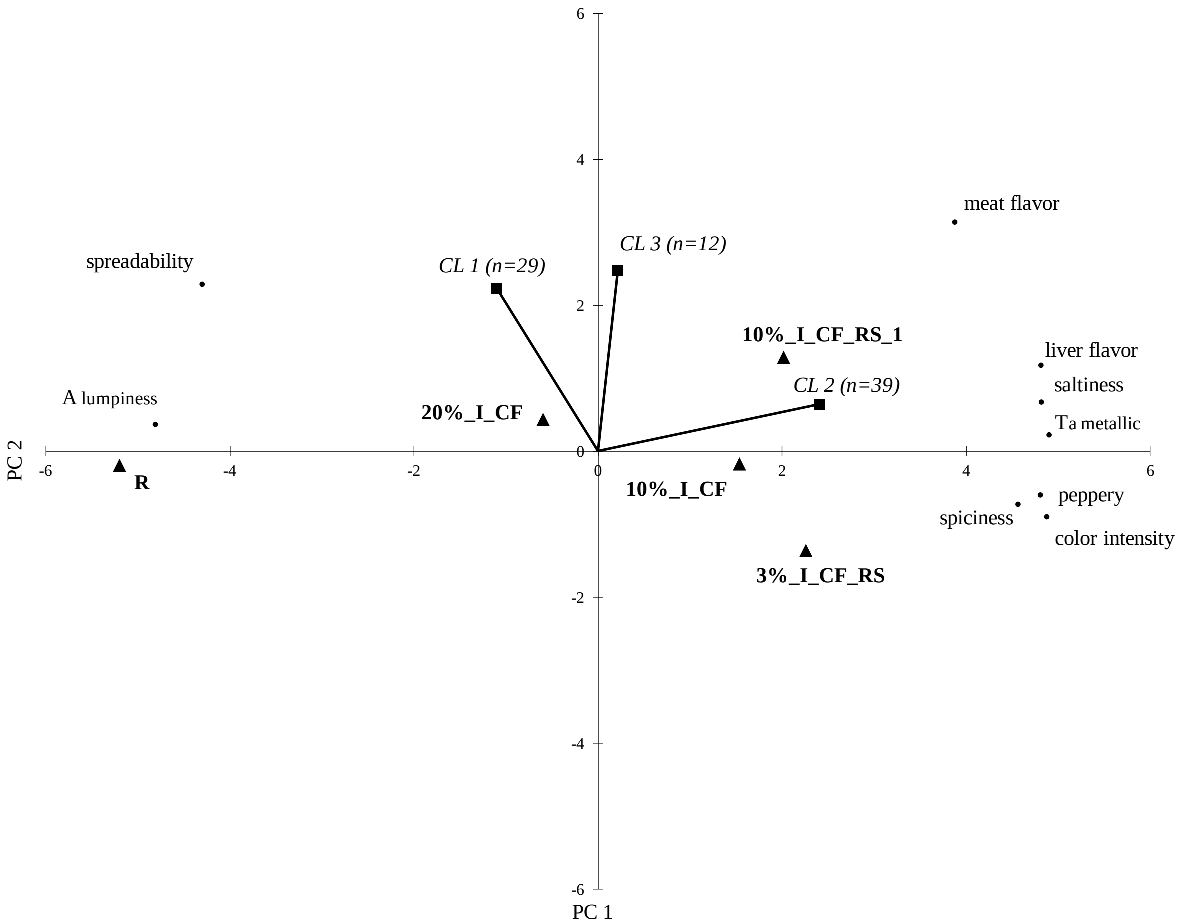

Figure 6.3: Parameter loadings and factor scores for principal component 1 (PC 1) (86.5%) and principal component (PC 2) (8.4%) relating descriptive and overall liking data of the five liver sausages for the evaluation of liver sausages on a piece of bread. Samples, sensory attributes and consumer clusters, obtained from cluster analysis, which were treated as supplementary data, are displayed. Identification of samples can be seen in Table 6.2. Attribute definitions can be seen in Table 6.4. CL, cluster; n, number of consumers; A, appearance; Ta, taste.

On a piece of bread, the fattier samples (20%_I_CF and especially the reference), were mainly described by visual lumpiness and spreadability. The other fat reduced samples were similar to each other and were associated with color intensity and the flavor attributes. The comparison of the evaluation of pure liver sausages and liver sausages on a piece of bread yielded, that some attributes did not differ significantly in pure liver sausage but on a piece of bread (meat flavor, saltiness and spiciness (taste)) and *vice versa* (bitterness, aftertaste, sweetness and off-flavor). Attribute sourness did not show significant differences neither in pure liver sausage nor on a piece of bread. Bitterness, aftertaste, sweetness and off-flavor as well as texture and odor properties consequently did not play a decisive role for liver sausages on a piece of bread. On the opposite, meat flavor, saltiness and spiciness intensities were perceived more intensive with fat reduction and addition of fibers when consuming liver sausages on bread.

6.3.4 Consumers' acceptability

6.3.4.1 Lyon-style sausages

The AIC of the latent class regression indicated a two-class solution. **Table 6.9** summarizes the overall liking means for the two obtained consumer groups. The first group included the greater proportion of the consumers (n=104), whereas consumer group 2 consisted of the remaining 36 assessors.

Besides explaining the relation between the samples and the sensory attributes, the PCA map shown in **Figure 6.1** furthermore displays the relationship between descriptive and overall liking data of the Lyon-style sausages. Most consumers (consumer group 1, n=104) liked the samples with 17% and 10% fat with added inulin and citrus fiber the best, followed by the sample with 10% fat without additives, and the reference. Moreover, they rejected both low-fat (3%) samples the most. Summarizing up, the preferred sausages featured medium to high intensities in the attributes juiciness, greasiness and meat flavor. Too dark red, spicy, coarse and firm Lyon-style sausages, causing a raspy throat were disliked. Positive correlations between meat flavor and overall acceptability were also found by Homer et al. (2000). Solheim (1992) also found juiciness to be important for the acceptance of fat reduced sausages. The smaller group of consumers (consumer group 2, n=36) preferred the 10% fat sample without fat replacers and the 3% fat sample containing inulin, citrus fiber and rice starch, and liked the full-fat reference the least. Differences in liking were not significant between the remaining samples. Thus, there were also consumers preferring darker red, firmer, more spicy and coarse samples, being less juicy, greasy with lower meat flavor intensity.

Table 6.9: Overall mean liking scores for the evaluated seven Lyon-style sausage samples derived from Latent class regression model for a two-class solution.

Sample	R	17%_LM	17%_I_CF_1	10%_LM	10%_I_CF_1	3%_I_CF_RS	3%_I_CF_1
Consumer group 1 (n=104)	6.4^{b}	7.2^{c}	7.4^{c}	6.5^{b}	6.7^{bc}	5.5^{a}	5.5^{a}
Consumer group 2 (n=36)	3.9^{a}	4.3^{ab}	5.1^{ab}	5.8^{b}	4.8^{ab}	5.4^{b}	5.0^{ab}

$^{a\text{-}c}$ Means followed by the same letters within a row did not differ significantly (P < 0.05) (Tukey's test).
Overall liking was scored on a nine-point hedonic scale. Identification of samples can be seen in Table 6.1.
n, number of consumers.

Previous studies, at which fruit fibers (0.9 to 3.9%) or inulin (2.5% to 7.5%) were incorporated into sausage formulations to achieve energy or rather fat reductions of about 30% to 40%, resulted in good acceptability scores (García et al., 2006, 2007; García et al., 2002; Grigelmo-Miguel et al., 1999; Selgas et al., 2005). In comparison, our results revealed good acceptability scores for sausages, which had 32% to 60% or rather 88% less fat than the full-fat control, with fiber amounts of 1% to 3.25%.

6.3.4.2 Liver sausages

Cluster analysis revealed three consumer clusters with the first cluster consisting of 29 consumers, the second cluster consisting of 39 assessors and the third cluster including the remaining twelve participants. The correspondent mean overall liking scores are shown in **Table 6.10**. **Figure 6.3** visualizes the relation between consumer's data obtained from cluster analysis and descriptive data of the evaluation of liver sausages on a piece of bread. Cluster 1 (n=29) did not distinguish in liking between the samples with the exception of the least-liked low-fat (3%) sample and the best-liked full-fat reference. As a result, samples with higher intensities in attributes spreadability and lumpiness, lower intensities in all the flavor attributes and a light red color seemed to be preferred. In contrast, cluster 2 (n=39) liked the 10% fat sample containing inulin and citrus fiber best, followed by the other fat reduced samples and the least-liked full-fat reference. This clustered group showed preferences for higher intensities in red color intensity, meat flavor, liver flavor, metallic, saltiness, peppery and spiciness and for lower intensities in spreadability and visual lumpiness. Cluster 3 (n=12) liked the 10% sample with inulin, citrus fiber and rice starch the best, but could not distinguish in liking between the other samples. However, due to the low number of respondents, these results were presumably caused by chance.

Table 6.10. Overall mean liking scores for the evaluated five liver sausage samples for the three clusters derived from cluster analysis.

Sample	R	20%_I_CF	10%_I_CF	10%_I_CF_RS_1	3%_I_CF_RS
CL 1 (n=29)	6.8[b]	6.2[ab]	6.2[ab]	6.2[ab]	5.5[a]
CL 2 (n=39)	3.5[a]	5.7[b]	7.2[c]	6.0[b]	5.9[b]
CL 3 (n=12)	3.8[a]	4.9[a]	3.5[a]	6.7[b]	5.6[a]

[a-c] Means followed by the same letters within a row did not differ significantly ($P < 0.05$) (Tukey's test).
Overall liking was scored on a nine-point hedonic scale. Identification of samples can be seen in Table 6.2.
CL, cluster; n, number of consumers.

The results demonstrate that there are two different consumer groups, one preferring full-fat liver sausages and the other one liking lower-fat samples best. However, acceptable fat reduced liver sausages (33% to 90% fat reduction), enriched in fiber (2.4% to 5.6%) were produced, highlighting the 10% fat samples, which reached high liking scores in all groups.

6.4 Conclusions

The addition of inulin, citrus fiber (and rice starch) offers potential to produce acceptable Lyon-style sausages with fat contents reduced by 32% to 88%, and liver sausages with fat contents reduced by 33% to 90%, possessing lower fat contents than most established light variants of Lyon-style and liver sausages on the German market and being enriched in fiber (1.0% to 5.6%).

For most consumers, the drivers of liking were associated with samples high in fat content, which could partially be imitated by the added fibers. Nevertheless, there were also consumers that preferred attributes characterizing samples low in fat content. In summary, medium fat Lyon-style and liver sausages were liked best. Further research will be addressed to study the effect of spices and salt on sensory attributes and preference of fat reduced sausages in order to adapt meat formulations with health promoting fiber.

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7 Concluding remarks, practical applicability and outlook

7.1 Concluding remarks

This work studied the effects of fat and fat reduction on the sensory properties and consumers' acceptability of different popular meat and dairy products. **Figure 7.1** summarizes the main results of the sensory studies on yoghurt (Chapter 2 and 4), vanilla custard (Chapter 5) as well as Lyon-style and liver sausages (Chapter 6), which were previously discussed in detail.

7.1.1 Comparing the effects of fat on the sensory properties of the different matrices

Figure 7.1 summarizes the various effects of fat on sensory attributes depending on the matrix by means of showing those attributes on which fat had a decreasing/increasing effect as well as those sensory descriptors, which were unaffected. **Figure 7.2** furthermore illustrates the effect of fat on the main sensory attributes of the different products.

Regarding *yoghurt*, fat increased 'fat-related attributes' creamy (flavor and texture), viscous (appearance and texture) and fatty mouth feel. Furthermore, a quadratic relation of fat was found for attributes color and grainy (appearance and texture) and 'typical yoghurt attributes' (sour, aromatic and astringent). However, these effects of fat were furthermore found to correlate with the casein-to-whey protein ratio (Chapter 2), which implied lowest scores in graininess and color as well as highest scores in 'typical yoghurt attributes' at high casein-to-whey protein ratios and high fat contents, as well as the opposite effect at low casein-to-whey protein ratios and low fat contents. Regarding **Figure 7.2a**, intensities in 'typical yoghurt attributes' in summary increased from 0.1% to 3.5% fat, but decreased from 3.5% to 12.0% fat. Graininess and yellow color decreased from 0.1% to 3.5% fat, and increased from 3.5% to 12.0% fat. However, these effects may also be explained by simultaneous variations in protein and the casein-to-whey protein ratio. Attributes off-flavor, furred tongue and slimy differed between the yoghurt samples, but no obvious effect of fat could be determined.

Concerning *vanilla custards* (**Figure 7.2b**), fat had an increasing effect on descriptors thick (appearance and texture), creamy flavor and 'fat-related attributes' (sticky, fatty and creamy texture), as well as a decreasing effect on attributes color (yellowness), surface shine, jelly, and the 'pudding-like flavor' descriptors cooked, vanilla and harmonious. However, 'pudding-like flavor' increased from 0.1% to 1.5% fat, but decreased from 1.5% to 15.8%.

Figure 7.1: Main results of the studies on yoghurt, vanilla custard, Lyon and liver sausages
A, appearance; TE, texture; FL, flavor; O, odor; ↑, increasing effect of fat; ↓, decreasing effect of fat; DoL, drivers of liking; DoD: drivers of disliking; *c/w*, casein-to-whey protein ratio, Quadr., quadratic.

Jelly texture decreased from 0.1% to 3.5% and remained nearly constant from 3.5% to 15.8% fat. Color and surface shine intensities decreased from 0.1% to 8.6% and remained almost constant from 8.6% to 15.8% fat. No significant differences were found between the custards in attributes vanilla odor and sweet, whereas the skin formation varied between the custard samples but without an evident effect of fat.

In *Lyon-style sausages* (**Figure 7.2c**), fat raised the intensities of the 'high-fat attributes' (meat flavor and meat flavor aftertaste as well as texture descriptors greasiness and juiciness). The 'low-fat attributes' (red color intensity, flavor descriptors spiciness and spiciness aftertaste as well as texture attributes raspy throat, coarseness and firmness) decreased with increasing fat content. However, differences between 10.0% and 17.0% fat were marginal.

With regard to *liver sausages* (**Figure 7.2d**), 'high-fat attributes' (off-flavor, sweetness, greasiness, creaminess (texture), lumpiness (appearance and texture), and foamy (appearance)) were increased by fat. On the opposite, an increase in fat resulted in a decrease in 'low-fat attributes' (red color intensity, odor attributes spicy, liver and metallic, flavor descriptors liver, aftertaste, peppery, bitterness and metallic, and also texture attributes firmness and furred tongue). Differences between 3.0% and 10.0% fat were very small. Descriptor spreadability differed between the liver sausages but could not be attributed to a difference in the fat content. No significant differences were found between the samples in attributes porous (appearance), off-odor, meat flavor, saltiness, sourness and graininess. Same regarded to spiciness (flavor), but as the amount of spices was reduced with decreasing fat content, a decreasing effect of fat on spiciness is supposed. Consequently, the various effects of fat or rather fat reduction on the sensory properties of the different food matrices are supposed to be product-specific.

Creamy texture was increased by fat in yoghurt, custard and liver sausages, but generally did not appear in Lyon-style sausages. Creaminess is a key attribute of many semi-solid foods, particularly of dairy products (Kokini, 1987). Attribute *viscous* (in yoghurt) and attribute *thick* (in custard), which are comparable, were raised by fat in both products. Regarding the sausages, *firmness*, which is comparable to attributes viscous and thick, was on the contrary decreased by fat. The decreasing effect of fat on firmness in the sausages may be explained by the effect of fat to reduce friction and/or binding among meat particles causing a reduction in hardness (Barbut & Mittal, 1996). Regarding the dairy products, the lubricating and coating properties of fat (de Wijk, van Gemert, Terpstra, & Wilkinson, 2003) are supposed to be responsible for an increased viscosity or rather thickness at increased fat contents.

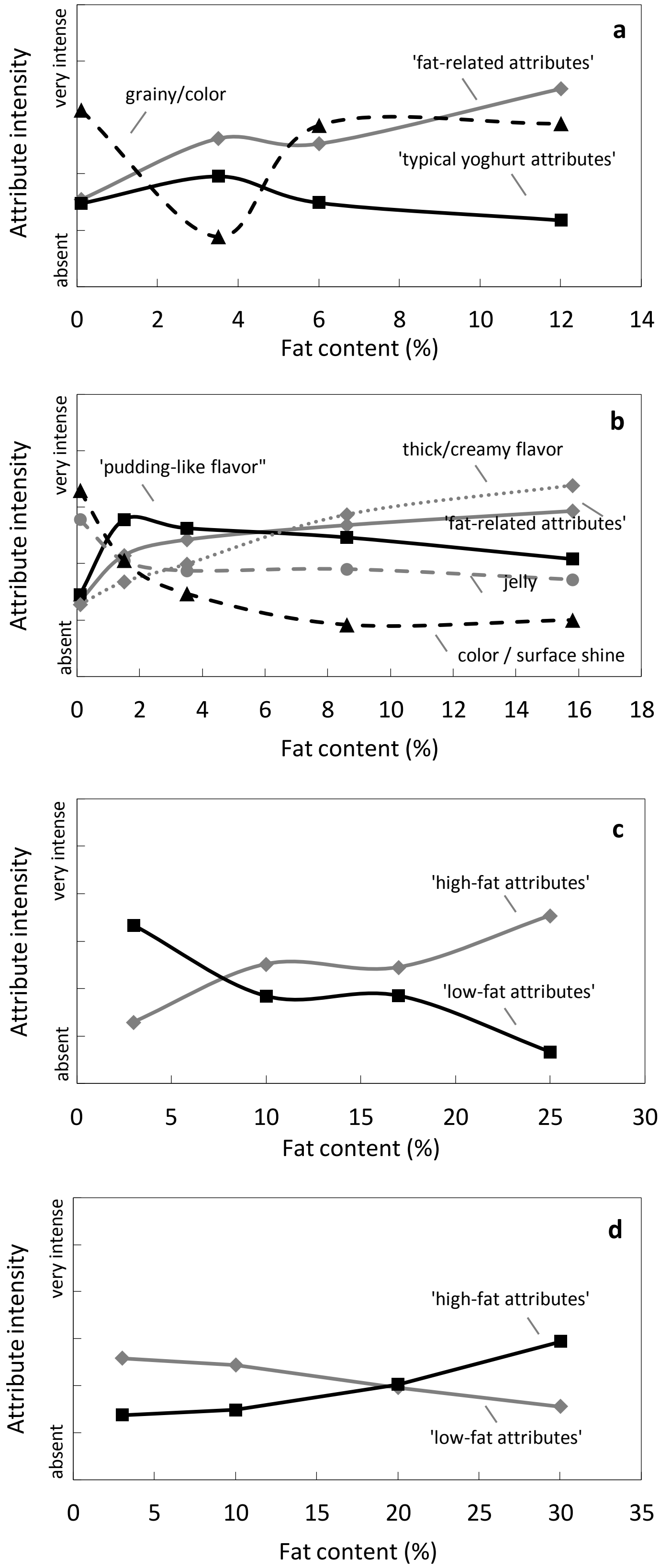

Fig. 7.2: Schematic illustration of the effects of fat on the main sensory properties of the evaluated plain stirred yoghurts (a), vanilla custards (b), Lyon-style sausages (c) and liver sausages (d), based on the results from chapter 2, 5 and 6. Data of samples with the same fat content were combined to an average value. Attributes, which were found to correlate in previous PCAs, were summarized to an average value.

Attributes *fatty mouth feel* (yoghurt) and accordingly *fatty* (custard) or rather *greasy* (sausages) were increased with increasing fat content in all four product types, which is self-explanatory. Comparing the *color* properties of the products, it is observable that *yellowness* (custard) or rather *red color intensity* (sausages) decreased with increasing fat content. Hence, the higher the fat content, the weaker the color intensity or rather the brighter the color of a product. These effects of fat can be explained by a reduction in the overall light scattering due to the scattering properties of fat globules (Pietrasik & Duda, 2000). Regarding yoghurt, fat exerted influence on yellowness by means of a quadratic relation and an interaction with the casein-to-whey protein ratio. The interaction implied lowest scores in yellow color at high fat and high casein-to-whey protein ratios, as well as the opposite effect at low casein-to-whey protein ratios and low fat contents. However, the casein-to-whey protein ratio had a higher effect (Chapter 2). Consequently, the effect of fat on color cannot be considered separately. Attribute *off-flavor* was not affected by fat in yoghurt, was irrelevant for custard and Lyon-style sausages, but increased in liver sausages with increasing fat content. However, this effect presumably occurred due to an increased amount of spices in the sausages with increased fat contents (Chapter 6). Descriptor *furred tongue*, which was irrelevant for vanilla custard and Lyon-style sausages, was not affected by fat in yoghurt, but decreased with increasing fat content in liver sausages. This effect was assumed to appear due to simultaneous moderate creaminess and greasiness intensities at low-fat contents, which possibly caused a drier mouth feel. The direction of the effect of fat on '*product-related'* flavor attributes varied between the different food matrices. In yoghurt, fat exerted influence on attributes sour and aromatic by means of a quadratic relation and an interaction with the casein-to-whey protein ratio, which implied highest scores in attributes sour and aromatic at high fat contents and simultaneous high casein-to-whey protein ratios, as well as the opposite effect at low casein-to-whey protein ratios and low fat contents. However, the casein-to-whey protein ratio had the main effect on descriptors sour and aromatic (Chapter 2). Therefore, the effect of fat on attributes sour and aromatic cannot be regarded separately. In vanilla custards, the 'pudding-like flavor' attributes cooked, vanilla and harmonious decreased with increasing fat content. In Lyon-style sausages, meat flavor was increased with increasing fat content but spiciness was decreased. Regarding liver sausages, sweetness was increased by fat, whereas attributes liver and spicy flavor, peppery, bitter and metallic were decreased. Creamy flavor increased with increasing fat content in yoghurt and vanilla custard, but was irrelevant for the meat products because creamy flavor especially appears in dairy products and is caused by milk fat (Dunkley, 1982). Basically, fat contributes a flavor on its own, acts as a solvent for various aroma compounds and slows the release of flavor compounds, which affects the intensity, the duration and the balance of other flavors (Frost & Janhoj, 2007; Lucca & Tepper, 1994). Variations in the effects of fat on flavor release of different flavor properties can be ascribed to polarity, because greater effects of fat were found on lipophilic compounds than on hydrophilic compounds (Arancibia, Jublot, Costell, & Bayarri, 2011; Guinard, Wee, McSunas, & Fritter, 2002; Ventanas et al., 2010).

7.1.2 Comparing the effects of fat on liking of the different matrices

The main acceptability results of the different studies on yoghurt, vanilla custard, Lyon-style and liver sausages are summarized in **Figure 7.1** and the effects of fat on liking are furthermore illustrated in **Figure 7.3**.

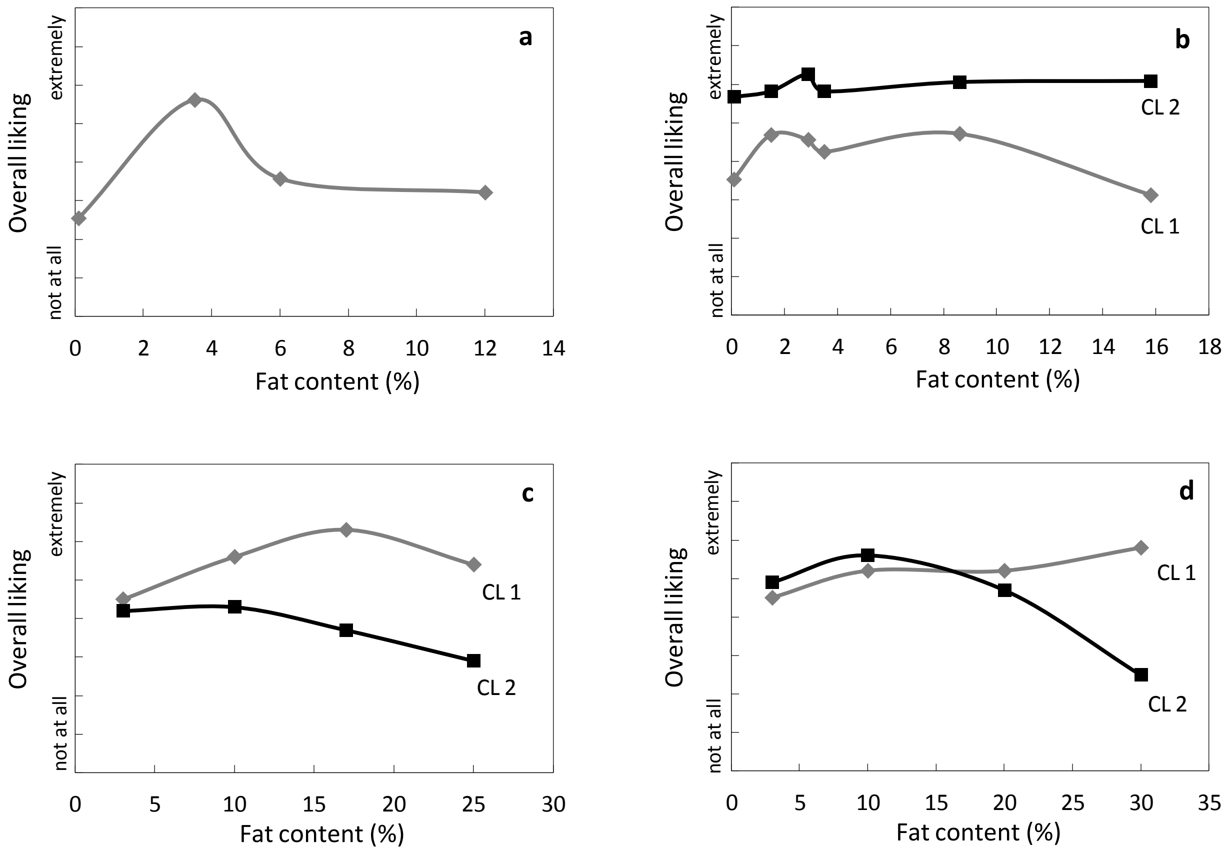

Fig. 7.3: Schematic illustration of the changes in the overall liking in relation to the fat content of the evaluated plain stirred yoghurts (a), vanilla custards (b), Lyon-style sausages (c) and liver sausages (d), based on the results from chapter 4, 5 and 6. Data of samples with the same fat content were combined to an average value. Liking data of yoghurt was transformed from a seven-point-hedonic scale to a nine-point-hedonic scale. CL, cluster.

In summary, liking scores were best for samples with medium fat contents regarding all products. Liking for *yoghurt* was best at medium fat (3.5%), followed by the high-fat variants (6.0% and 12.0%) and the least liked non-fat (0.1%) sample (**Figure 7.3a**). Best acceptability results for *vanilla custard* mainly varied between low-fat (1.5%) and medium fat (2.9% to 8.6%) samples, whereas non-fat (0.1%) custards were in summary liked the least. High-fat (15.8%) custards were disliked by consumer cluster 1, but were preferred by cluster 2 (**Figure 7.3b**). Regarding *both sausages types*, besides preferences for medium fat sausages (10.0% and 17.0%), good liking results were partially also found for the low-fat (3.0%) and the high-fat (25.0% or 30.0%) variants, depending on the different consumer clusters (**Figure 7.3c/d**). Regarding Lyon-style sausages, liking of cluster 1 (n=104) increased from 3.0% to 17.0% fat, and decreased from 17.0% to 25.0% fat. Liking of the smaller cluster 2 (n=36) was best at 3.0% fat and decreased with increasing fat content. Concerning liver sausages, cluster 1 consumers' liking increased with increasing fat content, whereas liking of cluster 2 increased from 3.0% to 10% fat and decreased from 10.0% to 30.0% fat.

7.1.3 Comparing the drivers of liking and disliking of different matrices

The determined drivers of liking and disliking for yoghurt, vanilla custard and Lyon-style sausage are summarized in **Figure 7.1** and are additionally illustrated in **Figure 7.4**. Concerning *yoghurt* (**Figure 7.4a**), 'typical yoghurt attributes' and 'fat-related attributes' were found to drive liking, whereas graininess and yellow color were found to drive disliking. Well-liked plain stirred yoghurt is supposed to be medium sour, aromatic and astringent as well as medium to high in attributes creamy (flavor and texture), viscous (appearance and texture) and fatty mouth feel. To avoid rejection, graininess should not appear and color should be white.

Regarding *vanilla custard* (**Figure 7.4b/c**), 'pudding-like flavor attributes', vegetable fat flavor and 'fat-related attributes' drove liking. Contrariwise, jelly texture drove disliking. The direction of the effect of thickness, color and creamy flavor on liking depended on the consumer cluster. Acceptable vanilla custards are supposed to have medium to high intensities in descriptors vanilla, cooked flavor and harmonious, and should be apparently yellow.

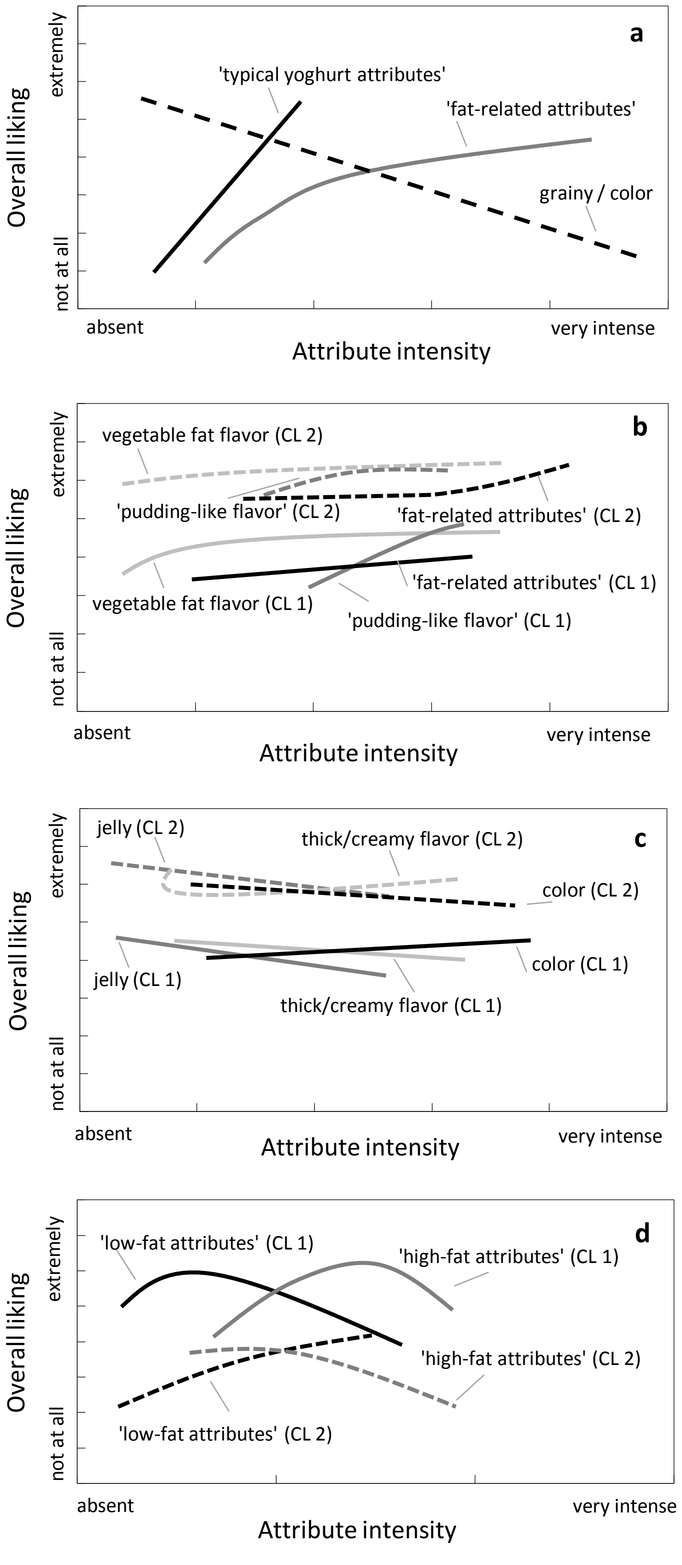

Fig. 7.4: Schematic illustration of the drivers of liking/disliking for yoghurt (a), vanilla custard (b, c) and Lyon-style sausages (d), based on the results from chapter 2, 4, 5 and 6. Liking data of yoghurt was transformed from a seven-point-hedonic scale to a nine-point-hedonic scale. Attributes, which were found to correlate in previous PCAs, were summarized to an average value. CL, cluster.

A vegetable fat flavor as well as medium to high scores in attributes sticky, fatty and creamy texture may lead to an increase in liking. A too intensive jelly texture could lead to rejection, while thickness and creamy flavor should be medium to high or low, depending on the cluster. Regarding *Lyon-style sausages* (**Figure 7.4d**), most consumers (cluster 1, n=104) preferred samples with medium intensities in juiciness, greasiness, meat flavor and meat flavor aftertaste (‘high-fat attributes’), and rejected sausages too dark in red color as well as too spicy, coarse and firm, causing a raspy throat (‘low-fat attributes’). Therefore, ‘high-fat attributes’ are considered as drivers of liking, whereas ‘low-fat attributes’ are regarded as drivers of disliking. However, the smaller consumer cluster (n=36) preferred darker red, firmer, more spicy and coarse samples, being less juicy, greasy with lower meat flavor intensity. As preferences for *liver sausages* varied between different consumer clusters (with a similar group size), no clear drivers of liking could be detected. Furthermore, texture properties of liver sausages were irrelevant for liking, because differences in texture could not be perceived on a piece of bread (and the consumption of liver sausage on a piece of bread is typical).

As no clear drivers of liking and disliking could be detected for the liver sausages, a comparison can only be drawn between yoghurt, vanilla custard and Lyon-style sausages. Both, the ‘typical flavor attributes’ of yoghurt (sour and aromatic) and custard (vanilla flavor, cooked flavor and harmonious) as well as the meat flavor in Lyon-style sausages respectively drove liking. However, spiciness drove disliking in Lyon-style sausages. Creamy flavor drove liking in yoghurt but partially drove disliking in custards at too high intensities. Concerning custards, vegetable fat flavor furthermore increased liking, which arose due to the addition of the vegetable fat cream. With reference to color, yellowness drove disliking of yoghurt and a white color was preferred. Contrariwise, too much whiteness partially decreased liking of vanilla custard. Regarding Lyon-style sausages, a too dark red color primarily reduced liking. These effects are believed to be product-specific: Plain stirred yoghurt is presumably expected to be white, whereas vanilla custard is expected to be yellow. Lyon-style sausages are probably expected to show a light red color. Regarding texture, ‘fat-related texture properties’ of yoghurt (creamy, viscous and fatty mouth feel), vanilla custard (sticky, fatty and creamy) and Lyon-style sausage (juicy and greasy) respectively drove liking. A too intensive jelly texture and too high thickness in custards, graininess and low viscosity in yoghurt, as well as a coarse and too firm texture of Lyon-style sausages causing a raspy throat, drove disliking.

7.1.4 Suitability of the applied methods to substitute fat

In general, the results demonstrate the suitability of the applied methods to reduce fat in yoghurts, vanilla custards, Lyon-style and liver sausages, by means of giving evidence to produce acceptable fat reduced products or rather by means of providing similar or even more accepted sensory properties in fat reduced variants in comparison to the full-fat counterparts. Medium to high-fat *yoghurts* were liked best, but regarding the aim to produce acceptable non-fat yoghurts, it was established that an increase in the protein content offers potential to partially substitute fat and to lead to accepted non-fat products. The results furthermore showed that the casein-to-whey protein ratio should be kept at 80/20 to get well-accepted yoghurts. Relating sensory to rheological yoghurt data (Chapter 3) moreover showed that yoghurt product development could be enhanced by means of applying particle size analysis and rheological measurement, because graininess (with a decreasing effect on liking) was found to correlate with particle size-related parameters. Additionally, sensory viscosity was found to correlate with destructive rheological parameters and creaminess with both parameters – both sensory properties were found to have a positive effect on consumers' liking. The addition of a commercially available vegetable fat cream to the *vanilla custard* formulation led to a well-liked low-fat (2.9%) vanilla custard, which was in summary better liked than the high-fat (15.8%) counterpart, although the sensory profiles differed. Substituting fat in *Lyon-style* and *liver sausages* by means of adding inulin, citrus fiber and partially rice starch gives evidence to produce acceptable fat reduced sausages, which are furthermore fiber enriched. Compared to the full-fat variants (25.0% or rather 30.0%), medium fat (10.0% and 17.0%) and partially also low-fat (3.0%) Lyon-style and liver sausages were found to be similarly or rather more accepted. Additionally, inulin and citrus fiber were found to partially imitate high-fat sensory properties.

7.2 Practical applicability of the results

Although the topic of fat reduction in food was already studied by several researchers (see Chapter 2, 4, 5 and 6), the results presented in this work provide useful information for the food industry regarding the development of low-fat products, especially for the dairy and meat industry. First of all, it gives an interesting overview about the effects of fat and fat reduction depending on the food matrix as well as about consumers' attitudes towards the different food types and the associated effects of fat. Furthermore, the applied methods give evidence for a successful development of an assortment of popular fat reduced meat and dairy products. Additionally, the results demonstrate the importance of the determination of the drivers of liking and disliking for a certain product during the process of product development and the importance of imitating or rather increasing the intensity of certain sensory descriptors (drivers of liking) and to decrease the intensities of others (drivers of disliking).

In conclusion, the results of the different examinations confirm, that (i) depending on a specific food, fat affects different sensory properties. It was shown (ii), that there are certain attributes which are increased by fat in some food matrices but decreased in others (viscosity/thickness/firmness). (iii) The findings prove that certain attributes are important for certain foods, but less important for others (creamy flavor), and also that certain attributes drive liking of some products but drive disliking of other products (viscosity/thickness/firmness). In addition, (iv) the results partially approve the hypothesis and the statement of Drewnowski (1992) as well as Drewnowski and Almiron-Roig (2010) that the palatability of foods is related to their fat content, that high-fat products are often preferred and that the sensory properties of fat reduced foods are primarily expected to be similar to those of the full-fat counterparts. However, changes caused by fat reduction may also be accepted or even preferred, especially when fat is suitably substituted by means of adapted technologies. Additionally, it has been shown that liking by trend seems to decrease from a certain fat content. Furthermore, the results revealed that liking for some products (vanilla custard, Lyon-style and liver sausages) differed as a function of varying preferences within different consumer clusters.

7.3 Outlook

This study provides useful information for the development of an assortment of fat reduced meat and dairy products. The applied methods to substitute fat in yoghurt, vanilla custard, Lyon-style and liver sausages may be improved and extended. The application of inulin and citrus fiber in further varying concentrations may lead to accepted meat and also dairy products, and may moreover lead to the advantage of increasing the intake of dietary fibers. Furthermore, future research should be based on the determined drivers of liking and disliking of the various products by means of finding and applying methods to increase the intensities of the drivers of liking and to decrease the intensities of the drivers of disliking. Additionally, measuring rheological data for all product categories for a prescreening of samples can save costs and time during the process of product development.

The evaluation of the effect of fat on sensory properties and liking may also be extended to fluid dairy products, to further dairy products such as curd and cream cheese as well as to more solid systems such as cheese and further popular meat products such as bratwurst, bockwurst and salami.

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SUMMARY

The number of overweight and obese people all over the world increases and overweight and obesity promote the risk for a number of diseases. From the viewpoint of the consumer, it is important to change eating habits and to enhance the extent of physical activity in today's sedentary lifestyles. From the viewpoint of the industry, the amount of fat in foods may be reduced. However, the degree of liking for a food is often related to its fat content because of the various effects of fat on sensory properties. The effect of fat depends on the food matrix and furthermore, consumers expect the presence of different properties as well as different intensities of certain properties depending on the food. Consequently, a detailed sensory approach is needed to successfully develop foods reduced in fat.

Selection of samples for this study based on popularity, on differences in the food matrix as well as on the fact of belonging to the category of meat or rather dairy products, because current data showed that an increased fat intake amongst others arises from an increased consumption of meat and dairy products. Selection resulted in plain stirred yoghurt (0.1 to 12.0% fat) and starch-based vanilla custard (0.1 to 15.8% fat) as well as Lyon-style sausages (3.0 to 25.0% fat) and liver sausages (3.0 to 30.0% fat). Technologies to reduce or rather to substitute fat were adapted to each food matrix, applying innovative approaches. For each food matrix, samples with varying fat content were produced and were evaluated in terms of sensory properties using descriptive analysis, and consumers' acceptability using hedonic tests. Afterwards, descriptive and hedonic data were statistically correlated.

Therefore, the present work on the one hand aimed to apply adapted innovative technologies to reduce or rather to substitute fat in different food matrices and to survey their acceptability. On the other hand, the effects of fat and fat reduction on sensory properties and liking as well as the various drivers of liking and disliking were aimed to be examined and contrasted.

Concerning yoghurt, the results showed an increasing effect of fat on attributes creamy (flavor and texture), viscous (appearance and texture) as well as fatty mouth feel. Consumers preferred yoghurts with medium fat (3.5 to 6.0%) and also high fat (12.0%) contents. Liking was driven by attributes sour, aromatic, astringent and partially by descriptors creamy, viscous and fatty mouth feel. Contrariwise, graininess and yellowness as well as too high intensities in attributes creamy, viscous and fatty mouth feel led to rejection. Substituting fat by means of adding whey protein did not enhance liking, but increasing protein did. Finally, the results showed that medium protein contents (4.5%) and high casein-to-whey protein ratios (80/20) could lead to accepted low-fat yoghurts.

Regarding vanilla custard, fat increased intensities in attributes thick (appearance and texture), creamy (flavor and texture), sticky and fatty, whereas yellowness, surface shine, jelly, cooked and vanilla flavor, as well as harmonious were decreased by fat. Low to medium fat custards (1.5 to 8.6%) showed best liking scores and attributes vanilla and cooked flavor, harmonious, vegetable fat flavor, sticky, fatty and creamy texture were found to drive liking. On the opposite, custards high in jelly texture and partially too high in thickness, whiteness and creamy flavor were disliked. The addition of a vegetable fat cream led to well accepted medium fat (2.9%) vanilla custards.

In Lyon-style sausages, fat exerted an increasing effect on attributes meat flavor, aftertaste meat flavor, greasy and juicy, and a decreasing effect on red color intensity, spicy, spicy aftertaste, raspy throat, coarse and firm. Regarding liver sausages, fat increased scores in attributes greasy, creamy texture, lumpy (appearance and texture), foamy, off-flavor and sweet. Contrariwise, it decreased red color intensity, odor attributes spicy, liver and metallic as well as flavor descriptors spicy, liver, aftertaste, peppery, bitter and metallic and also texture properties firm and furred tongue. For both types of sausage, preferences were mainly found for medium fat contents (10.0 and 17.0%), but consumers partially also liked sausages high in fat (25.0 or rather 30.0%) and low in fat (3.0%). No clear drivers of liking could be detected for the sausages. The results showed that the addition of inulin, citrus fiber and partially rice starch led to a successful imitation of fat or rather to acceptable fat-reduced sausages which are furthermore fiber enriched.

The current study gives an interesting overview of the various effects of fat depending on the food matrix. It furthermore gives evidence for the successful development of an assortment of popular fat reduced meat and dairy products.

ZUSAMMENFASSUNG

Die Zahl der übergewichtigen und fettleibigen Menschen auf der ganzen Welt steigt, wobei Übergewicht und Fettleibigkeit das Risiko für zahlreiche Krankheiten fördert. Aus Sicht des Konsumenten ist es wichtig, die Essgewohnheiten zu ändern und den Umfang an körperlicher Aktivität des oftmals bewegungsarmen Lebensstils zu steigern. Aus Sicht der Industrie kann u.a. der Fettgehalt in Lebensmitteln reduziert werden, jedoch ist die Akzeptanz eines Produktes durch die vielfältigen Einflüsse von Fett auf das sensorische Profil meist abhängig von dessen Fettgehalt. Der Einfluss von Fett hängt von der Lebensmittelmatrix ab. Desweiteren erwarten Konsumenten je nach Produkt, das Vorhandensein unterschiedlicher Eigenschaften sowie unterschiedlich stark ausgeprägte Eigenschaften. Für die erfolgreiche Entwicklung fettreduzierter Produkte ist somit eine genaue sensorische Herangehensweise notwendig.

Das Untersuchungsmaterial für diese Arbeit wurde nach dem Aspekt der allgemeinen Beliebtheit sowie nach Unterschieden in der Matrix ausgewählt. Desweiteren wurden die Produkte hinsichtlich ihrer Zugehörigkeit zur Gruppe der Milchprodukte bzw. der Fleischerzeugnisse ausgewählt, da aktuelle Daten zeigen, dass eine erhöhte tägliche Fettzufuhr unter anderem aus einem erhöhtem Verzehr an Milch- und Fleischprodukten resultiert. Es wurden die vier Produkte gerührter Naturjoghurt (0,1 bis 12,0% Fett), Vanillepudding auf Stärkebasis (0,1 bis 15,8% Fett) sowie Lyoner (3,0 bis 25,0% Fett) und Leberwurst (3,0 bis 30,0% Fett) ausgewählt. Um Fett zu reduzieren bzw. zu ersetzen wurden innovative Methoden angewandt, angepasst an die jeweilige Lebensmittelmatrix. Für jede Matrix wurden Proben mit unterschiedlichen Fettgehalten hergestellt und schließlich auf ihre sensorischen Eigenschaften mittels deskriptiver Analyse, sowie Konsumentenakzeptanz mittels hedonischer Tests, untersucht. Schließlich wurden die ermittelten deskriptiven und hedonischen Daten statistisch miteinander verknüpft.

Das Ziel der vorliegenden Arbeit lag somit zum Einen in der Anwendung innovativer Technologien zur Fettreduktion bzw. Fettsubstitution in unterschiedlichen Lebensmittelmatrices sowie in der Überprüfung ihrer Akzeptanz. Ferner sollte der Einfluss von Fett und Fettreduzierung auf die sensorischen Eigenschaften und die Beliebtheit sowie die entsprechenden „Drivers of liking“ und „Drivers of disliking“ ermittelt und gegenübergestellt werden.

In Naturjoghurt wurde ein steigender Effekt von Fett bezüglich der Attribute cremig, sahnig, viskos (Aussehen und Textur) sowie Fettfilm ermittelt. Konsumenten bevorzugten Joghurts mit mittlerem Fettgehalt (3,5 bis 6,0%) und auch hohem (12,0%) Fettgehalt, wobei die Beliebtheit durch die Attribute sauer, aromatisch und adstringierend sowie zum Teil cremig, sahnig, viskos und Fettfilm gesteigert wurde. Dagegen führten Griessigkeit und gelbe Farbe sowie sehr hohe Intensitäten in den Attributen cremig, sahnig, viskos und Fettfilm zu Ablehnung beim Konsumenten. Fettersatz durch Einsatz von Molkenprotein zeigte keine

Verbesserung der Beliebtheit, das Erhöhen des Proteingehalts hingegen schon. Die Ergebnisse zeigten, dass mittlere Proteingehalte (4,5%) und ein hohes Casein/Molkenprotein-Verhältnis (80/20) zur Herstellung akzeptierter, fettarmer Joghurts führen können.

In Vanillepuddings führte ein höherer Fettgehalt zu höheren Intensitäten in den Eigenschaften fest (Aussehen und Textur), cremig, sahnig, klebrig und schmierig, wohingegen niedrigere Intensitäten in den Attributen gelbe Farbe, Glanz, gelatineartig, Koch- und Vanillegeschmack sowie harmonisch ermittelt wurden. Vanillepuddings mit geringem bis mittlerem Fettgehalt (1,5 – 8,6%) waren am beliebtesten, wobei Konsumenten Puddings mit intensivem Koch-, Vanille- und Pflanzenfettgeschmack bevorzugten, die zudem hohe Intensitäten in den Attributen harmonisch, klebrig, schmierig und cremig besaßen. Dagegen wurden stark gelatineartige Puddings mit teilweise zu intensiver Festigkeit, weißer Farbe und zu sahnigem Geschmack abgelehnt. Die Verwendung einer Pflanzenfettcreme führte zu hoch akzeptierten Vanillepuddings mit mittlerem Fettgehalt (2,9%).

Bezüglich der Lyoner Würste wurde ermittelt, dass Fett die Intensitäten der Attribute Fleischgeschmack, Fleisch-Nachgeschmack, fettig und saftig erhöht, während die Ausprägungen in den Eigenschaften rote Farbintensität, würzig, würziger Nachgeschmack, kratzig, rau und fest durch Fett verringert wurden. In Leberwurst wurden mit steigendem Fettgehalt höhere Intensitäten in den Attributen fettig, cremig, klumpig (Aussehen und Textur), schaumig, Fehlgeschmack und süß beobachtet. Hingegen wurden die Ausprägungen der Deskriptoren Farbintensität, würziger Geruch, Lebergeruch, metallischer Geruch, Lebergeschmack, Nachgeschmack, würzig, pfeffrig, bitter und metallisch sowie fest und pelzig durch Fett verringert. Für beide Wurstarten wurden vorrangig Präferenzen für Proben mit mittlerem Fettgehalt (10,0 und 17,0%) ermittelt, jedoch waren zum Teil auch Würste mit hohem (25,0 oder 30,0%) bzw. niedrigem (3,0%) Fettgehalt beim Konsumenten beliebt. Für beide Wurstarten konnten keine konkreten „Drivers of liking“ und „Drivers of disliking“ ermittelt werden. Die Ergebnisse zeigten, dass der Einsatz von Inulin, Citrusfasern sowie teilweise Reisstärke zu erfolgreicher Imitation von Fett führte bzw., dass vom Konsumenten akzeptierte fettreduzierte Würste hergestellt werden konnten, welche desweiteren mit Ballastoffen angereichert sind.

Die vorliegende Studie gibt einen interessanten Überblick über die zahlreichen Einflüsse von Fett in Abhängigkeit von der Matrix und liefert Hinweise für die Entwicklung ausgewählter beliebter fettreduzierter Milch- und Fleischprodukte.

Eidesstattliche Versicherung gemäß § 7 Absatz 7 der Promotionsordnung der Universität Hohenheim zum Dr. rer. nat.

1. Bei der eingereichten Dissertation zum Thema

"Sensory and consumer-oriented studies on the effect of fat in different food matrices: A comparison between yoghurt, vanilla custard, Lyon-style and liver sausages"

handelt es sich um meine eigenständig erbrachte Leistung.

2. Ich habe nur die angegebenen Quellen und Hilfsmittel benutzt und mich keiner unzulässigen Hilfe Dritter bedient. Insbesondere habe ich wörtlich oder sinngemäß aus anderen Werken übernommene Inhalte als solche kenntlich gemacht.

3. Ich habe nicht die Hilfe einer kommerziellen Promotionsvermittlung oder -beratung in Anspruch genommen.

4. Die Bedeutung der eidesstattlichen Versicherung und der strafrechtlichen Folgen einer unrichtigen oder unvollständigen eidesstattlichen Versicherung sind mir bekannt.

Die Richtigkeit der vorstehenden Erklärung bestätige ich: Ich versichere an Eides Statt, dass ich nach bestem Wissen die reine Wahrheit erklärt und nichts verschwiegen habe.

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Ort und Datum Unterschrift

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