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Title	Fundamental studies on the reduction of fat and salt in laminated doughs
Authors	Silow, Christoph
Publication date	2018
Original Citation	Silow, C. 2018. Fundamental studies on the reduction of fat and salt in laminated doughs. PhD Thesis, University College Cork.
Type of publication	Doctoral thesis
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Download date	2026-11-17 12:09:35
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Fundamental studies on the reduction of fat and salt in laminated doughs

Thesis presented by

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State-approved Diplom Food Chemist

Under the supervision of
Prof. Dr. Elke K. Arendt
To obtain the degree of
Doctor of Philosophy – PhD in Food Science and Technology

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January 2018

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Declaration

I, Christoph Silow, hereby declare that this thesis is my own work and effort, and that it has not been submitted for another degree, neither at the National University Ireland, Cork nor elsewhere. Where other sources of information have been used, they have been acknowledged. I have read and understood the regulations of University College Cork concerning plagiarism.

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Signature

Abbreviations

2xS	Two-fold salt
4xS	Four-fold salt
5SD	5% sourdough
10SD	10% sourdough
20SD	20% sourdough
ACE	Angiotensin I converting enzyme
ANOVA	Analysis of variance
APLSR	ANOVA-Partial Least Squares Regression
BE	Brabender Equivalents
cfu/g	Colony forming unit per g sample
CLSM	Confocal laser scanning microscopy
db	Dough basis
DSC	Differential scanning calorimetry
EC	European Commission
ECK	Extended Craft Knife
E^k	Extensibility (distance to rupture)
EU	European Union
FB	Fat blend
FFP	Full fat puff pastry
FSA	Food Standards Agency (UK)
FSAI	Food Safety Authority of Ireland
G´	Storage modulus
G´´	Loss modulus
GABA	γ-aminobutyrate
HDL	High density lipoprotein
LAB	Lactic acid bacteria
LD	Laminated dough
LDL	Low-density lipoprotein
LS	Low salt
LVR	Linear viscoelastic region
M	Molar, moles per liter
mM	Millimolar
mmol	Millimoles
MRS agar	De Man, Rogosa and Sharpe agar
MT	Maximum Torque
MUFA	Mono unsaturated fatty acids
N	Equivalent molarity
NaCl	Sodium chloride, salt
NoS	No salt

p	Probability value
PMT	Peak Maximum Time
PS	Palm stearin
PUFA	Poly unsaturated fatty acids
r	Correlation coefficient
RDA	Ranking descriptive analysis
RFP	Reduced fat puff pastry (-40%)
RFPRS	Puff pastry with reduced salt (-30%) and fat (-40%) content
RIF	Roll-in fat
R^k_{max}	Resistance to extension (maximum force)
RO	Rapeseed oil
rpm	Rounds per minute
RSM	Response surface methodology
SAFA	Saturated fatty acids
SD	Sourdough
SFC	Solid fat content
TAG	Triacylglyceride
TFA	*Trans*-fatty acid
TTA	Total titratable acids
VLS	Very low salt
WHO	World Health Organization

Abstract

Puff pastry is well known for its layered, light and flaky structure. Additionally, it is a major contributor of fat and sodium intake in many countries. Excessive intake of saturated fatty acids (SAFA) and cholesterol but also sodium chloride (NaCl) are linked to various health risks such as obesity and hypertension. In turn, these may result in cardiovascular diseases (strokes, heart attacks, heart failure, etc.) which, according to the WHO, are the leading cause of preventable death worldwide. Amongst others, ingredient reformulation and process adaptations of many foods, including puff pastry, are necessary to reduce dietary SAFA and sodium intake. Initially, response surface methodology (RSM) was successfully used to evaluate puff pastry quality for the development of a fat-reduced version. Process parameters, number of layers and final dough thickness, in combination with the amount of roll-in fat, were found to have a significant impact on internal and external structural quality parameters. Furthermore, four vegetable fat blends (FBs) with various ratios of palm stearin (PS) and rapeseed oil (RO), and with a low *trans*-fatty acid (TFA ≤ 0.6%) content were characterised and examined for their application in puff pastry production. A range of analytical methods, including solid fat content (SFC), differential scanning calorimetry (DSC), cone penetrometry and rheological measurements were used to characterise these FBs. Excellent baking results were achieved by FB1 and FB2, while FB2 simultaneously reached a SAFA reduction by 49% compared to the control containing FB1. Subsequently, it was determined how NaCl (0–8.4 g/100 g flour) impacts the structure and quality characteristics of puff pastry with full and reduced (-40%) fat content. Finally, the impact of sourdough (SD) (5, 10 and 20% flour basis) on the structure, flavour and quality characteristics of reduced fat (-40%) and salt (-30%) puff pastry were analysed.

Results showed that fat and salt reduction impacted all investigated quality characteristics and the dough rheology. Nevertheless, through the employment of technological changes, a significant reduction of fat (-40%) and salt (-30%) in puff pastry was possible. The perception, visual impression or attributes like volume, firmness and flavour of the final products were not significantly affected. Finally, the flavour and texture of reduced-fat and -salt puff pastry was distinctly improved by SD addition. All results were confirmed by numerous sensory acceptance tests.

Acknowledgements

Firstly I would like to express my gratitude to Prof. Elke Arendt for her excellent and honest supervision and for giving me the opportunity to work in such interesting projects. I also want to thank Dr. Emanuele Zannini for his great project management and critical input throughout this work. It was a pleasure for me to be part of the outstanding cereal and beverage research group. Thanks to everybody being part of this group or just passing through during my UCC years, especially Markus, Anika, Birgit, Iven, Mareile and Manu.

A very big and special thanks goes to you Dr. Claudia Axel. Thank you for all your support and for always being a good friend especially in hard times. Thank you too, Florian.

Thanks to my students Inken Rethwisch, James O'Connor and Melanie Chucholowius for countless baking trials and letting me be your supervisor. More thanks to Valentyn Maidannyk and the other guys of Prof. Roos' group. For their help and support I also would like to thank all the technical and administrative staff, especially Tom Hannon, Jim McNamara, Maurice Conway, Donal Humphries, Dave Waldron, Eddie Beatty, Jimmi Borns and Diarmuid O'Dwyer. Big thanks to everybody who participated in the puff pastry sensory analyses.

No words can express the gratitude I feel for my family Susi, Paul Finlay and little Theo by the stars. Thank you so much for every day with you!

Very special thanks to my parents Doris and Günter and my grandparents for supporting me throughout my whole life. Even more thanks to my brothers Karsten and Torsten and everybody from JC Terpe for just being there and help making me who I am today.

Finally, I want to thank everybody who was not mentioned here by name (even if it is only a small consolation, sorry!).

This study received financial support of the "PLEASURE" Project from the European Commission, FP7, Thematic Area KBBE, (Grant agreement no: 289536).

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Horas non numero nisi serenas.

Chapter 1

Introduction

Puff pastry, well known for its layered, light and flaky structure, is made of unleavened wheat dough and fat without use of any rising agents (Cauvain and Young, 2001). In its present form it is has been known for several hundred years but nowadays it is also a contributor of fat and sodium intake in many countries (Davidson, 1999). To obtain a puff pastry's delicate structure, the fat (traditionally butter) is wrapped with the basic dough according to the French method and then folded and sheeted several times to obtain a multi-layered dough. Hence, this bakery product has a high fat content, of up to 40 % and contains approximately 1.0–1.2 % salt (NaCl) (The French Information Center on Food Quality, 2012).

One health risk that may result in cardiovascular diseases (strokes, heart attacks, heart failure) is the excessive intake of saturated fatty acids and cholesterol. Those are linked to increase the plasma low-density lipoprotein (LDL) level which, in turn, can lead to plaque build-up in arteries (Grundy and Denke, 1990). Since fat has a relatively high energy density (9kcal/g) a diet rich in fat can easily lead to excessive weight gain and obesity. Obesity, in turn, is linked to further diseases, such as; respiratory difficulties, chronic musculoskeletal problems, infertility, diabetes mellitus, certain types of cancers and gallbladder disease (WHO, 2000).

Excessive NaCl consumption is also linked to hypertension and bakery products including puff pastry are generally a major contributor to sodium intake. According to the World Health Organization (WHO), cardiovascular disease, including hypertension, is the leading cause of preventable death worldwide. Since dietary sodium reduction is one of the most effective mechanisms to improve population health, the WHO is driving measures to reduce worldwide population's daily intake of salt but also saturated fat by raising consumers' awareness (WHO, 2003; WHO, 2012). Moreover, ingredient reformulation and process adaptations are necessary to achieve this target.

Although it may sound simple, fat and salt reduction in baked goods is not as straight forward since both fat and salt are impacting the processability during the production. Both ingredients positively influence several technological, rheological and sensory parameters and thus the quality characteristics of the final products.

In puff pastry production fat plays a key role; it is important for the characteristic puff pastry properties such as the flaky shape, layered effect, texture, appearance, volume and lift (Boode-Boissevain and Van Houdt-Moree, 1996). During lamination, fat helps to separate the many thin dough layers from each other as well

as after melting which happens during baking, fat protects the starch granules from gelatinization (Anonymous, 2000a). Moreover, fat is essential as flavour carrier and gives the final product its specific mouthfeel (Ghotra et al., 2002; Miskandar et al., 2005). For that reason, fat cannot be replaced or reduced entirely without adversely affecting puff pastry production and the product quality (Fuentes, 2012).

One possibility of fat reduction is to substitute the fat by another solid substance with a fat content. Fuentes et al. (2012), for example, completely replaced the roll-in fat (RIF) by frozen dough or shaved ice. Few studies focused on the reduction of saturated and trans-fatty acids in the RIF (Garcia-Macias et al., 2011; Simovic et al., 2009). In further previous studies maltodextrins, pentosans or other hydrocolloids were used to produce fat-reduced margarine-like emulsions containing aqueous gels (Boode-Boissevain and Van Houdt-Moree, 1996; Vessière and De Mol, 2013). Additionally, those food additives must appear in the list of ingredients according to the EU regulation no. 1333/2008 (EC, 2008) but increasingly they do not fit in the current health-conscious consumer life-style.

Nevertheless, the first objective of this thesis was to reduce the total fat content of puff pastry as much as possible without adversely affecting the product quality by solely reducing the amount of RIF and adjusting the processing parameters number of fat layers and final thickness (**chapter 3**). Additionally, response surface methodology (RSM) was used to determine the optimal processing conditions for fat-reduced puff pastry to achieve quality characteristics comparable to full-fat standard products. For this purpose, based on various recipes from German bakery literature (Anonymous, 2000b; Schünemann and Treu, 1993), a basic puff pastry recipe with a fat content of 33 wt. % and a salt level of 21 g/kg flour was chosen. As RIF was used a vegetable fat blend (FB) made of 66% palm stearin and 34% rapeseed oil.

Traditionally butter was used for puff pastry production and principally artisanal bakeries still prefer butter as RIF. Nowadays, specifically manufactured margarines and tailor-made fat blends which contain animal and/or vegetable fats are employed and used during industrial processing of puff pastry (Dörr, 1982). Primarily, those fat blends are offering a better process ability (fat plasticity) and lower costs.

Previous studies mainly focused on the characteristics of shortenings and fats used in puff pastry production, e.g. (Lefébure et al., 2013; Pajin et al., 2011), rather than the characteristics of the final baked products (Cavillot et al., 2009; Simovic et al., 2009). One more objective of this thesis was to gain a better understanding of the

impact of vegetable FBs on the internal and external structural quality characteristics of baked puff pastry. Thus, in **chapter 4** four vegetable FBs with low *trans*-fatty acid (TFA ≤ 0.6 %) content with various ratios of palm stearin (PS) and rapeseed oil (RO) were investigated. Additionally, those FBs were physically characterised and evaluated for their suitability in puff pastry production.

Besides fat, salt is another essential ingredient in baked goods and thus also in puff pastry. Generally, salt aids the workability and increases the mixing tolerance of doughs. It also appears to have a beneficial effect on strengthening the gluten network and thus increases the dough stability and flexibility (Kaur et al., 2011). This strengthening effect is important during the baking process as it, among others, improves the steam retention properties of the puff pastry dough. Good steam retention in turn is leading to decent puff pastry lift and volume.

Furthermore, stickiness and water absorption of wheat dough are decreased by salt (Beck et al., 2012) why a reduction of NaCl may induce less desirable properties such as stickier and difficult to process dough. Additionally, salt is responsible for the perception of 'saltiness', while it decreases bitterness, increases that of sweetness and enhances other flavours in food systems (Liem et al., 2011).

Because of the health issues already mentioned above the WHO and European Union (EU) have recommended a reduction in sodium content in products to their lowest feasible level. This includes a target of reducing mean population NaCl intake by 30% to ≤ 5 g/day by 2025 (WHO, 2013). Therefore, the main strategy to decrease the sodium intake is to lower the salt content in food products mainly in cooperation with the food industry.

Hence, in **chapter 5** the effects of various NaCl concentrations (0–84 g/kg flour) on the quality of puff pastry with full and reduced (-40%) fat content were evaluated, including changes in lift, volume and firmness of the baked puff pastries. Moreover, a relationship between empirical wheat dough properties, such as stickiness, resistance to extension and Peak Maximum Time and puff pastry quality parameters was determined.

A final objective of this thesis was the incorporation of sourdough (SD) to improve the product quality of puff pastry (**chapter 6**). SD is a fermented mixture of flour and water and an extremely complex ecosystem comprising of yeasts and lactic acid bacteria (LAB). It is a natural ingredient and has been traditionally used as a leavening agent in bread for thousands of years.

Several recent reviews (Arendt et al., 2007; Galle and Arendt, 2014; Gänzle, 2014; Gobbetti et al., 2014) have summarized the technological effects of SD on the texture, flavour, shelf life and nutritional quality of bread. Especially the salty perception is enhanced by SD and additional flavour compounds are imparted (Thiele et al., 2002). Therefore, SD has the highly promising potential to compensate the adverse effects of salt reduction and consequently positively influence further sensory characteristics (Belz et al., 2012).

Therefore, the incorporation of SD may improve flavour, texture and therefore palatability of reduced fat and salt puff pastry. Consequently, the impact of various SD levels (5, 10 and 20% flour basis) on the structure, flavour and quality characteristics of reduced fat (-40%) and salt (-30%) puff pastry was evaluated. Again, the rheological properties of the resulting dough were analysed with a range of empirical rheological tests (dough extensibility, dough stickiness and GlutoPeak test). *Lactobacillus reuteri* R29 was selected as functional starter culture due to its antifungal traits.

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Chapter 2

Literature review: Current status of salt reduction in bakery products

Christoph Silow, Claudia Axel, Emanuele Zannini, Elke K. Arendt

Published as Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016) "Current status of salt reduction in bread and bakery products–A review" in *Journal of Cereal Science*, 72: 135-145

Abstract

Cardiovascular disease, including hypertension, is the leading cause of preventable death worldwide. Sodium chloride (NaCl) associated with its excessive consumption is linked to hypertension while the global dietary NaCl intake has increased extensively. Thus, limitations on sodium (Na) consumption were recommended by the WHO and further international health agencies (< 2 g Na/day).

Bread and other cereal products contribute about 30% to the daily intake of sodium in the western human diet. Although it may sound simple, salt reduction in foods is not as straight forward since salt impacts the processability during the production and the quality characteristics of the final bakery products. To achieve the final reduction goals long-term strategies and reformulation of recipes are required. Numerous different techniques have been proposed to reduce the NaCl content. Other approaches include salt replacers or enhancers. These are summarized with special attention given to recent developments over the last 5 years. One of the promising strategies to reduce salt has been the addition of sourdough to bakery goods. Sourdough can counteract some of the negative impacts salt reduction has on bread (e.g., flavour, shelf-life) improving the overall quality.

The present review describes and assesses the impact of NaCl reduction on a range of bakery products, including dough characteristics, sensory properties and shelf-life. It further outlines the progress that has been made in salt reduction and indicates existing problems in the bakery sector.

2.1 Introduction

Increased consumption of dietary sodium is a leading cause of cardiovascular disease (CVD) and hypertension and has also been linked to an increased risk of stroke, stomach cancer, kidney disease and bone demineralization (Wardener and MacGregor, 2002). According to the American Heart Association CVD and stroke are the first and second-leading global causes of death which, together with their related diseases, account for 17.3 million deaths per year (Mozaffarian D et al., 2015). High blood pressure has been noted as one of the major modifiable factors in the development of CVD. Several epidemiological, genetic, animal and population based intervention studies have established high sodium chloride intake as a factor in the increase in blood pressure with age in industrialised countries (He and MacGregor, 2007). From a public health perspective, this makes controlling hypertension related to sodium intake an important issue. Numerous national and international organisations have introduced recommendations and actions for lowering sodium chloride levels in foods. Among others the WHO and EU have recommended cooperation with the food industry to encourage the reduction in sodium content of products to their lowest feasible level. The recent National Adult Nutrition Survey conducted in the Republic of Ireland (Walton, 2011) revealed that between 65 and 70% of sodium chloride in the diet comes from processed foods, of which 22% originates from bread and bread products. The World Health Assembly has approved a set of nine voluntary targets for reducing behavioural and physiological risk factors for non-communicable diseases, including a target of reducing mean population sodium chloride intake by 30% to ≤ 5g/ day by 2025 (WHO, 2013). Those particularly vulnerable to high sodium chloride intakes are those over the age of fifty, people with high or elevated blood pressure and diabetics. In order to reduce salt intake effectively in the general population, EU salt reduction activities have concentrated on a limited number of food categories. Bread, classed worldwide as a staple food, is the only bakery product listed within these 12 priority categories.

The Food Standards Agency of the UK (FSA) and the Food Safety Authority of Ireland (FSAI) began their salt reduction programmes in 2003 when Irish bread contained average 1.2% salt (Lynch et al., 2009). Since then, the bread producing industry in Ireland and the UK has been actively trying to reduce sodium content in

their products; however, its role in both the sensory and technological aspects of the bread product must be taken into consideration. The periodic monitoring over the last 12 years showed that the concentration of salt in processed food was reducing towards the set targets (FSAI, 2015).

Generally, many food additives contain sodium such as baking powder and soda which are used as leavening agents in various baked goods. Furthermore, sodium chloride is added to bakery products to improve taste, flavour and aroma (Cauvain, 2007a). Moreover, it plays a vital role in processing by improving textural properties and water binding capacity of the dough (Beck et al., 2012a; Belz et al., 2012a; Lynch et al., 2009). Sodium chloride also acts as a preservative against microbial spoilage by reducing the water activity (Hutton, 2002).

This review illustrates the current situation in salt reduction, problems arising in the bakery sector as a consequence of such reduction, and provides possible solutions (Figure 2-1).

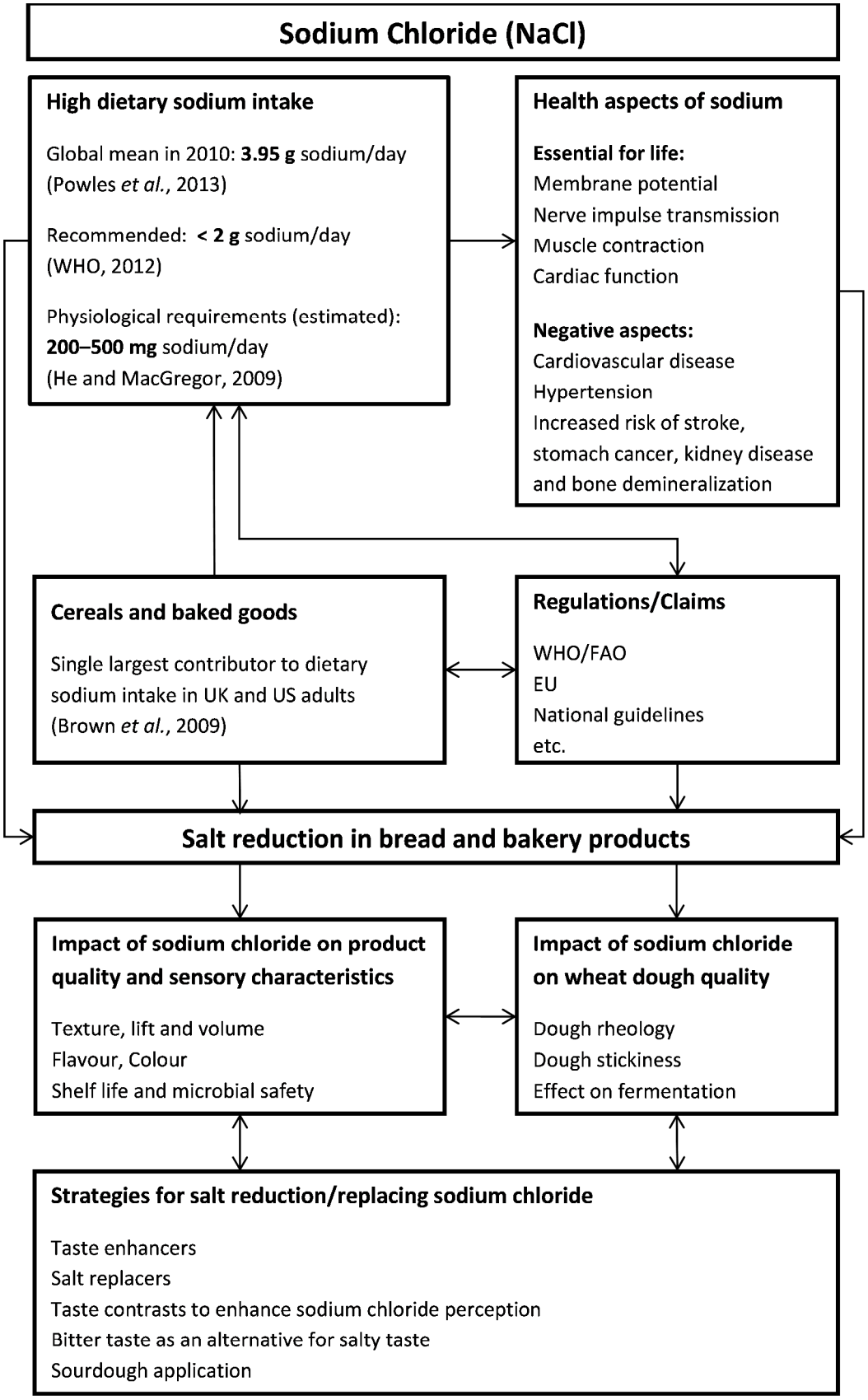


Figure 2-1 Overview of salt and salt reduction in bread and bakery products

2.2 Sodium chloride and health

2.2.1 Sodium chloride

Sodium chloride (NaCl) is composed of sodium (NaCl) and chloride (Cl^-) ions joined by an ionic bond. Sodium chloride is essential for life and is better known as (table) salt. Throughout the following review, the terms 'salt' and 'sodium chloride' are not synonymous with the term 'sodium'. For the conversion of sodium into sodium chloride its weight must be multiplied by 2.54. Tight regulation of the body's sodium and chloride concentrations is an important biological process, with multiple mechanisms working to control it. Sodium chloride is required for survival, however health implications of excess sodium chloride intake represent an area of continued investigation among scientists, clinicians and public health experts.

Sodium and chloride, which are principal ions in extracellular fluid, which includes blood plasma, play a critical role in life-sustaining processes. They maintain membrane potential which is critical for nerve impulse transmission, muscle contraction and cardiac function. The absorption of NaCl in the small intestine plays an important role in the absorption of chloride, amino acids, glucose and water. Similar mechanisms are involved in re-absorption of these nutrients after filtration from the blood by the kidneys.

Only a few studies have investigated the effects of sodium reduction on cardiovascular disease and on mortality, with mixed results. In general, the studies suggest a direct association, particularly those studies that used urinary sodium as a measure of sodium intake (Nagata et al., 2004). The TONE study (a randomized controlled trial of nonpharmacological interventions in the elderly) indicated a trend toward reduced cardiovascular disease in participants assigned to the sodium reduction intervention (Whelton et al., 1998). A subsequent study found that participants initially without hypertension who were enrolled in the sodium interventions in the two previous trials of hypertension prevention (TOHP) had 25% reduction in cardiovascular events 10–15 years later compared with the control groups (Cook et al., 2007). Analyses from this TOHP follow-up study showed that the sodium-potassium ratio was associated with increased risk of cardiovascular disease in a dose-response relationship (Cook et al., 2009), providing complementary evidence for the adverse association between sodium chloride intake and cardiovascular disease.

2.2.2 Recommended and actual levels of sodium intake

Currently the WHO/FAO provides a guideline of <2 g of sodium intake per day (WHO, 2012). Most countries also have their own guidelines on sodium intake. In the US the food and nutrition board have approved dietary reference intakes of 1.5 g sodium per day with an upper limit of 2.3 g for those aged 18–50, 1.3 g for those aged 51–70 years and 1.2 g sodium per day for those over 70 years (Institute of Medicine (US), 2008). Similarly the UK suggests limiting sodium to 2.4 g per day (Scientific Advisory Committee on Nutrition, 2003), with this level being established as a guideline daily amount (GDA). Currently physiological requirements for salt (not well defined) are estimated to be as low as 0.5–1.2 g/day (200–500 mg Na) most of which will be excreted by the kidneys (He and MacGregor, 2009).

Several studies such as Brown et al. (2009) and Powles et al. (2013) give a comprehensive overview of the actual salt intake worldwide. In 2009 about 75% of sodium intake in European and Northern American countries was dominated by sodium added in manufactured foods, while cereals and baked goods were the single largest contributor to dietary sodium intake in UK and US adults (Brown et al., 2009). Around the world, with some exceptions in Africa and Asia, most adult populations have mean sodium intakes well in excess of 2.3 g/day (Brown et al., 2009). In contrast to the WHO advice, in 2010 the global mean sodium intake was 3.95 g/day (10.06 g/day of salt), nearly twice the WHO recommended limit (Powles et al., 2013).

Salt reduction initiatives have already resulted in 1.1 g of salt being removed from the Irish diet. Coronary Heart Disease (CHD) mortality rates in Ireland fell by over two-thirds in men and women between 1985 and 2006 (Brown and Jennings, 2014). About 28% of this decline was attributable to population blood pressure fall besides improvements in treatment uptake and risk factor improvements such as smoking, cholesterol and more physical activity. Blood pressure in turn is linked to sodium intake as discussed above. To achieve the UK recommendation of 6 g salt a day by 2015, in the early 2000s a voluntarily program was started where all members of the food industry were encouraged to agree to the salt targets and work towards them within an acceptable timeframe. Every 2 years the targets for salt reduction on over 80 food categories were reset and thus many food products are now 20–40% reduced in salt compared to 10 years ago (CASH, 2015). Due to the first achievements of the salt reduction programs, the UK Department of Health (DoH) has set new reduction

targets for a total of 76 food groups, including breads and cakes, for 2017 (DoH, 2014). These new targets include an additional 10% reduction to a salt average of 0.9 g per 100 g in bread and rolls by 2017 compared to the 2012 target (1 g per 100 g). Furthermore, new reduction targets for salt in cakes (down from 0.5 g to 0.43 g per 100 g) and pastries (down from 0.5 g to 0.35 g per 100 g) were presented (DoH, 2014).

According to the Center for Science in the Public Interest (2014) reducing sodium consumption by half in the US would save an estimated 100,000 lives per year and would reduce medical care and other costs by roughly $1 trillion over the next 10 years. Even a modest gradual reduction of 1 g per day between 2010 and 2019 would be more cost-effective than using medications to lower blood pressure in all persons with hypertension (Bibbins-Domingo et al., 2010).

The effects of sodium and its levels are controversially discussed. Sodium reduction might well benefit those at the very high end of sodium intakes as can be seen from the substantial data available. According to Alderman and Cohen (2014) there must be a broad ‘safe zone’ of sodium intake (about 2.5–5 g/day). As with other essential nutrients, there is evidence of increased morbidity and mortality above and below a safe mid-range intake. It may be harmful if sodium reduction is pushed too far. Thus, it is also important to identify the dimensions of a ‘safe zone’ of sodium intake.

2.2.3 Regulations

Worldwide, several political institutions like the European Union have taken action to actively promote a reduction in salt levels in foods. In 2006 the European Parliament and the Council of the EU passed a regulation on “nutrition and health claims made on foods” (EC) No 1924/2006 (European Commission (EC), 2006). This document allows, amongst others, the use of nutrition claims regarding the content of sodium/sodium chloride in foods. Article 8 of regulation (EC) No 1924/2006 lists the following restrictions for claims on sodium/sodium chloride in its Annex:

Reduced (sodium/sodium chloride)

“A claim stating that the content in one or more nutrients has been reduced, and any claim likely to have the same meaning for the consumer, may only be made where

the reduction in content is at least 30% compared to a similar product, except […] for sodium, or the equivalent value for salt, where a 25% difference shall be acceptable."

Low sodium/sodium chloride
"A claim that a food is low in sodium/sodium chloride, and any claim likely to have the same meaning for the consumer, may only be made where the product contains no more than 0.12 g of sodium, or the equivalent value for sodium chloride [0.3 g], per 100 g or per 100 ml."

Very low sodium/sodium chloride
"A claim that a food is very low in sodium/sodium chloride, and any claim likely to have the same meaning for the consumer, may only be made where the product contains no more than 0.04 g of sodium, or the equivalent value for sodium chloride [0.1 g], per 100 g or per 100 ml."

Sodium-free or sodium chloride-free
"A claim that a food is sodium-free or sodium chloride-free, and any claim likely to have the same meaning for the consumer, may only be made where the product contains no more than 0.005 g of sodium, or the equivalent value for sodium chloride [0.013 g], per 100 g."
Food companies favour a 'quiet' approach; while the use of salt replacers is growing, low salt claims are not. Low/no/reduced sodium claims are rarely used and appear on less than 4 percent of food and drink products launched globally (less than 1 percent in Europe and Asia) between 2010 and 2014 (Gray, 2014). This is an indication for a stealthy sodium reduction over time where changes are less noticeable and more palatable.

2.2.4 Consumption and current sodium chloride levels in bread and bakery goods

Bread belongs to those foods that form the basis of many civilizations' diets due to its nutritive value, its low price, and the simplicity of using its primary ingredient, the cereals, for culinary purposes. Bread is rich in complex carbohydrates (starch being the major component) and fibre, it has a high content of plant proteins, and contains hardly any fat. It is a good source of B vitamins and minerals such as phosphorus, potassium, and magnesium. All these components are particularly enriched in bread made from whole-meal flour, where the bran fraction is reintroduced into the milled

white flour. Due to these nutritional properties, it comes as no surprise that nutrition experts define bread as an essential part of the food pyramid's base, as it should also constitute the base of the diet (in countries where bread is a staple source of carbohydrates).

In 2010, bakery product sales, including frozen bakery and desserts, reached a value of $145.9 billion in Western Europe (Agriculture and Agri-Food Canada, 2011). Average bread consumption in Europe is approximately 59 kg per person per year (AISBL, 2015). Bread consumption patterns differ widely between countries, with the highest reported being Turkey (app. 104 kg) and Bulgaria (app. 95 kg), while the lowest consumption is reported in the UK (app. 32 kg) (AISBL, 2015). Although bread is relatively low in sodium chloride, its high contribution to sodium chloride intake is due to the high quantities of this product consumed by the general population. The situation is similar with the consumption of puff pastry even though not consumed so frequently.

Globally there are wide variations in the levels of sodium chloride in bread and bakery products (Table 2-1). There is a difference of over 1 g of sodium chloride between the lowest country (UK) and the highest (Germany). Taking the UK as a case study, it is evident that a reduction in sodium chloride to an average of 0.98 g has not had any adverse effects on consumer acceptability and bread consumption as a whole (He et al., 2014).

Health Canada Guidance for the Food Industry suggests for pantry bread and rolls, bagels, croissants and flatbreads a reduction from currently 430 mg–330 mg sodium per 100 g by the end of 2016 (Bureau of Nutritional Sciences (2012)).

Table 2-1 Reported sodium chloride/sodium levels in bread and bakery products

Country	Reference	Year	Bread type	Sodium level (mg/100g	Equivalent as sodium chloride (g/100g)
Australia	Dunford *et al.*, (2011)	2011	All breads (mean)	435	1.1
Canada	Health Canada (2011)	2011	Bread (all types)	651–680	1.65–1.73
Canada	Health Canada (2011)	2011	Bagel (all varieties)	442–502	1.12–1.28
New Zealand	Dunford *et al.*, (2011)	2011	All breads (mean)	435	1.1
US	Cauvain (2007b)		US pan bread		1.04
European Union					
France	CIQUAL (2012)	2012	Bread, country style	669	1.70
France	CIQUAL (2012)	2012	French baguette	681	1.73
France	CIQUAL (2012)	2012	Croissant	471-582	1.12–1.48
France	CIQUAL (2012)	2012	Puff pastry, sweet	382	0.97
Germany	CVUA Stuttgart (2015)	2014	Bread, bread rolls (all types)		1.0–2.9
Ireland	FSAI (2015)	2013	White bread	438	1.10
			Brown bread	428	1.09
Spain	Ballesteros (2010)	2009	Bread (all types)	642	1.63
UK	Brinsden *et al.* (2013)	2011	White & Brown		0.98 ± 0.13
UK	Cauvain (2007a)		UK fruit buns		0.72 ± 0.86
UK	Cauvain (2007a)		UK plain cake		0.39 ± 0.52
UK	Cauvain (2007a)		UK fruited cake		0.32 ± 0.42

2.3 Techno-functional impact of sodium chloride on wheat dough quality

Sodium chloride makes wheat gluten more stable and less extensible, making it less sticky. It also affects the fermentation rate, reducing the rate of gas production by yeast. Inadequate amounts of sodium chloride result in loaves with open grain and poor texture (Hutton, 2002).

Cauvain (2007b) has summarized the main technological functions of sodium as:

- Impacting the development of gluten structures in the mixing of bread and other fermented products
- Inhibition of bakers' yeast in the fermentation of (bread) doughs resulting in a lower gas release
- Control of water activity in the baked product and thus a reduction of spoilage

The development of an extensible gluten network in the dough is a fundamental feature of the bread making process. This network contributes to gas cell formation and their subsequent retention during the fermentation and baking stages (Cauvain and Young, 2006). Hydration of the flour with water initiates the gluten network formation, and this is further developed by mixing which imparts energy into the dough. During mixing there are marked changes in the rheological properties of the dough mixture. It has been suggested that sodium chloride delays gluten hydration and thus increases mixing time of the dough, however there had been no direct evidence to confirm this hypothesis. In the case of puff pastry dough, the protein structure needs not be fully developed during mixing as the force of the subsequent lamination process is absorbed by the dough and thus the gluten network (Cauvain and Young, 2001). Since salt reduction weakens the gluten network it can cause problems during lamination. Thus, the dough layers, which need to stay intact, could break easily, as during baking the gluten in the dough layers serves to trap steam that results in the rising of puff pastry.

A recent study by McCann and Day (2013) examined dough microstructure in the early stages of dough development using confocal laser scanning microscopy. Results indicated that the hydration of gluten protein and the development of the gluten matrix in the dough were delayed in the presence of NaCl, resulting in a gluten network with a more fibrous structure. Gluten protein consists of about 40% hydrophobic amino acids (mainly leucine and isoleucine) and a low proportion of charged amino acids at the protein surface. In the presence of NaCl some of the

charges on these exterior amino acids may be shielded, therefore slowing down protein hydration. This reduction of protein surface charge reduces the electrostatic repulsion between the protein molecules allowing for them to interact more closely through strong hydrophobic interactions which increases protein intermolecular β-sheet structure (Wellner et al., 2005). The overall effect of increasing mixing time is to increase loaf height and improvement of overall bread quality. A reduction of sodium chloride levels in dough leads to a weakening of the gluten network, increasing dough stickiness. During the industrial manufacture of bread this can stop processing lines leading to down time and wastage (Wehrle et al., 1997).

The impact of salt is most readily observed in bread and fermented goods such as rolls and buns but also in laminated products such as croissant and puff pastry (Cauvain, 2007a). Where the gluten formation is limited or absent in cakes, biscuits, cookies and many pastry products there appears to be no significant effect of salt (Cauvain, 2007a). Therefore, these products are rarely investigated regarding salt reduction with many studies focused on the impact of salt reduction in bread (Belz et al., 2012a; Lynch et al., 2009; Noort et al., 2010).

2.3.1 Effect on dough rheology

The fundamental mechanical properties of wheat flour dough are important because they affect the dough handling behaviour during processing and also influence the interactions among dough components. To understand what is happening during dough formation rheological analysis are applied. Wheat dough is a diverse and complex material that exhibits viscoelastic properties. Gluten displays viscoelastic behaviour in which the gliadin fraction represents viscous behaviour and the glutenin fraction represents elastic behaviour (Edwards et al., 2001). The incorporation of sodium chloride into the wheat dough influences interactions between the gluten strands due to its ionic nature. In addition, sodium chloride is known to cause changes in water absorption which affects the formation of the viscoelastic network of dough.

Empirical methods apply simple elongation, shear or compression and are rapid, low cost, and simple to perform methods of measuring rheological properties. Farinograph measurements showed that for dough consistency at 500 Brabender Units (BU), NaCl addition produces a reduction in water absorption and an increase in dough development time (Hlynka, 1962). This is in agreement with subsequent

studies carried out by Salovaara (1982) who compared salted wheat doughs using the farinograph and found that dough with 1–2% sodium chloride added had an increase in peak time (i.e. increase in dough strength), while water adsorption decreased (i.e. a decrease in water binding).

Extensibility is an important characteristic in wheat dough, particularly in the moulding step (e.g. bread) or lamination step (e.g. puff pastry). It is one of the characteristics used to relate the properties of a dough piece to its probable performance in processing and to possibly predict the end product quality. Lynch et al. (2009) used an extensograph to define extensibility and resistance to extension of doughs containing 0, 0.3, 0.6 and 1.2% sodium chloride. It was found that doughs that contained 0.3–1.2% sodium chloride did not differ significantly in their resistance to extension (R_{max}) and extensibility (E´). However, dough containing 1.2% sodium chloride significantly differed from dough containing 0% sodium chloride. These results would indicate that only omission of sodium chloride entirely would significantly affect dough extensibility.

Numerous studies have applied fundamental rheological measurements to investigate the effect of NaCl on dough rheology, however the results have been contradictory. Some studies found a decrease in the storage modulus G´ with an increase in NaCl addition (Angioloni and Dalla Rosa, 2005; Lynch et al., 2009; McCann and Day, 2013). In contrast to this, a study by Beck et al. (2012b) reported an increase in G´ when NaCl was added to the dough. This study showed that a reduced level of NaCl in dough changed the gluten protein network structure from elongated protein strands to less connected protein particles.

2.3.2 Effect on dough stickiness

Stickiness is a combination of adhesion, the interaction between a material and a surface, and cohesion, the interactions within the material (Wang et al., 1996). In industry dough stickiness is a major problem as sticky dough can lead to process disruption and product loss. Agraria (2009) gives an overview of the determination of stickiness -mainly expressed as work of adhesion- of dough including methods, parameters and the corresponding references.

Several studies showed that a reduction of sodium chloride lead to a significant increase of stickiness of wheat dough (Diler et al., 2016; Silow et al., 2016). Moreover, the adhesive work decreased significantly as soon as a small amount of

salt (0.35% db.) was added (Diler et al., 2016). Contrary, Beck et al. (2012b) reported a decreased dough stickiness with decreasing NaCl concentration (40–0 g/kg flour) in bread dough. Regarding the rheological properties of wheat dough including stickiness a salt reduction up to 25% in pizza (Diler et al., 2016) or even 30% in puff pastry (Silow et al., 2016) was possible.

2.3.3 Effect on fermentation

A decrease in the level of salt added leads to an increase in gas production by the yeast. This is due to the decrease in the osmotic pressure and the electrochemical potential of sodium and chloride ions on the membrane of the yeast (Matz, 1992). The resulting dough may become 'over proved' in a standard proof time in the bakery why proofing time has to be adapted, whenever the salt level is changed (Lynch et al., 2009) observed a significant increase in the maximum dough height as the salt level decreased. At the same time an increase in the total volume of gas (CO2) released was observed using a rheofermentometer. This indicates a weakening of the gluten network as the NaCl level was reduced. During proofing a continuously stretching of the dough gas cells in a biaxial way causes further development and hardening of the gluten network while the specific volume increases.

2.4 Impact of sodium chloride on product quality and sensory characteristics

2.4.1 Texture, lift and volume

Sodium is responsible for the formation of an even crumb (Matz, 1992). Lynch et al. (2009) reported much larger pores in bread without added salt than those containing 0.3–1.2% salt. In the course of proof and baking the growth of gas bubbles determines the expansion of the dough and ultimately volume and texture of the baked product (He and Hoseney, 1991). The limit of expansion of these bubbles is related directly to their stability, due to coalescence and the eventual loss of gas when the bubbles fail. The rheological properties of the bubble walls will therefore be important in maintaining stability against premature failure during baking, and also in relation to gas cell stabilization and gas retention during proofing, and thus to the final structure and volume of the baked product (Dobraszczyk et al., 2001). The specific volume (volume to weight ratio) is directly linked to the volume of a baked good and is commonly used in the assessment of bread quality. Different trends can

be seen for the specific volume of bread when salt levels were reduced. On the one hand, specific bread volume slightly decreased when no salt was added (Czuchajowska et al., 1989). On the other hand, Lynch et al. (2009) and Okano and Mizutani (1995) reported no significant difference but a trend towards increase in the specific volume of bread at reduced salt levels. For puff pastry with full and reduced fat content Silow et al. (2016) reported an increase of the maximal lift and the specific volume for increasing NaCl levels.

Major physical changes occur in all baked goods during baking. At temperatures above 100 °C steam and CO_2, if present, expand rapidly and cause high pressure on the surrounding cell walls. In these walls made of dough the gluten will trap the gases and retain them to a certain extent. Furthermore, starch starts to gelatinise, protein starts to denature (Cauvain and Young, 2001) and Maillard Reaction will yield browning products (see also 2.4.3). Finally, the dough layers form little cracks, the gluten cannot retain the gases anymore and they will diffuse or escape (Cauvain and Young, 2001). Salt reduction influences the texture of baked goods, in so far as salt impacts the gluten strength and if present the yeast activity.

2.4.2 Flavour

Sodium is responsible for overall aroma and flavour impression and can enhance sweetness (Ugawa et al., 1992) as well as mask bitterness (Breslin and Beauchamp, 1995). Only free Na^+ ions in solution which are available for sodium chloride taste perception on the tongue can elicit a sodium chloride taste. At the same time the contribution of the Cl^- ion on taste is not entirely clear yet. Due to extensive interaction between sodium chloride and wheat proteins during dough formation, a certain amount of sodium is bound due to ionic interactions with the negatively charged amino acids. As demonstrated by Pflaum et al. (2013a), neither Na^+ nor Cl^- ions are irreversibly bound in bread and it is only a matter of time until 100% of sodium ions are released by chewing. The velocity of sodium release during the first seconds of mastication seems to be rather important for the perceived saltiness. Among others, this release velocity depends on the crump structure (see also 2.5.3).

Bread without sodium chloride has been reported to be perceived as tasteless and have yeasty and sourdough like flavours (Lynch et al., 2009; Miller and Hoseney, 2008). The study by Pflaum et al. (2013a) revealed that an increase in sodium chloride level lead to a decrease in floury/watery, yeasty and musty flavours. When

salt levels were reduced from 1.3% to 1% a difference in sodium chloride level could be detected, which were not detected at higher concentrations. This would indicate that 1% salt seems to be a critical concentration for sodium chloride detection.

2.4.3 Colour

Sodium chloride influences Maillard reactions which occur during baking. These are reactions between proteins or amino acids and reducing sugars resulting in the formation of compounds like melanoidins which help to form the crust colour of the bread and other baked products (Belitz et al., 2008). Various factors are influencing the formation rate and types of compounds in the final product, such as the pH, the protein/amino acids ratio, the water and sugar level, temperature and cooking time. It has been shown that sodium chloride has a plasticising effect during the heating of cereal products. This improves mobility of the reactants, enhancing the Maillard reactions, producing a darker coloured crust (Moreau et al., 2009). On the other hand, in absence of salt baked bread has a lighter coloured crust (Czuchajowska et al., 1989). Due to higher yeast activity more sugar is metabolised and not available for the formation of browning products (Skobranek, 1998). Thus, in non-fermented baked goods a reduced salt level should have no impact on the colour.

2.4.4 Shelf-life and microbial safety

Sodium chloride prevents rapid spoilage, thus extends product shelf-life, and creates an inhospitable environment for pathogens. Sodium chloride is an effective preservative because it reduces the water activity (a_w) of foods. Increased osmotic pressure causes cells to lose water into the environment which in turn inhibits cell growth. In bread, sodium chloride helps control the growth of moulds and bacteria such as *Bacillius* species, thus extending shelf-life (Betts et al., 2007). Challenge tests carried out with fungi commonly found in the bakery environment (such as *Penicillium expansium*, *Fusarium culmorum* and *Aspergillus niger*) exhibited a reduced shelf-life of bread by 1–2 days when sodium chloride levels were decreased (Belz et al., 2012a). The use of lower sodium chloride levels must be compensated by the use of alternative anti-microbial strategies due to an increase in water activity. Generally, with a_w values between 0.96 and 0.98, bread is known as a high moisture product (Smith et al., 2004). In bakery products which are consumed within the baking day, like croissants or puff pastry, the higher water activity and spoilage issue

can be mainly neglected. Apart from possibly moist fillings, a_w of these products is quite low even when salt reduced.

2.5 Strategies for salt reduction/replacing sodium chloride

Consumers are concerned more than ever about sodium content in their foods, but refuse to compromise on taste – and, of course, they also demand a clean label. Therefore industry aims to design ingredients for salt reduction which address these needs and keep the consumer-craved salty, hearty flavour.

Numerous different strategies have been proposed to reduce the sodium chloride content of foods. Methods to solve the technological, sensory and shelf-life problems associated with sodium chloride removal have been developed. Technologically, a reduction in salt to 0.6–0.3% would be feasible without a significant deterioration in rheological properties or performance during manufacture (Lynch et al., 2009). However, its effect on the organoleptic properties of bread is still a critical factor in consumer acceptance. With regards to this many strategies have been developed to improve taste quality.

Ideally the replacement of sodium is realised with compounds that evoke a similar pure saltiness when consumed. Such a replacement appears to be unlikely due the high specificity of sodium for the epithelial Na^+ channel (ENaC). Until now the whole mechanism of salt taste transduction has not been elucidated. Nevertheless, the ENaC seems to be very important for this mechanism, but cannot fully explain salt taste.

Partial replacement with inorganic salts such as potassium chloride (KCl) can work well up to 20–30% replacement, after which point metallic and bitter aftertastes are detected (Braschi et al., 2009).

Gradual reduction in sodium levels by stealth has been employed with some success which is reported by the Food and Drink Federation and British Retail Consortium (Wilson et al., 2012). The strategy (“small step reduction”) aims to slowly and gradually reduce the salt content in recipes without the consumer’s notice. Girgis et al. (2003) found evidence to support this strategy by conducting an intervention study (110 participants). In that study, it was possible to reduce the salt content in bread by 25% and maintain consumer’s acceptance. However this approach is limited as it takes a lot of time and can only be applied up to a critical point after which the product becomes unacceptable to consumers. Accordingly, the strategy

also includes the use of spices, salt replacers and taste enhancers (Wilson et al., 2012). Due to these limitations the search for alternative strategies is still ongoing. More promising and recent approaches are the use of sourdough and taste contrast which could provide more effective solutions to salt reduction.

2.5.1 Taste enhancers

To overcome the blandness of low-salt bread, taste enhancers can be used. These include bread flavour preparations which can be purchased commercially, but also the addition of spices, malt or other flours like barley have been suggested to improve the flavour of low-salt breads (Rodbotten et al., 2015).

Specific salt enhancers are substances that do not have a salty taste in them, but enhance a sodium salty taste when used in combination with sodium chloride. A range of ingredients are reported to act as sodium chloride enhancers such as amino acids, monosodium glutamate, lactates, yeast products, soy based ingredients and other flavourings (Nakagawa et al., 2014). However, scientific data for bread are scarce. Taste enhancers activate taste receptors in the mouth and throat, which helps compensate for the salt reduction and enhance flavour. However, some of these salt enhancers may have consumer acceptability issues as they need to be stated on the ingredients list. Furthermore, they often cause changes in taste, aroma and also browning of the products.

2.5.2 Salt replacer (KCl)

The most commonly used salt replacer is potassium chloride, although other alternatives such as calcium chloride, magnesium chloride or magnesium sulphate have also been proposed (Kaur et al., 2011). Considering the metallic-bitter aftertaste of KCl, various studies have evaluated the levels of which salt can be replaced by KCl in bread recipes and are briefly summarized by Quilez and Salas-Salvado (2012). The group of Mueller et al. (2016) demonstrated for pizza crust that it was possible to replace 30% of sodium chloride by KCl without a noticeable loss of salty taste.

Shelf-life tests on wheat bread revealed similar antifungal activity, when salt was replaced up to 30% with a mixture of various salt replacers (Samapundo et al., 2010).

2.5.3 Enhancement of sodium chloride perception by taste contrast

A study by Meiselman and Halpern (1973) showed that the delivery of continuously alternating concentrations of aqueous sodium chloride solutions enhance saltiness intensity compared to model solutions delivered in a non-alternating fashion. Thus, contrasting sodium chloride intensities can be used to enhance sodium chloride perception while still reducing the tastant. There are two main methods that have been developed to inhomogenously distribute sodium chloride in bread.

Noort et al. (2010) spatially separated different sodium chloride concentrations using horizontally laminated bread dough. This method does have a disadvantage in that production lines would have to be altered for manufacture on an industrial scale, which would be an added cost. Furthermore, the amount of yeast in each portion of dough needs to be adjusted to obtain constant fermentation speed between the doughs, independent of actual fermentation speed within a dough. Noort et al. (2012) used encapsulated salts to enhance sodium chloride perception by taste contrast. The average saltiness of the breads prepared with 1% large sodium chloride encapsulates (1000–2000 mm) were found to be equal or higher compared to those prepared with 2% normal sodium chloride. The disadvantage of using encapsulated salts is that there is no NaCl available to interact with the flour during mixing, therefore having a negative effect on dough development and also on the yeast fermentation rate, water activity and on the final bread texture and volume.

The use of coarse-grained sodium chloride showed the same result (Konitzer et al., 2013) causing increased contrast of sodium concentration which is known to trigger salt perception (Busch et al., 2009). The use of coarse-grained salt in bread making led to an inhomogeneous spatial distribution of sodium in the crumb. This resulted in accelerated sodium release and led to enhanced sodium chloride taste, allowing a sodium reduction in bread by 25% while maintaining taste quality. This sodium chloride taste enhancement can be explained by the increasing contrast in sodium concentration, which is known to determine sodium chloride taste perception. The same strategy also allowed successfully reduction of the salt content in pizza crust up to 25% (Mueller et al., 2016).

Pflaum et al. (2013b) reported the direct impact of the crumb texture on the saltiness perception. The bread crumb was impacted by different proofer conditions and the various crumb cell structures, particularly the more coarse-pored the bread crumb, resulted in enhanced saltiness perception. Considering that the use of sourdough can

also change the crumb texture suggests that use of sourdough technology could positively influence low-salt bread.

2.5.4 Is bitter the new salty?

According to the recent Mintel's report (Mogelonsky, 2015) there is a growing consumer interest in bitter flavours. Sour and bitter flavours are added by industry to products reduced in sodium and sugar. In 2014 the American Heart Association reported that snack sales dropped by 40–50% when manufacturers reduced sodium. Thus, food and beverage companies added sweeteners to compensate for this sodium reduction. That was, however, rather counterproductive, since consumers generally pay more attention to their diet and search for healthier options.

Particularly in salty snacks "bitter" is the flavour profile which is becoming increasingly popular in US foodservice menu items. "Salty" is a flavour that is dominant in snack markets and sub-categories whereas sweet flavour profiles are not as common and usually fall into the confectionery or bakery categories. Since 2013, only 5% "sweet" snack products have been launched, such as cereal bars and popcorn (Mogelonsky, 2015). Moreover, compared to 2014 in 2015 34% of US adults were limiting their intake of sweet snacks, and 33% were looking for healthier foods (Mogelonsky, 2015).

This is a big opportunity for bitter snacks to grow their share as consumers become more familiar with bitter-tasting food. An increase in menu items that are described as "bitter" can be observed in the US foodservice category, including cauliflower, Brussels sprouts and a range of bitter greens such as collards, kale, chicory, and mustard greens. Snacks with a bitter flavour profile may be less common, but they are gaining popularity, e.g. kale and root vegetable-based chips. The beverage industry is also tapping into bitter flavours. Bitter flavoured beverages, including bitter lemon, herbal cocktail bitters, matcha green tea, and beer formulations are becoming more popular with restaurant diners (Mogelonsky, 2015).

"Bitter" as a strong flavour note, may be one way of reducing the use of sodium in snacks and various other foods. In the past many foodservice trends found their way into retail, bitter-flavoured products may do likewise.

2.5.5 Sourdough application

Sourdough is a fermented mixture of flour and water and has traditionally been used as a leavening agent in bread for thousands of years. In more recent times sourdough has been reintroduced as a functional ingredient to improve bread quality and to replace additives. Sourdough influences all aspects of bread quality. Technological effects of sourdough on the flavour, texture, shelf-life (delay of staling, spoilage prevention), and nutritional quality of bread are well established and summarized in several recent reviews (Axel et al., n.d.; Galle and Arendt, 2014; Gänzle, 2014; Gobbetti et al., 2014). Conclusively, sourdough as an ingredient in bakery products favours the demand for clean label, natural products including a reduced use of additives. This is also more widely accepted by today's health conscious consumer.

The benefits of sourdough mentioned earlier may also be positively applied in salt reduced products to create functional foods. Belz et al. (2012b) suggested the highly promising potential of sourdough use to compensate the effect of salt reduction on flavour and the consequent influence on further sensory characteristics, like crumb texture.

The same research group demonstrated that the addition of sourdough, fermented with the antifungal *Lb. amylovorus* DSM19280, to salt-reduced bread prolonged the shelf-life when compared to the control (Belz et al., 2012a).

Bread containing lactic acid bacteria (LAB)-fermented wheat germ tasted more salty when compared to control bread (Rizzello et al., 2010). The higher saltiness was assumed to be a combined effect of acidification and proteolysis. Due to the addition of rye malt sourdough fermented with glutamate-accumulating *Lb. reuteri* strains, it was possible to reduce the salt content in bread from 1.5 to 1% (flour base), keeping taste and other quality features unchanged (Zhao et al., 2015). A trained panel judged all sourdough breads to be also higher in umami and sour taste; this compensated overall for lower saltiness in NaCl-reduced bread, whereas the glutamate concentration met approximately the taste threshold for glutamate in bread; 0.03% monosodium glutamate (w/w) (Zhao et al., 2015).

Lactobacilli can further convert glutamate to γ-aminobutyrate (GABA) during fermentation by glutamate decarboxylase. GABA has several well-characterized bioactive functions, such as neuro-transmission, diuretic effects, tranquilizer effects and induction of hypotension (Diana et al., 2014a; Li and Cao, 2010). The latter is the most important characteristic and has been studied intensively in human

intervention trials (Hayakawa et al., 2002). During sourdough fermentation LAB may also synthesize Angiotensin I converting enzyme (ACE)-inhibitory peptides and antioxidant peptides (Coda et al., 2012; Hu et al., 2011; Rizzello et al., 2008). ACE-inhibitory peptides have shown to hinder the vaso-constrictory effects of Angiotensin II and to enhance the vaso-dilatory effects of Bradykinin which both result in a lowering of blood-pressure (De Leo et al., 2009). The benefits of GABA and ACE-inhibitory peptides were recently used by Diana et al. (2014b) and Penas et al. (2015) to develop a sourdough bread targeted towards blood-pressure reduction. A liquid sourdough fermentation (whole wheat flour (16.5%), soya flour (2%), protease (1.5%); dough yield 500) was carried out using *Lb. brevis* CECT 8183 and additional protease. The thus produced low-sodium wheat-sourdough bread with potassium citrate (0.13%) contained 7 times more GABA at 24 mg/100 g and 3 fold higher peptide content (<3 kDa) at 7.5 mg/g when compared to the control (Penas et al., 2015). The GABA concentration in commercial sourdough breads ranges from 2 to 9 mg/100 g (Diana et al., 2014b). A daily intake of 10–12 mg GABA for 12 weeks significantly reduced the systolic blood pressure ($p < 0.01$) in an intervention study with hypertensive human patients who consumed 100 mL of LAB-fermented milk (Inoue et al., 2003). Since bread is a staple food, the consumption of 100 g GABA-rich bread easily reaches effective levels. However, clinical studies are needed to prove the efficiency of the functional sourdough bread to decrease blood pressure in hypertensive patients. To increase the concentration of GABA in sourdoughs, studies have aimed to ferment protein rich flours from pseudocereals (quinoa, amaranth, buckwheat) and chickpea (Coda et al., 2010) or buckwheat sprouts (Nakamura et al., 2013).

In conclusion, sourdough enhances the salty perception as well as imparting additional flavour compounds. Due to the production of bioactive compounds like GABA, ACE-inhibitory peptides or antifungal substances, sourdough is a useful functional ingredient for salt-reduced breads. Moreover, the use of sourdough is not limited solely to bread alone. It may be incorporated into products other than bread. One possibility is the incorporation of sourdough in salt-reduced puff pastry or croissants to improve their flavour, texture and therefore their palatability.

2.6 Conclusion

According to the WHO, reducing dietary sodium chloride is one of the most effective mechanisms to improve population health. Bread is a major contributor to sodium intake which means that ingredient reformulation and process adaptations are necessary to achieve this. Although some progress has been made further reductions are necessary. However, this is difficult due to the important role of sodium chloride in bread making. To reduce sodium level in baked goods, it is first important to gain a fundamental understanding of its roles from both techno-functional and sensory aspects. Only after establishing this solutions can be developed to obtain comparable qualities in the product. Nevertheless, industry undertakes efforts to reduce the salt content in their products (Ahuja et al., 2015; Wilson et al., 2012). At least, it is also the responsibility of the consumer to more openly accept salt reduced products and avoid the general action of adding more salt to a product before consuming it (Zandstra et al., 2015).

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Chapter 3

Optimization of fat-reduced puff pastry using response surface methodology

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Published as Silow, C., Zannini, E., Axel, C., Belz, M. C. E. & Arendt, E. K. (2017) "Optimization of fat-reduced puff pastry using response surface methodology" in *Foods*, 6 (2): 15

Abstract

Puff pastry is a high-fat bakery product with fat playing a key role, both during the production process and in the final pastry. In this study, response surface methodology (RSM) was successfully used to evaluate puff pastry quality for the development of a fat-reduced version. The technological parameters modified included the level of roll-in fat, the number of fat layers (50–200) and the final thickness (1.0–3.5 mm) of the laminated dough. Quality characteristics of puff pastry were measured using the Texture Analyzer with an attached Extended Craft Knife (ECK) and Multiple Puncture Probe (MPP), the VolScan and the C-Cell imaging system. The number of fat layers and final dough thickness, in combination with the amount of roll-in fat, had a significant impact on the internal and external structural quality parameters. With technological changes alone, a fat-reduced (≥30 %) puff pastry was developed. The qualities of fat-reduced puff pastries were comparable to conventional full-fat (33 wt. %) products. A sensory acceptance test revealed no significant differences in taste of fatness or 'liking of mouthfeel'. Additionally, the fat-reduced puff pastry resulted in a significant ($p < 0.05$) positive correlation to 'liking of flavour' and overall acceptance by the assessors.

3.1 Introduction

The history of layered doughs is thousands of years old and even puff pastry in its present form has been known for several hundred years (Davidson, 1999). Puff pastry is a light and flaky pastry made of laminated dough which can be topped or filled, sweet or savoury, enabling a large range of product variations. Unlike other laminated baked goods such as croissants and Danish pastry, puff pastry is made of unleavened dough without any other rising agents (Cauvain and Young, 2001).

According to the so-called French method—the most common way to produce puff pastry—a piece of fat (traditionally butter) is wrapped with basic dough, which is then folded and sheeted several times to obtain a multi-layered dough. To date, no global uniform standard exists for the preparation of puff pastry or related products. For instance, in the German literature, the French method describes that a piece of dough is wrapped in fat. The Dutch or Scottish method describes a rapid preparation of puff pastry with lower volume and quality (Cauvain and Young, 2001). The cold fat is cut into cubes which are added and mixed with the basic dough before the lamination, which results in discontinuous layers. However, with combinations of different, repeated folding steps, products with numerous layers, usually from 48 to 256, can be obtained. Typically, these multi-layered doughs have a relatively high amount of fat (20 %–35 % on total mass).

Primarily, high costs and the difficult handling of the traditionally used butter during industrial processing initiated the development of specifically manufactured fat blends (Dörr, 1982). These fat blends are derived mainly from vegetable oils and fats, offering a better process ability (fat plasticity). Thus, nowadays, they are preferred for commercial puff pastry production. Nevertheless, artisanal bakeries still prefer butter.

The functional roles of fat in puff pastry making are to separate the many thin dough layers from each other and, after melting, to protect the starch granules from gelatinization (Anonymous, 2000a). During the baking process, the water located in the dough vaporizes and generates steam which expands but cannot pass the coagulated gluten network within the dough layers (Anonymous, 2000a). This expansion of steam between the dough layers causes the rise of the puff pastry. In addition, fat is essential as a flavour carrier and gives the final product its specific

characteristics, such as a good structure, texture and mouth feel (Ghotra et al., 2002; Miskandar et al., 2005).

To conclude, fat plays a key role in puff pastry production and cannot be replaced or reduced entirely without adversely affecting its production and the product quality (Fuentes, 2012). This is a challenge for the puff pastry producing industry which is forced to reduce its fat and calorie content due to the increasing global trend towards the production of more wholesome foods. Thus, the food industry bears great responsibility to produce healthy foods and therefore, cost-effective strategies are needed for the successful reduction of fat in their products. In principle, two strategies exist to accomplish fat reduction in puff pastry: either by reducing the total amount of roll-in fat used or by replacing the fat component with a low-fat or fat-free substance.

Previous studies in which fat was substituted by another solid substance having a fat content have been described for Danish pastries. In this case, the roll-in fat was completely replaced by frozen dough or shaved ice (Fuentes, 2012). Other studies focused on the reduction of saturated and trans-fatty acids in the roll-in fat (Garcia-Macias et al., 2011; Simovic et al., 2009). Further studies dealt with the use of maltodextrins, pentosans or other hydrocolloids to produce fat-reduced margarine-like emulsions containing aqueous gels (Boode-Boissevain and Van Houdt-Moree, 1996; Vessière and De Mol, 2013).

These so-called fat replacers such as hydrocolloids belong to the group of food additives which must appear in the list of ingredients according to the EU regulation No. 1169/2011 (EC, 2008). However, increasingly, the application of food additives does not fit in the current health-conscious consumer life-style. Moreover, fat reduction in foods has become increasingly popular in recent decades. Multiple reports have demonstrated that the consumption of low-fat products can lower the energy and fat intake and may help with long-term weight control and the maintenance of good general health.

The aim of the present study was to reduce the total fat content of puff pastry as much as possible without adversely affecting the product quality by only reducing the amount of roll-in fat and adjusting the processing parameters. Hence, only technological parameters were modified, guaranteeing a food additive-free labelling. Changes included the number of fat layers and the final thickness of the laminated dough. Confocal laser scanning microscopy was used to investigate the

microstructure of the unbaked laminated dough. Finally, response surface methodology (RSM) was used to determine the optimal processing conditions for fat-reduced puff pastry with quality characteristics comparable to full-fat standard products. This strategy describes an alternative approach for fat-reduction on a cost-neutral basis, making it also accessible for implementation in the bakery industry. In addition, sensory evaluation of fat-reduced puff pastry compared to full-fat puff pastry products was performed with a sensory acceptance test, which provided insights into which attributes are important when describing puff pastry quality.

3.2 Experimental

3.2.1 Materials

The ingredients used in this study were wheat flour (Grand Moulins de Paris, France, type T45, moisture 13.5%, protein 11.5%), salt (Glacia British Salt Limited, UK), commercially available lemon juice (Tesco) and tap water. The vegetable fat blend 8324 G. Olmatech Cobalt (s.a. Aigremont n.v., Awirs-Flémalle, Belgium) had a composition of 66% palm stearin and 34% rapeseed oil and was used as roll-in fat (RIF) for puff pastry preparation. The solid fat content (SFC) of the fat blend was provided by the retailer (Temperature (◦C)/SFC (%): 10.0/48.2; 20.0/36.0; 30.0/25.1; 40.0/15.5).

3.2.2 Puff Pastry Production

Puff pastries were produced according to the so-called French method, wherein a piece of fat is wrapped with basic dough and then folded several times to obtain a multi-layered dough. The basic recipe was taken from different German bakery literature (Anonymous, 2000b; Schünemann and Treu, 1993) and slightly modified. Instead of a butter/flour mix, a vegetable fat blend (66% palm stearin, 34% rapeseed oil) was used as roll-in fat (RIF).

The dough was prepared in a standard mixer (Model: A200, Hobart Mfg. Co. Ltd., London, UK) with a kneading hook. The formulation for the basic dough consisted of 1000 g flour, 21 g salt, 15 g lemon juice and 510 g cooled tap water (12.5 °C–16.0 °C). Flour and salt were premixed. Subsequently, the liquids were added and the mixing was carried out at a first speed (48 rpm) for 2 min and for a further 3 min at a second speed (90 rpm). Dough temperature after mixing was in the range of about 22.5 ± 1.5 °C. A portion of 1500 g basic dough was wrapped in a plastic bag to

prevent dehydration and left to rest at room temperature for 20 min. If not clearly identifiable by the context, hereafter, the term 'basic dough' refers to the mixture of ingredients (flour, salt, lemon juice and water) before incorporating the RIF; 'laminated dough' refers to the laminated mix of basic dough and RIF before baking; and 'pastry' refers to the final baked product.

Calculations of the required RIF (in grams, g) were based on the fat percentage of the laminated dough ($FC_{LD} = (RIF)/(m_{BD} + RIF) \times 100$) before baking by rearranging this equation accordingly:

$$RIF\,[g] = \frac{(m_{BD} \cdot FC_{LD})}{(100 - FC_{LD})} \tag{1}$$

where m_{BD} is the mass of basic dough in g and FC_{LD} is the fat content in laminated dough in percent (*w*/*w*). RIF, according to Table 3-1, was formed to a square and sheeted on a Rondo sheeter (Model: SSO 605, Seewer AG, Burgdorf, Switzerland).

Table 3-1 Used roll-in fat and fat content in laminated dough (LD)

Basic dough	Roll-in fat	Laminated dough (LD)	Fat content in LD	Fat reduction
[g]	[g]	[g]	[%]	[%]
1500	740	2240	33.0	0
1500	494	1994	24.8	25
1500	371	1871	19.8	40
1500	297	1797	16.5	50
1500	184	1684	10.9	67

The basic dough was also formed to a square and sheeted to a size just twice as large as the corresponding fat block. The fat block was placed on the dough and encased with this dough while the edges were sealed together. There are two conventional ways of folding laminated dough to produce puff pastry: a single turn (three theoretical fat + four dough layers) and a double turn (four theoretical fat + five dough layers). With variable combinations of single and double turns, different numbers of theoretical layers can be obtained: e.g., one double turn followed by one single turn which results in 12 theoretical fat layers (4 × 3) or, if these steps are repeated another time, 144 theoretical fat layers (12 × 12) will be created (Table 3-2). Once the fat was enclosed by the dough, it was laminated to a thickness of 10 mm. The number of turns to obtain the appropriate number of fat layers and resting

periods are shown in Table 3-2. Before each turn, the laminated dough was turned 90° in horizontal orientation and subsequently rolled down to 10 mm.

Layered dough was rolled down gradually to the desired final thickness (1.00 – 3.50 mm) at which stage two passages were performed. After a rest of 20 min, samples of 10×10 cm were cut out randomly and were allowed to rest at 4 °C over night within baking paper in an airtight bag. The puff pastry control had a full-fat content (0% fat reduction), 144 theoretical fat layers and a final thickness of 2.50 mm.

Table 3-2 Theoretical number of fat layers and sequence of turns

Fat layers	Sequence of turns *
12	4 - RP30 - 3
36	4 - RP30 - 3 - RP90 - 3
48	4 - RP30 - 4 - RP90 - 3
64	4 - RP30 - 4 - RP90 - 4
81	3 - RP30 - 3 - RP90 - 3 - RP30 - 3
108	3 - RP30 - 3 - RP90 - 3 - RP30 - 4
128	4 - RP30 - 4 - RP90 - 4 - RP30 - 2
144	4 - RP30 - 3 - RP90 - 4 - RP30 - 3
192	4 - RP30 - 4 - RP90 - 4 - RP30 - 3
256	4 - RP30 - 4 - RP90 - 4 - RP30 - 4

* double turn (4), single turn (3), simple fold (2), resting period of 30 min (RP30) and 90 min (RP90)

After refrigeration, overnight samples were allowed to reach room temperature and baked afterwards on trays with baking paper at 210 °C in a top- and bottom-heated, unventilated, preheated deck oven (Model: MIWE condo INT 01/01, Michael Wenz GmbH, Arnstein, Germany). Optimal baking times had been determined based on the degree of browning by an experienced baker in preliminary trials. Baking times varied for the different final thicknesses: (baking time (min)/final thickness (mm): 7.0/1.00; 9.5/1.50; 11.0/1.75; 12.5/2.00; 14.0/2.25; 15.0/2.50; 15.5/3.00; 16.0/3.50).

3.2.3 Physicochemical Analysis of Puff Pastry

After baking and cooling to room temperature (~30 min), physicochemical analysis of puff pastry was conducted. Therefore, samples were weighed, and specific volume and maximum lift (maximum height) were evaluated using a VolScan Profiler (Stable Micro Systems, Godalming, UK). Turning speed of the VolScan Profiler was

set to one round per second; vertical step of the laser was set to 1 mm. Product length and width were determined manually over the sample middle using an electronic calliper.

Texture analyses of puff pastry were carried out 2 h after baking. The firmness of puff pastry was determined by penetration tests using a Texture Analyzer TA-XTplus (Stable Micro Systems Ltd., Godalming, UK). Two different methods were set up using an Extended Craft Knife (ECK) as well as a Multiple Puncture Probe (MPP; both Stable Micro Systems Ltd., Godalming, UK) equipped with a load cell of 30 kg (Force Sensitivity: 1 g). Total firmness was obtained from the 'work of shear', which represents the area under the characteristic compression curve. The tests were conducted under the following conditions: test mode: compression, test speed: 5.00 $mm \cdot s^{-1}$ (for ECK); 2.00 $mm \cdot s^{-1}$ (for MPP), post-test speed: 10.00 $mm \cdot s^{-1}$, target mode: distance, distance: 64.500 mm, trigger type: button, return distance: 65 mm, contact force: 15 g; software: Texture Exponent 32, version 4.0 (Stable Micro Systems Ltd., Godalming, UK).

For ECK measurements, the sample was cut breadthwise through its centre. To standardize all ECK results, total firmness values were divided by their respective width (in mm) and multiplied by 100. MPP was used with nine needles from which eight needles were arranged in the outer circle and one needle in the centre of the probe. The needle arrangement was determined in preliminary trials (data not shown), since tests with all needles compressed the samples rather than penetrated them.

For internal structure characterization of baked puff pastry, an image analysis of the cross sections of puff pastry halves was conducted using a C-Cell imaging system (Calibre Control International Ltd., Warrington, UK). Images of the samples, cut with the ECK, were taken. The number of cells and slice brightness were the parameters to describe the internal structure. Furthermore, the ratios of number of cells/height and number of cells/slice area were calculated to include the relationship of the average (avg) height and the area of the puff pastry cross sections to the structure.

Following data evaluation, limits and ranges of the physicochemical parameters were set for the subsequent RSM optimization procedure.

3.2.4 Experimental Design

RSM was applied to the experimental data to evaluate the effect of the independent variables (fat reduction, number of fat layers and final dough thickness) on the dependent variables (total firmness (ECK), total firmness (MPP), specific volume, number of cells and slice brightness). Herein, optimum parameter levels could be determined.

A circumscribed, three-dimensional central composite design was developed featuring variations in fat reduction (ranging from 0% to 50%, based on fat percentage of the laminated dough), number of fat layers (ranging from 50 to 200) and final dough thickness (ranging from 1.00 mm to 3.50 mm). The upper and lower limits of these levels were selected based on general empirical values from the literature and on preliminary trials conducted (data not shown). A total of 17 trials were carried out, comprising eight for the factorial, six for the axial and three as central points.

In addition, the response data of a further 37 randomized trials, within the above-mentioned ranges, were included in the design. The response of each of the investigated parameters was analysed by fitting cubic models to the data with least square regression in order to identify the significant effects of the variations in parameter levels on the responses ($p < 0.05$). To visualize the overall trend, three-dimensional graphs for the models were used.

3.2.5 Sensory Evaluation of Puff Pastry

The sensory acceptance test was performed according to Stone et al. (2012) and Stone and Sidel (2004). The sensory panel consisted of 60 untrained assessors. After tasting, they had to fill in a questionnaire in which they were asked for personal details and for questions regarding the puff pastry products. The test was conducted for puff pastry control, improved puff pastry control and fat-reduced puff pastry. All samples were prepared as described above. After cooling, the samples were cut in two equal halves, labelled with a random 3-digit code and served to the assessors at the same time on a white plate in a randomized order. The experiment was conducted at room temperature in panel booths which conformed to International Standards (ISO, 1988). All samples were presented in duplicate with a different sample order (Stone et al., 2012a). The assessors were asked to assess, on a continuous line scale from1 to 10 cm, the following attributes: ‘liking of appearance’, ‘liking of colour’,

'liking of volume', 'liking of flavour', 'liking of mouthfeel/texture' and overall acceptability (hedonic). The assessors then participated in a ranking descriptive analysis (RDA) (Richter et al., 2010) using the consensus list of sensory descriptors including the number of layers, fatness, saltiness, moisture, total firmness, crispiness and off-flavour (intensity), which was also measured on a 10 cm line scale. The sensory acceptance test was done in duplicate (Stone et al., 2012a).

All data were evaluated with ANOVA (analysis of variance)-Partial least squares regression (APLSR) using Unscrambler software version 9.7 (CAMO Software AS, Oslo, Norway).

3.2.6 Confocal Laser Scanning Microscope

For confocal laser scanning microscopy (CLSM) (Biorad, Herts, UK), sample preparation was conducted with frozen unbaked laminated dough. Briefly, samples were stored at −18 °C and thin slices of approximately 0.2 to 0.5 mm of the dough cross section were cut off using a scalpel. The slices were stained with 0.2% aqueous Rhodamine B solution (Sigma-Aldrich, Dublin, Ireland) on a glass plate for 2 min and rinsed with water afterwards. Samples were examined with a FV300 confocal laser-scanning system mounted on an Olympus IX80 inverted microscope with a 10× dry objective (Olympus, Center Valley, PA, USA), using λ_{ex} = 543 nm.

3.2.7 Compositional Analysis

Compositional analysis was performed for the improved puff pastry control (0% fat reduction, 81 fat layers, 2.50 mm final thickness) and the fat-reduced puff pastry (40% fat reduction, 48 fat layers, 2.25 mm final thickness). Five random samples per recipe were frozen in a plastic bag to −32 °C for 30 min using a Blast Freezer (BF 35, Foster Cross Refrigeration Ltd. Norfolk,UK). Instantly, frozen samples were blended using a Büchi Mixer B-400 (BÜCHI Labortechnik AG, Flawil, Switzerland) to ascertain homogeneity. Crude fat was determined by extraction of a 6.5 g homogenized sample using a Soxtec Manual ExtractionUnit 2055 (Foss, Hillerød, Denmark). For determining the ash content, approximately 8.0 g of blended sample was heated to 600 °C for 12 h (Hertwig, 1923). Protein content was determined from approximately 1.0 g of the homogenized sample using the Kjeldahl method (Suhre et al., 1982). Moisture content was determined according to the approved AACC

method 44-15.02. (AACC, 1995). Total carbohydrates were calculated by difference. All determinations were done in triplicate.

3.2.8 Statistical Analysis

Design Expert Version 7 (Stat-Ease Inc., Minneapolis, MN, USA) was used for experimental design and to generate surface response plots that permitted evaluation of the linear, quadratic and interactive effects of independent variables on the selected dependent variables and to optimize puff pastry formulations for levels of 0% and 40% fat reduction.

All values were tested for outliers according to Grubbs (ISO, 2002). For comparison reasons, Statistica 7.1 (StatSoft, Tulsa, OK, USA) was used to carry out statistical analysis on the test results. A normality test (Shapiro–Wilk) was followed by an all pair wise multiple comparison procedure (Fisher LSD, post hoc test) to evaluate significant differences.

3.3 Results and Discussion

3.3.1 Baking Trials and Experimental Design

In the present study, RSM was used to evaluate the effect of the technological parameters which were, number of fat layers, final dough thickness and, especially, the level of roll-in fat on puff pastry quality. Therefore, 17 trials of the central composite design with variations in fat reduction, number of fat layers and final dough thickness were carried out. The evaluation of the response data showed that these 17 trials did not provide sufficient information to describe the correlations of the independent variables adequately. Hence, the response data of a further 37 randomized trials within the design ranges were included in the design and data evaluation was repeated.

In Table 3-3, the ANOVA results for quality parameters of puff pastry are presented. The best fit model, which evaluated the effect of the independent variables on the response, was chosen. Thus, the significance of the lack of fit error term, coefficient R2, coefficient of variation (CV) and model significance were used to judge the adequacy of the model fit. The predictive models developed for total firmness (ECK), total firmness (MPP), specific volume, number of cells and slice brightness of puff pastry were considered adequate since they had a non-significant lack of fit and had satisfactory levels of R2, CV and model significance (Table 3-3).

Table 3-3 Analysis of variance (ANOVA) for evaluation of models for quality parameters of puff pastry

Response	Source	Sum of squares	F value	*p* value
Total firmness/Width (ECK)	Model	28338.43	21.98	< 0.0001
	Residual	2307.26		
R^2 = 0.92	Lack of fit	1257.91	0.65	0.8130
C.V. [%] = 12.43	Pure error	1049.35		
Total firmness (MPP)	Model	26812.75	8.74	< 0.0001
	Residual	3230.47		
R^2 = 0.89	Lack of fit	2291.63	1.63	0.2492
C.V. [%] = 17.29	Pure error	938.83		
Specific Volume	Model	135.48	6.91	< 0.0001
	Residual	34.05		
R^2 = 0.80	Lack of fit	26.59	2.04	0.1026
C.V. [%] = 10.93	Pure error	7.46		
Number of Cells	Model	$6.404 \cdot 10^6$	10.07	< 0.0001
	Residual	$7.364 \cdot 10^5$		
R^2 = 0.89	Lack of fit	$5.822 \cdot 10^5$	2.16	0.1381
C.V. [%] = 13.81	Pure error	$1.542 \cdot 10^5$		
Slice Brightness	Model	8054.35	17.24	< 0.0001
	Residual	540.99		
R^2 = 0.94	Lack of fit	389.57	1.47	0.2977
C.V. [%] = 4.90	Pure error	151.42		

RSM was further used for the generation of response surface plots, which are a helpful tool to better understand the link between each factor and its response. Therefore, the effect of the two factors—the number of layers and final thickness—on one specific response were displayed in three-dimensional view while keeping fat reduction (third factor) as fixed values (0%, 40%). Eight selected surface plots are presented in Figure 3-1.

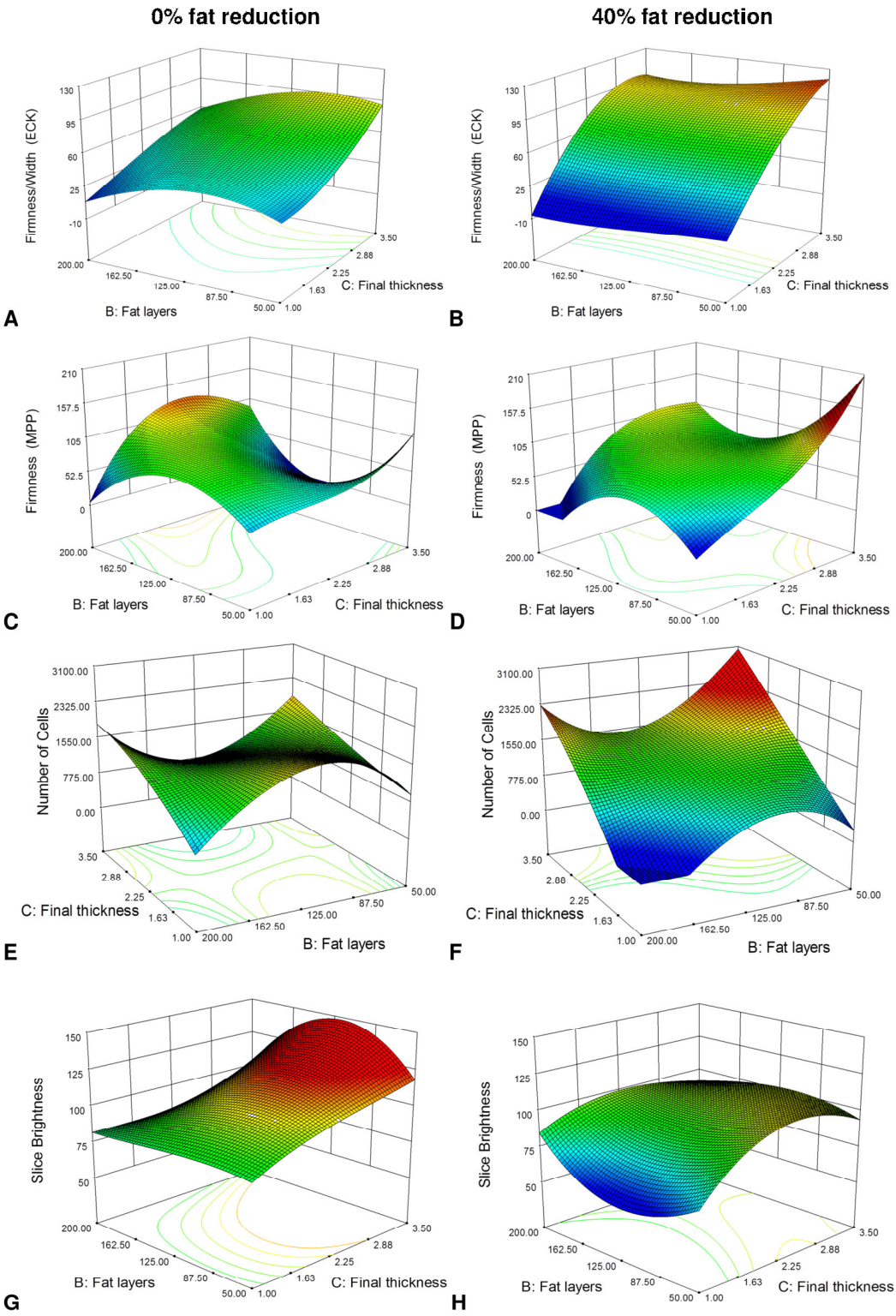


Figure 3-1 Response surface plots: Effect of final dough thickness and number of fat layers on total firmness (ECK) (**A**, **B**), total firmness (MPP) (**C**, **D**), number of cells (**E**, **F**) and slice brightness (**G**, **H**) of puff pastry at levels of 0 % and 40 % fat reduction

3.3.2 Firmness

In order to satisfy consumers' preferences, puff pastry must have an acceptable firmness, internal structure and texture. Firmness is one of the main parameters describing the internal structure of the baked puff pastry. The method using a thin sharp blade (ECK)—imitates best the initial bite into a puff pastry. In contrast, the MPP hits the surface of the sample just at the very beginning and at the very end of the penetration which measures internal structure. Total firmness is defined as the work required to cut (ECK) and to penetrate (MPP) the whole puff pastry sample. Typical force–time curves displaying total firmness measurements (ECK) are shown in Figure 3-2.

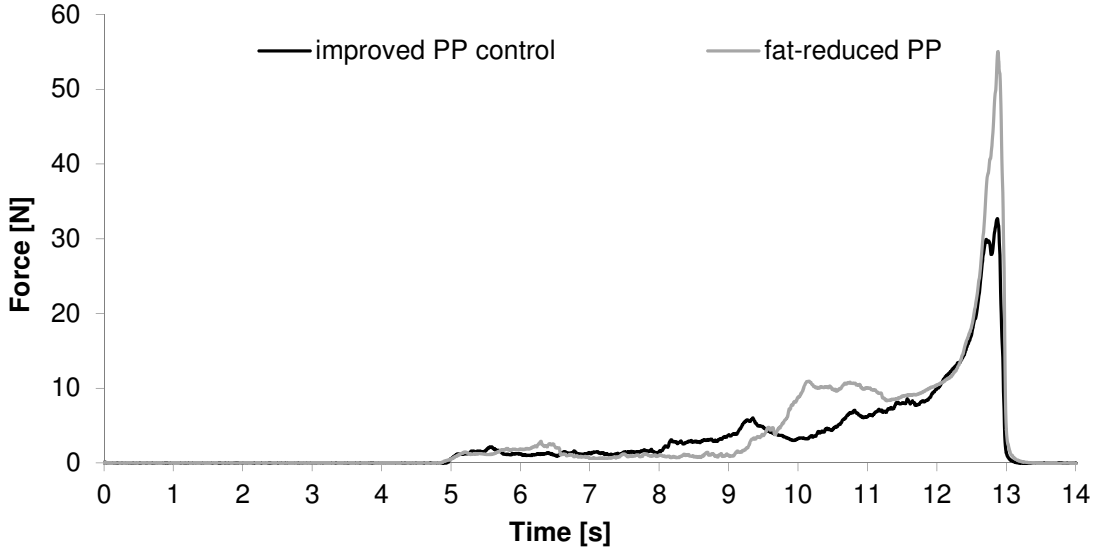


Figure 3-2 Force-time plot of 40 % fat-reduced puff pastry (48 layers, 2.25 mm) and improved puff pastry control (81 layers, 2.50 mm)

As shown in Figure 3-1 A, B, an increasing final thickness and decreasing number of layers led to firmer puff pastry. This effect is stronger for fat-reduced puff pastries. Total firmness of the puff pastry varied significantly among the experiments, ranging from 7.0 to 124.5 N×s/mm for ECK measurements and 18.7 to 144.5 N×s for MPP (Table 3-4).

Table 3-4 Optimum ranges for independent parameters and predicted (by Response Surface Methodology) and measured values for the responses of puff pastry (PP) at 0% and 40% fat reduction

	Settings for Optimization			**Range of experimental design**	**PP control**	**improved PP control**		**fat-reduced PP**	
	Target for optimization	**Lower limit**	**Upper limit**		**Standard Dough**	**Predicted parameters**	**Chosen parameters**	**Predicted parameters**	**Chosen parameters**
Fat reduction [%]	target = 0*	0	40	0 - 50	0.0	0.0	0.0		
	target = 40**	0	40	0 - 50				40.0	40.0
Fat layers	in range	36	144	12 - 256	144	82	81	46	48
Final thickness [mm]	in range	1.0	3.5	1.0 - 4.5	2.50	2.48	2.50	2.27	2.25
				Range of responses	Measured values	Predicted values	Measured values	Predicted values	Measured values
Firmness*100/Width (ECK) [N*s/mm]	minimize	50	110	7.0 - 124.5	65.2 ± 6.0 [b]	63.9	54.6 ± 4.8 [c]	80.2	80.4 ± 6.6 [a]
Firmness (MPP) [N*s]	minimize	50	110	18.7 - 144.5	62.5 ± 4.8 [b]	50.0	59.4 ± 8.1 [b]	78.8	69.4 ± 5.9 [a]
Specific Volume calc. [ml/g]	in range	7	13	5.3 - 13.3	6.6 ± 0.8 [c]	8.8	8.3 ± 1.0 [b]	10.3	10.4 ± 0.9 [a]
Number of Cells	maximize	1200	2307	213 - 2307	1273 ± 105 [c]	1431	1396 ± 264 [b]	1672	1742 ± 245 [a]
Slice Brightness	maximize	80.0	122.8	57.0 - 122.8	116.3 ± 8.5 [a]	120.1	106.5 ± 7.8 [b]	107.7	102.6 ± 11.1 [b]
Number of Cells/ Height (avg) [1/mm]	maximize	25.0	39.9	16.6 - 39.9	37.0 ± 4.2 [a]	36.0	33.3 ± 3.5 [b]	35.0	36.3 ± 4.2 [a]
Number of Cells/ Slice Area [1/mm^2]	in range	0.450	0.600	0.382 - 0.606	0.519 ± 0.050 [a]	0.515	0.484 ± 0.047 [b]	0.508	0.508 ± 0.049 [a]

Target for optimization * for improved puff pastry control, ** for fat reduced puff pastry, values are means ± SD; [a] values in one row followed by the same letter are not significantly different ($p < 0.05$)

Comparison of the analytical values (range of responses, Table 3-4) and the subsequent sensorial evaluation by an experienced baker gave a range of total firmness (ECK) values between 50 and 110 Ns/mm, relating to an acceptable total firmness and texture of the puff pastry samples. Total firmness values out of this range were related to puff pastries with poor internal structure and mouthfeel. The thinner the final paste was sheeted and the more dough layers it contained, the thinner were the single dough layers in the end. It seems that many thin dough layers led to a lower total firmness (ECK) in the product than few thicker dough layers. Total firmness (MPP) for low-fat contents (minus 40%) basically followed the same trend and increased with increasing final thickness and decreasing number of layers (Figure 3-1 D).

For full-fat puff pastry, the highest total firmness (MPP) was obtained for high numbers of fat layers and medium final thicknesses (Figure 3-1 C). For a lower number of layers, the total firmness of full-fat puff pastry decreased. This is probably due to the higher fat content. During the baking process, the melted fat is partially moving into the dough layers (Anonymous, 2000a; Dörr, 1982) and crystallizes again when cooling down after baking. The fat crystals in the final product cause a softening of the dough layers by lubrication and make them tenderer (Dörr, 1982; Ghotra et al., 2002). This softening effect increases for higher fat contents (Telloke, 1991). The findings are in accordance with the results reported by Baardseth et al. (25) who investigated different types and concentrations (350, 500 and 650 g/kg dough) of shortenings in Danish pastry. Firmness measurements were conducted with a Kramer shear cell and compared to results of a trained sensory panel. It was found that firmness decreases when the shortening concentration increases. Both sensory analysis and textural measurements were in good agreement. Sternhagen and Hoseney (1994) reported contrary results analysing the firmness of croissants with different levels of roll-in fat (15%, 20% and 25% dough based) using a compression test and a 36 mm diameter plunger. They could not find any significant differences in firmness. Keeping in mind that croissants and Danish pastry are made with leavened dough and additional ingredients, these results are only partially comparable to those of puff pastry, but give a good indication.

3.3.3 Number of Cells/Slice Brightness

In addition to total firmness, the layered structure and exceptional flakiness of puff pastry are two of the most important characteristics influencing consumers' choice (Kincs and Minor, 1995). Moreover, the internal structure of the baked puff pastry is directly related to the mouthfeel and crispiness (Simovic et al., 2009). Figure 3-3 images (A, D, G), taken with the C-Cell, which are representative of baked puff pastry samples with a well-developed internal structure.

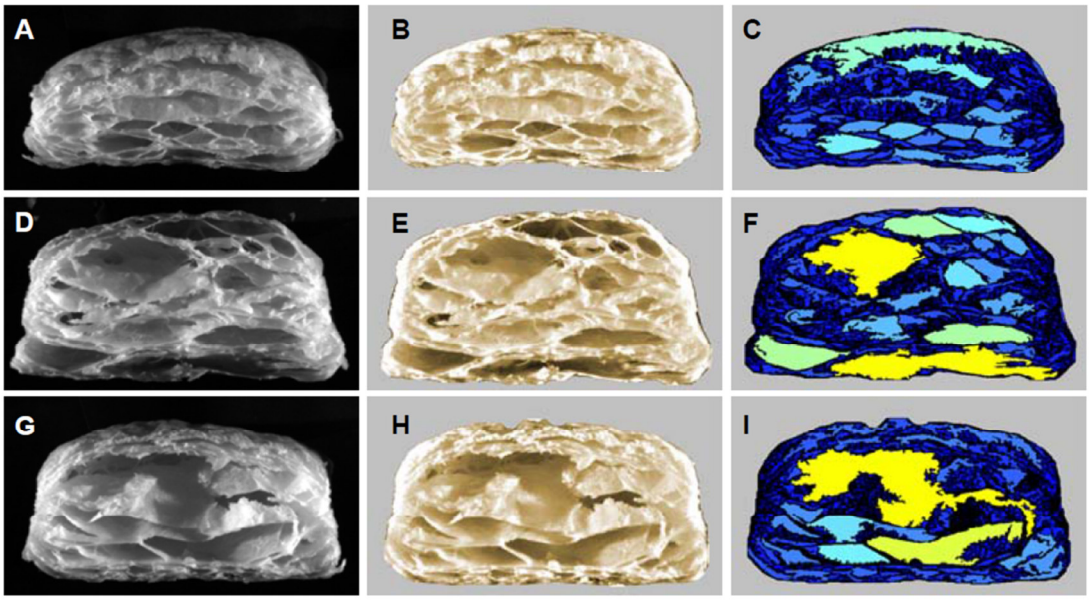


Figure 3-3 C-Cell images from cross sections of baked puff pastry with 40 % fat reduction, 48 layers, 2.00 mm (1st row), 0 % fat reduction, 81 layers, 2.50 mm (2nd row) and 0 % fat reduction 144 layers, 2.50 mm (3rd row), raw images (**A**, **D**, **G**), brightness image (**B**, **E**, **H**) and cell image (**C**, **F**, **I**)

Number of cells (Figure 3-3 C, F, I) and slice brightness (Figure 3-3 B, E, H) values were found to be the parameters which correlated best and allowed a prediction of the cellular and layered structure of the inner pastry.

In general, a larger number of cells is a good indication of a good internal puff pastry structure (data not shown). This is due to the fact that a higher number of cells represents a higher degree of crosslinking of the single dough layers, but also a larger cross-sectional area in the product. On the other hand, a higher number of cells within the same cross-sectional area implies that the cells are smaller and, thus, the internal structure is better. With an average of 1273 cells, the puff pastry control showed an acceptable internal structure (Table 3-4). The number of cells of 40% fat-reduced puff pastry at higher final thickness values has a minimum at about 140

layers and increases to both sides along the number of layers (Figure 3-1 F). In theory, it should be assumed that more cells are created by higher numbers of dough and fat layers. However, in puff pastry with 100 or more dough layers, they were probably not separated properly by the fat layers to create cells which are big enough to be detected by the C-Cell system. The actually existing number of layers in puff pastry is well below the theoretically possible number, as observed by Noll et al. (1997) and Telloke (1988). This effect can be seen in Figure 3-3 for full-fat puff pastries with 81 fat layers (second row) and 144 fat layers (third row).

Since each cell is encased by a cell wall of dough, more cells lead to a higher number of cell walls. The light reflected by these cell walls makes the product cross section appear brighter (Figure 3-3 B, E, H). Thus, a high number of cells in the cross sectional area of the product basically results in high brightness values since the slice brightness positively correlates to the number and the thickness of dough cell walls. Unlike in bread analysis, the slice brightness value cannot be used as an independent parameter for puff pastry quality and has to be considered in conjunction with the other analytical parameters. The values might be false positive and the result is limited in information if, for example, products consist of only few thick dough layers. According to the RSM model (Figure 3-1 G), the highest slice brightness values for full-fat puff pastry were obtained for high final thicknesses and about 140 layers. However, the slice brightness in relation to the number of layers for full-fat puff pastry seems to follow almost exactly the opposite trend to the number of cells as with increasing numbers of fat layers, lower numbers of cells were shown in the response surface plot (Figure 3-1 E), which would result into lower values in brightness. The 40% fat-reduced puff pastry slice brightness achieved its highest values in the area of around 90 fat layers and a final thickness of 2.30mmand decreased towards the sides (Figure 3-1 H).

Conclusively, the number of cells and slice brightness values followed different trends depending on the amount of RIF used, which reflects the challenge in finding the best optimum.

3.3.4 Optimization of Process Variables

Optimum levels for the number of layers and final thickness were determined by superimposing the surface plots for all response variables using Design Expert software (Floros and Chinnan, 1988). The regions that best satisfy all the quality

requirements were selected as optimum conditions. For this reason, the responses of the physicochemical analysis were compared to the results and impressions of the sensorial analyses and thereof, the threshold values and ranges for qualitatively acceptable puff pastries were defined (Table 3-4). After evaluation of all data, minimum total firmness (ECK and MPP), maximum number of cells and maximum slice brightness were the main quality criteria for the puff pastry optimization.

First, it was determined whether the puff pastry control may be improved by using the RSM. Therefore, fat reduction was set to 0%. An overview of all further limits and ranges for the optimization process of improved puff pastry control is given in Table 3-4. Lower and upper limits for the independent and dependent variables and the optimization target (‘maximize’, ‘minimize’ or ‘in range’) were set. These limitations resulted in the zone of the optimum conditions (Nazni and George, 2012). Taking into account all these limitations (Table 3-4), the optimization revealed few possible combinations for the parameters, number of fat layers and final thickness, for an improved puff pastry control (data not shown). One of these obtained combinations (82 layers, 2.48 mm thickness) was chosen for experimentally testing the optimized process. In practice, the technical capabilities to achieve the predicted number of fat layers and final thickness are limited by the method of preparation (folding steps) and the dough sheeter (roller gap). Thus, an improved puff pastry control with the closest feasible parameters, 81 layers and 2.50 mm final thickness, was prepared and analysed. Afterwards, the results were compared to those predicted by the mathematical RSM model (Table 3-4). The measured values for the number of cells and the ratios, number of cells/height and number of cells/slice area, for the improved puff pastry control corresponded well to the predictions (RSM), while the predicted (RSM) value for total firmness (MPP) was overestimated. Values for total firmness (ECK), specific volume and slice brightness were lower than predicted by the Design Expert software. The RSM model does not include all possible external factors that might influence the final products and is therefore only an approximation. Hence, not all analysed data can exactly match the values predicted by the mathematical RSM model.

However, to summarize, by using RSM modelling the improved puff pastry control (81 layers, 2.50 mm final thickness) gave better results compared to the puff pastry control (144 layers, 2.50 mm final thickness). In particular, total firmness (ECK) decreased significantly and specific volume and number of cells increased

significantly ($p < 0.05$) for the improved puff pastry control compared to the puff pastry control. This quality improvement of the puff pastry control by changing the number of layers was confirmed later by sensory evaluation.

After the successful optimization for the improved puff pastry control for the maximum fat reduction in puff pastry, a desired fat reduction of 40% was considered, while all further settings remained the same as before (Table 3-4). In this case, 46 layers and 2.27 mm thickness were obtained as one of the optimum operating points. Finally, to match the technical limits, fat-reduced puff pastry with 48 layers and 2.25 mm final thickness was baked and analysed. The predicted and measured results are presented in Table 3-4. For 40% fat-reduced puff pastry, measurements of total firmness (ECK), specific volume, number of cells and slice brightness corresponded well with the predictions of the RSM model, but slightly lower total firmness (MPP) was measured than predicted.

3.3.5 Compositional Analysis

Compositional analysis was conducted for the optimized puff pastries: fat-reduced puff pastry and the improved puff pastry control (Table 3-5).

Table 3-5 Compositional analysis of puff pastry (PP)

	Improved PP control	Fat-reduced PP	Reference PP*
Protein [g/100 g]	5.4 ± 0.1	6.7 ± 0.1	6.7
Carbohydrates [g/100 g]	42.5 ± 0.7	52.6 ± 1.2	42.8
Fat [g/100 g]	45.0 ± 0.9	29.0 ± 0.6	33.2
Moisture [g/100 g]	6.0 ± 0.4	10.2 ± 1.3	13.4
Ash [g/100 g]	1.1 ± 0.1	1.5 ± 0.1	1.5

Values are means ± SD of three measurements. *Nutrient analysis survey of biscuits, buns, cakes and pastries – FSA Analytical report (Food Standards Agency, 2011)

Fat content in the baked product was 29.0 ± 0.6 g/100 g and 45.0 ± 0.9 g/100 g for fat-reduced puff pastry and the improved puff pastry control, respectively. This is equivalent to a total fat reduction of 36%. Thus, the actual fat reduction in the fat-reduced puff pastry was slightly lower than calculated before (cf. Table 3-1) which was probably due the production process. The rough edges of the dough wide sides were trimmed before each further lamination. Finally, the total ratio shifts in favour of the fat since the removed edges contained mainly dough.

According to EU Regulation (EC) No. 1924/2006 on nutrition and health claims made on foods, a product can be stated as "reduced in fat" where the reduction in (fat) content is at least 30% compared to a similar product (EC, 2007). Since the total fat content in the fat-reduced puff pastry was reduced by more than 30%, this fat-reduced puff pastry can be claimed "reduced in fat".

3.3.6 Confocal Laser Scanning Microscope

To get a better understanding of the puff pastry dough, cross sections of the frozen samples were stained and examined with help of the CLSM. The micrographs (Figure 3-4) show the single dough and fat layers.

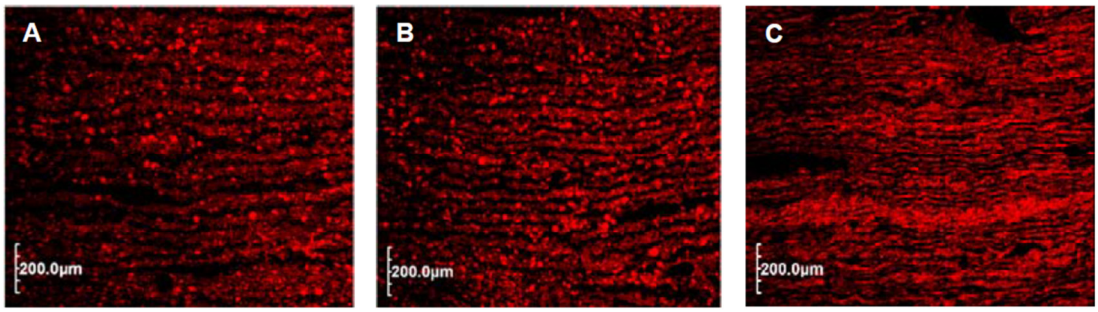


Figure 3-4 Confocal Laser Scanning Microscope representations of cross sections of laminated puff pastry dough (unbaked); protein network and starch granules (red) of the dough layers and intermediate fat layers (black). **A**: 40 % fat-reduced puff pastry (48 layers, 2.25 mm) **B**: improved puff pastry control (81 layers, 2.50 mm) **C**: puff pastry control (144 layers, 2.50 mm)

The dough layers (proteins, gluten network) appear red and the brighter red spots represent starch granules. Generally, wheat starch can be separated into two fractions based on their granule size. Larger A-granules ranging from ~15 to 40 µm in diameter and smaller B-granules with a diameter range of ~1–10 µm (Sasaki and Matsuki, 1998). Starch granules of both fractions are relatively uniformly distributed within the dough layers (Figure 3-4). Since the fat was not stained by the fluorescent dye, it appears as black. The parallel arrangement of the different layers and the variation in the thickness of the fat and dough layers can also be seen well. Since all micrographs have the same magnification, it is clearly recognizable that the number and thickness of the dough and fat layers vary.

Due to its well-developed gluten network, wheat dough is a viscoelastic material, even when containing several fat layers, and does not show ideal plastic behaviour (Dobraszczyk and Morgenstern, 2003). Hence, details on thickness do not represent

the actual thickness of the laminated dough as the dough is expanding in the vertical direction (thickness) while contracting in the horizontal direction after passing the roller gap. For example, the actual thicknesses of the laminated doughs were 3.3 ± 0.1 mm for the 2.25 mm gap (final thickness) and 3.6 ± 0.1 mm for the 2.50 mm gap. For this reason, roller speed and number of passes were kept constant during all trials.

If the thickness of the dough is divided by the number of theoretical fat and dough layers, the theoretical thickness of a single layer can be obtained. A dough thickness of 3.3 mm divided by 97 layers (48 fat + 49 dough layers) gives an average thickness of 34 µm per layer. In this regard, for a final thickness of 2.50 mm (dough: 3.6 ± 0.1 mm), 81 and 144 fat layers, an average thickness per layer of 22 µm and 12 µm, respectively, will be obtained. According to Noll et al. (1997), after the final lamination, every dough and fat layer in the puff pastry dough is thinner than a sheet of silk paper.

In the present study, the amount of fat used was reduced without replacing it with other ingredients. Hence, the volume of RIF which is available for building the fat layers was reduced and the thickness of fat layers decreased while the thickness of the dough layers increased, keeping the number of layers and final thickness constant. Assuming now that the dough layers expand more in the vertical direction and that they have a larger volume than the fat layers, the dough layers should be thicker than the fat layers. This is well visible in Figure 3-4 A.

Apparently, there is a better distribution of the fat layers in the improved puff pastry control (Figure 3-4 B) than for the 144 fat layers of the puff pastry control (Figure 3-4 C). Here, the fat layers are too thin, broken at many points and probably cannot separate the dough layers from each other which ultimately led to poorer product quality (1988).

3.3.7 Sensory Evaluation of Puff Pastry

A total of 60 panellists from 14 nations (28 Ireland, 9 Germany, 8 France, 15 other) participated in the sensory acceptance test. A total of 34 participants were female and the average age was 30±11 years. Forty out of 60 panellists stated that they eat puff pastry monthly or even more often and two had never eaten it. Furthermore, 55% of the panellists had consumed fat-reduced food products previously.

The results of the sensory evaluation are presented as an APLSR plot (Figure 3-5) in conjunction with the ANOVA values (Table 3-6).

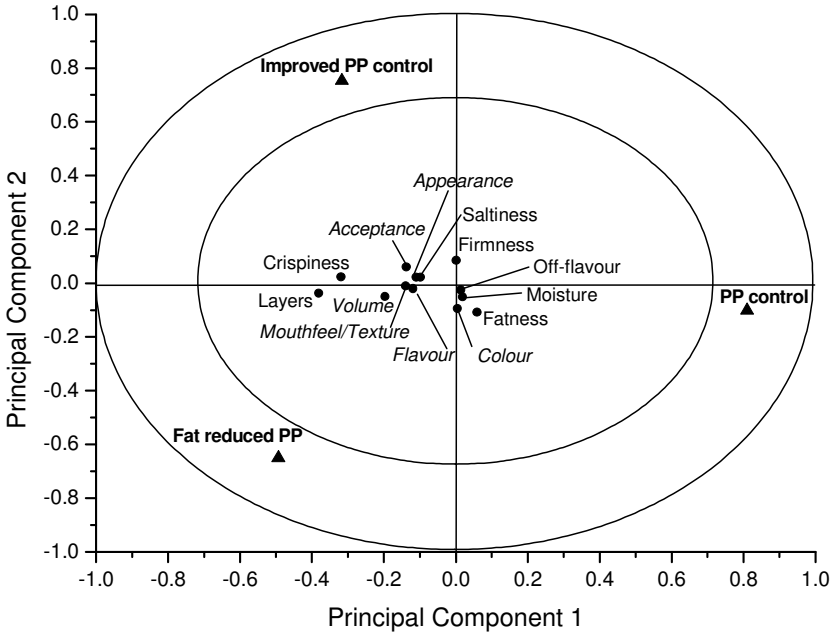


Figure 3-5 ANOVA-partial least squares regression (APLSR) correlation loadings plot for puff pastry (PP) samples. ▲= samples, ● = sensory attributes (cursive style: hedonic attributes, not cursive: intensity attributes)

In the right hand quadrant of the APLSR plot, the puff pastry control can be seen and in the opposite quadrant, the improved puff pastry control and fat-reduced puff pastry are located. The sensory attributes are accumulated in the plot centre, whereby the sample puff pastry control shows opposite properties.

In detail, the puff pastry control was scored significantly ($p < 0.05$) lower in 'liking of appearance'. Furthermore, positive trends were observed for the improved puff pastry control and the fat-reduced puff pastry in 'liking of appearance' (Table 3-6). Therefore, the attribute 'liking of appearance' was improved by the two new formulations.

Seemingly, no effect on colour was found between the three puff pastry recipes since no significant assessment for 'liking of colour' by the assessors was found.

Table 3-6 Significance of regression coefficients (ANOVA values) for the correlation of hedonic and intensity sensory terms for puff pastry (PP) formulations

Sample	PP control	improved PP control	fat-reduced PP
Hedonic			
Liking of Appearance	-0.0495 *	0.1225 ns	0.0861 ns
Liking of Colour	0.9384 ns	-0.9396 ns	-0.9376 ns
Liking of Volume	-0.0015 **	0.0415 *	0.0227 *
Liking of Flavour	-0.0195 *	0.1247 ns	0.0292 *
Liking of Mouthfeel/Texture	-0.0338 *	0.1132 ns	0.0641 ns
Overall Acceptability	-0.0103 **	0.1246 ns	0.0128 *
Intensity			
Layers	-1.0E-08 ***	0.0223 *	0.0016 **
Fatness	0.4047 ns	-0.4934 ns	-0.3588 ns
Saltiness	-0.0994 ns	0.2083 ns	0.1073 ns
Moisture	0.7625 ns	-0.7719 ns	-0.7582 ns
Total firmness	0.9872 ns	-0.9872 ns	-0.9872 ns
Crispiness	1.8E-07 ***	0.0421 *	0.0007 ***
Off-flavour	0.8251 ns	-0.8295 ns	-0.8229 ns

Significance of regression coefficients; ns, not significant; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.0010$

Data for the puff pastry control also showed a very significant ($p < 0.01$) negative correlation to 'liking of volume', and for the improved puff pastry control and the fat-reduced puff pastry, a significant ($p < 0.05$) positive correlation was observed (Table 3-6). The analytical results (Table 3-4) show a significant higher volume for the two new puff pastry formulations which the panellists preferred. Contrary results were achieved in the study by Simovic et al. (2009). In this case, high fat puff pastry (55% margarine type MLT2) with a 45 min rest period gave a significantly increased volume and firmness which the panellists assessed as excellent quality. It is noteworthy that Simovic et al. (2009) did not achieve their results by reducing the fat technologically as in the present study. However, in both studies, the panellists preferred puff pastries with higher volumes which showed that varying the number of fat layers and final thickness of puff pastry affects the sensory attribute 'liking of the volume'.

Panellists assessed a significant negative correlation for puff pastry control ($p < 0.05$) to the 'liking of mouthfeel/texture' (Table 3-6).

Puff pastries are characterized by the laminated structure formed by layers (Figure 3-4) whereby the number of layers is an important sensory criterion. The puff pastry control contains, in theory, more layers than the improved puff pastry control and the fat-reduced puff pastry. However, the sensorial assessment of the puff pastry control showed a high significantly ($p < 0.001$) negative correlation to the number of layers (Table 3-6). The improved puff pastry control and the fat-reduced puff pastry were, however, significantly ($p < 0.05$, $p < 0.01$) positively correlated with the number of layers. The dough layers in the puff pastry control probably adhered to each other due to fat layers being too thin, as previously mentioned.

The attribute fatness, which represents the greasy mouthfeel of the puff pastry, was just associated with the sample puff pastry control and not to the improved puff pastry control which contains the same amount of fat. However, for all three samples, no significant differences in fatness were achieved (Table 3-6).

For the sensory attribute saltiness, no significant differences could be obtained which is consistent with the puff pastry formulations (cf. Table 3-1). The salt content in the basic dough was equal for full-fat and the fat-reduced puff pastry. However, due to the varied production processes, the absolute salt content in fat-reduced puff pastry was slightly higher since the dough and fat ratio shifts in favour of the dough.

Inverse instrumental results for firmness were achieved, whereby the fat-reduced puff pastry had significantly higher values ($p < 0.05$) than the puff pastry control and the improved puff pastry control (Table 3-4).

The attribute crispiness is an important characteristic of puff pastry, which is mainly caused by the properties of the dough layers. All analysed puff pastry samples could be positively correlated ($p < 0.001$, $p < 0.05$) to the attribute crispiness.

All samples were baked fresh on the sensory day. No significant positive correlations to off-flavour were determined by the assessors.

The main criteria associated with the repeated purchase of a food product are ‘liking of flavour’ and an overall satisfaction with the quality parameters. No correlation was found between the ‘liking of flavour’ and the overall acceptability for the puff pastry control $p < 0.05$, $p < 0.01$). The modified formulations, the improved puff pastry control and fat-reduced puff pastry, obtained from the RSM modelling, resulted in a significant ($p < 0.05$) positive correlation between flavour and overall acceptability. Thus, the modified puff pastry formulations were clearly preferred in taste. The sensory acceptance test showed that RIF could be reduced by 36% without

adversely affecting the products when compared to conventional products with a high fat content of 33 wt.% With the help of the RSM model and the Design Expert software, it was finally possible to reduce the fat content in puff pastry solely by changing the two technological parameters: the number of layers and final thickness.

3.4 Conclusions

Analytical methods for measuring the quality characteristics (total firmness, specific volume, number of cells and slice brightness) of puff pastry were applied, including a Texture Analyzer attached with ECK and MPP, VolScan and a C-Cell image system. In particular, the parameters of the number of layers and final dough thickness were determined to play an important role as technological parameters which can be modified to allow a reduction in RIF. Using the RSM design as a tool for the optimization of fat-reduced puff pastry, with consideration of the independent parameters—fat reduction, number of fat layers and final thickness—was successful. The optimized parameters for fat-reduced puff pastry were 48 layers and 2.25 mm final thickness. This demonstrates that a reduction in the fat content in puff pastry is achievable with technological changes only and without the addition of fat replacers or fat-mimicking substances. As shown through sensory analysis, puff pastry products with a reduced fat content (36% reduced) can be produced with the best possible quality characteristics when compared to conventional products.

3.5 Acknowledgments

The authors want to thank Inken Rethwisch and Susann Fellendorf for their support in the sensory study and further Dr. Kieran Lynch for proofreading the manuscript. This study was carried out with financial support from the European Commission, FP7, Thematic Area KBBE, Project “PLEASURE” (Grant agreement no: 289536). It does not necessarily reflect its views and in no way anticipates the Commission’s future policy in this area.

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Chapter 4

Impact of low-*trans* fat compositions on the quality of conventional and fat-reduced puff pastry

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Published as Silow, C., Zannini, E. & Arendt, E. K. (2016) "Impact of low-*trans* fat compositions on the quality of conventional and fat-reduced puff pastry" in *Journal of Food Science and Technology*, 53 (4): 2117-2126

Abstract

Four vegetable fat blends (FBs) with low *trans*- fatty acid (TFA ≤ 0.6 %) content with various ratios of palm stearin (PS) and rapeseed oil (RO) were characterised and examined for their application in puff pastry production. The amount of PS decreased from FB1 to FB4 and simultaneously the RO content increased. A range of analytical methods were used to characterise the FBs, including solid fat content (SFC), differential scanning calorimetry (DSC), cone penetrometry and rheological measurements. The internal and external structural quality parameters of baked puff pastry were investigated using texture analyser equipped with an Extended Craft Knife (ECK), VolScan and C-Cell image system. Puff pastry containing FB1 and FB2 achieved excellent baking results for full fat and fat-reduced puff pastry; hence these FBs contained adequate shortening properties. A fat reduction by 40 % using FB2 and a reduction of saturated fatty acids (SAFA) by 49 %, compared to the control, did not lead to adverse effects in lift and specific volume. The higher amount of RO and the lower SAFA content compared to FB1 coupled with the satisfying baking results makes FB2 the fat of choice in this study. FB3 and FB4 were found to be unsuitable for puff pastry production because of their melting behaviour.

4.1 Introduction

Puff pastry is a bakery product with a high fat content, of up to 40 %, and is known for its light and flaky, layered structure (Anonymous 2000a). This delicate structure is obtained by repeated lamination of unleavened wheat dough and fat (Cauvain and Young 2001) without use of any rising agents.

Fat is important for the development of the characteristic puff pastry properties such as the flaky shape, layered effect, texture, appearance, volume and lift (Boode-Boissevain and Van Houdt-Moree 1996). As alternatives to butter, nowadays, specifically manufactured margarines and tailor-made fat blends (FBs) which contain animal and/or vegetable fats are employed for puff pastry production. While margarines contain a low amount of water, so called shortenings are virtually water-free. Shortenings have to hold a wide plastic range and have to match the properties of the dough (Anonymous 2000b). They also have to be highly structured providing spreadability during lamination and giving a good texture to the baked product (Garcia-Macias et al. 2011). A solid fat content (SFC) of 11 % at 40 °C enables good processing ability, producing a good layering effect during the production in the warm bakery (Stauffer 1999). Additionally, to enable butter- like quality, fat should be stable in the β´-crystal form (Kincs and Minor 1995) as this provides flakiness (Nor Aini and Miskandar 2007).

To allow utilization in a wider product range, oils were hydrogenated to transform mono (MUFA) and poly unsaturated fatty acids (PUFA) into SAFA with higher melting points. Additionally, *trans*-fatty acids (TFA) are often formed as by-products of the oil hardening. TFA and SAFA have been shown to increase the LDL (low density lipoprotein) cholesterol level and decrease the HDL (high density lipoprotein) cholesterol, which can contribute to various coronary and cardiovascular diseases (Stauffer 1999; Erkkilä et al. 2008; Baum et al. 2012). For this reason, many guidelines and legislations to reduce the TFA content in foods have been developed. Therefore, in order to provide healthier convenience food products there is a continuing need to reduce the levels of SAFA and TFA (Boode-Boissevain and Van Houdt-Moree 1996).

Due to its key role in puff pastry, fat cannot be reduced entirely without adversely affecting product quality (Boode-Boissevain and Van Houdt-Moree 1996). Several studies ad- dressing the reduction of fat, SAFA and TFA in puff pastry have been

performed (Boode-Boissevain and Van Houdt-Moree 1996; Simovic et al. 2009; Garcia-Macias et al. 2012). The majority of studies focussed on the characteristics of shortenings and fats used in puff pastry production, e.g. (Pajin et al. 2011; Lefébure et al. 2013), rather than the characteristics of the final baked products (Cavillot et al. 2009; Simovic et al. 2009).

The present study focuses on the application and utilization of four FBs with low-*trans* content and reduced SAFA content and on the characteristics of the resulting baked puff pastry products. For this reason four vegetable FBs with different ratios of palm stearin (PS) and rapeseed oil (RO) were physically characterised and evaluated for their suitability in puff pastry production.

PS is a fraction of palm oil containing mainly palmitic (C 16:0) and oleic acid (C 18:1) (Nor Aini and Miskandar 2007). It is widely used in shortenings (Stauffer 1999) as PS prevents the shortening from melting during preparation. A mixture of PS and oil, for example RO, provides good plasticity and fulfils the users' requirements for a good puff pastry shortening (Nor Aini and Miskandar 2007). RO is produced from the seed of rapeseed cultivars (Canola), which are genetically low in both erucic acid and glucosinolates (Yap et al. 1989). RO has a balanced and healthy fatty acid composition containing mainly oleic acid and high amounts of long-chain PUFA such as linoleic (C 18:2; 58 %) and linolenic acid (C 18:3; 0.7 %), which are important in the human diet (Siew et al. 2007). The commonly used liquid oil has a low melting point and is widely used in various food products as well as being blended with other solid fats to produce structured lipids (Siew et al. 2007).

4.2 Materials and methods

4.2.1 Materials

Puff pastry dough was prepared with wheat flour (Grand Moulins de Paris, France; type T45, 13.5 % moisture, 11.5 % protein), salt (Glacia British salt Ltd., UK), lemon juice (Tesco, UK) and tap water. Four specially manufactured non-interesterified FBs with different ratios of PS and RO were used as roll-in fat. The PS content decreased from FB1 (standard fat) to FB4, while the content of RO increased (Table 4-1). All FBs contained no other ingredients than the vegetable fats/oils. Table 4-1 gives a short overview of the main fatty acid composition of the four FBs. The SFC of the fat blends was provided by the retailer (see 3.2.1).

Table 4-1 Fatty acid composition [%] of fat blends (FB)

Fatty acid	FB1[a]	FB2[a]	FB3[a]	FB4[a]	Palm stearin[b]	Rapeseed oil[b]
C 16:0	41.0	35.6	32.3	26.8	47.2-73.8	3.6
C 18:0	4.0	3.6	3.4	3.1	4.4-5.6	1.5
C 18:1/9 *cis*	36.7	40.0	41.9	45.2	15.6-37.0*	61.6*
C 18:1/11 *cis*	1.5	1.8	2.0	2.3	n. s.	n. s.
C 18:2 *cis*	10.5	11.9	12.7	14.1	3.2-9.8*	21.7*
C 18:3 *cis*	2.9	3.8	4.3	5.1	0.1-0.6*	9.6*
C 18:1 *trans*	0.1	0.1	0.1	0.1	n. s.	n. s.
C 18:2 *trans*	0.2	0.2	0.2	0.2	n. s.	n. s.
C 18:3 *trans*	0.2	0.3	0.3	0.4	n. s.	n. s.
Total C18 *trans*	0.5	0.6	0.6	0.6	n. s.	n. s.
Total Saturated	48.2	40.9	37.3	31.4	52-80	6.3
Total Unsaturated (mono + poly)	50.4	58.5	62.0	67.9	19-47	93.7

Source: [a] Retailer, [b] Vegetable Oils in Food Technology (Gunstone 2011), * no *cis/trans* differentiation, n. s. not specified

4.2.2 Characterization of fat blends

4.2.2.1 Viscoelasticity measurements

To measure the viscoelastic behaviour of the FBs, a frequency sweep test was performed on a controlled-stress rheometer (Anton Paar MCR 301, Ostfildern, Germany) fitted with a serrated parallel plate system (MP 25, Ø: 25 mm) to avoid slippage of samples. The linear viscoelastic region (LVR) for the fat samples was determined at 1 Hz with a strain sweep of 10^{-3} to 10^{2} %. Small frequency sweeps from 0.1 to 100 Hz were carried out at constant temperature (25 ± 0.1 °C) within the LVR at a constant strain of 5×10^{-3} % to avoid the destruction of the samples. Storage modulus (G´) and loss modulus (G´´) were the obtained parameters and chosen for comparison purposes.

The fat samples were initially moulded in steel tubes with an internal diameter of 48 mm and length of 100 mm. Samples were pushed out with a piston and specimens of ca. 3 mm were sliced with a stretched wire from each cylinder and immediately placed between the plates of the rheometer. To obtain contact over the whole surface area, the samples were slightly compressed by lowering the top plate to a final gap of 2.0 mm, before excessive sample was trimmed off. Prior to testing the samples were

conditioned for approximately 1 h at the measuring temperature. All results are reported as the average and standard deviation of at least three individual replicates.

4.2.2.2 Thermal analysis by DSC

Differential scanning calorimetry (DSC) was performed using a Mettler Toledo DSC 821e equipped with liquid nitrogen. Nitrogen was used as purge gas and indium, mercury and water were used for calibration. An empty punctured aluminium pan was used as a reference and the instrument was calibrated for temperature and heat flow as reported by Roos and Karel (1991). Samples of 8–12 mg were transferred to pre-weighed aluminium pans (40 µl, Mettler Toledo, Greifensee, Switzerland) and hermetically sealed before weighing. For melting behaviour, samples were held for 5 min at 0 °C and scanned from 0 °C to 70 °C with a heating rate of 5 °C/min. Thermograms were analysed with the provided STARe software (version 8.10, Mettler Toledo, Greifensee, Switzerland). Triplicate samples were analysed and the average peak temperature was calculated.

4.2.2.3 Consistency

Consistency of FBs was determined by penetration tests. An acrylic cone with an apex angle of 60° and no truncation was fitted to a constant speed texture analyser TA-XTplus (Stable Micro Systems Ltd., Godalming, UK). Test settings were: 30 kg load cell, penetration depth: 10.0 mm; test speed: 2 mm/s and time: 5 s. The compression force data in g_f was converted to a yield value according to Haighton (1959):

$$C\left[g / cm^2 \right] = K \frac{W}{p^{1.6}}$$

where C is the yield value, K is a factor depending on the cone angle (equal to 2815 for a 60° cone), W is the compression force in g_f and p is the penetration depth in mm. Fat samples were filled as solids into 60 ml plastic containers (Ø 33 mm) at room temperature. Conditioning was performed in an incubator for 24 h at 5, 10, 15, 20 and 25 °C. Six samples per FB were analysed.

4.2.3 Puff pastry production

The basic dough consisted of 1000 g wheat flour, 21 g salt, 15 g lemon juice and 510 g water. For full fat puff pastry (FFP) 740 g FB (33.0 wt %) and for 40 % fat-reduced puff pastry (RFP) 370 g FB (19.8 wt %) were used as roll-in fat.

All dry ingredients were premixed, liquids were added and the dough was mixed for two minutes on speed one (48 rpm) and three minutes on speed two (90 rpm) in a standard mixer (A200, Hobart Mfg.Co.Ltd., London, UK) with a kneading hook. Using tempered water the dough temperature after mixing was 23 ± 1 °C. A 1500 g portion of dough was covered in an airtight bag and left to rest for 20 min at room temperature (20 ± 2 °C).

Puff pastries were produced according to the French method. The basic dough was formed to a rectangle and sheeted down to a thickness of 7 mm (11 mm for RFP) using a Rondo sheeter (SSO 605, Seewer AG, Burgdorf, Switzerland). A squared block of FB was sheeted to a thickness of 15 mm (12 mm for RFP), placed on the dough and encased with the same while the edges were sealed together. Next, the layered dough was laminated to a thickness of 10 mm and the first folding turn was carried out followed by a rest period of 30 min. The dough was turned horizontally by 90° and the second turn was conducted followed by a rest period of 90 min. The third and the fourth turn (only FFP) were done by repeating the first and second turn with rest periods of 30 min. To achieve the desired number of theoretical fat layers, for FFP four single turns (81 fat layers) and for the RFP two double turns and one single turn (48 fat layers) were performed.

After a rest of 20 min the dough was sheeted to a final thickness of 2.50 mm (FFP) or 2.25 mm (RFP) while gradually decreasing the roller gap. Two passes were given to the dough at the final thickness. Samples of 10 × 10 cm were cut out randomly after a further 10 min rest and stored chilled in an airtight bag.

After refrigeration (4 °C) overnight, samples were allowed to reach room temperature and baked at 210 °C in a top- and bottom heated, unventilated, preheated deck oven (MIWE condo INT 01/01, Michael Wenz GmbH, Arnstein, Germany) for 15 min (FFP) or 14 min (RFP). FFP containing FB1 was defined as the control.

4.2.4 Physical analysis of puff pastry

After cooling to room temperature the samples were weighed and evaluated for specific volume and maximum lift using a VolScan Profiler (Stable Micro Systems, UK). Product length (longer distance) and width were determined manually over the sample middle using an electronic calliper.

Two hours after baking the texture analysis of puff pastry was determined using a texture analyser TA-XTplus equipped with an Extended Craft Knife (ECK, Stable

Micro Systems Ltd.) with the following settings: 30 kg load cell, compression mode, test speed: 5 mm/s, post-test speed: 10 mm/s, distance: 64.5 mm, trigger type: button, return distance: 65 mm, contact force: 15 g; software: Texture Exponent 32, version 4,0,9,0. Total firmness was obtained from the area under the characteristic compression curve. Peak firmness represents the highest peak of the compression curve. Each sample was cut breadthwise through its centre. To standardize the results all values were divided by their respective width (in mm) and multiplied by 100.

Internal structure characterization was conducted on cross sections of puff pastry halves (ECK test) using the C-Cell imaging system (Calibre Control International Ltd., UK). Images were analysed with the included software and the number of cells and slice brightness were the parameters used to describe the internal structure.

All baking trials were performed in triplicate while 5 random samples per trial were analysed. After all measurements the samples were generally compared and evaluated in terms of appearance, lift, structure, texture and mouthfeel by a panel of 3 experts.

4.2.5 Statistical analysis

Minitab 16 (Minitab Inc.) was used to carry out statistical analysis on the test results. A normality test (Shapiro-Wilk) was followed by one-way ANOVA with Tukey's post-hoc test to evaluate significant differences ($p \leq 0.05$).

4.3 Results and discussion

4.3.1 Fat composition

TFA concentrations of the FBs used in the present study are ≤ 0.6 % and can therefore be referred to as low-*trans* (Table 4-1).

The SFC curves, another important fat characteristic, of the four FBs are shown in Figure 4-1. With increasing temperature the SFC is decreasing, indicating a reduction in solid fat crystals. FB1 and FB4 exhibited the highest and lowest SFC values, respectively, over the whole temperature range. An increase of RO in the FBs resulted in a gradual reduction of the SFC which is in accordance to the literature (Siew et al. 2007). The SFC curves of the FBs were relatively shallow and consistent (Figure 4-1). Generally, puff pastry margarines show higher SFC values than other margarines (Wassell and Young 2007; Cavillot et al. 2009). In addition, Cavillot et al. (2009) found that TFA-free margarines at high temperature (above 40 °C)

generally presented a higher SFC content than products containing *trans*-fats. For good performance during the dough preparation and baking a nonzero SFC at a temperature above 40 °C is typical for puff pastry margarines (Cavillot et al. 2009). By combining different amounts of PS and vegetable oil, the SFC can be optimised and precise SFC profiles can be obtained (Wassell and Young 2007). It is important that, within the temperature range of production, FBs show a SFC high enough that they are not liquid but low enough that they are still spreadable. Telloke (1994) found that for health and sensorial reasons the SFC should be below 5 % at 40 °C. In order to allow complete melting in the mouth without leaving a waxy coating on the palate the SFC at 35 °C should be below 10 % (Siew et al. 2007). None of the four FBs fulfilled these two conditions (Figure 4-1). FB4 showed the lowest SFC while FB1 showed the highest SFC values for 35 °C (10.9 %, 20.6 %) and 40 °C (8.1 %, 15.5 %).

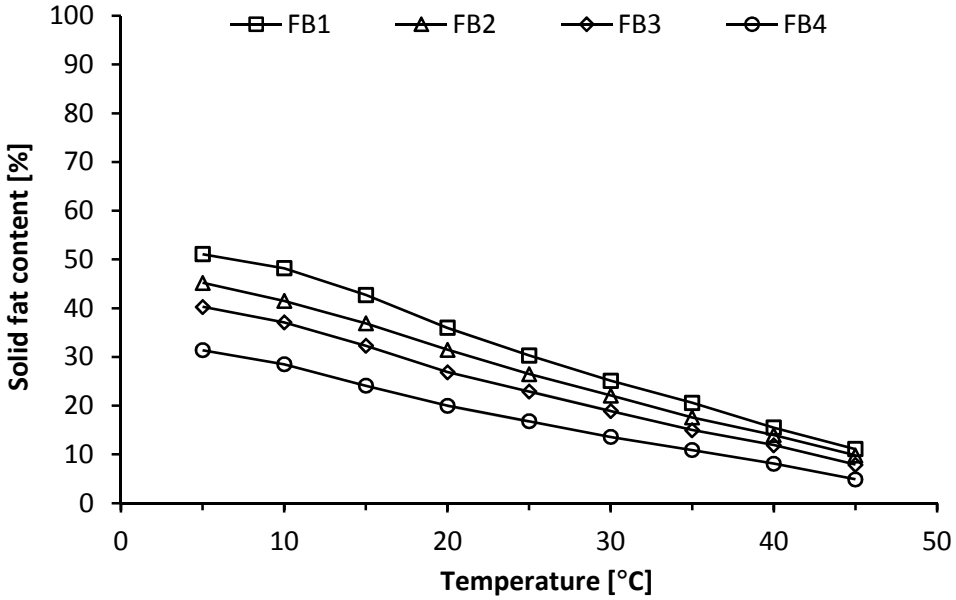


Figure 4-1 Solid fat content of fat blends (FB) 1 to 4. Values are means (n = 3)

4.3.2 Differential scanning calorimetry (DSC)

In order to study the melting behaviour of the FBs, the fats were heated directly from storage. Figure 4-2 shows the melting curves of the FBs, which represents the heat flow during the melting process of the fats. At higher temperatures a major peak was observed, with the maximum location steadily increasing from FB4 (47.8 °C) to FB1 (51.6 °C). These peaks are indicative of the high levels of higher-melting triacylglycerides (TAGs, e.g. tripalmitin) (Siew et al. 2007; Garcia-Macias et al.

2011). With increasing amounts of PS the endothermic curve had an observable shoulder occurring at a lower temperature than the main peak (Figure 4-2). It seems that a second peak is overlaid with the main peak. FB1 formed a second peak instead of a shoulder which can be clearly seen at 41.8 °C. Changes in the shape of the enthalpy curves may be due to the variances in polymorphic structure of the sample (Marangoni 2004). As the content of PS decreased, the peak heights and areas at higher temperature also decreased. In pretests broad multicomponent endothermic peaks could be observed for all FBs at temperatures when measured below 0 °C (data not shown). The peaks shifted slightly to a lower temperature when the RO content increased from FB1 to FB4, which was due to the increased low-melting glyceride content. The main fatty acids of RO melt in the range of −5 °C (Linoleic) to 13 °C (Oleic) (Gunstone 2011) or even lower. The group of Siew et al. (2007) detected similar peaks for non-interesterified FBs of hard palm stearin and canola oil. They assumed that the canola oil is responsible for peaks in the range of −28 to −12 °C and hard palm stearin for peaks in the range of 53 to 59 °C. Good correlations were found for the combination of the thermograms of hard palm stearin and canola oil, representing the higher- and lower-melting TAGs of these oils (Siew et al. 2007). For investigating the transition of crystal forms during melting of fats DSC is a useful technique (Yap et al. 1989). Fat can exhibit multiple melting points when it is being heated. The transition peak temperature can serve as an important indicator of the polymorphic form of the crystals, since the more stable crystal form has a higher melting point than the less stable form (Yap et al. 1989). The shoulder peak (Figure 4-2) indicated weaker polymorphs melting at lower temperatures mixed with stronger polymorphs melting at higher temperatures. In the current study it is probable that a mixture of β´and β polymorphs was present. While some studies stated that blends of PS are stable in β form (Garcia-Macias et al. 2011) others found that PS crystallizes in β´-crystal form (Miskandar et al. 2005). RO, in turn, generally has a β-crystallization tendency. It is known that the typical puff pastry structure is achieved by using fat which has a mixture of β´- and β-crystals (Kincs and Minor 1995). The greater β-tending property of PS may be explained by its higher concentration of tripalmitin (triglyceride of palmitic acid), since this triglyceride is a strong β-tending molecule (Nor Aini and Miskandar 2007). PS composition is dependent on fractionation conditions and may contain between 10 to 32 % tripalmitin (Yap et al. 1989). The PS content in the investigated FBs decreased from

FB1 to FB4, as did the SAFA content, when palmitic acid was included (48.2 %, 31.4 %, Table 4-1).

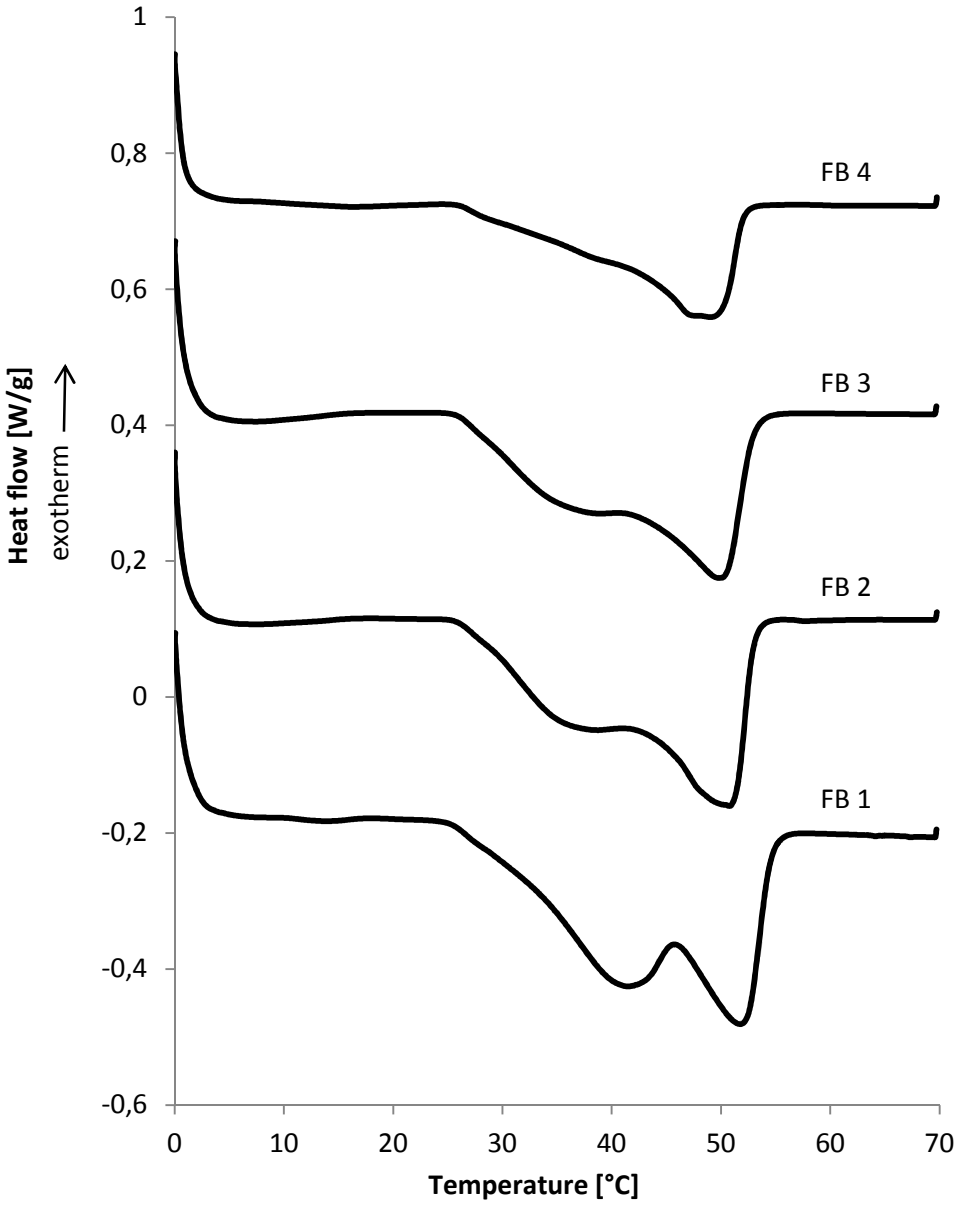


Figure 4-2 DSC melting curves of fat blends (FB) 1 to 4 at a heating rate of 5 °C/min

The findings of the DSC measurements correlate well with the SFC results of the four FBs. Greater amounts of higher melting TAGs were responsible for higher SFC values. While the amount of these higher melting TAGs decreased from FB1 to FB4 (Figure 4-2) the SFC similarly decreased (Figure 4-1).

4.3.3 Consistency of fat blends

Using a cone penetrometer the consistency for the four different FBs was determined. Figure 4-3 shows the calculated average yield values at various

temperatures. All FBs showed significant ($p < 0.05$) differences in their yield values at the same temperature. The highest yield values were obtained for all FBs at 5 °C, while increasing temperature from 5 to 10 °C resulted in a diminished consistency for all 4 samples. At higher temperatures every FB, depending on its composition, showed a relatively uniform consistency. From15 to 25 °C the yield values for all four FBs either did not decrease or decreased only slightly, with increasing temperature. Individually, for each fat composition, the yield values appeared to level off at a specific value, which was increasing significantly ($p < 0.05$) from FB4 to FB1. Interestingly this is the temperature range within which the fats were used for the puff pastry manufacturing process.

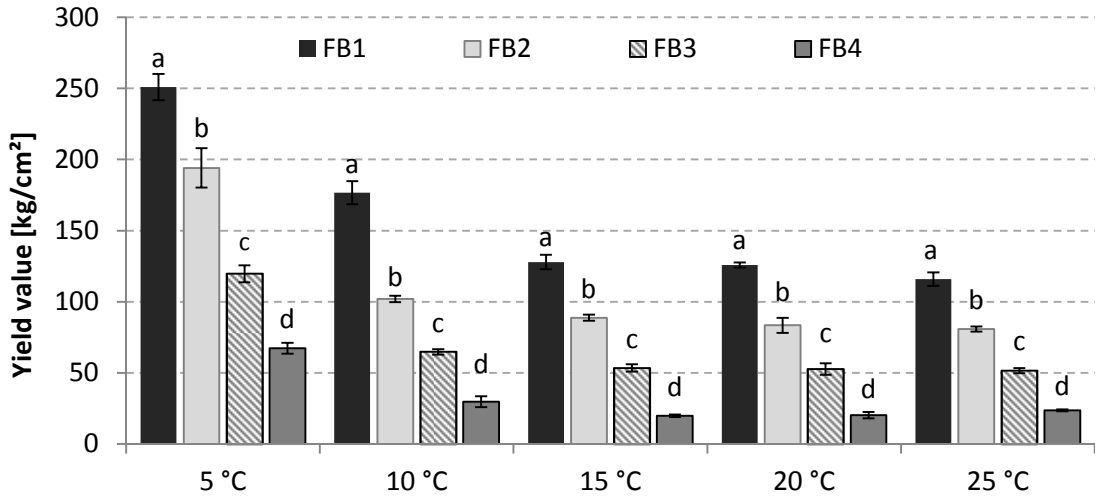


Figure 4-3 Yield value of fat blends (FB) 1 to 4. Mean ± confidence interval. Means followed by the same letter within same temperature indicate no significant difference ($p < 0.05$)

During puff pastry production roll-in fats are exposed to shearing forces due to lamination. Telloke (1994) found that yield values for puff pastry margarines only show a high correlation to puff pastry baking quality, if a pre-treatment under defined conditions was done before the measurements to simulate these shearing forces. Apart from the sample preparation the FBs in the current study were not pre-treated since the lamination procedure for puff pastries was similar for all FBs.

Yield values obtained by cone penetrometry do not relate to any fundamental properties of the fat, since large shearing forces are involved which produce substantial breakdown of structure (DeMan and Beers 1987). According to Haighton (1959), fats with yield values above 1.5 kg_f/cm^2 are considered as 'too hard' and for investigated puff pastry margarines/ fats he found yield values in the range of 0.8 to 1.6 kg_f/cm^2. Taking into account the best results of the present baking trials,

'extremely hard' FBs with yield values of 81 to 128 kg_f/cm^2 (20 °C) seem to be optimal for use in puff pastry production.

4.3.4 Rheology

In contrast to the cone penetrometry, rheology is a fundamental method. Linear viscoelastic testing such as oscillatory testing provides the most relevant data with respect to the molecular structure of the fat crystal network (DeMan and Beers 1987). Nevertheless, it should be noted, that rheological analysis is really sensitive and might not explain fully the behaviour of the roll-in fat in the puff pastry dough during the lamination process since much larger shear forces are applied.

The values for the storage modulus (G´) and loss modulus (G´´) for the four FBs are shown in Figure 4-4. For all fats G´ increased over the whole frequency range. With increasing frequency within the LVR G´´ was consistent for FB1, with slight increases for FB2 and slight decreases for FB3 and FB4.

This dependency of all FBs on frequency indicates a viscoelastic solid-like behaviour. Increasing G´ and decreasing G´´ with frequency indicates a transition from a more viscous to a more elastic material (Cheong et al. 2009). Furthermore, G´ values for all fats were higher than for G´´, indicating a more elastic than viscous behaviour. Differences in storage modulus are illustrated in Figure 4-4. FB1 and FB4 showed the highest and lowest average value for G´ over the whole frequency range, respectively (Figure 4-4). This indicated, an increasing firmness from FB4 to FB1. This result is correlated to the yield values, which are shown in Figure 4-3.

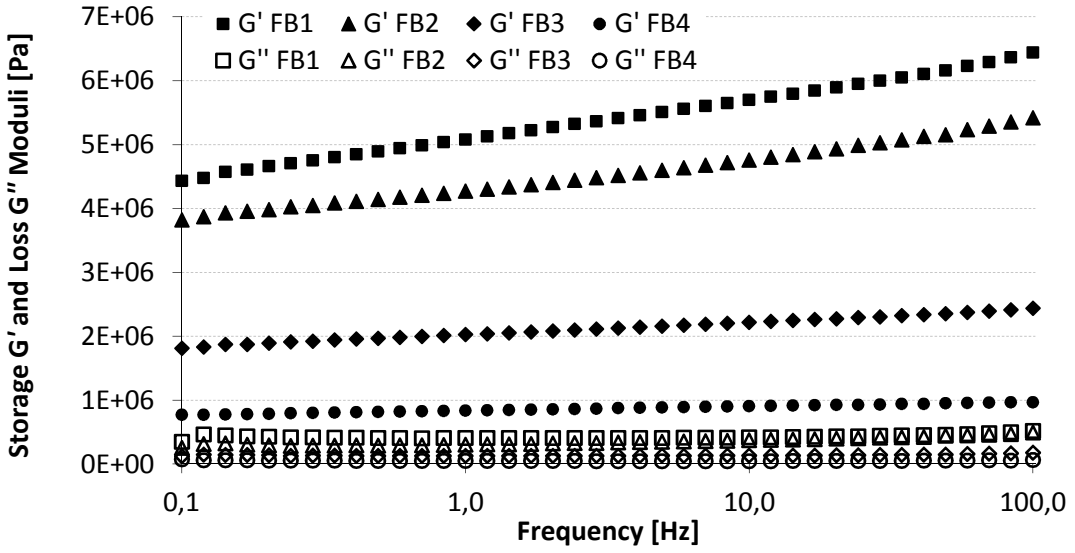


Figure 4-4 Storage (G') and loss (G'') moduli as a function of frequency of fat blends (FB) 1 to 4 at 25 °C and a constant strain of 5 x 10-3 %. Values are means (n = 3)

While the two firmest fats, FB1 and FB2, showed nearly the same viscoelastic behaviour, the softest fat, FB4, showed a high tendency towards more viscous behaviour, independent of the frequency. This was probably due to the higher oil content and lower content of higher melting TAGs (see DSC). It is also known that a higher SFC leads to higher values of G´ in fat systems (Bell et al. 2007). Comparing the SFC values of the FBs at 25 °C (Figure 4-1) this can be confirmed for all FBs. Fat crystal networks can be seen as a combination of "strong" and "weak" regions (Bell et al. 2007). More liquid or semi-solid lipids link a larger number of small solid crystals together and therefore are dominating the physical behaviour of the fats (Bell et al. 2007). FB3 had a higher content of UFAs than FB1 and FB2 (Table 4-1), and thus a higher number of weak bounds but was still more solid than FB4.

After the FBs were characterised they were tested for their utilization in puff pastry manufacture.

4.3.5 Puff pastry quality

The impact of the four FBs on the quality of FFP and 40 % RFP was investigated. Recipes and parameters used for the lamination procedure were established in chapter 3.

The first impression a consumer gets from puff pastry is the lift and (specific) volume, therefore these parameters are two important criteria in the assessment of puff pastry. Puff pastries with a high lift and specific volume are preferred by consumers (Simovic et al. 2009). According to Noll et al. (1997) a lift of 50 mm is regarded as optimal. The specific volume gives an indication of how dense a puff pastry is. Table 4-2 shows the lift and the specific volume of FFP and RFP, which was dependent on the four different FBs. The visual appearance of the puff pastries containing different FBs is shown in Figure 4-5.

FFP with FB2 reached the highest lift, at 60 mm ($p < 0.05$) and the highest specific volume (10.6 ml/g) followed by the control, which was 10 % lower in lift and 8 % lower in specific volume. RFP containing FB1 and FB2 also had a good lift (51 mm, 50 mm) and a high specific volume (9.5 ml/g, 8.9 ml/g). As previously discussed, FB1 was slightly harder than FB2 which may have caused little cracks in the fat and dough layers during sheeting what leads to less puffing during baking (Cauvain and Young 2001). But, in general it can be stated that the harder the fat, the higher the lift (Telloke 1994). Compared to the control these attributes were 20 to 60 % lower for

baked products with FB3 and FB4. This demonstrates that a softer FB adversely affects the rising of the puff pastry during baking, and confirms that a roll-in fat needs to contain a certain amount of SAFAs to deliver satisfactory puff pastry (Stauffer 1999).

FFP and RFP produced with FB4, containing the lowest amount of SAFA (31.4 %), were not acceptable in terms of lift and specific volume. This is in accordance with the findings of Garcia-Macias et al. (2011, 2012), who reported a lower lift for puff pastry produced with vegetable roll-in fats compared to puff pastry containing butter (66 % SAFA). These studies used FBs which contained about 30 % SAFA, namely palmitic acid (Garcia-Macias et al. 2011) and stearic acid, respectively (Garcia-Macias et al. 2012).

Products containing FB2 achieved excellent baking results; hence this FB contained adequate shortening properties. A fat reduction by 40 % and a simultaneous reduction of SAFA by 49 % in comparison to the control (Table 4-2) did not lead to adverse effects in lift and specific volume.

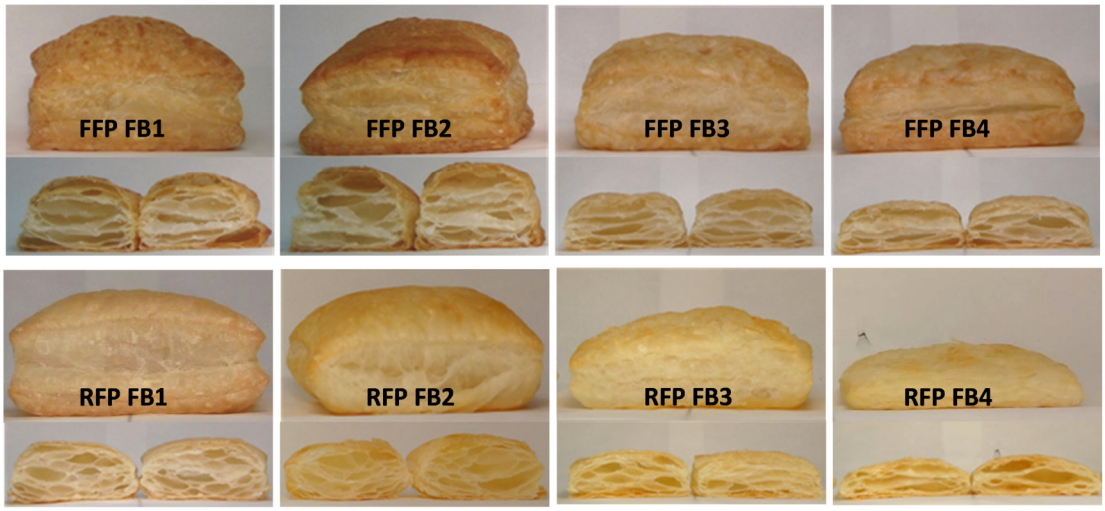


Figure 4-5 Images of full fat puff pastry (FFP, upper row) and fat-reduced puff pastry (RFP, lower row) samples and the corresponding cross sections containing fat blends (FB) 1 to 4

Firmness is another important parameter to describe the texture and the internal structure of puff pastry. The total amount of work needed to cut the sample is defined as “total firmness”, while the “peak firmness” represents the peak of the force expended during measurement. The ECK imitates the first bite of a consumer, because a very sharp and thin blade enables shearing with nearly no compression so that samples are cut. The peak firmness of the ECK describes the force, which is applied to completely bite through the sample.

Table 4-2 Physicochemical tests for baked full fat (FFP) and reduced fat (RFP) puff pastry containing fat blends (FB) 1 to 4

Parameter	FFP FB1	FFP FB2	FFP FB3	FFP FB4	RFP FB1	RFP FB2	RFP FB3	RFP FB4
Peak firmness [N/mm]	47.5 ± 4.1 ^{e}	56.6 ± 3.6 ^{d}	60.3 ± 2.8 ^{d}	73.7 ± 2.8 ^{c}	73.2 ± 5.6 ^{c}	89.4 ± 5.5 ^{ab}	85.3 ± 5.0 ^{b}	93.3 ± 5.1 ^{a}
Total firmness [N*s/mm]	65.1 ± 2.7 ^{b}	65.2 ± 1.9 ^{b}	57.2 ± 1.5 ^{c}	57.1 ± 2.0 ^{c}	76.6 ± 1.7 ^{a}	76.0 ± 3.9 ^{a}	65.0 ± 4.0 ^{b}	54.4 ± 2.3 ^{c}
Maximal lift [mm]	54 ± 3 ^{b}	60 ± 2 ^{a}	42 ± 2 ^{d}	39 ± 2 ^{d}	51 ± 3 ^{c}	50 ± 2 ^{c}	41 ± 2 ^{d}	29 ± 1 ^{e}
Specific volume [ml/g]	9.8 ± 0.4 ^{b}	10.6 ± 0.3 ^{a}	7.7 ± 0.3 ^{d}	6.2 ± 0.4 ^{f}	9.5 ± 0.4 ^{b}	8.9 ± 0.3 ^{c}	6.9 ± 0.3 ^{e}	3.9 ± 0.5 ^{g}
Number of cells	1832 ± 125 ^{b}	1973 ± 82 ^{a}	1543 ± 54 ^{d}	1428 ± 97 ^{de}	1683 ± 85 ^{c}	1674 ± 90 ^{c}	1344 ± 68 ^{e}	872 ± 53 ^{f}
Slice brightness	109 ± 3 ^{a}	108 ± 3 ^{a}	106 ± 2 ^{ab}	94 ± 2 ^{d}	106 ± 3 ^{ab}	104 ± 2 ^{bc}	101 ± 2 ^{c}	81 ± 2 ^{e}

Values are means ± confidence interval; ^{a} means in one row followed by the same letter indicate no significant difference ($p < 0.05$)

For products containing the same FB, the FFP showed significantly ($p < 0.05$) lower total firmness values than the corresponding RFP (Table 4-2). This trend might be due to the fat reduction and the fact that RFP contained a higher dough/ fat ratio (80 wt% dough) and less layers than the FFP (67 wt% dough). As a result, the dough layers in RFP were slightly thicker, so that more force was needed to cut and penetrate these samples. However, the softest fat, FB4, did not show significantly ($p < 0.05$) different results for total firmness for both, FFP and RFP. FFP prepared with FB1 and FB2, and RFP prepared with FB3 showed consistent total firmness results ranging from 76.6 to 64.9 N*s/mm. With softer FBs the products also became less firm for both FFP and RFP (Table 4-2). The lowest total firmness values were obtained for RFP with FB4 which contained 93 % more RO than FB1.

Interestingly, while the total firmness decreased significantly ($p < 0.05$) with increasing softness of the FBs, from FB1 to FB4, the peak firmness followed the opposite trend and increased (Table 4-2). Fat and dough can be mingled during sheeting, when a FB becomes softer and less plastic, due to its increasing oil content (Nor Aini and Miskandar 2007). Thus, the fat cannot properly separate the single dough layers any more and more of them stick together. Furthermore, fat within the dough causes lubrication and softening of the final product (Ghotra et al. 2002). The resulting thicker dough layers could not get crispy during the short baking period, becoming more tender instead (Ghotra et al. 2002; Nor Aini and Miskandar 2007). The partly-baked, thicker dough layers probably caused a softening of the products when FB3 and FB4 were used. The samples containing FB3 and FB4 were compressed rather than cut during the measurements. As a result, the shear stress (total firmness) between probe and puff pastry decreased with an increasing amount of RO (Table 4-2). In contrast, the peak firmness for FB3 and FB4 increased as samples were cut at the very end of the measurement. In fact, products containing the softer FB3 and FB4 were also low in lift (Table 4-2) and showed a denser structure (Figure 4-5). In addition to this, the total firmness decreased due to the smaller cross-sectional area.

Products containing FB1 and FB2 achieved excellent baking results; hence these FBs contained adequate shortening properties. A fat reduction of 40 % using FB2 and a simultaneous reduction of SAFA by 49 % compared to the full fat control did not lead to adverse effects in lift and specific volume.

4.3.6 Image analysis

To gain a better understanding of the internal structure of the puff pastry, cross sections of the baked samples were analysed with the C-Cell system. A high number of cells is a desirable attribute for puff pastry, as it reflects a good layered structure with a good lift. Multiple thin dough layers with crosslinks lead to more cells, whereas thick layers yield thicker cell walls, bigger holes and fewer cells in puff pastry (see chapter 3).

FFP with FB2, displaying the highest lift and specific volume, showed the most cells (Table 4-2). Generally samples that had a high number of cells demonstrated a low peak firmness in combination with higher total firmness values (Table 4-2). The control showed 7 % less cells than FFP containing FB2. The control is followed by RFP with FB1 and FB2 containing 8 % less cells. FFP with FB3 contained significantly ($p < 0.05$) less cells than samples with FB1 and FB2. RFP with FB3 and all products produced with FB4 revealed up to 25 to 50 % less cells than the control.

This negative trend in baking performance was already apparent through the measurement of lift, specific volume and firmness. Image analysis confirmed the results of texture analysis, indicating that the fewer cells the sample contained, the lower the total amount of work needed to cut the sample. These findings are also supported by the results obtained for FB1 and FB2, which were the best performing roll-in fats for puff pastry production. FB2 performed even better than FB1 in terms of number of cells and lift.

Slice brightness is a dimensionless parameter and an indicator for the light reflected by the cell walls of the product. The slice brightness depends on the number and the thickness of dough cell walls. A high number of cells, and thus cell walls in the cross sectional area of the product, results in a high brightness. Furthermore, big and deep holes lead to lower brightness values. The slice brightness value can only be considered in conjunction with the other analytical parameters and not independently. If cross sections of products consist of only few thick dough layers, as previously mentioned, the values might be false positive and the result is limited in information.

Slice brightness values for the investigated products generally correlated well with the number of cells. Highest slice brightness was detected for FFP and RFP containing FB1 and FB2 (Table 4-2) and results in products with a high number of cells and a good lift. On the other hand, the lowest values for slice brightness ware

detected for puff pastries with FB4 which had already shown a low number of cells, poor lift and specific volume (Table 4-2).

4.4 Conclusion

Four low-*trans* FBs (TFA ≤ 0.6 %) with various ratios of PS and RO were characterised and examined for their application in puff pastry production. The amount of PS decreased from FB1 to FB4 and simultaneously the RO content increased. FB4 contained the highest amount of RO and thus UFAs, and showed the lowest SFC, while FB1 showed the highest SFC values over the whole investigated temperature range. The findings of the DSC measurements correlated well with the SFC results of the four FBs. Greater amounts of higher melting TAGs are responsible for higher SFC values. While the amount of these higher melting TAGs decreased from FB1 to FB4, the SFC decreased in the same way. Rheological measurements revealed a dependency of all FBs on frequency and demonstrated a more elastic than viscous behaviour. FB1 had the highest and FB4 had the lowest average values for G´ over the whole frequency range indicating that the firmness increased from FB4 to FB1.

Based on the baking trials, 'extremely hard' FBs with yield values of 81 to 128 kg_f/cm^2 seemed to be optimal for use in puff pastry production. Firmness can be correlated to the yield values and this increased from FB4 to FB1. The analyses of the baked products showed that FFP had significantly ($p < 0.05$) lower total firmness values than RFP when containing the same FB. FFP prepared with FB1 and FB2, and RFP prepared with FB3 showed consistent, medium to high total firmness results. The lowest total firmness values were obtained for RFP with FB4 which contained 93 % more RO than FB1. Products containing the softer FB3 and FB4 were low in lift, denser in structure and exhibited a decrease in total firmness.

FFP with FB2 had the most cells, and at the same time had the highest lift and specific volume. Generally samples that had a high number of cells showed lower peak firmness, in combination with higher total firmness values. FB2 was even better than FB1 in terms of number of cells and lift. Highest slice brightness was detected for FFP and RFP containing FB1 and FB2.

Generally, puff pastry containing FB1 and FB2 achieved excellent baking results for FFP and RFP; hence these FBs contained adequate shortening properties. Using FB2, a fat reduction by 40 % and a simultaneous reduction of SAFA by 49 %, compared to

the control, did not lead to adverse effects in lift and specific volume. Due to the higher amount of RO and the lower SAFA content compared to FB1, coupled with the satisfying baking results, FB2 was the fat of choice in this study. Because of their melting behaviour FB3 and FB4 were unsuitable for puff pastry production.

4.5 Acknowledgements

The authors want to thank Inken Rethwisch for her support in the baking trials and analysis and Valentyn Maidannyk for his support with the DSC. This study was carried out with financial support from the European Commission, FP7, Thematic Area KBBE, Project "PLEASURE" (Grant agreement no: 289536).

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Chapter 5

Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content

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Published as Silow, C., Zannini, E., Axel, C., Lynch, K. M. & Arendt, E. K (2016) "Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content" in *Food Research International*, 89: 330–337

Abstract

Puff pastry is a major contributor of fat and sodium intake in many countries. The objective of this research was to determine the impact of salt (0–8.4 g/100 g flour) on the structure and quality characteristics of puff pastry with full and reduced (-40%) fat content as well as the rheological properties of the resulting dough. Therefore, empirical rheological tests were carried out including dough extensibility, dough stickiness and GlutoPeak test. The quality of the puff pastry was characterized with the VolScan, Texture Analyzer and C-Cell. NaCl reduction significantly changed rheological properties of the basic dough as well as a number of major quality characteristics of the puff pastry. Significant differences due to NaCl addition were found in particular for dough resistance, dough stickiness, Peak Maximum Time and Maximum Torque ($p < 0.05$). Peak firmness and total firmness decreased significantly ($p < 0.05$) with increasing salt levels for puff pastry containing full fat. Likewise, maximal lift, specific volume, number of cells and slice brightness increased with increasing NaCl at both fat levels. Although a sensorial comparison of puff pastries revealed that salt reduction (30%) was perceptible, no significant differences were found for all other investigated attributes. Nevertheless, a reduction of 30% salt and 40% fat in puff pastry is achievable as neither the perception and visual impression nor attributes such as volume, firmness and flavour of the final products were significantly affected.

5.1 Introduction

Puff pastry, well known for its light and flaky texture, is a laminated dough, which is leavened without the use of yeast or any rising agents (Cauvain & Young, 2001). Puff pastry consists of the basic dough and a fat phase. Through a series of folds and sheeting of the pastry many thin fat and dough layers are obtained (Anonymous, 2000a). During baking the dough layers separate from each other as the pastry rises (Ghotra, Dyal, & Narine, 2002). Traditionally wheat dough is used for puff pastry production. Butter, margarines or various fat blends act as roll-in fat, which is important for the layering effect, flavour, flaky structure, texture, appearance, volume and lift (Boode-Boissevain & Van Houdt-Moree, 1996).

Sodium chloride (NaCl, or more commonly, salt) has been traditionally used in the production of baked goods since it positively influences several technological, rheological and sensory parameters. Generally, salt aids the workability of the dough during puff pastry production. It increases the mixing tolerance of doughs and also appears to have a beneficial effect on strengthening the gluten network and therefore increases the dough stability and flexibility (Kaur, Bala, Singh, & Rehal, 2011). Among others, this strengthening effect improves the gas retention properties of the puff pastry dough, which is important for steam retention during the baking process, leading to good pastry lift and volume. Salt also decreases stickiness and water absorption of the dough (Beck, Jekle, &Becker, 2012a). Therefore, decreasing NaCl concentration may induce less desirable properties such as stickier, difficult to process dough, and a lack of stability and lower resistance and extensibility will lead to products with poor quality. Furthermore, salt is responsible for the perception of ‘saltiness’, while it increases that of sweetness, decreases bitterness and enhances other flavours in food systems (Liem, Miremadi, & Keast, 2011). In additional, salt acts as a preservative in bakery goods by lowering the water activity and inhibiting microorganisms (Naidu, 2000).

High sodium intake is a leading cause of cardiovascular diseases and hypertension and has also been linked to an increased risk of stroke, stomach cancer, kidney disease and bone demineralization (Wardener & MacGregor, 2002). The effect of sodium on hypertension is dose dependent; the more sodium consumed, the greater the increase in blood pressure (Panel on Dietary Reference Intakes for Electrolytes and Water, 2005). Since these health issues came into focus, numerous national and

international organisations have introduced recommendations and actions for the lowering of sodium chloride levels in foods. Processed foods account for about 70–75% of sodium intake (EFSA Scientific Panel on Dietetic Products, 2005) in western diets with up to 35% of the daily sodium intake originating from cereal products (Angus, 2007). Among others, the World Health Organisation (WHO) and European Union (EU) have recommended cooperation with the food industry to encourage a reduction in sodium content in products to their lowest feasible level, including a target of reducing mean population NaCl intake by 30% to ≤ 5 g/day by 2025 (WHO, 2013). Therefore, the main strategy to decrease the sodium intake is to lower the salt content in food products.

However, to date no studies regarding the effects of salt reduction on the structure and quality characteristics of puff pastry with full and/or reduced fat content have been published. Puff pastry contains approximately 1.0–1.2% NaCl (The French Information Center on Food Quality, 2012). The aim of the present study was to evaluate the effects of various NaCl concentrations (0–84 g/kg flour) on the quality of puff pastry with full and reduced (−40%) fat content, including change in lift, volume and firmness of the baked puff pastries. Starting from a salt content of 21 g/kg flour (Control) all calculation were based on EU regulation (EC) No 1924/2006 “nutrition and health claims made on foods” and its Annex (European Commission (EC), 2006). Furthermore, a relationship between puff pastry quality parameters and empirical wheat dough properties, such as stickiness, resistance to extension and Peak Maximum Time was determined.

5.2 Materials and Methods

5.2.1 Materials

In this study wheat flour (Grand Moulins de Paris, France, type T45 (45 mg ash/10 g flour), moisture 13.5%, Protein 11.5%), salt (Glacia British Salt Limited, UK), commercially available lemon juice (Tesco, Ireland), food grade ethanol (85%, (v/v), France Alcools, France) and tap water were used for the basic dough. A vegetable fat blend of 66% palm stearin and 34% rapeseed oil (s.a. Aigremont n.v., Awirs-Flemalle, Belgium) was used as roll-in fat.

5.2.2 Salt levels

In total, twelve puff pastry recipes with different salt (Table 5-1) and fat levels were prepared for the present study. The puff pastry dough used as Control contained 21 g salt and 740 g roll-in fat based on 1000 g flour. All calculations for salt levels in this study were based on the Control and on EU regulation 1924/2006 and its appendix (European Commission (EC), 2006). In the appendix of EU regulation 1924/2006 (EC) the sodium levels for sodium-reduced products are defined (25% reduction, compared to a reference), in addition for products containing low sodium (0.12 g/100 g), very low sodium (0.04 g/100 g) and no sodium (0.005 g/100 g). All ingredients were assumed as being basically sodium/salt free. Therefore, only the added sodium chloride has been considered for the calculation of the final sodium/salt levels in the products. For full fat (FFP) and reduced fat (RFP) puff pastry 740 g and 370 g roll-in fat were used, respectively. Full salt and four reduced salt levels were used for each fat level (see Table 5-1). Salt contents for low salt (LS) and very low salt (VLS) were based on baked pastries and a bake loss of approximately 20% determined in preliminary tests. For no salt (NoS) puff pastries, no salt was added. In addition, two-fold (2xS) and four-fold (4xS) salt amounts (compared to Control) were used in the FFP. Puff pastry with those high salt levels was not intended for consumption but only for the purpose of analysis.

Table 5-1 Salt levels for puff pastry doughs

Salt level	Abbreviation	Salt [g/100 g flour]	Salt [g/100 g dough]
Full fat (FF)			
Fourfold salt	FFP 4xS [a]	8.40	3.50
Twofold salt	FFP 2xS [a]	4.20	1.79
Full salt	Control [a]	2.10	0.91
Reduced salt (-30%)	FFP RS [a]	1.44	0.67
Low salt	FFP LS [a]	0.56	0.25
Very low salt	FFP VLS [a]	0.19	0.08
No salt	FFP NoS [a]	0	0
Reduced fat (RF)			
Full salt	RFP FS	2.10	1.06
Reduced salt (-30%)	RFP RS	1.40	0.79
Low salt content	RFP LS	0.47	0.24
Very low salt content	RFP VLS	0.15	0.08
No salt	FFP NoS	0	0

[a] salt levels in basic dough used for dough extensibility test and dough stickiness test

5.2.3 Dough preparation and puff pastry production

5.2.3.1 Basic dough preparation

The basic dough consisted of 1000 g wheat flour, 15 g lemon juice, 510 g water and the appropriate amount of salt (Table 5-1). Flour and salt were premixed, liquids were added and the dough was mixed for 2 min on speed one (48 rpm) and 3 min on speed two (90 rpm) in a standard mixer with a kneading hook (A200, Hobart Mfg. Co. Ltd., London, UK). After mixing the temperature of the dough was 23 ± 1 °C using tempered water. If not clearly identifiable by the context, hereafter, the term 'basic dough' refers to the mixture of ingredients (flour, salt, lemon juice and water) before incorporating the roll-in fat, the term 'dough' referring to the laminated mix of basic dough and roll-in fat before baking, and the term 'pastry' to the final baked product.

5.2.3.2 Puff pastry production

All doughs were prepared according to chapter 4. 1500 g basic dough was left to relax at room temperature (20 ± 2 °C) for 20 min. During all rest periods the dough was placed in an airtight bag to prevent dehydration. The basic dough was sheeted to a thickness of 7 mm (11 mm for RFP) using a Rondo sheeter (Model: SSO605, Seewer AG, Burgdorf, Switzerland). A 15 mm thick (12 mm for RFP) block of roll-in fat was placed on the basic dough and encased with the same. Next, the layered dough was laminated to a thickness of 10 mm and the first folding turn was carried out followed by a rest period of 30 min. The dough was turned horizontally by 90° and the second turn was conducted followed by a rest period of 90 min. Subsequent turns followed with rest periods of 30 min.

For the FFP dough, four single turns (81 fat layers) were performed and for the RFP dough two double turns and one single turn (48 fat layers) were performed. After a 20 min rest the dough was sheeted to a final thickness of 2.50 mm (FFP) or 2.25 mm (RFP). 10 min after final lamination, squares of 10 × 10 cm were cut, stacked in units of eight using layers of baking parchment and stored chilled (4 °C) overnight in an airtight bag.

5.2.4 Dough extensibility test

Extensibility measurements of the basic dough were determined by the Kieffer dough extensibility test using a Texture Analyser equipped with a 5 kg load cell and the

SMS/Kieffer rig (Stable Micro Systems Ltd., UK). As a small scale version of the standard Brabender Extensograph, the Kieffer rig produces values with significant ($p < 0.001$) correlation to results of a standard Extensograph (Grausgruber, Schöggl, & Ruckenbauer, 2002). Basic dough (500 g) with the corresponding amount of salt (see Table 5-1, only FF) was prepared as described under Section 5.2.3.1. The dough was directly transferred from the mixing bowl and carefully placed into a lubricated (mineral oil, Bio-Rad Laboratories, CA, USA) Teflon mold and compressed with the lubricated upper part of the mold. After 20 min rest at room temperature 10 strings per dough were tested. The dough strings were removed from the mold one at a time, clamped between the two plates of Kieffer rig and extended with the hook at a constant rate of 3.3 mm/s (Mode: compression, option: return to start, pre-test speed: 2 mm/s, post-test speed: 10 mm/s, distance: 75 mm, trigger force: 5.0 g). Extensibility (distance to rupture, E^k) and resistance to extension (maximum force, R^k_{max}) were obtained from the force-distance curves and used as indicator of dough resistance (Dunnewind, Sliwinski, & Grolle, 2004; Kieffer, Wieser, Henderson, & Graveland, 1998).

5.2.5 Dough stickiness

Stickiness of the basic dough was determined by following the procedure proposed by Grausgruber, Hatzenbichler, and Ruckenbauer (2003) using a Texture Analyser equipped with a 5 kg load cell and a SMS/Chen-Hoseney device (Stable Micro Systems Ltd., UK). Basic dough with the corresponding amount of salt (Table 5-1, only FF) was prepared according to section 5.2.3.1 and stored in an airtight plastic box. After 20 min at room temperature a small sample from the centre of the dough was cut and placed into the SMS/Chen-Hoseney stickiness cell. A methacrylate 25 mm cylinder (P/25P) was used for compression (pre-test speed: 0.4 mm/s, test speed: 0.5 mm/s, post-test speed: 10 mm/s, applied force: 80 g, return distance: 4 mm, contact time: 0.1 s, trigger force: 10.0 g and trigger distance: 2 mm). The following parameters obtained from the force-time curve were used for dough characterization: the positive maximum force (adhesive force) was defined as stickiness, the positive area under the curve (adhesive energy) as work of adhesion and the distance the sample is extended on probe return as sample cohesion or dough strength. The test was done in triplicate with 10 measures per dough sample and salt level performed.

5.2.6 GlutoPeak test

A GlutoPeak (Brabender GmbH and Co KG, Duisburg, Germany) was used to investigate the impact of the various salt levels on the gluten aggregation properties. The GlutoPeak is an instrument designed to measure the influence of high shear when mixing a high moisture content flour/water slurry to create a gluten network (Melnyk, Dreisoerner, Bonomi, Marcone, & Seetharaman, 2011). Based on 9 g water (liquids) and 9 g flour (solids) the recipe of the basic dough was adapted in accordance to the various salt levels (Table 5-2) for the GlutoPeak measurements. Water and lemon juice were weighed into the sample cup. Flour and salt were added and the measurement was started immediately. Sample temperature was maintained at 36 °C by circulating water through the jacketed sample cup and the paddle speed was set to 2750 rpm. The torque reading was recorded over time, with a peak occurring as gluten aggregates, and the torque falling off when gluten breaks down (Melnyk et al., 2011). Tests ran for a maximum of 10 min and were stopped approx. 30 s after the major peak was detected. Maximum Torque (MT, expressed in Brabender Equivalents – BE), and Peak Maximum Time (PMT, expressed in s) were evaluated automatically by the software provided with the instrument. All runs were done in triplicate.

Table 5-2 Ingredient composition for GlutoPeak measurements

Salt level	Flour [g]	Salt [g]	Lemon juice [g]	Water [g]
4xS	8.303	0.697	0.125	8.875
2xS	8.637	0.363	0.130	8.870
FS	8.815	0.185	0.132	8.868
RS	8.872	0.128	0.133	8.867
LS	8.950	0.050	0.134	8.866
VLS	8.983	0.017	0.135	8.865
NoS	9.000	0.000	0.135	8.865

Salt level: 4xS – fourfold salt, 2xS – twofold salt, FS – full salt, RS – reduced salt, LS – low salt, VLS – very low salt, NoS – no salt

5.2.7 Physical analysis of puff pastry

All samples were baked and analysed as previously described in chapter 4. Pastries were weighed and evaluated for specific volume and maximal lift using a VolScan (Stable Micro Systems, UK). Maximal lift was directly obtained from the VolScan software and specific volume was calculated from the volume (obtained from VolScan) divided by the weight of each individual sample. Product length (longer

distance) and width were determined manually over the sample middle using an electronic calliper. Total firmness (area under the curve) and peak firmness (highest peak) were obtained from the compression curve using a texture analyser TA-XTplus equipped with an Extended Craft Knife (ECK) (both Stable Micro Systems Ltd.) 2 h after baking. The following settings were used: 30 kg load cell, compression mode, test speed: 5 mm/s, post-test speed: 10 mm/s, distance: 64.5 mm, trigger type: button, return distance: 65 mm, contact force: 15 g. Each sample was cut breadthwise through its centre. Finally, all values were divided by their respective width (in mm) and multiplied by 100 to standardize the results. A C-Cell imaging system (Calibre Control International Ltd., UK) was used to investigate the internal structure of pastry halves. The number of cells and slice brightness were recorded. Five random samples per trial and salt level were analysed.

5.2.8 Sensory evaluation of puff pastry

Sensory analysis was performed according to a modified Flash Profile Analysis (Dairou & Sieffermann, 2002) whereby Control, RFP FS and RFP RS were compared to each other. The samples were prepared as described above. After cooling, samples were cut in halves, labelled with a random 3 digit code and presented at the same time on a white plate in a randomized order. The test was conducted at room temperature and repeated with a different sample order. A continuous structured scale of 10 cm length was used. The test was divided into an hedonic and an intensity part where the panellists were asked for preferences and basic (structural) properties such as 'liking of …' appearance, colour, volume, flavour, mouthfeel/texture and overall acceptability, as well as amount of layers, fatness, saltiness, moisture, firmness, crispiness and off-flavour. The sensory panel consisted of 56 untrained panellists (32 female, 24 male, age: 31 ± 8 years). 35 of the 56 panellists stated that they eat puff pastry monthly or more often. All data were evaluated with ANOVA (analysis of variance)-Partial least squares regression (APLSR) using Unscrambler software version 9.7 (CAMO Software AS, Oslo, Norway).

5.2.9 Statistical analysis

All experiments were done in triplicate. Minitab 17 (Minitab Inc.) was used to carry out statistical analysis on the test results. A normality test (Shapiro-Wilk) was

followed by one-way ANOVA, with Tukey's post-hoc test used to evaluate significant differences ($p < 0.05$). To explore relationships between variables the Pearson correlation was calculated using Minitab 17. The correlation coefficient r was used for illustration of the degree of correlation.

5.3 Results and discussion

5.3.1 Dough extensibility test

Overall, basic dough showed low extensibility ($E^k < 31$ mm) and low resistance ($R^k_{max} < 381$ mN) values (Table 5-3). Due to the repeated folding and sheeting of the puff pastry during manufacture, shear and other forces are continuously acting on the dough. Therefore, basic dough for puff pastry is usually under-mixed and the gluten network not yet fully developed.

For all salt levels less than FS the R^k_{max} values were significantly lower than for the Control. At the same time no trend and no significant differences for R^k_{max} values were found among these salt levels (Table 5-3). Only the higher salt levels 2xS and 4xS showed significant ($p < 0.05$) differences to the Control. These findings are in accordance with results of Beck et al. (2012a) and Lynch, Dal Bello, Sheehan, Cashman, and Arendt (2009) who observed no significant differences for R^k_{max} at lower salt values but a general increase in dough resistance with increasing NaCl concentration in wheat bread doughs.

There was no unique trend on E^k values caused by the different salt levels. Although not significantly different, the E^k means slightly increased with increasing salt level until the Control and decreased again with further increases in salt level (Table 5-3). Similar trends for E^k were described in recent studies (Beck et al., 2012a; Lynch et al., 2009). While R^k_{max} continuously increased with increasing salt levels (2xS and 4xS), as interaction between polymer crosslinks became even stronger, the extensibility decreased again after reaching a maximum (Control). Probably more and more inter- and intramolecular bounds in the gluten network started to break and were not able to completely restore after deformation leading to protein network destruction.

Table 5-3 Rheological properties of doughs containing different salt levels

	Kieffer Rig		**Chen/Hoseney Rig**			**Gluto Peak**	
Dough	Resistance to extension (R^K_{max}) [mN]	Extensibility (E^K) [mm]	Stickiness [g]	Work of Adhesion [g*sec]	Dough Strength [mm]	Peak Maximum Time (PMT) [s]	Maximum Torque (MT) [BE]
4xS	381 ± 52^{a}	18 ± 2^{b}	45.2 ± 2.8^{d}	2.6 ± 1.0^{d}	1.1 ± 0.1^{d}	n.m.	n.m.
2xS	310 ± 49^{ab}	24 ± 5^{ab}	51.1 ± 3.1^{c}	3.5 ± 0.5^{cd}	1.4 ± 0.2^{cd}	169 ± 2^{a}	62 ± 0^{e}
FS	299 ± 29^{b}	31 ± 3^{a}	51.7 ± 1.8^{c}	3.7 ± 0.4^{c}	1.4 ± 0.1^{cd}	108 ± 5^{b}	69 ± 1^{d}
RS	196 ± 18^{c}	31 ± 3^{a}	52.2 ± 2.0^{c}	4.2 ± 0.5^{c}	1.6 ± 0.2^{c}	90 ± 7^{c}	72 ± 0^{d}
LS	201 ± 22^{c}	27 ± 3^{a}	59.5 ± 2.0^{ab}	5.7 ± 0.4^{b}	2.0 ± 0.1^{b}	65 ± 8^{d}	77 ± 1^{c}
VLS	186 ± 19^{c}	27 ± 3^{a}	58.8 ± 1.9^{b}	5.7 ± 0.5^{b}	2.2 ± 0.2^{b}	48 ± 5^{e}	80 ± 2^{b}
NoS	193 ± 17^{c}	25 ± 3^{ab}	65.0 ± 2.0^{a}	9.6 ± 0.8^{a}	3.1 ± 0.2^{a}	31 ± 2^{f}	86 ± 2^{a}

Values are means ± confidence interval. Values followed by the same lower case letter in the same column indicate no significant difference ($p < 0.05$), n.m. - not measurable. Salt level: 4xS – fourfold salt, 2xS – twofold salt, FS – full salt, RS –reduced salt, LS – low salt, VLS – very low salt, NoS – no salt

In general, doughs with no or low salt levels are more viscous, lack stability and are expected to be very weak, due to lower protein-network formation and thus few elastic components (Beck et al., 2012a). Lower extensibility and thus flexibility may result in less gas retention compared to doughs with higher salt contents. By increasing NaCl addition, less shielding of charged gluten molecules is achieved. The interaction between polymer crosslinks becomes stronger, improves gluten network formation and thus, increases the dough resistance and extensibility (Beck et al., 2012a). Nevertheless, low salt levels or the absence of salt may not have such negative effects in stronger flours with a higher protein content when compared to low-protein flours (McCann & Day, 2013). In this case the dough may still exhibit good rheological properties even when the salt content is reduced.

5.3.2 Dough stickiness

In industry, dough stickiness is a major problem as sticky dough cannot be processed and may lead to process disruption and product loss. It can be seen from Table 5-3 that all three parameters, stickiness, work of adhesion and dough strength increased significantly ($p < 0.05$) with decreasing salt levels. The highest and lowest stickiness values were detected for dough containing no/low salt and the 4xS salt amount, respectively. For doughs 2xS, Control and RS, no significant differences were observed for the three parameters investigated (Table 5-3). Similar findings for the dough strength were observed by Beck et al. (2012a). Contrary to the expectations of most cereal scientists, the same group reported a decreased dough stickiness with decreasing NaCl concentration (40–0 g/kg flour) in bread dough (Beck et al., 2012a). The mechanism behind dough stickiness is not well understood and determining the cause is difficult as reliable measurements are hard to achieve (Hoseney & Smewing, 1999). Basically, stickiness is a combination of adhesion, the interaction between a material and a surface, and cohesion, the interactions within the material (Wang, Watts, Lukow, Schlichting, & Bushuk, 1996). Therefore, it is a result of a combination of surface and rheological properties. In the present study, stickiness showed very significant ($p < 0.01$) positive correlation to work of adhesion ($r = 0.95$) and dough strength ($r = 0.96$). Work of adhesion and dough strength even correlated highly ($p < 0.001$, $r = 0.99$). During puff pastry production, adhering of the stickier dough to the steel rolls was prevented insofar that some flour was sprinkled on the dough surface before lamination as is common practice. Based on the practical

experience of bakers, it is known that NaCl strengthens dough and makes it tighter. At the same time dough without NaCl is subjectively stickier and more liquid-like (Beck et al., 2012a; Danno & Hoseney, 1982). Results obtained with the Chen-Hoseney Cell correlate well with subjectively evaluated stickiness. The findings of the present study can confirm this ascertainment as all measured stickiness parameters increased significantly ($p < 0.05$) with decreasing salt levels.

5.3.3 GlutoPeak test

The GlutoPeak test measures the aggregation behaviour of gluten upon addition of water and high-speed mixing, recording the torque over time (Chandi & Seetharaman, 2012). This new method has been proposed for the evaluation of wheat flour quality (Marti, Augst, Cox, & Koehler, 2015). In Table 5-3 the results of GlutoPeak measurements on basic dough with different salt levels are presented. Figure 5-1 shows typical curves obtained from GlutoPeak measurements. The time until the peak appears (Peak Maximum Time – PMT) shows how fast the gluten network is able to form, and the peak height (Maximum Torque – MT) indicates how strong the gluten network is. Increasing sodium chloride levels continuously led to a delay in gluten network development and thus, increasing PMTs (Figure 5-1, Table 5-3). Simultaneously, the MT decreased significantly ($p < 0.05$) with increasing salt levels. This applies to all investigated salt concentrations up to 2xS within the study. Furthermore, the PMT showed a very significant negative correlation to the MT ($p < 0.01$, $r = -0.98$). This is in contrast to the findings of Melnyk et al. (2011) who reported an increasing torque as salt concentration increased.

McCann and Day (2013) reported that NaCl addition delays protein hydration and gluten network formation which, in turn, results in increasing dough development time and dough stability. A similar effect was observed in a previous study which reported that the mixing time distinctly increased for increasing salt levels when dry salt was added to the flour before mixing (Danno & Hoseney, 1982).

For the highest salt concentration, 4xS, neither PMT nor MT were detected (Figure 5-1). The group of Melnyk et al. (2011) investigated the impact of different salt concentrations and ions on the gluten aggregation of wheat flour using a GlutoPeak. They suggested the following explanation: At low concentration, salt ions neutralize charges on amino acids allowing for inter-protein aggregation of hydrophobic surface polypeptides and hydrogen bonding (Melnyk et al., 2011). At the same time

the native organization of the gluten proteins are preserved. For higher salt concentrations (N = 0.3 M), a concentration-dependant increase of PMT was found and the type of ion was considerably more important for the aggregation behaviour. In the case of NaCl, the structure-enhancing effects of the kosmotropic chloride anion and sodium cation result in less water availability for gluten, which in turn enhances hydrophobic interactions between gluten proteins in their native form (Melnyk et al., 2011). As a consequence, less unfolding and hydrogen bonding between unfolded chains occur. For a fully developed gluten network a longer mixing time (here PMT) is required to unravel proteins and allow for inter-protein interactions through hydrogen bonding and hydrophobic interactions, including inter-disulphide bonding (Melnyk et al., 2011). However, the ratio of salt, water and flour in the 4xS dough appears to have been so unfavourable that the effect of Na^+ and Cl^- ions on the flour proteins completely hindered proper gluten network development.

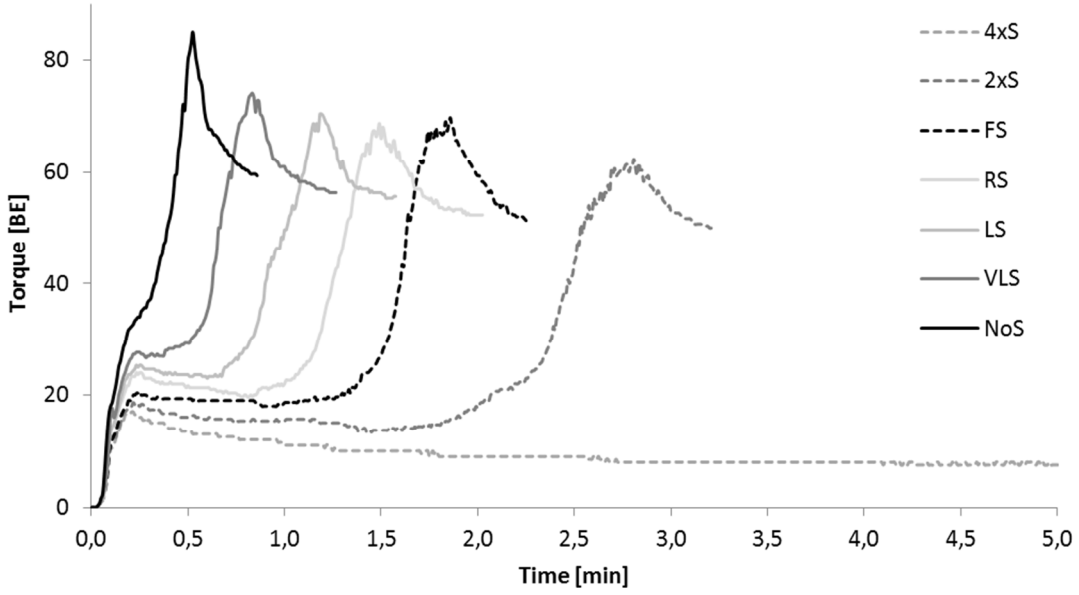


Figure 5-1 GlutoPeak curves of puff pastry basic dough with different salt levels: 4xS – fourfold salt, 2xS – twofold salt, FS – full salt, RS –reduced salt, LS – low salt, VLS – very low salt, NoS – no salt

In the case of puff pastry dough – which is under-mixed as mentioned above – the addition of NaCl and, thus an increase in PMT, will lead to more under-mixed dough. Theoretically even more turns and laminations are possible for those doughs with higher salt contents before the gluten network is fully developed and starts to degrade. Another option is a slightly longer mixing time, still ensuring an under-

mixing of dough. In turn, for puff pastry dough with reduced salt levels this means that mixing times have to be adjusted and reduced accordingly.

5.3.4 Puff pastry quality

Puff pastry were analysed regarding their quality parameters to determine the impact of salt on these parameters. As there are no uniform standards to measure quality parameters of puff pastry maximal lift and specific volume were chosen for external characterization and number of cells and slice brightness were chosen for internal characterization. In addition, the firmness of puff pastries was determined to describe the texture.

5.3.4.1 Maximal lift and specific volume

Two important criteria in the assessment of puff pastry are the lift and the (specific) volume because these are the first impressions a consumer gets from puff pastry. Generally, puff pastries with a high lift are preferred by the consumer (Simovic, Pajin, Seres, & Filipovic, 2009) and the specific volume, as the ratio of volume and weight, reflects a light and open or dense structure of the pastry. However, both parameters need to be considered along with the results of other physical analyses as they do not give enough information about the actual internal quality of the puff pastry.

It can be seen from Table 5-4 that the lift of RFP FS and Control were not significantly different. In general, the lift decreased for RFP with decreasing salt levels and RFP containing very low and no salt produced the significantly ($p < 0.05$) lowest lift of all puff pastries.

The resistance to extension and the peak maximum also decreased with decreasing salt levels (see Section 5.3.1 and 5.3.3) indicating that during mixing and laminating the gluten network in pastries with lower salt contents could already be over-stretched and become weaker. In turn, this can decrease the gas holding capacity of the dough layers during baking, resulting in a lower lift. This is comparable to studies of other dough products such as that of Lynch et al. (2009), who showed that lowering the concentration of NaCl in a bread dough decreased the gas retention properties.

Table 5-4 Physicochemical tests for baked samples of puff pastry with full fat (FFP) and reduced fat (RFP) content and various salt levels

Dough	Peak firmness [N/mm]	Total firmness [N*s/mm]	Maximal lift [mm]	Specific volume [ml/g]	Number of cells	Slice brightness
Full Fat						
FFP 4xS	77.8 ± 4.6 ^{a}	96.3 ± 3.5 ^{a}	51 ± 2 ^{cd}	6.8 ± 0.9 ^{g}	1271 ± 106 ^{ef}	105 ± 4 ^{abc}
FFP 2xS	59.8 ± 2.9 ^{b}	87.1 ± 3.6 ^{b}	60 ± 2 ^{a}	9.0 ± 0.4 ^{cde}	1850 ± 83 ^{ab}	107 ± 3 ^{ab}
FFP FS	47.5 ± 4.1 ^{c}	65.1 ± 2.7 ^{d}	54 ± 3 ^{bc}	9.8 ± 0.4 ^{abc}	1832 ± 125 ^{ab}	109 ± 3 ^{a}
FFP RS	44.7 ± 5.7 ^{c}	65.2 ± 3.0 ^{d}	60 ± 2 ^{a}	10.4 ± 0.5 ^{ab}	2029 ± 63 ^{a}	109 ± 3 ^{a}
FFP LS	40.5 ± 4.3 ^{c}	56.2 ± 3.3 ^{e}	56 ± 2 ^{ab}	10.6 ± 0.3 ^{a}	1880 ± 88 ^{ab}	107 ± 2 ^{ab}
FFP VLS	40.1 ± 3.7 ^{c}	54.6 ± 2.3 ^{e}	54 ± 2 ^{bc}	10.5 ± 0.3 ^{ab}	1897 ± 95 ^{a}	103 ± 3 ^{abc}
FF NoS	40.3 ± 2.2 ^{c}	53.6 ± 2.6 ^{e}	47 ± 2 ^{de}	9.2 ± 0.4 ^{cd}	1570 ± 98 ^{cd}	99 ± 2 ^{cd}
Reduced Fat						
RF FS	73.2 ± 5.6 ^{a}	76.6 ± 1.7 ^{c}	51 ± 3 ^{cd}	9.5 ± 0.4 ^{bc}	1683 ± 85 ^{bc}	106 ± 3 ^{ab}
RF RS	75.6 ± 2.4 ^{a}	66.1 ± 3.1 ^{d}	43 ± 1 ^{ef}	8.1 ± 0.3 ^{ef}	1397 ± 60 ^{de}	102 ± 2 ^{bc}
RF LS	76.2 ± 4.7 ^{a}	69.4 ± 3.3 ^{cd}	43 ± 1 ^{ef}	8.3 ± 0.3 ^{def}	1225 ± 57 ^{ef}	92 ± 3 ^{e}
RF VLS	79.0 ± 3.2 ^{a}	69.4 ± 3.0 ^{cd}	42 ± 1 ^{f}	7.8 ± 0.2 ^{f}	1218 ± 50 ^{ef}	94 ± 3 ^{de}
RF NoS	70.6 ± 4.9 ^{a}	67.9 ± 3.7 ^{d}	41 ± 2 ^{f}	8.2 ± 0.3 ^{def}	1183 ± 75 ^{f}	93 ± 3 ^{de}

Values are means ± confidence interval. Values followed by the same lower case letter in the same column indicate no significant difference ($p < 0.05$). Salt level: 4xS – fourfold salt, 2xS – twofold salt, FS – full salt, RS –reduced salt, LS – low salt, VLS – very low salt, NoS – no salt

A converse trend was observed for FFP, where the lift slightly increased with decreasing salt levels but did not show significant differences compared to the Control. FFP with 2xS, RS and LS showed the most significant lift overall. The only exception was FFP NoS which showed significantly lower lift compared to the Control. While 2xS increased the lift compared to the Control, very high salt levels (4xS) again decreased the lift of pastries (Table 5-4).

The specific volume of the investigated puff pastries basically followed the trend of the maximal lift (Table 5-4) which was expected since the two parameters correlate ($p < 0.05$, r = 0.64). FFP 4xS showed lowest significant specific volume and thus the densest structure. One explanation could be the high resistance to extension and the low extensibility of the dough layers (see Section 5.3.1). Due to the strong gluten network the dough containing the highest salt content is contracting more than all other doughs during lamination resulting in a heavy and thick dough piece when finally cut. During baking the dough layers are still contracting and are less flexible than in other doughs which resulted in heavy and dense pastries.

5.3.4.2 Image analysis

In addition to maximal lift and specific volume, the internal structure of puff pastry was characterised with the C-Cell system. Originally developed to investigate bread structures, the C-Cell, with its unique software, analyses a slice of a cellular structured product and enables objective and consistent evaluation and a permanent record of a product (Salmon, 2004). Number of cells and slice brightness were found to be the parameters which correlated best and allowed a prediction of the cellular and layered structure of the inner pastry. In general, a high number of cells was assumed for a high number of theoretical layers. This was the case for all FFP (81 theoretical fat layers) which exhibited generally significantly higher number of cells than there corresponding RFP (48 theoretical fat layers) with the same salt level. Nonetheless, the number of layers found in the baked product is generally lower than the calculated layers (Noll, Gräber, Kitta, Neumann, & Kuhn, 1997). However, RFP FS produced a lower (though not significantly) number of cells than the Control with the same salt level (Table 5-4). Overall, the number of cells increased significantly ($p < 0.05$) with increasing salt levels for both FFP and RFP. Previous studies showed that the number of cells in bread also increased significantly with increasing salt levels (Lynch et al., 2009; McCann & Day, 2013). A high number of

cells reflect a well-structured puff pastry with a good lift and many thin cross-linked layers. Conversely, a puff pastry with a low number of cells tends to have fewer layers which tend to be thicker with little cross-linking between the layers. The number of cells of the investigated products showed a highly significant ($p < 0.001$) positive correlation to maximal lift (r = 0.90) and specific volume (r = 0.89).

The unit-less slice brightness is used as indicator for the light reflected by the cell walls of the product. It can be used in addition to, and only be considered, in conjunction with the other analytical parameters. Basically, a high number of cells in the cross sectional area of the product results in high brightness values since the slice brightness positively correlates to the number and thickness of dough cell walls. Slice brightness values for the investigated products correlated well with the number of cells (r = 0.82, $p < 0.01$) and maximal lift (r = 0.87, $p < 0.001$). From Table 5-4 it can be seen that slice brightness results basically follow the trend of the number of cells. Higher salt levels produced higher slice brightness for both FFP and RFP. This is again linked to higher lift and specific volume and indicates a good internal pastry structure.

These values complement the findings for maximal lift and specific volume, as discussed above. Basically, the mechanism by which salt in dough development is responsible for number of cells and slice brightness is the same as for maximal lift and specific volume, since all these parameters are linked to each other.

NaCl seems to support a better internal structure of puff pastries up to a certain level (2xS) characterized by high number of cells and slice brightness values.

5.3.4.3 Firmness

Firmness is important in describing the texture of puff pastry. The total amount of work needed to cut the sample is defined as total firmness, while peak firmness represents the peak of the force expended during measurement. The first bite of a consumer is imitated by the ECK, a very sharp and thin blade, that enables cutting of the sample with nearly no compression. Total firmness results for the pastries are shown in Table 5-4.

Peak firmness for FFP and RFP at NaCl levels of FS to NoS did not show significant differences within the respective fat level. At the same time, a general softening of the pastries could be seen since total firmness decreased significantly ($p < 0.05$) for both FFP and RFP with decreasing salt levels (Table 5-4). These firming effects of

NaCl were more pronounced for the FFP. Higher salt levels of 2xS and 4xS significantly ($p < 0.05$) increased both peak firmness and total firmness in FFP. As shown and discussed above, increasing NaCl levels lead to stronger gluten networks with higher resistance (see Section 5.3.1–5.3.3). This in turn, leads to lower lift and specific volume and thus denser products with thick dough layers which are harder to cut. The specific volume demonstrated a very significant negative correlation to peak firmness ($p < 0.01$, $r = -0.85$) and a significant negative correlation to total firmness ($p < 0.05$, $r = -0.64$). In addition, peak firmness and number of cells correlated well ($p < 0.05$, $r = -0.80$). In general, FFP samples with a high number of cells had a lower peak firmness (Table 5-4). Previously, an increase in crumb firmness has been described for bread products with increasing NaCl levels although both instrumental method and recipe differ from the present study (Beck, Jekle, & Becker, 2012b).

However, FFP showed, in general, significantly ($p < 0.05$) lower peak firmness than RFP with the same salt content (Table 5-4). Previous studies revealed that higher fat content in puff pastries resulted in lower product firmness (Baardseth, Næs, & Vogt, 1995; Telloke, 1991; chapter 4). Some of the melted fat is moving into the dough layers during the baking process and crystallizes again after baking (Anonymous, 2000b; Dörr, 1982). The lubricating effect of the fat makes it easier to cut (Ghotra et al., 2002) while fat crystals in the final product leave the dough layers more tender.

Products containing full fat and reduced salt achieved excellent baking results without differing significantly from the Control, hence a salt reduction (30%) in puff pastry with full fat content is relatively easy to implement. A salt reduction of 30% and a simultaneous reduction of fat by 40%, compared to the Control lead to significantly higher peak firmness and significantly lower lift, specific volume and number of cells.

5.3.5 Sensory

For the three puff pastries, Control, RFP FS and RFP RS a sensory analysis was performed. All hedonic attributes showed highly significant ($p < 0.001$) positive correlations to each other. The highest positive correlation was found for ‘liking of appearance’ and ‘liking of colour’ ($r = 0.81$). Furthermore, overall acceptability displayed high correlations to ‘liking of flavour’ ($r = 0.80$) and ‘liking of mouthfeel/texture’ ($r = 0.77$). This illustrates how important the flavour and texture of the pastries are for the consumer.

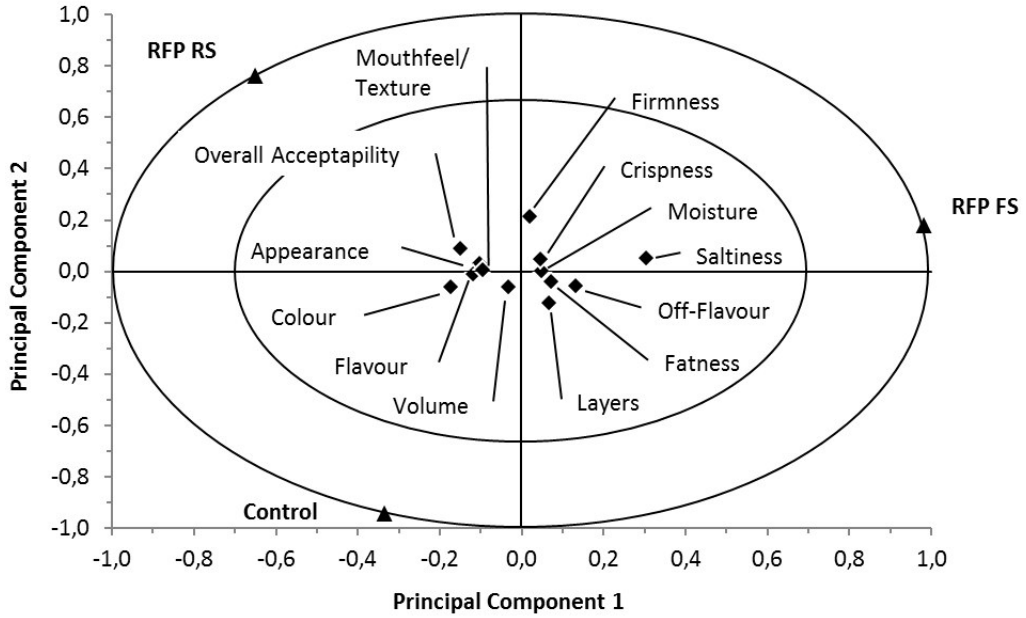


Figure 5-2 ANOVA-partial least squares regression (APLSR) correlation loadings plot for Control puff pastry, reduced fat puff pastry (RFP) with full salt (FS) and reduced salt (RS) content. ▲ samples, ♦ sensory attributes (cursive style: hedonic attributes, not cursive: intensity attributes)

The results of the consumer sensory study are presented in Figure 5-2 as an APLSR plot in conjunction with the ANOVA values in Table 5-5. The right hand quadrant of Figure 5-2 shows RFP FS and in the opposite quadrant are the Control and RFP RS samples and the plot centre accumulates the sensory attributes whereby RFP FS shows opposite properties. All attributes located close to the centre of the axes indicate that no correlations exist for all the puff pastry samples. Basically, for all puff pastries and attributes, excluding saltiness, no significant correlations were found. RFP FS showed a very significantly positive correlation ($p < 0.010$) and RFP RS showed a trend of negative correlation ($p = -0.052$) to saltiness (Table 5-5). Furthermore, RFP FS indicated a negative correlation trend to overall acceptability ($p = -0.083$). This is due to the production process. For RFP FS more basic dough, containing the added NaCl, is used than for the Control which in turn increases the salt content of the baked puff pastry (see Table 5-1).

When comparing the attributes to each other, saltiness also showed a highly significant positive correlation to fatness ($p < 0.001$, $r = 0.33$), although only the Control had a higher fat content and the other two tested puff pastries were reduced fat. The attribute firmness is located further on the side of the reduced fat pastries, in correlation with the instrumental results (see Section 5.3.4.3).

Table 5-5 Significance of regression coefficients (ANOVA values) for the correlation of hedonic and intensity sensory terms for Control puff pastry, reduced fat puff pastry (RFP) with full salt (FS) and reduced salt (RS) content

Attribute	Control	RFP FS	RFP RS
Hedonic			
Liking of Appearance	0,4889 ns	-0,1944 ns	0,2988 ns
Liking of Colour	0,5097 ns	-0,0536 ns	0,0782 ns
Liking of Volume	0,7382 ns	-0,6713 ns	0,6500 ns
Liking of Flavour	0,4863 ns	-0,1500 ns	0,2549 ns
Liking of Mouthfeeling/Texture	0,4979 ns	-0,2509 ns	0,3483 ns
Overall Acceptability	0,3680 ns	-0,0830 ns	0,3128 ns
Intensity			
Saltiness	-0,4737 ns	0,0015*	-0,0516 ns
Fatness	-0,4631 ns	0,3597 ns	-0,4744 ns
Moisture	-0,6224 ns	0,5197 ns	-0,5374 ns
Layers	-0,3983 ns	0,4923 ns	-0,6026 ns
Firmness	-0,8969 ns	0,8801 ns	-0,8705 ns
Crispness	-0,6872 ns	0,5737 ns	-0,5485 ns
Off-flavour	-0,4060 ns	0,1087 ns	-0,3092 ns

Significance of regression coefficients, ns not significant, * $p < 0.010$

These figures demonstrate that the salt reduction (30%) in puff pastry was notable to the assessors but did not significantly affect the perception, visual impressions or liking of the other attributes and properties. Recently, it was reported that a gradual reduction in sodium levels by stealth ("small step reduction") has been employed with some success (Wilson, Komitopoulou, & Incles, 2012). In an intervention study (110 participants), it was possible to reduce the salt content in bread by 25% and maintain consumer acceptance (Girgis et al., 2003).

5.4 Conclusion

NaCl reduction had a significant impact on empirical dough properties. While dough resistance R^k_{max} continuously increased with increasing salt levels the dough extensibility E^k slightly increased initially and decreased at higher salt levels. Furthermore, increasing NaCl levels continuously lead to a delay in gluten network development resulting in significantly increasing PMTs and simultaneously decreasing MTs. Besides, the increasing NaCl levels decreased significantly the stickiness, work of adhesion and dough strength.

Depending on the fat level the lift generally decreased (RFP) with decreasing salt levels while the lift of FFP slightly increased for lower NaCl levels (except NoS). In

addition, the specific volume basically followed the trend of the maximum lift. Moreover, increasing salt levels impacted the internal pastry characteristics and produced significantly more cells for both FFP and RFP.

A general softening of the pastries was detected as total firmness decreased significantly with decreasing salt levels for both FFP and RFP. Overall, firming effects of NaCl were more pronounced for FFP, as high salt levels significantly increased both peak firmness and total firmness of FFP. In general, FFP showed lower peak firmness than RFP.

Overall, products containing full fat and reduced salt achieved excellent baking results without differing significantly from the Control. A salt reduction of 30% and a simultaneous reduction of fat by 40% compared to the Control lead to significantly higher peak firmness, significantly lower lift, specific volume and number of cells. However, a sensory panel revealed that although consumers may discover differences in taste and texture they will get used to this new impression and still like the product. The results of this work may provide a good basis for reducing sodium and fat in puff pastry.

5.5 Acknowledgements

The authors want to thank Inken Rethwisch for her support in the baking trials. This study was carried out with financial support from the European Commission, FP7, Thematic Area KBBE, Project “PLEASURE” (Grant agreement no: 289536). It does not necessarily reflect its views and in no way anticipates the Commission's future policy in this area.

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Chapter 6

Application of sourdough in the production of fat- and salt-reduced puff pastry

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Published as Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2018) "Application of sourdough in the production of fat- and salt-reduced puff pastry" in *European Food Research and Technology*, 1-13

Abstract

Sourdough (SD), as a natural ingredient, has the highly promising potential to compensate the effect of salt reduction on flavour and the consequent influence on further sensory characteristics in bakery products. The objective of this research was to determine the impact of SD (5, 10 and 20% flour basis) on the structure, flavour and quality characteristics of puff pastry with reduced fat (-40%) and salt (-30%) content as well as the rheological properties of the resulting dough. A range of empirical rheological tests was carried out including dough extensibility, dough stickiness and GlutoPeak test. Subsequently, the baked puff pastry quality was investigated using a VolScan, texture analyser, C-Cell and sensory analysis.

SD addition significantly changed rheological properties of the basic dough reduced in fat and salt as well as a number of major quality characteristics for the resulting puff pastry. In particular, dough resistance decreased and dough stickiness increased ($p < 0.05$). Gluten formation was delayed for the higher in salt control and accelerated upon salt reduction as well as increasing levels of SD incorporation. Furthermore, SD addition weakened the gluten network. To some extent, reduced fat and salt SD pastries were significantly enhanced in texture when compared to those reduced without SD including peak firmness and specific volume. Similarities between all samples were observed for total firmness and the maximal lift. Finally, supported by a sensory study, the flavour and texture of reduced fat and salt pastry was distinctly improved by SD addition.

6.1 Introduction

Puff pastry is a light and flaky pastry made from a paste consisting of many thin dough layers separated by alternate fat layers. Typically, these multi-layered doughs contain relatively high fat (20%–35%) and salt (1.0–1.2% NaCl) contents (The French Information Center on Food Quality, 2012).

Unhealthy diets consisting of high amounts of salt and fat but also sugar in combination with physical inactivity and other risk factors are related to a range of diseases such as obesity, cardiovascular diseases and hypertension. Since these health issues came into focus, numerous national and international organisations have introduced recommendations and actions, especially for the lowering of salt levels in foods.

While roll-in fat is important for the layering effect, flavour the flaky structure, texture, appearance and thus volume and lift of the pastry (Boode-Boissevain and Van Houdt-Moree, 1996) salt aids the workability of the dough during puff pastry production. Salt decreases stickiness and water absorption of the dough (Beck et al., 2012a). Furthermore, salt appears to have a beneficial effect on strengthening the gluten network (Kaur et al., 2011). During the baking process this strengthening is leading to improved gas retention properties of the dough and thus to improved pastry lift and volume. Additionally, salt is responsible for the perception of ‘saltiness’, while it decreases that of bitterness, increases sweetness and enhances other flavours in food systems (Liem et al., 2011).

Considering these facts, decreasing the salt and fat content of puff pastry may induce less acceptable properties and adversely affect its product quality, noticeable as sticky dough, lower lift and specific volume and softer products (see chapter 5). Moreover, salt reduction of 30% in puff pastry was perceptible to the assessors (see chapter 5). Conclusively, improved products are desirable.

One possibility to compensate for the adverse effects mentioned before in fat- and salt reduced puff pastry is the incorporation of sourdough (SD) to improve its flavour, texture and therefore its palatability.

SD is a fermented mixture of flour and water. The extremely complex ecosystem comprising of yeasts and lactic acid bacteria (LAB) has traditionally been used as a leavening agent in bread for thousands of years.

In more recent times SD has been reintroduced as a functional ingredient to improve all aspects of bread quality and to replace additives. The technological effects of SD on the texture, flavour, shelf life and nutritional quality of bread are well established and summarized in several recent reviews (Arendt et al., 2007; Galle and Arendt, 2014; Gänzle, 2014; Gobbetti et al., 2014). SD enhances the salty perception as well as imparting additional flavour compounds, e.g. bread flavour increased intensely by the addition of SD to the bread formulation (Thiele et al., 2002). Belz et al. (2012) suggested the potential use of SD to compensate the effect of salt reduction on flavour and the consequent influence on further sensory characteristics. Furthermore, SD is already applied as a useful functional ingredient for salt-reduced breads due to the production of bioactive compounds like glutamate, γ-aminobutyrate (GABA), Angiotensin I converting enzyme (ACE)-inhibitory peptides or antifungal substances (Belz et al., 2012; Zhao et al., 2015). Conclusively, SD favours the demand for clean label, natural products including a reduced use of additives. This is also more widely accepted by today's health conscious consumer.

No previous study has investigated the utilization of SD and its effects on the structure and quality characteristics of puff pastry. The aim of the present study was therefore to evaluate the impact of various SD levels (5, 10 and 20% flour basis) on the flavour and quality of puff pastry with reduced fat (-40%) and salt (-30%) content. The strain *Lactobacillus reuteri* R29 was selected as functional starter culture due to its antifungal traits. Furthermore, correlation analysis between puff pastry quality parameters and empirical wheat dough properties, such as stickiness, resistance to extension and gluten-network performance were carried out.

6.2 Materials and methods

A reduced salt and fat puff pastry recipe (see chapter 5) served as a calculation basis for all following recipes.

6.2.1 Materials

Basic dough of puff pastry was prepared with wheat flour (Grand Moulins de Paris, France; type T45, 13.5% moisture, 11.5% protein), salt (Glacia British Salt Ltd., Cheshire, UK), lemon juice (Tesco, UK) and tap water. A vegetable fat blend composed of 69% palm stearin and 31% rapeseed oil (s.a. Aigremont n.v., Awirs-Flemalle, Belgium) was used as roll-in fat.

Chemicals and analytical standards were purchased from Sigma Aldrich (Dublin, Ireland).

All analytical standards had a purity of ≥ 95%.

6.2.2 Sourdough Type II preparation and analysis

SD preparation was performed as previously described by Axel at al. (2016). *L. reuteri* R29 was selected as a starter culture to an initial inoculum size of 7 log cfu/g dough. This strain was obtained from the culture collection of UCC (School of Food and Nutritional Science, University College Cork, Cork, Ireland). It was preliminary evaluated for its antifungal activity in different substrates (Axel et al., 2016a, 2016b, Oliveira et al., 2015a, 2015b).

SD was prepared with an equal weight of flour and water (dough yield of 200 / Table 6-1) and fermented at 37 °C for 48 h. LAB cell counts were determined at 0 h and 48 h of fermentation for determining the cell growth. For SD cell counts commercial MRS agar (CM0361, Oxoid, Basingstoke, Hampshire, England) was dyed with 0.05 g/L bromocresol green (Sigma-Aldrich, Steinheim, Germany). Lactobacilli were grown at 37 °C for 48 h under anaerobic conditions. The identity of starter cultures was confirmed by colony morphology and metabolic patterns according to Wolter et al. (2014b). Fermentation microbiota were dominated by the starter culture since uniform colony morphology on agar plates were observed with absence of contaminations. Fermentations were carried out in triplicate independent experiments.

Table 6-1 Dough composition of control puff pastry (control), puff pastry with reduced fat and salt content with no added sourdough (RFPRS) and with 5% (5SD), 10% (10SD) and 20% (20SD) added sourdough

Ingredient	Control	RFPRS	RFPRS+5SD	RFPRS+10SD	RFPRS+20SD
Flour (g)	1000	1000	950	900	800
Water (g)	510	510	475	425	325
Salt (g)	21.0	14.4	14.4	14.4	14.4
Lemon juice (g)	15	15	/	/	/
Sourdough (g)	/	/	100	200	400
Roll-in fat (g)	740	370	370	370	370

Total titratable acidity (TTA) and pH values of the fermented SDs were measured using a standard procedure (Arbeitsgemeinschaft Getreideforschung e.V., 1994).

An Agilent 1260 high performance liquid chromatography system equipped a Hi-Plex H 112 column (300 x 7.7 mm, 8 µm, Agilent, Cork, Ireland) and an appropriate guard column (3.0 x 5.0 mm, 8 µm, Agilent, Cork, Ireland) was used to quantify sugars (0.5–16 mM) and organic acids (0.5–10 mM) from extracted freeze dried SD and flour samples. Sample preparation for sugars and organic acids was done according to Wolter et al. (2014a). Concentrations of sugars were analysed using a refractive index detector. Lactic and acetic acid were detected using a diode array detector (λ = 210 nm). Samples for sugar and acid determination were eluted with water or 0.004 M sulphuric acid at a flow rate of 0.6 mL/min and 25 °C or 65 °C, respectively. 3-phenyllactic acid was determined according to Axel at al. (2015).

6.2.3 Puff pastry production

The puff pastry-making procedure was carried out according to chapter 3. Basic dough consisted of the ingredients listed in Table 6-1. Flour and salt were premixed, liquids were added and the dough was mixed in a standard mixer with a kneading hook (A200, Hobart Mfg. Co. Ltd., London, UK) for two minutes on speed one (48 rpm) and three minutes on speed two (90 rpm). For SD-puff pastries, 5–20% of the flour was fermented (Table 6-1). The SD was added to the mixed dry ingredients along with the water. The term ‘basic dough’ refers to the mixture of ingredients (flour, salt, water and lemon juice or SD) before incorporating the roll-in fat, the term ‘laminated dough’ refers to the laminated mix of basic dough and roll-in fat before baking and the term ‘pastry’ to the final baked product. Using tempered water, the dough temperature after mixing was 23 ± 1 °C. A 1500 g portion of basic dough was covered in an airtight bag and left to rest for 20 minutes at room temperature (20 ± 2 °C). 740 g and 370 g roll-in fat were used for the control and the reduced fat puff pastries, respectively.

According to previous findings, the production method was adapted for the fat-reduced pastries and the control (see chapter 3). The basic dough was formed to a rectangle and sheeted down to a thickness of 7 mm for the control (11 mm all other pastries) using a Rondo sheeter (SSO 605, Seewer AG, Burgdorf, Switzerland). A squared fat block was sheeted to a thickness of 15 mm for the control (12 mm all other pastries), placed on the dough and encased with the same while the edges were sealed together. Subsequent, the laminated dough was sheeted to a thickness of 10 mm before the first folding turn was carried out followed by a rest period of 30 min.

The laminated dough was turned horizontally by 90° and the second turn was conducted followed by a rest period of 90 min. By repeating the first and second turn, the third and the fourth (only control) turn were realized with rest periods of 30 min in between. Four single turns (81 fat layers) for control and two double turns and one single turn (48 fat layers) for all other pastries were performed to achieve the desired number of theoretical fat layers. After another rest of 20 min the laminated dough was sheeted to a final thickness of 2.50 mm (control) or 2.25 mm (all other pastries) while gradually decreasing the roller gap. To finish lamination two passes were given to the laminated dough at the final thickness. Finally, samples of 10 x 10 cm were cut out randomly after further 10 minutes rest and stored chilled in an airtight bag.

After overnight refrigeration (4 °C), samples were allowed to reach room temperature. Baking was performed at 210 ºC in a top- and bottom heated, unventilated, preheated deck oven (MIWE condo INT 01/01, Michael Wenz GmbH, Arnstein, Germany) for 15 min (control) or 14 min (all other pastries).

6.2.4 Dough characterisation

For dough rheological measurements basic dough without and with the corresponding amount of SD (Table 6-1) was prepared according to section 6.2.3.

6.2.4.1 Dough extensibility test

For extensibility measurements of the basic dough a Texture Analyser equipped with a 5 kg load cell and the SMS/Kieffer rig (Stable Micro Systems Ltd., UK) was used. The basic dough was carefully placed into a lubricated (mineral oil, Bio-Rad Laboratories, CA, USA) Teflon mold and compressed with the lubricated upper part of the mold. After a relaxing period of 10 min at room temperature 10 strings per basic dough were analysed. The dough strings were removed from the mold one at a time, clamped between the two plates of Kieffer rig and extended with the hook at a constant rate of 3.3 mm/s (Mode: compression, option: return to start, pre-test speed: 2 mm/s, post-test speed: 10 mm/s, distance: 75 mm, trigger force: 5.0 g). From the force-distance curves extensibility (distance to rupture, E^k) and resistance to extension (maximum force, R^k_{max}) were obtained and used as indicator of dough resistance (Dunnewind et al., 2004; Kieffer et al., 1998).

6.2.4.2 Dough stickiness

Stickiness of the basic dough was determined by using a Texture Analyser equipped with a 5 kg load cell and a SMS/Chen-Hoseney device (Stable Micro Systems Ltd., UK) following the procedure proposed by Grausgruber et al. (2003). Basic dough was stored in an airtight plastic box. After 10 min at room temperature a small sample from the centre was cut and placed into the SMS/Chen-Hoseney stickiness cell. A methacrylate 25 mm cylinder (P/25P) was used for compression using the following setting: pre-test speed: 0.4 mm/s, test speed: 0.5 mm/s, post-test speed: 10 mm/s, applied force: 80 g, return distance: 4 mm, contact time: 0.1 s, trigger force: 10.0 g and trigger distance: 2 mm. Parameters which were obtained from the force-time curve were used for dough characterization, in detail: The positive maximum force (adhesive force) was defined as stickiness and the positive area under the curve (adhesive energy) as work of adhesion. The test was done in triplicate and 10 measures per dough sample and SD level were performed.

6.2.4.3 GlutoPeak test

The impact of the various SD levels on the gluten-aggregation properties were investigated using a GlutoPeak (Brabender GmbH and Co KG, Duisburg, Germany). The GlutoPeak is an instrument designed to measure the influence of high shear when mixing a high moisture content flour/water slurry to create a gluten network (Melnyk et al., 2011). For the GlutoPeak measurements the recipe of the basic dough was adapted in accordance to the various SD levels (Table 6-1) based on 9 g liquids (water and lemon juice) and 9 g solids (flour and salt). Salt and lemon juice levels were calculated based on flour. First, water and lemon juice were weighed into the sample cup. Flour, salt and SD were added and the measurement was started immediately. Sample temperature was maintained at 36 °C by circulating water through the jacketed sample cup and the paddle speed was set to 2750 rpm. The torque reading was recorded over time with a peak occurring as gluten aggregates, and the torque falling off when gluten breaks down (Melnyk et al., 2011). Tests ran for a maximum of 300 sec and were stopped approximately 30 seconds after the major peak was detected. Maximum Torque (MT, expressed in Brabender Equivalents – BE), and Peak Maximum Time (PMT, expressed in s) were evaluated automatically from the software provided with the instrument. All runs were done in triplicate.

6.2.5 Physical analysis of puff pastry

After cooling to room temperature the product length (longer distance) and width of the samples were determined manually over the sample middle using an electronic calliper. Samples were weighed and evaluated for specific volume and maximum lift using a VolScan Profiler (Stable Micro Systems, UK). Two hours after baking the texture of the puff pastry was analysed using a texture analyser TA-XTplus (equipped with an Extended Craft Knife (ECK, Stable Micro Systems Ltd.) using the following settings: 30 kg load cell, compression mode, test speed: 5 mm/s, post-test speed: 10 mm/s, distance: 64.5 mm, trigger type: button, return distance: 65 mm, contact force: 15 g; software: Texture Exponent 32, version 4,0,9,0. The parameter peak firmness represents the highest peak of the characteristic compression curve. Additionally, total firmness was obtained from the area under the compression curve. Each sample was cut breadthwise through its centre. To standardize the results all values were divided by their respective width (in mm) and multiplied by 100.

With the help of the C-Cell imaging system (Calibre Control International Ltd., UK) the internal structure characterization was conducted on cross sections of puff pastry halves (from ECK test). Number of cells and slice brightness were the parameters to describe the internal structure after the images were analysed with the included software. After all measurements the samples were generally compared and evaluated in appearance, lift, structure, texture and mouthfeel by a panel of 3 experts. All baking trials were performed in triplicate while 5 random samples per trial were analysed.

6.2.6 Sensory

Sensory acceptability of pastries was determined two hours after production in one session. Seven trained assessors evaluated hedonic attributes (appearance, volume, flavour, mouthfeel/texture, overall acceptability) and intensity (saltiness, fattiness, moisture, acidity, firmness) of puff pastries. A continuous structured scale of 10 cm length was used (0 = dislike extremely/not intense, 10 = like extremely/very intense). Two puff pastry halves were presented on white plates identified with random 3-digit numbers.

6.2.7 Statistical analysis

Minitab 17 was used to carry out statistical analysis on the test results. To evaluate significant differences ($p \leq 0.05$) a normality test (Shapiro-Wilk) was followed by one-way ANOVA with Tukey's post-hoc test.

6.3 Results and discussion

The main objective of this study was to evaluate the impact of various SD levels on the flavour and quality of reduced fat and salt puff pastry.

6.3.1 Sourdough characterization

L. reuteri R29 grew well in the wheat flour since cell counts reached 9.4 log cfu/g after 48 h of fermentation. An overview of the HPLC sourdough analysis is provided in Table 6-2. In general, initial sucrose in the flour (here 70.5 mmol/kg) is quickly depleted at the start of the fermentation. In addition, starch degradation takes place due to the action of amylolytic flour enzymes. During fermentation maltose and glucose are metabolised by the starter culture into organic acids acidifying the sourdough. At the end of fermentation, maltose concentration was higher than glucose content (Table 6-2). The flour used in this study was a French flour from the type T45. In comparison to Baker's flours, this flour is more finely ground and characterised by lower ash and protein contents. It is therefore not suitable for bread making but commonly used for patisserie applications. The lower mineral level also decreases the buffering capacity during fermentation. This explains the slightly lower levels of organic acids and 3-phenyllactic acid quantified in this study when compared with the study of Axel et al. (2016a) regardless the lower pH value.

Table 6-2 Sourdough (lyophilized) characterisation

Metabolite	Concentration [mmol/kg]
Maltose	154 ± 9
Glucose	55 ± 4
Lactic acid	244 ± 14
Acetic acid	25 ± 1
3-phenyllactic acid	1.2 ± 0.1

Means ± SD of three independent fermentations, each sample extracted three times, raffinose in the flour and fructose in the sourdoughs were below the limit of quantification (<20 mmol/kg)

For SD-puff pastries, 5, 10 and 20 % of the flour was fermented and the sourdough was incorporated in the basic dough before lamination. The acidity measurements for the resulting basic doughs are shown in Table 6-3.

Table 6-3 Total titratable acids (TTA) and pH of fresh puff pastry dough with and without added sourdough (SD)

Parameter	Control	RFPRS	RFPRS+5SD	RFPRS+10SD	RFPRS+20SD	Fresh SD
pH	5.2 ± 0.0 [a]	5.1 ± 0.0 [a]	5.1 ± 0.0 [a]	4.8 ± 0.0 [b]	4.3 ± 0.0 [c]	3.5 ± 0.0 [d]
TTA	1.75 ± 0.05 [e]	2.03 ± 0.06 [d]	2.01 ± 0.03 [d]	2.55 ± 0.01 [c]	3.42 ± 0.05 [b]	11.99 ± 0.55[a]

Means ± SD; values in one row followed by the same lower case letter indicate no significant difference ($p < 0.05$)

The pH values of the control, RFPRS (both containing lemon juice) and RFPRS+5SD were in the same range and did not show any significant differences. Further SD addition significantly decreased the values below pH 5 (Table 6-3). At the same time, the concentration of free acids in the basic doughs increased significantly from control to RFPRS+20SD. An addition of 20% SD even lowered the pH value below 4.5. Due to the presence of antimicrobial acids (here lactic acid, acetic acid and 3-phenyllactic acid), most pathogens are inhibited to grow (FSAI, 2014), which improves the microbiological stability of the dough. This is a great advantage considering that some pastry products are sold as refrigerated raw products.

6.3.2 Dough characterisation

6.3.2.1 Dough extensibility

The impact of SD on the uniaxial extension of the basic dough was analysed using a Kieffer dough and gluten extensibility rig and results are summarised in Table 6-4. Overall, basic dough of the control showed the highest extensibility (E^k) and resistance (R^k_{max}) values. This was expected since the control contained the highest salt level but no SD. It is noteworthy that the water level in puff pastry dough is much lower (52.5%) than in normal bread dough (usually about 60 % or more). Most of the studies conducted in the past evaluated the effect of SD in bread dough which impedes direct comparison. While increasing NaCl concentration generally increases the dough resistance within wheat bread doughs (Beck et al., 2012b; Lynch et al., 2009), SD can have various debilitating effects on the dough and gluten network.

Table 6-4 Rheological properties of basic doughs and physicochemical tests for baked puff pastry samples containing different sourdough levels

Parameter		Control	RFPRS	RFPRS+5SD	RFPRS+10SD	RFPRS+20SD
Rheological properties of basic doughs						
Kieffer Rig	Resistance to extension [g]	92.6 ± 4.4 ^{a}	75.4 ± 3.2 ^{b}	58.4 ± 4.1 ^{c}	61.3 ± 2.9 ^{c}	44.8 ± 1.6 ^{d}
	Extensibility [mm]	19.5 ± 1.0 ^{a}	16.6 ± 0.5 ^{b}	18.5 ± 1.0 ^{a}	15.9 ± 0.5 ^{bc}	14.7 ± 0.4 ^{c}
Chen/Hoseney Rig	Stickiness [g]	59.9 ± 2.4 ^{c}	59.5 ± 1.9 ^{c}	65.3 ± 1.4 ^{b}	70.7 ± 3.0 ^{b}	93.9 ± 3.5 ^{a}
	Work of adhesion [g*sec]	4.8 ± 0.5 ^{c}	6.6 ± 0.6 ^{b}	5.7 ± 0.4 ^{bc}	5.9 ± 0.3 ^{bc}	12.4 ± 0.9 ^{a}
GlutoPeak	Peak Maximum Time [s]	97 ± 3 ^{a}	81 ± 3 ^{b}	83 ± 4 ^{b}	81 ± 2 ^{b}	73 ± 1 ^{c}
	Maximum Torque [BE]	69 ± 1 ^{b}	72 ± 1 ^{a}	71 ± 1 ^{a}	69 ± 0 ^{b}	63 ± 1 ^{c}
Physicochemical tests for baked puff pastry						
Peak firmness [N/mm]		47.3 ± 2.7 ^{c}	77.1 ± 2.2 ^{a}	65.6 ± 1.8 ^{b}	67.5 ± 3.9 ^{b}	66.9 ± 2.3 ^{b}
Total firmness [N*s/mm]		61.6 ± 2.1 ^{b}	65.4 ± 1.9 ^{ab}	61.7 ± 1.9 ^{ab}	67.7 ± 4.5 ^{a}	64.3 ± 3.5 ^{ab}
Maximal lift [mm]		51 ± 1 ^{a}	44 ± 1 ^{b}	46 ± 2 ^{b}	46 ± 2 ^{b}	44 ± 2 ^{b}
Specific volume [ml/g]		9.2 ± 0.2 ^{ab}	8.6 ± 0.3 ^{c}	9.3 ± 0.4 ^{a}	9.3 ± 0.2 ^{a}	8.5 ± 0.4 ^{bc}
Number of cells		1587 ± 77 ^{a}	1399 ± 49 ^{b}	1450 ± 86 ^{ab}	1439 ± 69 ^{ab}	1335 ± 63 ^{b}
Slice brightness		108 ± 2 ^{a}	100 ± 2 ^{b}	105 ± 4 ^{ab}	109 ± 3 ^{a}	106 ± 3 ^{a}

Values are means ± confidence interval of puff pastry with full salt and fat content (control), with reduced fat and reduced salt content (RFPRS) and with 5, 10 and 20% added sourdough (SD); mean values in one row followed by the same lower case letter indicate no significant difference ($p < 0.05$)

Within the SD-containing basic doughs the E^k and R^k_{max} values decreased significantly ($p < 0.05$) with increasing SD levels (Table 6-4). Furthermore, these doughs showed significantly lower R^k_{max} compared to the control and RFPRS.

These findings are in accordance with Koceva Komlenić et al. (2010) and Clarke et al. (2002) who investigated the effect of sourdough on wheat bread dough extensibility.

Compared to RFPRS higher SD values affect rather disadvantageously the extensibility and resistance of the basic dough. SD is partially leading to protein network destruction, lower dough extensibility and thus flexibility. As the gluten network is important for the gas holding capacity this may result in less steam retention and thus affect the lift and specific volume of puff pastries.

6.3.2.2 Dough stickiness

The impact of different SD levels on the stickiness of the basic dough was tested with the Chen-Hoseney Cell. From Table 6-4 it can be seen that RFPRS+20SD showed the significantly highest values for both parameters stickiness and work of adhesion while the control generally exhibited the lowest values. Basic dough from the control and RFPRS showed significantly lower stickiness compared to the SD containing samples. No significant differences for all three parameters were identified for RFPRS+5SD and RFPRS+10SD (Table 6-4). Similar findings were observed by different studies which already indicated that increasing SD and higher acidity values resulted in greater dough stickiness (Armero and Collar, 1997; Tamani et al., 2013).

Still, the mechanism behind dough stickiness is not well understood and determining the cause is difficult (Hoseney and Smewing, 1999). Basically, stickiness is a combination of adhesion and cohesion (Wang et al., 1996) and therefore a result of a combination of surface and rheological properties. Based on the practical experience of bakers, it is known that SD weakens the dough with less resistance to extension. At the same time the dough containing SD is subjectively stickier and more liquid like. Armero & Collar (1997) observed that stickier doughs being those showing a lower viscosity.

Furthermore, stickiness is markedly influenced by water content which in puff pastry is generally lower than in e.g. bread dough (Beck et al., 2012b). However, water holding capacities in doughs containing SD can be less due to gluten degradation to

some extent. In the industrial production of puff pastry, too sticky dough cannot be processed and may lead to process disruption and product loss. A usual practice to avoiding the adhering of the stickier dough to the steel rolls is to sprinkle some flour on the laminated dough during puff pastry sheeting.

6.3.2.3 GlutoPeak test

The GlutoPeak test is a new method that has been proposed primarily for the evaluation of wheat flour quality (Marti et al., 2015). This test measures the aggregation behaviour of gluten upon addition of water and high-speed mixing recording the torque over time (Chandi and Seetharaman, 2012). In Table 6-4 the results of GlutoPeak measurements on basic dough with various SD levels are presented. Typical curves obtained from GlutoPeak measurements are presented in Figure 6-1. Peak Maximum Time (PMT) is the time until the peak appears and indicates the time required for gluten to aggregate and exhibit maximum torque. Besides, the peak height (Maximum Torque – MT) is an indicator for the strength of the gluten network.

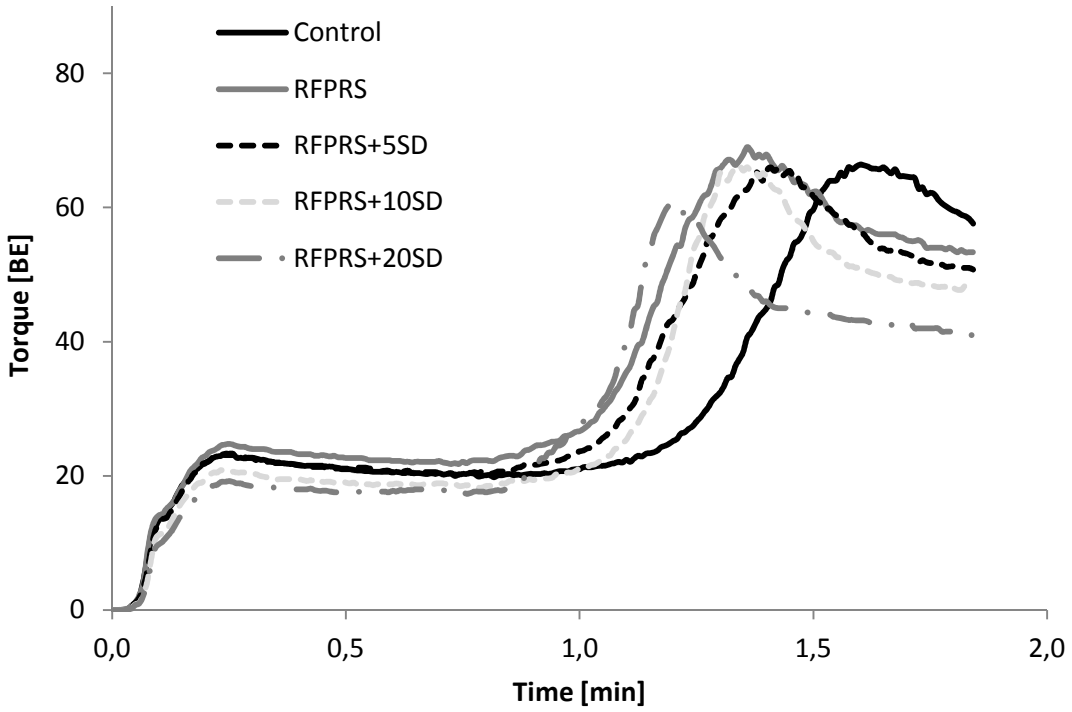


Figure 6-1 GlutoPeak curves of puff pastry basic dough with full salt and fat content (Control), with reduced fat and reduced salt content (RFPRS) and with 5, 10 and 20 % sourdough (SD)

Higher SD levels continuously led to an acceleration of gluten-network development and thus to decreasing PMTs (Figure 6-1, Table 6-4). Simultaneously, the MT declined significantly ($p < 0.05$) with increasing SD levels. This applies to all investigated SD concentrations within this study. Compared to RFPRS the addition of 5 and 10% SD had nearly no effect on PMT and MT. RFPRS+20SD exhibited both, the significantly lowest PMT and MT of all sample doughs. These findings are in accordance with pre-trials where organic acids substantially decreased mixing time of wheat dough and weakened the dough (unpublished data). A pH decrease due to lactic acid addition causes a fast gluten aggregation followed by a rapid gluten break down which is indicated by the sharp peak appearance and explained by strong intermolecular electrostatic repulsive forces hindering new bonds to be formed (Bouachra et al., 2017). When salt was added to the dough recipe an increase of mixing time and a strengthening of the dough was observed. Previously, McCann and Day (2013) reported that NaCl addition delays protein hydration and gluten-network formation which, in turn, results in prolonging dough development time and dough stability. A similar effect was observed in an earlier study reporting that the mixing time distinctly increased for higher salt levels when dry salt was added to the flour before mixing (Danno and Hoseney, 1982). In the case of the present study solely salt reduction led to significantly shorter PMT and higher MT while increasing SD levels under reduced salt contents led to a further decrease of PMT and MT (Table 6-4).

When performing rheological studies on chemically acidified doughs Wehrle, Grau, & Arendt (1997) observed that the addition of acids led to doughs with a more elastic behaviour at optimal mixing conditions and after some rest time. Furthermore, doughs with a lower pH value require a shorter mixing and are less stable (Galal et al., 1978; Wehrle and Arendt, 1998). On the other hand, higher NaCl concentrations result in less water availability for gluten which in turn enhances hydrophobic interactions between gluten proteins in their native form (Melnyk et al., 2011). Less unfolding and hydrogen bonding between unfolded chains are experienced as a consequence and thus longer mixing time (here PMT) is required for a fully developed gluten network.

In the case of puff pastry basic dough, mixing time is kept short for obtaining an under-mixed dough due to the subsequent lamination. The addition of NaCl and thus an increase in PMT will lead to a basic dough with a higher grade of under-mixing.

In turn, this means for puff pastry dough with reduced salt levels and added SD that mixing times have to be adjusted and reduced accordingly ensuring well-structured but still under-mixed basic dough. Reduction of folding and lamination steps is also conceivable. Otherwise, an already fully developed gluten network will start to degrade during lamination process.

6.3.3 Puff pastry quality

Puff pastries were analysed regarding their quality parameters to determine the impact of SD on pastry quality. For external characterization the parameters maximal lift and specific volume were chosen and number of cells and slice brightness were used for internal characterization. To describe the texture properties, the firmness of puff pastry was determined.

6.3.3.1 Maximal lift and specific volume

A main goal is to achieve good quality puff pastry with high volume and improved texture. Therefore, the lift is the first impression the consumer gets from baked puff pastry and generally a high lift is preferred (Simovic et al., 2009). In Table 6-4 the analysis results are presented. Compared to the control all RFPRS pastries exposed significantly lower ($p < 0.05$) maximal lift despite the fact that various SD levels had no significant effect ($p < 0.05$) on the lift. Previous studies already showed that higher salt levels generally increased the lift of reduced fat puff pastries (see chapter 5). Good gas retention properties of the puff pastry dough are important for steam retention during the baking process, which is leading to good pastry lift and volume. Salt has a strengthening effect that improves those gas retention properties. On the other hand, SD weakened the basic dough and decreased its extensibility and resistance (see 6.3.2.1). Therefore, in the present study SD can not compensate the partially missing salt in the basic dough in a way that could improve the pastry's lift.
Besides maximal lift, the specific volume is another important parameter in the assessment of puff pastry as the volume-weight ratio reflects a light and open or otherwise dense structure. No significant correlations between the specific volume and GlutoPeak parameters PMT and MT was found for the samples. The specific volume of RFPRS with 5% and 10% SD was in the range of the Control (Table 6-4) and was even significantly higher than for RFPRS containing no SD. RFPRS and RFPRS+20SD showed the significantly lowest specific volume and thus the densest

structure (Table 6-4). Higher specific volume without increase of the maximal lift is synonymous with a lower product weight. Due to SD addition after each lamination step, the dough layers are not contracting as much and stay thinner and more detailed. Furthermore, pastries containing SD may have lost more water during the baking process.

Thus, SD added in certain concentration can improve and increase the specific volume of reduced fat and salt puff pastries but is not necessarily aiding the maximal lift of the pastries. More information about the actual internal quality of the puff pastry is needed and will be considered along with the results of the further physical tests.

6.3.3.2 Firmness

For describing the puff pastry texture another important parameter is firmness. While total firmness represents the total amount of work needed to cut the sample, the peak of the force expended during measurement was defined as peak firmness. The ECK is a very thin and sharp blade which enables cutting the sample with nearly no compression and is imitating the first bite of a consumer. Generally, consumers prefer crispy but not too chewy puff pastry which is indicated as a lower peak firmness. Firmness results of the pastries can be obtained from Table 6-4.

Compared to the control, the peak firmness was significantly higher for RFPRS and for all pastries containing SD. This is in line with findings of previous studies which revealed that a higher fat content in puff pastries generally decreased the product firmness (Baardseth et al., 1995; Telloke, 1991; chapter 5). During the baking process some fat moves into the dough layers and crystallizes again after baking (Anonymuos, 2000; Dörr, 1982). The resulting fat crystals in the final product leave the dough layers more tender and make them easier to cut (Ghotra et al., 2002). Moreover, salt reduction within the same fat level did not lead to significant differences for peak firmness values (see chapter 5). Interestingly, SD addition helped to decrease significantly the peak firmness of RFPRS pastries in comparison to RFPRS without added SD (Table 6-4). This decrease of peak firmness might be associated with the specific volume and number of cells. Chapter 5 showed that specific volume of puff pastry had a very significant negative correlation to peak firmness while it exhibited a significant positive correlation to number of cells. Although no such significant correlations were found, similarities to this effect were

observed in the present study. In the case of specific volume, the values were significantly higher for SD-containing pastries compared to RFPRS, as discussed above (Table 6-4). Number of cells tended to be higher for SD-containing pastries.
Total firmness did not show significant differences for control and the further tested pastries except for RFPRS+10SD which showed marginally higher total firmness values when compared with the control. Similar results for total firmness in terms of a reduced salt content were obtained in a previous study (see chapter5).
Overall, in terms of firmness, especially peak firmness, SD addition improved the texture of reduced salt and fat puff pastry.

6.3.3.3 Image analysis

With the C-Cell system, originally developed to investigate bread structures, the internal structure of puff pastry was characterised. The C-Cell analyses a slice of a cellular structured product and enables objective and consistent evaluation and a permanent record of a product (Salmon, 2004). Several pre-tests revealed that the parameters number of cells and slice brightness correlated best and allowed a prediction of the cellular and layered structure of the internal pastry (chapter 3).
Generally, the number of layers found in laminated baked product is lower than the calculated layers (Noll et al., 1997). However, a high number of cells was assumed for a high number of theoretical layers which was the case for the control with 81 theoretical fat layers that exhibited the highest number of cells (Table 6-4). Control was followed by RFPRS+5SD and RFPRS+10SD, though number of cells values were not significantly different. Basically, a high value for number of cells reflects a well-structured puff pastry with many thin cross linked layers and a good lift (Figure 6-2 A, C, D). Conversely, a puff pastry with a low number of cells tends to have fewer thicker layers with little cross-linking in-between (Figure 6-2 E). Mainly, higher salt levels increase significantly the number of cells in bread (Lynch et al., 2009; McCann and Day, 2013) and in puff pastry (chapter 5). In the present study, SD seems to compensate partially the salt reduction. Conclusively, SD addition increased the number of cells compared to RFPRS without SD and thus improved the internal structure of the reduced-in puff pastries.

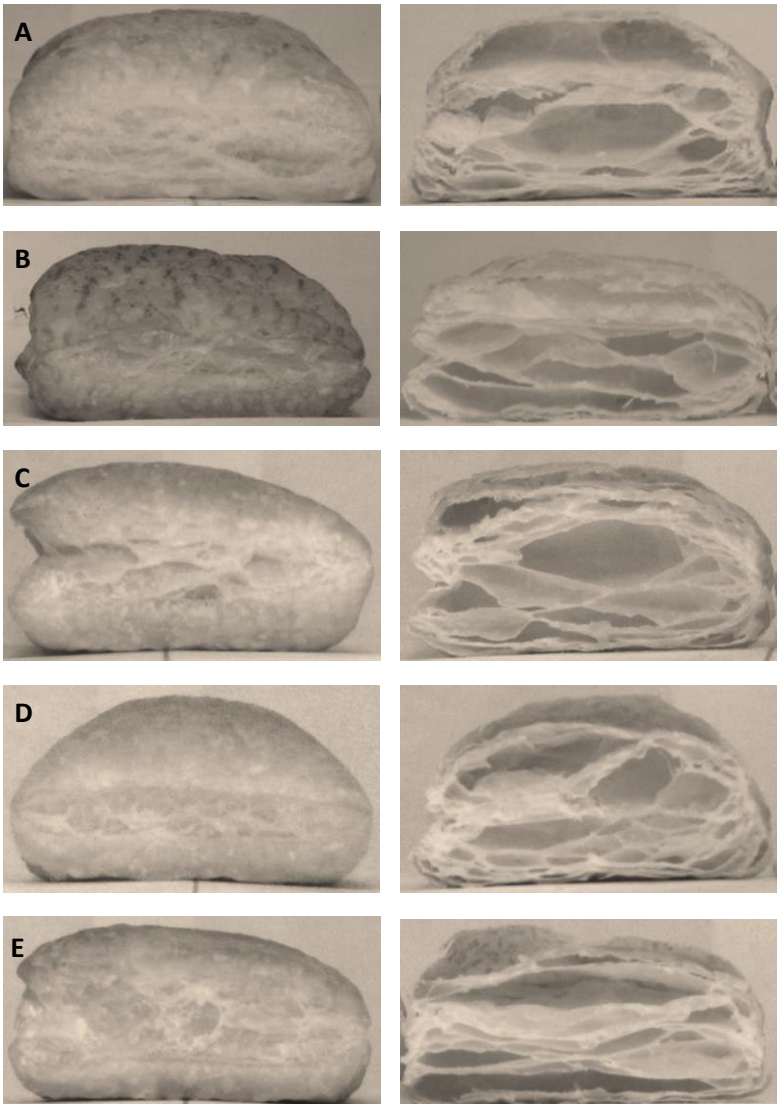


Figure 6-2 Images of baked puff pastry and the corresponding cross section of the control (**A**), puff pastry with reduced fat and salt content with no added sourdough (**B**) and with 5% (**C**), 10% (**D**) and 20% (**E**) added sourdough

Slice brightness is dimensionless and is used additionally in conjunction with the other analytical parameters as indicator for the light reflected by the cell walls of the product. Since the slice brightness is generally positively correlated to the number and the thickness of the product's cell walls, a high number of cells in the cross sectional area of the product basically results in high brightness values. For control, RFPRS and RFPRS+5SD the results of slice brightness basically follow the trend of the number of cells (Table 6-4). For increasing SD levels no trend in changing of slice brightness was observed. All slice brightness values of SD containing puff pastries did not show significant differences among each other. Nevertheless, they

obtained significantly higher values than RFPRS and were in the range of the control (Table 6-4). Among others, this can be again linked to the higher specific volume and indicates a good internal pastry structure.

Hence, all investigated parameters are connected to each other and clearly make the SD addition to the basic dough responsible for improving the number of cells, slice brightness, and specific volume in RFPRS-puff pastries. However, it still needs to be explored how SD is exactly influencing and changing those attributes and the dough structure during lamination also for controls. This study suggests that the application of SD up to a certain level definitely enhances the internal structure of puff pastries which are reduced in salt and fat by higher number of cells and slice brightness values.

6.3.4 Sensory

Sensory characteristics of the samples are summarized in Table 6-5 and Figure 6-3. As discussed earlier, SD can enhance the salty perception of bread and imparts additional flavour compounds (Thiele et al., 2002). This could be partly confirmed in this study for RFPRS-puff pastries. Panellists perceived samples of RFPRS+10SD and control as most salty, though not significant, followed by the further pastries (Table 6-5). The flavour of RFPRS+10SD was rated the highest by the panellists followed by the control and RFPRS+5SD. RFPRS+20SD scored the significant lowest liking of flavour. In this case, acidity had one big impact gaining the significantly highest values for RFPRS+20SD which was obviously perceived negatively as too sour. Acidity level of RFPRS+10SD was moderate but still significantly higher than the scores of control, RFPRS and RFPRS+5SD (Table 6-5).

Although firmness of the control was rated distinctly lower than for all reduced fat and salt samples, no significant differences were detected between all samples (Table 6-5). This is also in accordance with the total firmness results (see 6.3.3.2). Amongst others, firmness plays a major role for the texture and mouthfeel of the puff pastry and repeatedly, no significant differences were detected for this parameter between all samples.

For the perception of fattiness and moisture, no significant differences were found for all samples but the control showed a clearly higher fattiness score than the reduced fat samples. Moreover, moisture revealed higher values for pastries with sourdough addition. The lower fattiness scores for the reduced fat samples are a

logical consequence yet showing that SD addition cannot help to compensate the fatty impression in reduced fat puff pastries. Slightly increasing moisture scores may be explained amongst others by the fact that in SD-fermented wheat doughs increased contents of water-soluble polysaccharides contribute to a lower water absorption (Thiele et al., 2004).

Table 6-5 Sensory evaluation of baked puff pastry*

Attribute	Control	RFPRS	RFPRS+5SD	RFPRS+10SD	RFPRS+20SD
Hedonic					
Appearance	6,3 ^{a}	6,1 ^{a}	6,2 ^{a}	6,0 ^{a}	5,8 ^{a}
Volume	7,0 ^{a}	7,0 ^{a}	6,4 ^{ab}	6,0 ^{ab}	5,3 ^{b}
Flavour	6,3 ^{ab}	5,9 ^{ab}	6,1 ^{ab}	6,8 ^{a}	5,5 ^{b}
Mouthfeel/ Texture	6,0 ^{a}	6,0 ^{a}	5,9 ^{a}	5,8 ^{a}	5,4 ^{a}
Overall Acceptability	6,6 ^{a}	5,8 ^{ab}	6,0 ^{ab}	6,5 ^{a}	4,9 ^{b}
Intensity					
Saltiness	3,5 ^{a}	3,4 ^{a}	3,1 ^{a}	3,6 ^{a}	3,3 ^{a}
Fattiness	6,1 ^{a}	5,2 ^{a}	5,1 ^{a}	5,3 ^{a}	5,1 ^{a}
Moisture	4,6 ^{a}	4,6 ^{a}	4,5 ^{a}	5,1 ^{a}	5,4 ^{a}
Acidity	2,3 ^{c}	2,7 ^{bc}	2,6 ^{c}	4,3 ^{b}	6,8 ^{a}
Firmness	4,5 ^{a}	5,1 ^{a}	5,0 ^{a}	5,3 ^{a}	5,1 ^{a}

* with full salt and fat content (control), with reduced fat and reduced salt content (RFPRS) and with 5, 10 and 20% added sourdough (SD). Mean values in one row followed by the same lower case letter indicate no significant difference ($p < 0.05$)

Highest score for appearance was given to the control by the panellists. However, all other samples were in the same range and no significant differences were detected (Table 6-5). Regarding the scores for liking the volume, the panellists seemingly preferred the samples without SD, the control and RFPRS, that were rated with 7.0 both (Table 6-5). While RFPRS+5SD and RFPRS+10SD showed no significant differences to the best rated samples, but RFPRS+20SD achieved the significantly lowest score. Those volume results partially differ from the findings of the instrumental measurements (see 6.3.3.1) meaning that the panellist's eye and the subjective impression of volume are not necessarily reflected by the exact values of maximal lift and specific volume.

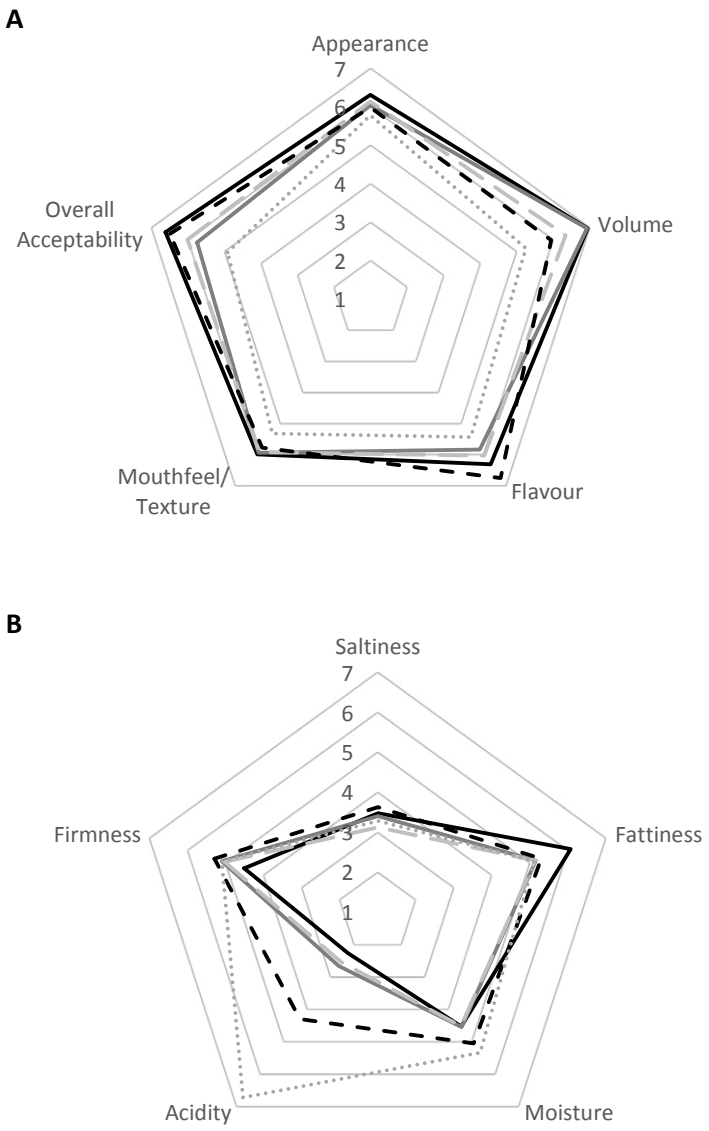


Figure 6-3 Sensory evaluation of baked puff pastry. Hedonic (A) and intensity (B) sensory terms of puff pastry with full salt and fat content (control, black line), puff pastry with reduced fat and salt content (RFPRS, dark grey line) and RFPRS with 5% (grey dashed line), 10% (black dashed line) and 20% (grey dotted line) added sourdough

Certainly, the results above demonstrate that it is possible to partially compensate a 30% salt and 40% fat reduction in puff pastry by the addition of 10% SD, keeping product overall acceptability similar to that of a control (Table 6-5).

6.4 Conclusion

The main objective of this study was to investigate the effect of SD on dough rheology and sensory characteristics of puff pastry reduced in salt (-30%) and fat (-40%) using the functional strain *L. reuteri* R29 as starter culture.

For SD-containing pastries the E^k and R^k_{max} values decreased significantly ($p < 0.05$) with increasing SD levels and revealed significantly lower R^k_{max} compared to the control and RFPRS. Dough from the control and RFPRS showed significantly ($p < 0.05$) lower stickiness compared to the SD containing samples. Furthermore, increasing SD levels continuously led to an acceleration of gluten-network development and thus to decreasing PMTs and simultaneously to significantly ($p < 0.05$) lower MTs. However, compared to RFPRS the addition of 5 and 10% SD had no effect on PMT and MT while RFPRS+20SD exhibited both the significantly lowest PMT and MT of all sample doughs.

Partially, the addition of SD significantly improved the texture and flavour of RFPRS pastry compared to RFPRS without SD. Similar results were obtained for specific volume, total firmness, number of cells and slice brightness. Interestingly, the specific volume was significantly better for RFPRS+5% and 10%SD compared to RFPRS and comparable with that of the control.

Sensory quality and texture was improved compared to RFPRS without SD. Best results were obtained for RFPRS+10SD showing an overall acceptability similar to that of the control. All results were supported by a sensory study.

SD has demonstrated to be a great tool to improve flavour and texture of puff pastry reduced in fat and salt without the use of any artificial ingredients.

6.5 Acknowledgements

This study was carried out with financial support from the European Commission, FP7, Thematic Area KBBE, Project “PLEASURE” (Grant agreement no: 289536).

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Chapter 7

General discussion

7.1 General discussion

Puff pastry is a non-leavened light and crispy pastry with unique textural properties of laminated structure. This pastry is prepared by repeated lamination of wheat dough and fat and has a fat content of up to 40 % and contains about 1.0–1.2 % salt (NaCl) (The French Information Center on Food Quality, 2012).

Nowadays, excessive consumption of sodium chloride and saturated fat is linked to a variety of diseases, particularly cardiovascular diseases (strokes, heart attacks, heart failure, etc.), weight gain and obesity (Grundy and Denke, 1990; WHO, 2000). One of the most effective mechanisms to improve population health is the reduction of dietary fat and sodium (WHO, 2003; WHO, 2012). This process includes a worldwide reduction of population's daily intake of salt but also saturated fat, an ingredient reformulation and process adaptations of food.

First of all, a literature review revealed the impact of salt on the product quality of puff pastry and other baked goods, mainly bread, including dough characteristics, sensory properties and shelf-life (**chapter 2**). Moreover, the review indicates existing problems due to the reduction of salt in the bakery sector and discusses the progress and possible strategies to achieve those targets. Fat and salt reduction in puff pastry is not as straight forward. Both salt and especially fat impact the processability during the production and positively influence several technological, rheological and sensory parameters and thus the quality characteristics of the final products.

Divided into several chapters, this thesis investigated the following main questions which are further elaborated below: How far can the total fat level of puff pastry be reduced to still obtain acceptable products (**chapter 3**)? What kind of vegetable fat blend with an even "healthier" fat composition is suitable for PP production (**chapter 4**)? How is salt affecting the dough properties and quality characteristics of puff pastry (**chapter 5**)? Can sourdough (SD) improve the quality and taste of fat- and salt-reduced puff pastries (**chapter 6**)?

In **chapter 3** partly new analytical methods to measure the quality characteristics of puff pastry were applied. Those methods included a Texture Analyzer attached with Extended Craft Knife (ECK) and Multiple Puncture Probe (MPP), VolScan and a C-Cell image system receiving the quality parameters of total firmness and peak firmness, specific volume, number of cells and slice brightness.

Firmness is one important parameter for describing the texture and the internal structure of baked puff pastry. The total amount of work needed to cut or penetrate the sample was defined as “total firmness”, while the peak of the force expended during measurement was defined as “peak firmness”. The ECK imitates the first bite of a consumer because the very sharp and thin blade enables cutting the sample with nearly no compression. Therefore, peak firmness of the ECK measurement describes the force, which is applied to completely bite through the sample. Consumers generally prefer crispy but not too chewy puff pastry which is described by a lower peak firmness and a decent internal structure and texture.

In **chapter 3** the total firmness values of the puff pastries ranged from 7.0 to 124.5 Ns/mm for ECK measurements and 18.7 to 144.5 Ns for MPP (Table 3-4) and varied significantly among the experiments.

To determine acceptable firmness and texture of the puff pastry samples the subsequent sensorial evaluation by an experienced baker was compared to the analytical values. Firmness values outside the range of 50 and 110 Ns/mm were related to puff pastries with poor internal structure and mouthfeel.

If the laminated pastry dough contained a higher number of dough layers and the final thickness was lower at the same time each individual dough layer became also thinner. Seemingly, many thin dough layers led to a lower total firmness (ECK) in the product than few thicker dough layers (Table 5-4).

Melted fat is partially moving into the dough layers during baking and crystallizes again when cooling down after baking (Anonymous, 2000; Dörr, 1982). Those fat crystals cause a softening of the dough layers by lubrication and make the final product more tender (Dörr, 1982; Ghotra et al., 2002). For higher fat contents this softening effect even increases (Telloke, 1991). The findings of this study are in accordance with the results reported by Baardseth et al. (1995) investigating different shortening types and concentrations (350, 500 and 650 g/kg dough) in Danish pastry. Both sensory analysis and textural measurements revealed that firmness decreases when the shortening concentration increases. Contrary, Sternhagen and Hoseney (1994) could not find any significant differences in firmness of croissants with different levels of roll-in fat (15, 20 and 25 % db).

MPP firmness measurements were solely used for the RSM optimization process of fat-reduced puff pastry in **chapter 3**. For all subsequent chapters (**4–6**) only ECK was used to measure the firmness. From here, however, peak firmness (the highest

point of the compression curve) was used as an additional characteristic parameter of puff pastry quality.

Two of the most important characteristics influencing consumer's choice are the layered structure and exceptional flakiness of puff pastry (Kincs and Minor, 1995). Moreover, mouthfeel and crispiness of baked puff pastry are directly related to its internal structure (Simovic et al., 2009). In **chapter 3** the parameters which correlated best and allowed a prediction of the cellular and layered structure of the inner pastry were the number of cells (Figure 3-3 C, F and I) and slice brightness (Figure 3-3 B, E and H).

Due to the fact that a high number of cells represent a higher degree of crosslinking of the single dough layers, but also a larger cross-sectional area in the product, a larger number of cells is a good indication of a decent internal puff pastry structure.

Theoretically, it should be assumed that higher amounts of dough and fat layers create a higher number of cells. However, this was not the case for puff pastry with 100 and more dough layers. Probably, the single dough layers were not separated properly by the fat layers to create cells which are big enough to be detected by the C-Cell system. Moreover, the actually existing number of layers in puff pastry is well below the theoretically possible number (Noll et al., 1997; Telloke, 1988). Each cell is encased by dough and more cells lead to a higher number of cell walls. When light is reflected by these cell walls the product cross section appear brighter (Figure 3-3 B, E and H). Accordingly, a high number of cells in the cross sectional area results in high brightness values. Generally, all number of cells and slice brightness values have to be considered in conjunction with the other analytical parameters.

Additionally, to investigate the microstructure of the unbaked laminated dough cross sections of frozen dough samples were stained and examined with help of the confocal laser scanning microscopy (CLSM). The micrographs in Figure 3-4 show the dough layers (proteins, gluten network) appearing red and the brighter red spots represent the starch granules. Fat was not dyed and appeared black. In detail, Figure 3-4 shows larger A-granules (~15-40 µm) and smaller B-granules (~1-10 µm) which are relatively uniformly distributed within the dough layers (Sasaki and Matsuki, 1998). The effect of variation of number and thickness of the dough and fat layers is clearly recognizable from Figure 3-4 A-C. When the fat level was reduced and the number of layers and final thickness were kept constant the thickness of fat layers decreased while the thickness of the dough layers increased. Due to higher expansion

in vertical direction the dough layers of fat-reduced puff pastry were even thicker than the fat layers (Figure 3-4 A). Due to its well-developed gluten network wheat dough is a viscoelastic material and does not show ideal plastic behaviour, even when containing several fat layers (Dobraszczyk and Morgenstern, 2003). Thus, after passing the steel rolls the dough is immediately expanding in vertical direction (thickness) while contracting in horizontal direction. This caused deviating actual thicknesses of laminated doughs of, for example, 3.3 ± 0.1 mm and 3.6 ± 0.1 mm for roller gaps of 2.25 mm and 2.50 mm, respectively. Thus, during all trials the roller speed and number of passes were kept constant.

According to Noll et al. (1997) every layer in a puff pastry dough is thinner than a sheet of silk paper after the final lamination. If the fat layers were too thin and broken at many points they may not sufficiently separate the dough layers what ultimately led to poorer product quality (Telloke, 1988). This is the case for puff pastry control (Figure 3-4 C) with 144 fat layers while less fat layers (81) in the improved puff pastry control are better distributed (Figure 3-4 B).

After the definition of all parameters the optimization of process variables is also described in **chapter 3**. Basically, the optimal levels for number of layers and final thickness were determined by superimposing the surface plots for all response variables and selecting the regions that best satisfy all the quality requirements (Floros and Chinnan, 1988).

Response surface methodology (RSM) was used to evaluate the effect of the three independent parameters fat reduction (0-40 %), number of fat layers (50–200) and final thickness (1.0–3.5 mm) on puff pastry quality to achieve an optimization of fat-reduced puff pastry (-40 %).

Primarily, the responses of the physicochemical analysis were compared to the results of the sensorial analyses. Subsequently, the ranges and threshold values for qualitatively acceptable puff pastries were defined (Table 3-4). In this context, minimum total firmness (ECK and MPP), maximum number of cells and maximum slice brightness were identified as the essential quality criteria for the puff pastry optimization. Table 3-4 gives a detailed overview of all limits and ranges for the optimization process. Using the Design Expert software the optimization revealed a few possible combinations for the parameters, number of fat layers and final thickness. One combination out of that was chosen and the puff pastry was prepared and analysed.

First, an optimization process was carried out with the originally selected puff pastry control (144 layers, 2.50 mm final thickness). Although not all analysed data can exactly match the predictions numerous measured values (number of cells, number of cells/height and number of cells/slice area) corresponded well to the values predicted by the mathematical RSM model. Other predicted values were overestimated (total firmness (MPP)) or underestimated (total firmness (ECK), specific volume and slice brightness).

However, regarding quality parameters the improved puff pastry control (full fat, 81 layers, and 2.50 mm final thickness) achieved noticeably better results compared to the puff pastry control. Additionally, these results were confirmed by sensory evaluation. The total firmness (ECK) decreased significantly and specific volume and number of cells increased significantly ($p < 0.05$) for the improved puff pastry control (Table 3-4). These process parameters obtained by the RSM approach were then kept as a full-fat control and used for further studies (**chapter 4–6**).

For the fat reduced puff pastry a maximum fat reduction of 40 % was desired and except the parameter fat reduction all settings remained the same as before (Table 3-4). Considering the technical limits, a fat-reduced puff pastry with 48 layers and 2.25 mm final thickness was baked and analysed (Table 3-4). Results of total firmness (ECK), specific volume, number of cells and slice brightness of 40 % fat-reduced puff pastry corresponded well with the predictions of the RSM model while slightly lower firmness (MPP) than predicted was measured. Those pastries were consequently labelled RFP (reduced fat puff pastry) while the full fat puff pastry was labelled (FFP) (**chapter 4–6**).

A sensory acceptance test with 60 untrained assessors was performed to confirm the results of **chapter 3** for puff pastry control, improved puff pastry control and fat-reduced puff pastry. The sensory analysis revealed no significant differences in taste of fatness or ‘liking of mouthfeel’ (Figure 3-5 and Table 3-6). Moreover, the fat-reduced puff pastry resulted in a significant ($p < 0.05$) positive correlation to ‘liking of flavour’ and overall acceptance by the assessors.

As the next step, four vegetable fat blends (FBs) composed of various ratios of palm stearin (PS) and rapeseed oil (RO) were characterised and tested for their use in full fat and reduced fat puff pastry production (**chapter 4**). All FBs had a low *trans*-fatty acid (TFA $\leq$ 0.6 %) content and the level of PS decreased from FB1 to FB4 while the RO content increased simultaneously (Table 4-1).

An increase of RO in the FBs resulted in a gradual reduction of the solid fat content (SFC) which was shown for FB1 to FB4 and is in accordance to the literature (Siew et al., 2007). The lowest SFC values were found for FB4 (35 °C: 10.9 %, 40 °C: 8.1 %) containing the highest amount of RO and thus UFAs, while FB1 (35 °C: 20.6 %, 40 °C: 15.5 %) showed the highest SFC values over the whole investigated temperature range. Generally, puff pastry margarines show higher SFC values than other margarines and TFA-free margarines even presented higher SFC contents than *trans*-fat containing products at temperatures above 40 °C (Cavillot et al., 2009; Wassell and Young, 2007). Within the temperature range of puff pastry production, FBs should show a SFC in the range of not being liquid but still spreadable. Such precise SFC profiles can be obtained by combining different amounts of PS and vegetable oil (Wassell and Young, 2007).

The DSC results correlated well with the SFC findings of the four FBs. Since they are responsible for higher SFC values the amount of higher melting TAGs decreased from FB1 to FB4 (Figure 4-2) while the SFC decreased in the same way (Figure 4-1) (Siew et al., 2007).

Rheological measurements revealed a dependency of all FBs on frequency indicating a viscoelastic solid-like behaviour. Storage modulus G´ of all fats increased over the whole frequency range while the loss modulus G´´ was consistent for FB1, slightly increased for FB2 and slightly decreased for FB3 and FB4. This increase of G´ combined with decreasing G´´ indicates a transition from a more viscous to a more elastic material (Cheong et al., 2009). Moreover, G´´ values for all fats were below G´ values, indicating a more elastic than viscous behaviour. Figure 4-4 illustrates the average values for G´ over the whole frequency range indicating a firmness increase from FB4 to FB1 what again correlates to the yield values (Figure 4-3).

According to DeMan and Beers (1987) yield values obtained by cone penetrometry do not relate to any fundamental properties of the fat, since large shearing forces are involved that produce substantial breakdown of structure. Haighton (1959) investigated puff pastry margarines/ fats with yield values in the range of 0.8 to 1.6 kg_f/cm^2 and yield values above 1.5 kg_f/cm^2 were considered as ‘too hard’. Nevertheless, based on the results of baking trials ‘extremely hard’ FBs with yield values of 81 to 128 kg_f/cm^2 (20 °C) seemed to be optimal for use in puff pastry production. Obviously processing and requirements on puff pastry fats have changed.

Total firmness values which increased from FB4 to FB1 can also be correlated to the yield values. Except for FB4, all FFP showed significantly ($p < 0.05$) lower total firmness values than the corresponding RFP when products contained the same FB (Table 4-2). Due to the fat reduction RFP contained a higher dough/ fat ratio (80 wt% dough) and at the same time fewer layers than FFP (67 wt% dough) resulting in slightly thicker dough layers in RFP. Thus, more force was needed to cut and penetrate these samples.

Interestingly, with increasing softness of the FBs (FB1 to FB4) the total firmness decreased significantly ($p < 0.05$) while the peak firmness followed the opposite trend and increased (Table 4-2). When a FB due to its increasing oil content becomes softer and less plastic during sheeting the fat and dough layers can be mingled (Nor Aini and Miskandar, 2007). As a result, the fat can no longer separate the individual layers of dough properly. Additionally, the fat causes lubrication and softening of the final product (Ghotra et al., 2002). During the short baking period the resulting denser dough layers could not get crispy but become more tender instead (Ghotra et al., 2002; Nor Aini and Miskandar, 2007).

Probably, the partly-baked, thicker dough layers were compressed rather than cut during the measurements when FB3 and FB4 were used. Hence, with an increasing amount of RO (Table 4-2) the shear stress (total firmness) between probe and puff pastry decreased. Concurrently, since samples were finally cut by ECK at the very end of the measurement the peak firmness for FB3 and FB4 increased. Indeed, products containing the softer FB3 and FB4 were also low in lift (Table 4-2) and showed a denser structure (Figure 4-5).

Lift and volume are the first impressions a consumer gets from puff pastry. Therefore, the parameters maximal lift and specific volume are two important criteria in the assessment of puff pastry. Puff pastries with a high lift and specific volume are preferred by consumers while a lift of 50 mm is regarded as optimal (Noll et al., 1997; Simovic et al., 2009).

Compared to the control the attributes maximal lift and specific volume were 20 to 60 % lower for baked products with FB3 and FB4. FFP and RFP produced with FB4, containing the lowest SAFA amount (31.4 %), were even not acceptable in terms of lift and specific volume. This demonstrates that softer FBs adversely affect the rising of the puff pastry during baking. Moreover, it confirms that a roll-in fat needs to contain a certain amount of SAFAs to deliver satisfactory puff pastry (Stauffer,

1999). This is also in accordance with the studies of Garcia-Macias et al. (2011; 2012), who reported a lower lift for puff pastry produced with vegetable roll-in fats (about 30 % SAFA) compared to those containing butter (66 % SAFA).

Generally, products using FB1 or FB2 achieved excellent baking results for FFP and RFP and had adequate shortening properties. In conclusion, compared to the FB1 containing control, the usage of FB2 did not lead to adverse effects in pastry lift and specific volume. Furthermore, a fat reduction by 40 % and a simultaneous reduction of SAFA by 49 % in comparison to the control (Table 4-2) were achieved why FB2 was the fat of choice in **chapter 4**. FB3 and FB4 were considered inadequate for puff pastry production because of their melting behaviour.

FB2 to FB4 were exclusively produced in small scale for the experiments of **chapter 4**. Since FB1 was the standard fat and available in sufficient amounts to perform all required experiments it was used as roll-in fat for all subsequent studies (**chapters 5–6**).

After clarifying the most suitable fat blend for puff pastry production, the objective of **chapter 5** was to determine the impact of salt (0–8.4 g/100 g flour) on the structure and quality characteristics of puff pastry with full and reduced (-40%) fat content. Therefore, the above described quality characteristics of baked puff pastry were investigated. Additionally, empirical rheological tests of the resulting dough were carried out including dough extensibility, dough stickiness and GlutoPeak test.

Using a Kieffer dough and gluten extensibility rig the impact of salt on the uniaxial extension of the basic dough was analysed and results are summarised in Table 5-3.

During puff pastry manufacture shear and other forces are continuously acting on the dough due to the repeated folding and sheeting steps. For that reason, the basic dough is usually prepared as under-mixed and the gluten network not yet fully developed.

The reduction of NaCl had a significant impact on empirical dough properties. First of all the dough resistance R^k_{max} continuously increased with increasing salt levels (Table 5-3). Compared to control all salt levels below control had significantly ($p < 0.05$) lower R^k_{max} values while only 4xS showed significantly higher R^k_{max} values.

A general increase in dough resistance with increasing NaCl concentration and no significant differences for R^k_{max} at lower salt values in wheat bread doughs were also observed by of Beck et al. (2012a) and Lynch et al. (2009).

No unique trend on extensibility E^k caused by the different salt levels was found. Initially E^k values slightly increased with increasing salt level until the Control and decreased again at higher salt levels (Table 5-3). Recent studies described similar trends for E^k (Beck et al., 2012a; Lynch et al., 2009). Since interaction between polymer crosslinks became stronger R^k_{max} continuously increased with increasing salt levels (2xS and 4xS) and decreased again after reaching a maximum (control). Most likely, within the gluten network more and more inter- and intramolecular bounds started to break and were not able to completely restore after deformation what finally is leading to protein network destruction. In general, doughs with low salt levels are more viscous, lack stability and are expected to be very weak. This is caused by a lower protein-network formation and thus few elastic components (Beck et al., 2012a). Compared to doughs with higher salt contents lower extensibility and thus flexibility may result in less gas retention. Less shielding of charged gluten molecules is achieved when NaCl levels increase. Hence, the interaction between polymer crosslinks becomes stronger, improves gluten network formation and thus, increases the dough resistance and extensibility (Beck et al., 2012a).

Sticky dough is a major problem in industry as it cannot be processed properly and may lead to process disruption and product loss. Basically, stickiness is a combination of surface and rheological properties but still, the mechanism behind dough stickiness is not well understood and reliable measurements are hard to achieve (Hoseney and Smewing, 1999; Wang et al., 1996).

All measured stickiness parameters in **chapter 5** increased significantly ($p < 0.05$) with decreasing salt levels (Table 5-3). Accordingly, the highest and lowest stickiness values were detected for dough containing no/low salt and the 4xS salt amount, respectively. Contrary to the expectations of most cereal scientists, Beck et al. (2012a) reported decreased dough stickiness with decreasing NaCl concentration (40–0 g/kg flour) in bread dough. Some flour was sprinkled on the dough surface before lamination as is common practice to prevent adhering of the stickier dough to the steel rolls during puff pastry production.

For the evaluation of wheat flour quality a new method has been proposed, the GlutoPeak test. The GlutoPeak measures the aggregation behaviour of gluten upon addition of water and high-speed mixing and records the torque over time (Chandi and Seetharaman, 2012; Marti et al., 2015). In **chapter 5** GlutoPeak measurements were performed on basic dough with different salt levels. Results and typical curves

of GlutoPeak measurements are presented in Table 5-3 and Figure 5-1. The Peak Maximum Time (PMT) shows how fast the gluten network is able to form and the Maximum Torque (MT) indicates the strength of the gluten network.

Increasing NaCl levels, up to 2xS, continuously lead to a delay in gluten network development what is visible in significantly ($p < 0.05$) increasing PMTs and simultaneously decreasing MTs (Table 5-3, Figure 5-1). Besides, increasing NaCl levels significantly decreased the stickiness, work of adhesion and dough strength. PMT in **chapter 5** showed a very significant negative correlation to the MT ($p < 0.01$, r = -0.98). This is in contrast to findings of Melnyk et al. (2011) who reported an increasing torque as salt concentration increased. Previous studies already revealed that NaCl addition distinctly increased the mixing time, delays protein hydration and gluten network formation which, in turn, results in increasing dough development time and dough stability (Danno and Hoseney, 1982; McCann and Day, 2013).

Melnyk et al. (2011) investigated the impact of different salt concentrations and ions on the gluten aggregation of wheat flour. Structure-enhancing effects of Cl^- and Na^+ result in less water availability for gluten which in turn enhances hydrophobic interactions between gluten proteins in their native form (Melnyk et al., 2011). Consequently, less unfolding and hydrogen bonding between unfolded chains were experienced. Hence, a longer mixing time (here PMT) is required for a fully developed gluten network and to unravel proteins, and allow for inter-protein interactions through hydrogen bonding and hydrophobic interactions as well as inter-disulphide bonding (Melnyk et al., 2011). Obviously, in the case of 4xS-dough the effect of Na^+ and Cl^- ions on the flour proteins completely hindered a proper gluten network development. Neither PMT nor MT was detected for the highest salt concentration 4xS.

In the case of basic dough – which is under-mixed like mentioned above – NaCl reducstion and thus a decrease of PMT will lead to dough with a higher grade of development. Therefore, theoretically fewer turns and laminations are possible for those doughs with lower salt contents before the gluten network is fully developed and starts to degrade. One more option is to adjust and reduce the mixing time, still ensuring an under-mixing of dough.

Generally, with salt decrease the lift decreased for RFP (Table 5-4). Moreover, RFP containing very low and no salt produced the significantly ($p < 0.05$) lowest lift of all

puff pastries. From sections 5.3.1 and 5.3.3 it can be seen that the resistance to extension and the peak maximum also decreased with decreasing salt levels. This indicates that the gluten network during mixing and lamination in pastries with lower salt contents may already be over-stretched and became weaker. Furthermore, this weak gluten network can decrease the gas holding capacity of the dough layers, as discussed above, what again results in lower lift during baking. These results are comparable to a study of Lynch et al. (2009), who showed that lowering the concentration of NaCl in bread dough decreased the gas retention properties.

For FFP a converse trend was observed as the lift slightly increased with decreasing salt levels. Except NoS which showed significantly lower lift no significant differences in lift of FFP were observed compared to the Control. Very high salt levels (4xS) again decreased the lift of pastries (Table 5-4).

Additionally, the specific volume had a good correlation ($p < 0.05$, r = 0.64) and basically followed the trend of the maximum lift (Table 5-4). FFP 4xS showed the lowest significant specific volume and thus the densest structure.

Regarding the internal pastry characteristics increasing salt levels produced significantly more cells for both FFP and RFP (Table 5-4). All FFP (81 theoretical fat layers) exhibited generally significantly higher number of cells than there corresponding RFP (48 theoretical fat layers) with the same salt level. This confirms the general assumption that a high number of theoretical layers generates a high number of cells.

In previous studies the number of cells in bread also increased significantly with increasing salt levels (Lynch et al., 2009; McCann and Day, 2013). The number of cells in **chapter 4** showed a highly significant ($p < 0.001$) positive correlation to maximal lift (r = 0.90) and specific volume (r = 0.89).

The slice brightness values for puff pastries in **chapter 5** correlated well with the number of cells (r = 0.82, $p < 0.01$) and maximal lift (r = 0.87, $p < 0.001$). Slice brightness results basically followed the trend of the number of cells (Table 5-4) while higher salt levels produced higher slice brightness for both FFP and RFP. Again, this is linked to higher lift and specific volume and indicates a good internal pastry structure. Basically, NaCl can support a better internal structure of puff pastries up to a certain level (2xS) what is characterized by high number of cells and slice brightness values.

Since total firmness in **chapter 5** decreased significantly ($p < 0.05$) with decreasing salt levels for both FFP and RFP (Table 5-4) a general softening of the pastries was detected. Overall, firming effects of NaCl were more pronounced for FFP, as high salt levels 2xS and 4xS significantly increased both peak firmness and total firmness of FFP. Increasing NaCl levels lead to stronger gluten networks with higher resistance (Section 5.3.1–5.3.3) what in turn, leads to lower lift and specific volume. Obviously, the denser products with thick dough layers are harder to cut.

In general, FFP samples with a high number of cells had a lower peak firmness (Table 5-4) while both parameters correlated well ($p < 0.05$, $r = -0.80$). For bread products with increasing NaCl levels an increase in crumb firmness has been previously described, although both instrumental method and recipe differ from the present study (Beck et al., 2012b).

Again, FFP showed generally significantly ($p < 0.05$) lower peak firmness than RFP with the same salt content (Table 5-4). **Chapter 4** and further previous studies already revealed that higher fat content in puff pastries resulted in lower product firmness (Baardseth et al., 1995; Telloke, 1991).

Finally, a sensorial comparison of control, RFP FS and RFP RS revealed that salt reduction (30 %) in puff pastry was noticed by the assessors but did not significantly affect the perception, visual impressions or liking of the further attributes and properties (Figure 5-2 and Table 5-5). Although consumers may discover differences in taste and texture they will get used to this new impression and still like the product.

Finally, after the successful reduction of puff pastry reduced in salt (-30%) and fat (-40%) the effect of various SD levels (5, 10 and 20% flour basis) on dough rheology and sensory characteristics was investigated using the functional strain *L. reuteri* R29 as starter culture (**chapter 6**). Once more, empirical rheological tests were carried out on the basic dough and the puff pastry quality was examined.

Basically, with increasing SD levels the extensibility (E^k) and resistance (R^k_{max}) values of SD-containing pastries decreased significantly ($p < 0.05$) and revealed significantly lower R^k_{max} compared to the control and RFPRS (Table 6-4). Overall, the basic dough of the control showed the highest E^k and R^k_{max} values. Since the control contained the highest salt level but no SD this was expected in about.

Most of the studies conducted in the past evaluated the effect of SD in bread dough that has a much higher water level (usually about 60 % or more) than puff pastry

dough (52.5%). This impedes direct comparison of both doughs. Increasing NaCl concentration generally increases the dough resistance within wheat bread doughs (Beck et al., 2012a; Lynch et al., 2009), while SD can have various debilitating effects on the dough and gluten network. With increasing SD levels E^k and R^k_{max} values of SD-containing basic doughs decreased significantly ($p < 0.05$) (Table 6-4). Furthermore, these doughs showed significantly lower R^k_{max} compared to the control and RFPRS. These results are consistent with Koceva Komlenić et al. (2010) and Clarke et al. (2002) who investigated the effect of SD on wheat bread dough extensibility.

Moreover, higher SD values rather disadvantageously affect the extensibility and resistance of the basic dough when compared to RFPRS (Table 6-4). Partially, SD is leading to protein network destruction, lower dough extensibility and thus flexibility. In turn, this may result in less steam retention and finally affect the lift and specific volume of puff pastries as the gluten network is important for the gas holding capacity (see above).

The basic dough of control and RFPRS showed significantly ($p < 0.05$) lower stickiness compared to the SD containing samples (Table 6-4). While the control generally exhibited the lowest values RFPRS+20SD showed the significantly highest values for stickiness. Different studies already observed similar findings which indicated that increasing SD and higher acidity values resulted in greater dough stickiness (Armero and Collar, 1997; Tamani et al., 2013). Stickiness is markedly influenced by water content and in SD-containing doughs the water holding capacities can be less due to gluten degradation to some extent.

In addition, increasing SD levels continuously led to an acceleration of gluten-network development what resulted in decreasing PMTs and simultaneously significantly ($p < 0.05$) lower MTs. The addition of 5 and 10% SD compared to RFPRS had no effect on PMT and MT while RFRS+20SD exhibited both the significantly lowest PMT and MT of all doughs. Wehrle, Grau, & Arendt (1997) observed that the addition of acids led to doughs with a more elastic behaviour at optimal mixing conditions and after some rest time. In fact, doughs with a lower pH value require a shorter mixing and are less stable (Galal et al., 1978; Wehrle and Arendt, 1998). Additionally, higher NaCl concentrations result in less water availability for gluten what enhances hydrophobic interactions between gluten proteins in their native form (Melnyk et al., 2011). Between the unfolded chains less

hydrogen bonding and unfolding are experienced. Consequently, a longer mixing time (here PMT) is required for a fully developed gluten network. However, due to the subsequent lamination the mixing time is kept short to obtain under-mixed basic dough (see above).

Regarding the textural quality parameters, the addition of SD significantly improved the texture of RFPRS pastry. Compared to RFPRS without SD the number of cells, slice brightness, total firmness and specific volume were improved (Table 6-4). Interestingly, compared to RFPRS the specific volume of RFPRS+5%SD and 10%SD was significantly higher and comparable with that of the control.

Finally, a sensory study revealed that it is possible to partially compensate a 30% salt and 40% fat reduction in puff pastry by the addition of 10% SD. Flavour and texture were distinctly improved compared to RFPRS without SD (Table 6-5 and Figure 6-3). Especially the product overall acceptability of RFPRS+10SD was similar to that of the control (Table 6-5).

7.2 Conclusion

To conclude, all questions from the beginning of this chapter can be answered as follows. This thesis demonstrates that puff pastry with a reduced fat content (-40%) can be produced with the best possible quality characteristics when compared to conventional products with 33 wt.% fat (**chapter 3**). Moreover, this is achievable with technological changes only and without the addition of fat replacers. FB2 was the fat of choice in **chapter 4**. Particularly, due to its higher amount of RO and the lower SAFA content compared to FB1 and coupled with the satisfying baking results. Furthermore, puff pastries containing full fat and reduced salt achieved excellent baking results without differing significantly from the control (**chapter 5**). Furthermore, a salt reduction (-30%) and a simultaneous reduction of fat by 40% lead to significantly higher peak firmness, significantly lower lift, specific volume and number of cells when compared to the control. Finally, SD has performed well and demonstrated to be a great tool to improve flavour and texture of puff pastry reduced in fat and salt without the use of any artificial ingredients (**chapter 6**). The best results were achieved by RFPRS with 10% SD showing an overall acceptability similar to that of the control.

The results of this thesis may provide a good basis for reducing sodium and fat in puff pastry but also other laminated products such as croissants.

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Appendix

Publications and presentations

Peer reviewed first author publications

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016) "Current status of salt reduction in bread and bakery products–A review" in *Journal of Cereal Science*, 72: 135-145, doi: 10.1016/j.jcs.2016.10.010

Silow, C., Zannini, E. & Arendt, E. K. (2016) "Impact of low-*trans* fat compositions on the quality of conventional and fat-reduced puff pastry" in *Journal of Food Science and Technology*, 53 (4): 2117-2126, doi: 10.1007/s13197-016-2186-z

Silow, C., Zannini, E., Axel, C., Lynch, K. M. & Arendt, E. K (2016) "Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content" in *Food Research International*, 89: 330-337, doi: 10.1016/j.foodres.2016.08.031

Silow, C., Zannini, E., Axel, C., Belz, M. C. E. & Arendt, E. K. (2017) "Optimization of fat-reduced puff pastry using response surface methodology" in *Foods*, 6 (2): 15, doi: 10.3390/foods6020015

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2018) "Application of sourdough in the production of fat- and salt-reduced puff pastry" in *European Food Research and Technology*, 1-13, doi: 10.1007/s00217-018-3071-y

Conferences and oral/poster presentations

Silow, C., Zannini, E. and Arendt, E. K. (2012) Reduction of salt, sugar and saturated fat in a puffing pastry (WP2). *PLeASURe 2nd GA Meeting. Amsterdam, The Netherlands, December 2012*

Silow, C., Zannini, E. and Arendt, E. K. (2013) Optimization of fat reduced puff pastry using response surface methodology. *64th Conference for Cereal Chemistry. Detmold, Germany, June 2013*

Silow, C. and Arendt, E. K. (2014) Salt and fat reduction in puff pastry. *1st International PLEASURE Conference. La Rochelle, France, June 2014*

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2018) Application of sourdough in the production of fat- and salt-reduced puff pastry. *7th International Symposium on Sourdough - Sourdough for Health. Cork, Ireland, June 2018* (poster presentation)