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

Christoph Silow¹ · Emanuele Zannini¹ · Elke K. Arendt¹

Revised: 6 January 2016 / Accepted: 20 January 2016 / Published online: 22 April 2016
© Association of Food Scientists & Technologists (India) 2016

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.

Keywords Puff pastry · Fat reduction · Low-*trans* · Rheology

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 (Anonymus 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 (Anonymus 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

✉ Elke K. Arendt
e.arendt@ucc.ie

¹ School of Food and Nutritional Sciences, National University of Ireland, University College Cork, Room 318, College Road, Cork, Ireland

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 addressing 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).

Materials and methods

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 1). All FBs contained no other ingredients than the vegetable fats/oils. Table 1 gives a short overview of the main fatty acid composition of the four FBs.

Characterization of fat blends

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 $5 \times 10^{-3}\%$ 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.

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 (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.

Table 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 <i>cis</i>	36.7	40.0	41.9	45.2	15.6–37.0*	61.6*
C 18:1/11 <i>cis</i>	1.5	1.8	2.0	2.3	n. s.	n. s.
C 18:2 <i>cis</i>	10.5	11.9	12.7	14.1	3.2–9.8*	21.7*
C 18:3 <i>cis</i>	2.9	3.8	4.3	5.1	0.1–0.6*	9.6*
C 18:1 <i>trans</i>	0.1	0.1	0.1	0.1	n. s.	n. s.
C 18:2 <i>trans</i>	0.2	0.2	0.2	0.2	n. s.	n. s.
C 18:3 <i>trans</i>	0.2	0.3	0.3	0.4	n. s.	n. s.
Total C18 <i>trans</i>	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

Consistency of fat blends

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):

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

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.

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.

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.

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 ($p \leq 0.05$).

Results and discussion

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 1).

The SFC curves, another important fat characteristic, of the four FBs are shown in Fig. 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 (Fig. 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)

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

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 (Fig. 1). FB4 showed the lowest SFC while FB1 showed the highest SFC values for 35 °C (8.1 %, 15.5 %) and 40 °C (10.9 %, 20.6 %).

Differential scanning calorimetry (DSC)

In order to study the melting behaviour of the FBs, the fats were heated directly from storage. Figure 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 (Fig. 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 pre-tests broad multicomponent endothermic peaks could be observed for all FBs at temperatures when measured below 0 °C

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

(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 (Fig. 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 1).

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 (Fig. 2) the SFC similarly decreased (Fig. 1).

Consistency of fat blends

Using a cone penetrometer the consistency for the four different FBs was determined. Figure 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. From 15 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.

During puff pastry production roll-in fats are exposed to shearing forces due to lamination. Tellocke (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 pasties 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 $1.5\text{ kg}_f/\text{cm}^2$ are considered as 'too hard' and for investigated puff pastry margarines/fats he found yield values in the range of 0.8 to $1.6\text{ kg}_f/\text{cm}^2$. Taking into account the best results of the present baking trials, 'extremely hard' FBs with yield values of 81 to 128

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

kg_f/cm^2 seem to be optimal for use in puff pastry production. Obviously processing and requirements on puff pastry fats are different between studies.

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 Fig. 4. For all fats G' increased over the whole frequency range. 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 Fig. 4. FB1 and FB4 showed the highest and lowest average value for G' over the whole frequency range, respectively (Fig. 4). This indicated, an increasing firmness from FB4 to FB1. This result is correlated to the yield values, which are shown in Fig. 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 (Fig. 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

Fig. 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 $5 \times 10^{-3}\%$. Values are means ($n = 3$)

(Table 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.

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 a previous study by Silow et al. (2014).

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 2 shows the lift and the specific volume of FFP and RFP, which was dependant of the four different FBs. The visual appearance of the puff pastries containing different FBs is shown in Fig. 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 that 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 2) did not lead to adverse effects in lift and specific volume.

Firmness

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.

For products containing the same FB, the FFP showed significantly ($p < 0.05$) lower total firmness values than the corresponding RFP (Table 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 2). The lowest total firmness values were obtained for RFP with FB4 which contained 93 % more RO than FB1.

Table 2 Physicochemical tests for baked full fat (FFP) and fat-reduced (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 ^c	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 ($p < 0.05$)

Fig. 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

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 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 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 2) and showed a denser structure (Fig. 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.

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 (Silow et al. 2014).

FFP with FB2, displaying the highest lift and specific volume, showed the most cells (Table 2). Generally samples that had a high number of cells demonstrated a low peak firmness in combination with higher total firmness values (Table 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 to the number of cells. Highest slice brightness was detected for FFP and RFP containing FB1 and FB2 (Table 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 were detected for puff pastries with FB4 which had already shown a low number of cells, poor lift and specific volume (Table 2).

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/cm² 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 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.

Acknowledgments 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).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Anonymus (2000a) Technologie gezogener Teige Teil II. brot und backwaren 48
- Anonymus (2000b) Technologie gezogener Teige Teil I. brot und backwaren 48
- Baum SJ, Kris-Etherton PM, Willett WC, et al. (2012) Fatty acids in cardiovascular health and disease: a comprehensive update. *J Clin Lipidol* 6:216–234. doi:10.1016/j.jacl.2012.04.077
- Bell A, Gordon MH, Jirasubkunakorn W, Smith KW (2007) Effects of composition on fat rheology and crystallisation. *Food Chem* 101: 799–805. doi:10.1016/j.foodchem.2006.02.033
- Boode-Boissevain K, Van Houdt-Moree JD (1996) Fat-reduced laminated doughs. U.S. Patent No 5480662
- Cauvain SP, Young LS (2001) Baking problems solved. Woodhead Publishing Ltd, Cambridge
- Cavillot V, Pierart C, Vincent M, et al. (2009) Margarines with and without trans fatty acids. *J Food Lipids* 16:273–286
- Cheong L-Z, Tan C-P, Long K, et al. (2009) Physicochemical, textural and viscoelastic properties of palm diacylglycerol bakery margarine during storage. *J Am Oil Chem Soc* 86:723–731. doi:10.1007/s11746-009-1413-4
- DeMan JM, Beers AM (1987) Fat crystal networks: structure and rheological properties (review). *J Texture Stud* 18:303–318
- Erkkilä A, de Mello VDF, Riserus U, Laaksonen DE (2008) Dietary fatty acids and cardiovascular disease: an epidemiological approach. *Prog Lipid Res* 47:172–187. doi:10.1016/j.plipres.2008.01.004
- Garcia-Macias P, Gordon MH, Frazier RA, et al. (2011) Performance of palm-based fat blends with a low saturated fat content in puff pastry. *Eur J Lipid Sci Technol* 113:1474–1480
- Garcia-Macias P, Gordon MH, Frazier RA, et al. (2012) Effect of TAG composition on performance of low saturate shortenings in puff pastry. *Eur J Lipid Sci Technol* 114:741–747. doi:10.1002/ejlt.201100147

- Ghotra BS, Dyal SD, Narine SS (2002) Lipid shortenings: a review. *Food Res Int* 35:1015–1048
- Gunstone FD (2011) Vegetable oils in food technology - composition, properties, and uses. Blackwell Publishing Ltd, Oxford
- Haighton AJ (1959) The measurement of the hardness of margarine and fats with cone penetrometers. *J Am Oil Chem Soc* 36:345–348
- Kincs FR, Minor MP (1995) Reduced fat roll-in baking compositions and baked goods. U.S. Patent No 5395638
- Lefébure É, Ronkart S, Brostaux Y, et al. (2013) Investigation of the influence of processing parameters on physicochemical properties of puff pastry margarines using surface response methodology. *LWT - Food Sci Technol* 51:225–232. doi:[10.1016/j.lwt.2012.09.018](https://doi.org/10.1016/j.lwt.2012.09.018)
- Marangoni AG (2004) Fat crystal networks. CRC Press, Boca Raton
- Miskandar MS, Man YC, Yusoff MSA, Rahman RA (2005) Quality of margarine: fats selection and processing parameters. *Asia Pac J Clin Nutr* 14:387–395
- Noll B, Gräber S, Kitta M, et al. (1997) Neue Erkenntnisse zur Herstellung von Blätterteiggebäcken. *Getreide Mehl und Brot* 51: 363–368
- Nor Aini I, Miskandar MS (2007) Utilization of palm oil and palm products in shortenings and margarines. *Eur J Lipid Sci Technol* 109: 422–432. doi:[10.1002/ejlt.200600232](https://doi.org/10.1002/ejlt.200600232)
- Pajin B, Šoronja-Simović D, Šereš Z, et al. (2011) Physicochemical and textural properties of puff pastry margarines. *Eur J Lipid Sci Technol* 113:262–268. doi:[10.1002/ejlt.201000293](https://doi.org/10.1002/ejlt.201000293)
- Roos Y, Karel M (1991) Plasticizing effect of water on thermal behavior and crystallization of amorphous food models. *J Food Sci* 56:38–43
- Siew WL, Cheah KY, Tang WL (2007) Physical properties of lipase-catalyzed interesterification of palm stearin with canola oil blends. *Eur J Lipid Sci Technol* 109:97–106. doi:[10.1002/ejlt.200600142](https://doi.org/10.1002/ejlt.200600142)
- Silow C, Zannini E, Belz MCE, Arendt EK (2014) Optimization of fat reduced puff pastry using response surface methodology. (submitted for publication to *Cereal Chemistry*)
- Simovic DS, Pajin B, Seres Z, Filipovic N (2009) Effect of low-trans margarine on physicochemical and sensory properties of puff pastry. *Int J Food Sci Technol* 44:1235–1244
- Stauffer CE (1999) Fats and oils, 2nd edn. Eagan Press, St. Paul, Minnesota
- Telloke GW (1994) Optimierung physikalischer Ziehfeteeigenschaften. *Getreide, Mehl und Brot* 48:74–80
- Wassell P, Young NWG (2007) Food applications of trans fatty acid substitutes. *Int J Food Sci Technol* 42:503–517
- Yap PH, deMan JM, deMan L (1989) Polymorphic stability of hydrogenated canola oil as affected by addition of palm oil. *J Am Oil Chem Soc* 66:1784–1791. doi:[10.1007/BF02660748](https://doi.org/10.1007/BF02660748)