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Lipases as cake batter improvers compared to a traditional emulsifier

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ABSTRACT

Lipases can act on the baking quality of cakes as clean-label improvers. Only little is known about their possible effects on the batter quality of cakes. Especially the importance of the cake formulation has not been studied before. We therefore aim to analyse the effects of seven baking lipases on three different cake formulations (an eggless basic cake, a pound cake and a yeast-based cake) in comparison to the emulsifier DATEM (mono- and diacetyl tartaric acid esters of mono- and diglycerides of fatty acids). The impact on batter density, stickiness and rheological properties was examined. Both the lipase and the cake formulation had an influence on the extent of batter improvement. The greatest lipase-induced effects occurred in the eggless cake, probably because no intrinsic emulsifiers were present. Lipase reactions seemed to be inhibited in the yeast-based cake. For basic cake and pound cake, three lipases decreased batter density (up to 3.7%) and stickiness (up to 42.7%) and caused a liquefaction of the batter. This leads to an eased machinability of lipase-treated batters for cake manufacturing and opens up many possibilities for application of lipases in cakes and other fine bakery goods.

1. Introduction

Cake doughs and batters are complex mixtures of a variety of ingredients (Delcour & Hoseney, 2010). Most include flour, sugar, eggs, fat or oil and leavening agents. However, there is no uniform definition for cakes and different recipes are used all around the world (Wilderjans et al., 2013). Cakes greatly differ in their ingredients and their preparation methods. While dough mostly refers to mixtures of flour and liquid which can be kneaded (e.g., for bread making), the term "batter" is more common for cakes and describes a more liquid-like dough. Cake batters can be understood as an aqueous system with several dispersed phases, namely fat, air and starch granules (Delcour & Hoseney, 2010). Each part of this system and each ingredient contributes to particular aspects of the resulting cake quality (Conforti, 2006). Studies even showed a predictive power of batter quality as defined by the ingredients and processing methods for the final cake quality (Christaki et al., 2017).

Besides the impact for the final product, monitoring changes in batter quality is also of interest to ease batter handling during processing (Psimouli & Oreopoulou, 2013). Properties of interest are, e.g., stability, density and stickiness of the batters. These properties can be improved by adding emulsifiers. They are usually applied to enhance the incorporation of air and to improve the dispersion of bakery fat within the batter (Gerits et al., 2014). Among the most used surfactants for bakery products are mono- and diacetyl tartaric acid esters of mono- and diglycerides of fatty acids (DATEM), sodium stearoyl lactylate (SSL) and lecithin. Especially DATEM is known for its positive effect on batter stability and resulting product volume (Yazar & Rosell, 2022). However, with an increasing demand for clean-label products, alternatives for traditional emulsifiers are needed. The use of baking lipases offers a possible solution. Lipases catalyze the hydrolysis of lipids in bakery goods and thus lead to the *in-situ* formation of surface-active molecules. Those newly formed molecules then act as replacers for traditional emulsifiers. As lipases are inactivated during baking, their use does not need to be declared. Additionally, compared to traditional emulsifiers, they reduce production costs, mostly due to lower amounts needed to achieve the same effects (Gerits et al., 2014). While their impact on bread has been studied in detail (Gerits et al., 2014; Melis et al., 2019), only few studies focus on their application in cakes. Rodríguez-García et al. (2014) found a lower degree of system structuring in lipase-treated low-fat cakes and lower temperatures for structure setting during baking. Even if the time for gas cell expansion was reduced by the earlier structure setting, the resulting cakes had similar volumes as the control cakes. Guy and Sahi (2006) additionally described a lower surface tension and less time needed for sufficient batter aeration. However, those

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studies included only one cake recipe and not more than two lipases.

We recently analysed the improvement of baking properties of three different cake recipes by a range of seven lipases compared to the traditional emulsifier DATEM. The extent of quality improvement depended on both the lipase and the recipe, probably due to different reaction patterns of the lipases (Stemler & Scherf, 2022b). In order to better understand the underlying mechanisms for quality improvement in cakes it is of great interest to analyse the transferability of those results to the properties of cake batters. The overall goal is to identify lipases suited to enhance both batter and baking properties of different cake formulations for new applications in cakes and fine bakery goods.

We hypothesize that baking lipases improve the batter quality of cakes. Based on previous results, we expect differences both between different lipases and different cake formulations. Therefore, the aim of our work was to compare the effects of a range of lipases and the traditional emulsifier DATEM on the batter properties of three different cake formulations. The properties analysed comprise density, stickiness and a characterisation of the rheological behaviour of the batters. Additionally, those results are compared to the baking properties of cakes. Compared to previous studies, the novelty of our work is the focus on batter quality in addition to existing studies on the quality of cakes.

2. Materials and methods

2.1. Reagents and ingredients

All chemical reagents were of analytical grade or higher. All ingredients were of commercial quality and partly purchased at a local supermarket (pasteurized whole eggs, baking powder and butter (82% fat)). Wheat flour type 405 by Good Mills GmbH (Hamburg, Germany) and extra-white powdered sugar by Nordzucker (Braunschweig, Germany) were kindly donated by Dr. August Oetker Nahrungsmittel KG (Bielefeld, Germany). DATEM was kindly donated by Backaldrin The Kornspitz Company (Asten, Austria).

2.2. Lipases

Commercial baking lipases were chosen according to Stemler and Scherf (2022b). In brief, seven baking lipases known for their suitable substrate specificity and already known effect on the baking properties of different cakes were used. The lipases were from Kerry Group (Tralee, Ireland), Novozymes (Bagsværd, Denmark), ABEnzymes (Darmstadt, Germany) and DSM (Heerlen, The Netherlands) and kindly donated by Kuchenmeister (Soest, Germany), DSM, ABEnzymes and Novozymes. In accordance with previous studies (Stemler & Scherf, 2022a; 2022b), they were named lipase A, E, G, J, K, M and O.

Before use, the lipases were dissolved in water. The final dosage was chosen according to the manufacturers' instructions and based on flour content (brioche) or batter content (basic cake (BC), pound cake (PC)): For lipase A 60 or 200 mg/kg, lipase E 75 or 250 mg/kg, lipase G 45 or 150 mg/kg, lipase J 10 or 35 mg/kg, lipase K 45 or 150 mg/kg, lipase M 30 or 100 mg/kg and lipase O 30 or 100 mg/kg for brioche or BC and PC were used, respectively.

2.3. Batter preparation

Cake batters were prepared as described in Stemler and Scherf (2022b). Although, depending on the recipe, both the terms "batter" and "dough" could be used in this work, solely the term "batter" will be applied to ease readability. A commercial food processor with planetary mixing (Robert Bosch GmbH, Stuttgart, Germany) equipped with a whisk and a kneading hook was used. The exact recipes are listed in Table 1.

For each batter, three replicates were prepared. The results for lipase-treated batters were compared with both untreated batters and batters containing DATEM as emulsifier.

Table 1
Recipes used for batter preparation.

	Basic cake	Pound cake	Brioche	
			Pre-batter	Batter
Wheat flour	100	100	60	40
Water	80	0	25	0
Butter	40	100	0	25
Sugar	20	100	0	10
Salt	1	1	0	1
Egg		100	10	0
Baking powder	6	0.3	0	0
			First fermentation (pre-batter) 120 min 35 °C	
			Second fermentation 20 min 35 °C	
	Baking 12 min 180 °C	**Baking** 12 min 180 °C	**Baking** 12 min 180 °C	

All values are given based on 100% flour content.

2.3.1. Basic cake

For BC, first butter, sugar and salt were stirred until creamy for 2.5 min. Water, flour and baking powder were then added and mixed for 3 min. Portions of 300 g of batter were thoroughly mixed with 4 mL of lipase solution or 4 mL of water (control) or 4 mL of water and 84 mg of DATEM and left to rest for 1 h at room temperature in plastic boxes.

2.3.2. Pound cake

For PC, after mixing butter, sugar and salt for 3 min, first pasteurized eggs and then a mixture of wheat flour and baking powder were blended in for 3 min each. Aliquots of 300 g of batter were incubated with or without improvers as described for BC.

2.3.3. Brioche

For brioche, first a pre-batter was prepared. It consisted of flour, preheated water (37 °C) and pasteurized egg which were kneaded for 10 min. To minimize measurement fluctuations, no yeast was applied. The pre-batter was incubated for 2 h at 37 °C in a proofing cabinet. Afterwards, the remaining flour, butter, sugar and salt were added and the mixture was kneaded for further 5 min.

Then, aliquots of 300 g of dough were thoroughly mixed with 2 mL of lipase solution or 2 mL of water (control) or 2 mL of water and 135 mg of DATEM and left to rest for 1 h at room temperature in plastic boxes.

2.4. Batter characteristics

All analyses were performed on three different batters unless indicated otherwise. To enhance the reproducibility of the experiments, they were performed in the same order on all batters.

2.4.1. Density

Density was measured using a measuring cup with a known volume of 60 mL and a known weight. It was filled to the brim with batter and any protruding material was scraped off. The filled cup was then weighed and the weight of the empty cup was subtracted. Density was calculated as the quotient of mass and volume. The measurement was performed in triplicate on each batter.

2.4.2. Stickiness

Batter stickiness was analysed using a TA.XTplus texture analyser (Stable Micro Systems, Godalming, UK) equipped with a 5 kg load cell, a heavy duty platform and a mini stickiness system. The latter is equivalent to the Warburtons dough stickiness system (Smewing, 2015), but instead of 500 g or 1 kg of batter, 250 g are sufficient for the measurement. The batter was filled into the cuboid container and covered with the retaining plate. Protruding material was removed with the help of a spatula. A narrow blade (9 cm × 7 cm) was then driven 25 mm through

Table 2
Density, linear viscoelastic region (LVE), storage modulus at the end of LVE (G') and crossover point of basic cake batter, pound cake batter and brioche batter.

Modifi-cation	Density [g/mL]	LVE [% strain]	G' [Pa]	Cross-over point [% strain]
Basic cake				
Control	1.081 ± 0.003	0.079 ± 0.000	3126.7 ± 166.8	51.5 ± 1.96
DATEM	1.090 ± 0.007	0.084 ± 0.004	2216.7* ±363.5	50.28 ± 2.37
A	1.060 ± 0.003	0.129* ±0.002	1483.3* ±203.7	30.99* ± 1.01
E	1.092 ± 0.009	0.086 ± 0.004	1930.0* ±196.1	47.72 ± 2.91
G	1.041* ±0.004	0.133* ±0.005	1040.0* ± 134.9	27.85* ± 2.31
J	1.050* ±0.004	0.135* ±0.005	811.0* ± 127.1	20.12* ± 3.56
K	1.092 ± 0.007	0.087 ± 0.003	1563.3* ± 204.2	35.79* ± 1.56
M	1.091 ± 0.012	0.086 ± 0.001	1673.3* ± 159.2	45.09 ± 3.80
O	1.094 ± 0.009	0.081 ± 0.005	1740.0* ± 153.0	38.90* ± 3.37
Pound cake				
Control	1.009 ± 0.003	0.123 ± 0.007	2136.7 ± 191.5	20.98 ± 2.36
DATEM	1.064* ± 0.004	0.128 ± 0.009	1793.3 ± 293.2	20.12 ± 1.29
A	1.028 ± 0.015	0.125 ± 0.006	971.3* ± 191.0	11.46* ± 2.59
E	1.033 ± 0.010	0.130 ± 0.004	1440.0* ± 129.6	21.47 ± 1.70
G	1.003 ± 0.005	0.127 ± 0.004	1203.3* ± 107.8	14.54* ± 2.00
J	1.042 ± 0.009	0.126 ± 0.003	1106.7* ± 66.0	14.58* ± 0.30
K	1.058* ± 0.033	0.117 ± 0.002	1443.3* ± 26.2	15.38* ± 0.79
M	1.048 ± 0.011	0.121 ± 0.002	1553.3* ± 216.4	19.49 ± 2.23
O	1.051* ± 0.015	0.124 ± 0.003	1570.0* ± 77.9	19.21 ± 1.69
Brioche				
Control	1.217 ± 0.004	0.083 ± 0.005	53300.0 ± 12221.3	70.24 ± 4.28
DATEM	1.228* ± 0.003	0.080 ± 0.004	71433.3 ± 4160.4	71.60 ± 7.30
A	1.219 ± 0.003	0.078 ± 0.001	59333.3 ± 1755.6	71.03 ± 8.16
E	1.224 ± 0.002	0.077 ± 0.002	67233.3 ± 3680.9	75.30 ± 2.68
G	1.227* ± 0.001	0.081 ± 0.002	57766.7 ± 3880.1	69.55 ± 6.75
J	1.226 ± 0.004	0.081 ± 0.002	45466.7 ± 4129.8	74.37 ± 2.10
K	1.221 ± 0.001	0.080 ± 0.005	57433.3 ± 6715.3	70.25 ± 3.61
M	1.224 ± 0.003	0.082 ± 0.004	56566.7 ± 8622.6	64.09 ± 3.93
O	1.226* ± 0.003	0.079 ± 0.002	64666.7 ± 3578.0	70.84 ± 4.23

Control: sample without lipase addition, DATEM: sample with addition of DATEM, A-O: samples with addition of the respective lipase. Values are given as mean (n = 3) ± standard deviation. Numbers with asterisks are significantly different compared to the control sample (ANOVA with Dunnett's *t*-test, $p \leq 0.05$).

the slot in the retaining plate. When the blade was withdrawn upwards, the stickiness of the batter was measured as the resulting area under the mass-time-curve. Data was analysed using the software Exponent (version 6.1.16.0, by Stable Micro Systems).

2.4.3. Rheological characterisation

Batter rheological properties were determined by oscillatory tests with a Physica rheometer MCR301 (Anton Paar Group AG, Graz, Austria) equipped with a circulating Viscotherm VT2 cooling water batch (Anton Paar Group AG) and a peltier temperature-controlled hood (H-PTD200, Anton Paar Group AG). A plate-plate sensor geometry (25 mm diameter, serrated surface) and a gap of 1 mm were applied at 25 °C. Approximately 2 g of batter were placed on the lower plate, the measuring bob was lowered to the measurement position of 1 mm and any protruding batter material was removed with a spatula. Afterwards, the hood was installed and the sample left to rest for 3 min before the measurements were started. A new batter sample was loaded for each test. The storage modulus G′, the loss modulus G'' and the loss factor tan δ, describing the relationship G''/G', were recorded for all measurements.

The following three tests were performed in the same order on all batters (Alvarez et al., 2017; Christaki et al., 2017; Hesso et al., 2015; Rodríguez-García et al., 2014):

First an amplitude sweep at a set frequency of 10 rad/s and a strain varying from 0.1 to 100% was carried out. It was used to determine (i) the linear viscoelastic region (LVE) of the batter, which corresponds to the strain applicable to the sample without destroying its structure, (ii) G' at the end of the LVE, corresponding to the structural strength of the sample within the LVE range and (iii) the cross-over point (CP) which represents the strain where tan δ corresponds to 1. The CP also represents the onset of flow in the sample.

Second, a frequency sweep with frequencies varying from 0.1 to 100 rad/s was applied within the LVE range to investigate the long-term and short-term behaviour of the sample. Low frequencies correspond to slow movements and high frequencies to fast movements of the batter.

Third, to mimic baking of the dough, a temperature sweep at a constant frequency of 1 Hz was carried out. Starting from 25 °C, the temperature was increased at a constant rate of 4 °C/min up to 100 °C (Christaki et al., 2017). The strain was chosen according to the LVE determined previously and also applied for the frequency sweep.

For data evaluation, the software Rheoplus/32 V3.40 (Anton Paar Group AG) was used.

2.5. Statistical analysis

Microsoft Excel was used for the calculation of means and standard deviations for all values. Additionally, an analysis of variance (ANOVA) test with two-sided Dunnett's t-tests ($p \leq 0.05$) was performed in IBM SPSS Statistics 27 (International Business Machines Corporation, Armonk, NY, USA) to detect significant differences between treated samples and the respective control samples.

3. Results

3.1. Basic cake

The density of BC samples ranged from 1.04 to 1.09 g/mL (Table 2). Only the lipases G and J led to significant changes, both reducing the density by up to 3.7% compared to the control.

Concerning BC stickiness, the batters displayed a wide range, ranging from 150.17 g*s (lipase G) up to 269.22 g*s (lipase K) (Fig. 1). Three lipases caused a significant reduction of batter stickiness, namely lipase A (by 32.7%), lipase G (by 42.7%) and lipase J (by 36.5%).

During the amplitude sweep, tan δ increased for all batters with increasing strain (Fig. 2A). The three lipases A, G and J led to visibly higher tan δ at high strains, hinting at a higher liquefaction. Their influence on batter properties was also expressed in a significant enlargement of the LVE (Table 2). G′ at the end of the LVE was

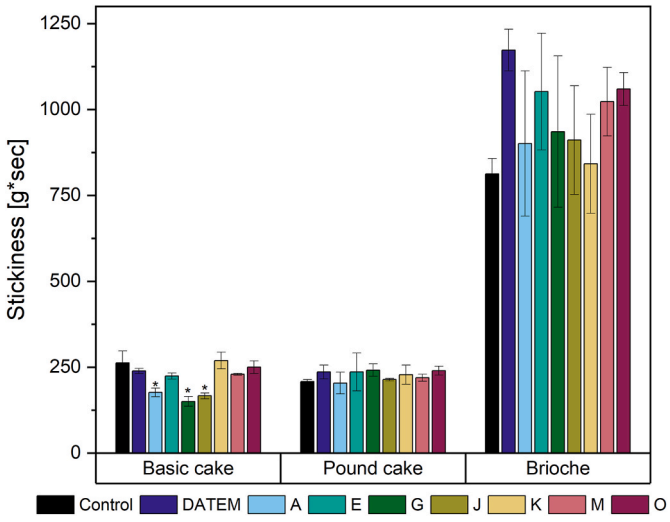

Fig. 1. Stickiness of differently treated batters of basic cake, pound cake and brioche batters. Control: sample without addition of improver; DATEM: sample with addition of DATEM; A–O: sample with addition of the respective lipase. Asterisks show a significant difference to the respective control (ANOVA with Dunnett's *t*-test, $p \leq 0.05$, $n = 3$).

significantly reduced by all improvers, resulting in 70.8% (DATEM) to 25.9% (lipase J) of the G' of the control. The onset of flow, measured as CP, was significantly lower when the lipases A, G, J, K or O were applied. The greatest reduction of strain (by 61.0%) was again achieved when using lipase J.

For the frequency sweep (Fig. 2B) all batters led to similar curves with low points around 3 rad/s. With tan $\delta < 1$ throughout the whole measurement, the batters showed solid-like behaviour during both slow and fast motions. All batters with improvers had overall higher tan δ than the control. The batters with DATEM, lipase E and lipase M showed similar behaviour, as did the batters with the lipases G, O and J. Lipase A led to a decrease of tan δ at high frequencies, while lipase K showed a strong increase at high frequencies.

The curves of the temperature sweeps (Fig. 2C) can be categorized into three groups with similar behaviour. Group 1 comprises the control and the batters treated with DATEM and the lipases K and O. Group 2 includes the batters with lipases E and M while the remaining three lipases (A, G and J) form group 3. The curves of the groups differed in their first peak: For groups 1 and 2, the maximum peak height occurred at around 35 °C (tan $\delta = 0.65$). For group 3, it was situated at 30 °C with a maximum of tan $\delta = 0.5$. Up to 70 °C, tan δ decreased for groups 1 and 2, while group 2 was characterized by overall higher tan δ than group 1. For group 3, tan δ changed only slightly between 45 °C and 70 °C. The maximum values for tan δ lay between 34.4 °C and 36.3 °C for groups 1 and 2 and between 63.2 °C and 65.7 °C for group 3. All curves showed a peak at around 76 °C which was at a tan δ of around 0.45 for groups 1 and 2 and around 0.55 for group 3. Tan δ at the end of the temperature sweep was lower for groups 1 and 2 than for group 3.

All rheological measurements showed a liquefaction of the dough by improvers with lipases A, G and J having the greatest impact.

3.2. Pound cake

The density of PC ranged from 1.00 to 1.06 g/mL (Table 2), lower than in BC. There were no significant changes caused by lipases or DATEM.

PC stickiness was comparable to the one in BC with a maximum of 241.24 g*s for lipase G (Fig. 1). Changes to stickiness by improvers were not significant.

The amplitude sweeps for PC batters are depicted in Fig. 3A. Comparable to BC, tan δ increased from 0.4 to 1.9. The lipases A, G, J and K

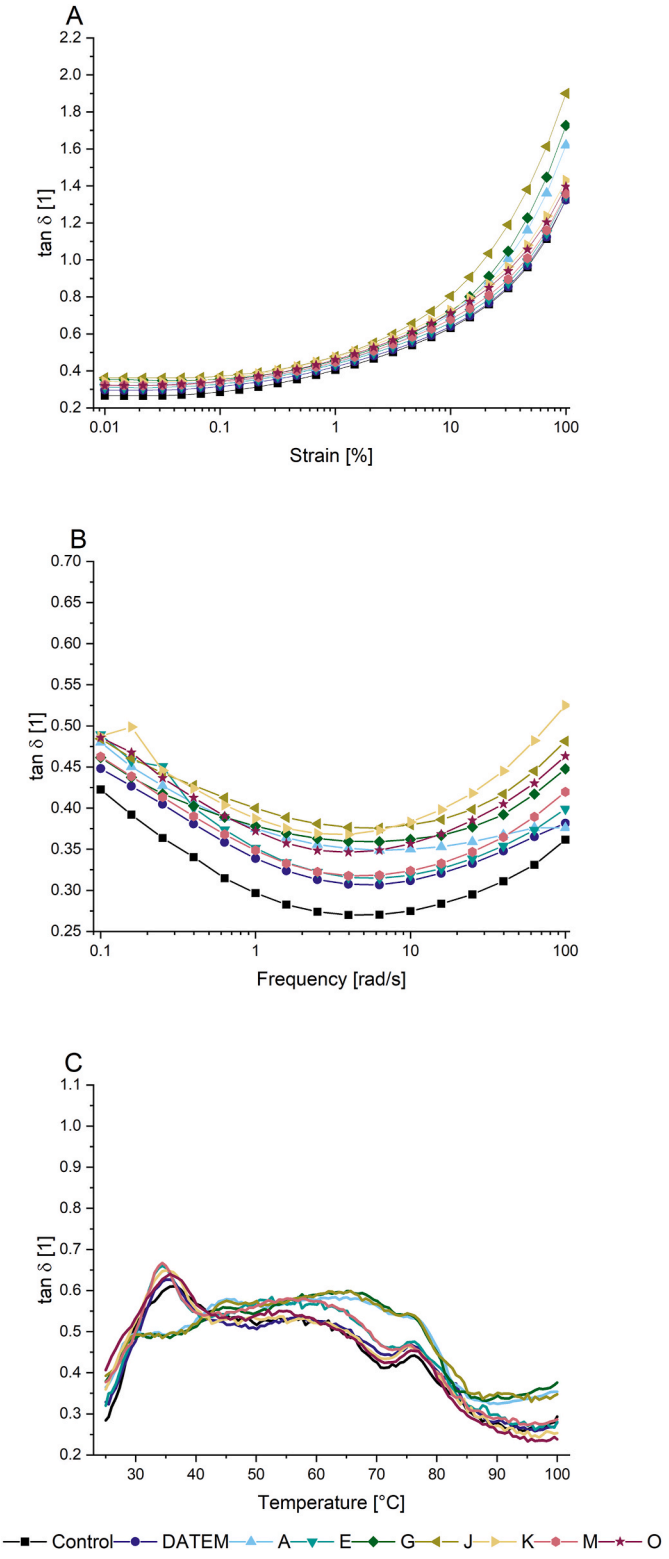

Fig. 2. Rheological characterisation of basic cake batters. Amplitude sweep (A), frequency sweep (B), and temperature sweep (C). All curves represent the average of three (amplitude sweep and frequency sweep) and two measurements (temperature sweep), respectively. Control: sample without addition of improver; DATEM: sample with addition of DATEM; A–O: sample with addition of the respective lipase.

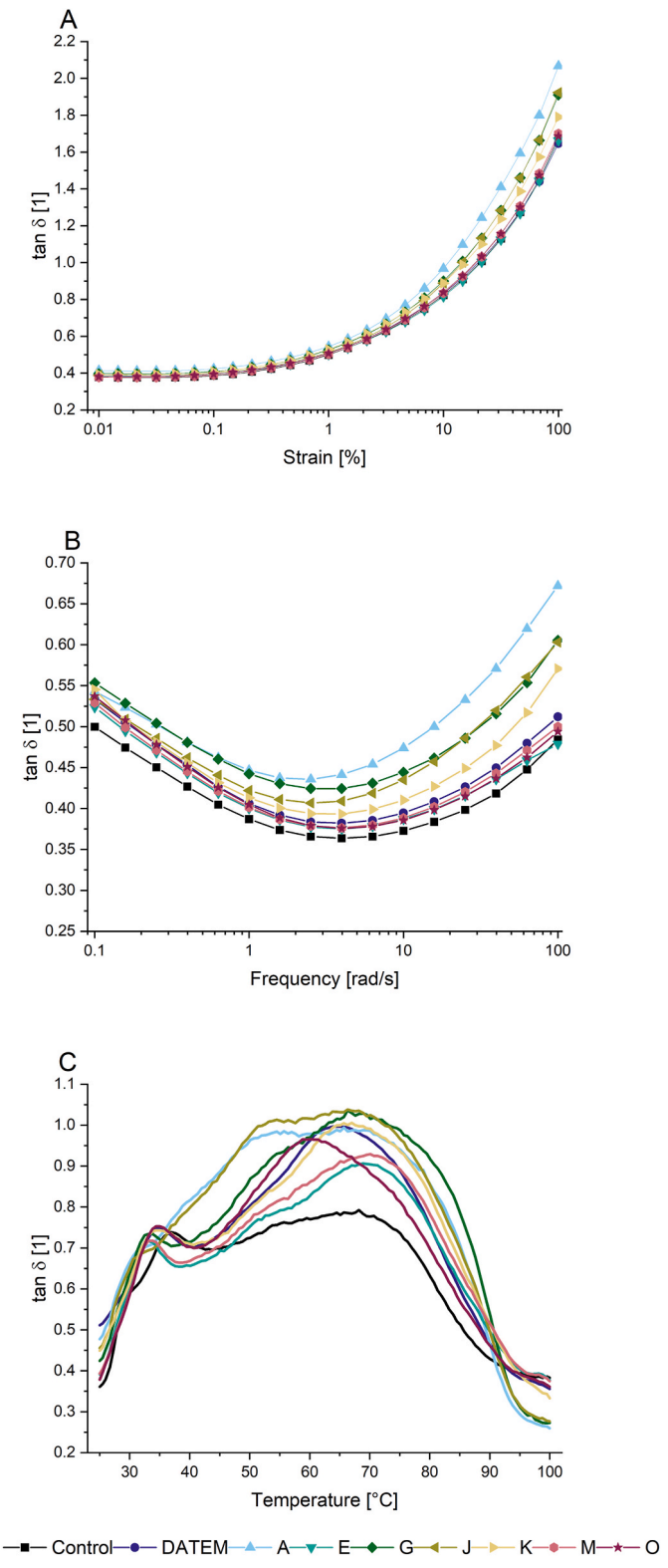

Fig. 3. Rheological characterisation of pound cake batters. Amplitude sweep (A), frequency sweep (B), and temperature sweep (C). All curves represent the average of three (amplitude sweep and frequency sweep) and two measurements (temperature sweep), respectively. Control: sample without addition of improver; DATEM: sample with addition of DATEM; A–O: sample with addition of the respective lipase.

lead to higher tan δ with increasing strain. However, the LVE was not affected significantly by any improver (Table 2). Still, it was larger than for BC. G' at the end of the LVE was decreased significantly by all lipases (but not by DATEM) compared to the control sample. Lipase A had the greatest effect with a reduction of 54.5%. The CP was significantly reduced by the use of the lipases A (by 45.4%), G (by 30.7%), J (by 30.5%) and K (by 26.7%). Again, lipase A had the greatest effect.

The curves for the frequency sweep (Fig. 3B) were similar to the ones for BC with a minimum around 3 rad/s. Tan δ was <1 for all measurements, showing again a solid-like behaviour during fast and slow movements. With increasing frequencies above 3 rad/s, tan δ increased. The highest tan δ was achieved with the use of lipase A, followed by the lipases G and J. This points to a liquefaction of the lipase-treated PC batters with fast movements.

In contrast to BC, no clear distinction into different groups was possible during the temperature sweep (Fig. 3C). The first peak (between 30 and 35 °C) was earliest for the batters with the lipases M, E and G, as early but smaller for the lipases A and J, later and higher for the lipases O, K and DATEM and latest for the control batter. The first peak was followed by an increase in tan δ with the highest slope for the lipases A and J, followed by G, O, DATEM and K. The slope was less steep for the batters with lipases E and M and least for the control. Maximum peak heights occurred between 60.1 °C (lipase O) and 70.1 °C (lipase M) with tan δ between 0.79 (control) and 1.0 (lipases G, J, K and DATEM). Concerning the final tan δ, the control sample, DATEM and the lipases E, K, M and O ranged between 0.33 and 0.38, while the lipases A, G and J caused visibly lower tan δ between 0.25 and 0.28.

3.3. Brioche

The density of brioche (Table 2) was higher than the one of BC and PC (1.22–1.23 g/mL). There were no significant changes by improvers.

The batter was stickier overall compared to BC and PC (812.23 g*s to 1172.93 g*s), but again not affected by improvers (Fig. 1).

During the amplitude sweep (Fig. 4A), tan δ increased from 0.4 to 1.1. The batters were stiffer than the ones of BC or PC. Neither the curves nor the characteristic parameters LVE, G' at the end of the LVE and CP were affected significantly by improvers (Table 2).

The frequency sweep, as depicted in Fig. 4B, started with tan δ around 0.55 for low frequencies and ended with tan δ of 0.48 for high frequencies. Its low point was at 4 rad/s for all samples. No effects occurred by either lipases or DATEM. All batters showed solid-like behaviour throughout the whole measurement (tan δ < 1).

For the temperature sweep (Fig. 4C), the improvers again showed no clear effect. All curves increased up to 45 °C and decreased again, showing a small peak around 80 °C.

4. Discussion

The density of cake batters depends on the amount and the volume of incorporated gas bubbles. Lipases cause the formation of a higher content of polar lipids in the batter, thus stabilizing the gas bubbles, improving gas retention and enlarging the entrapped gas volume fraction (Gan et al., 1995; Koksel & Scanlon, 2018; Primo-Martín et al., 2006). This effect occurred to a significant extent with the use of the lipases G and J in BC. In PC however, there was no improvement of batter density. This might be due to the egg yolk lecithins already included in PC, because they are known for their excellent emulsifying properties (Yazar & Rosell, 2022). Contrary to BC, PC includes 24.9% of egg, corresponding to 0.5% of lecithins (Belitz et al., 2007). The gas bubbles in PC might already be sufficiently covered and stabilized by surface-active lecithins, so that the availability of further polar lipids formed by lipases does not affect them further. This statement is supported by the fact that the overall density of all PC samples was lower compared to BC. A similar effect was already observed by Rodríguez-García et al. (2014), who found no improvement of cake batter

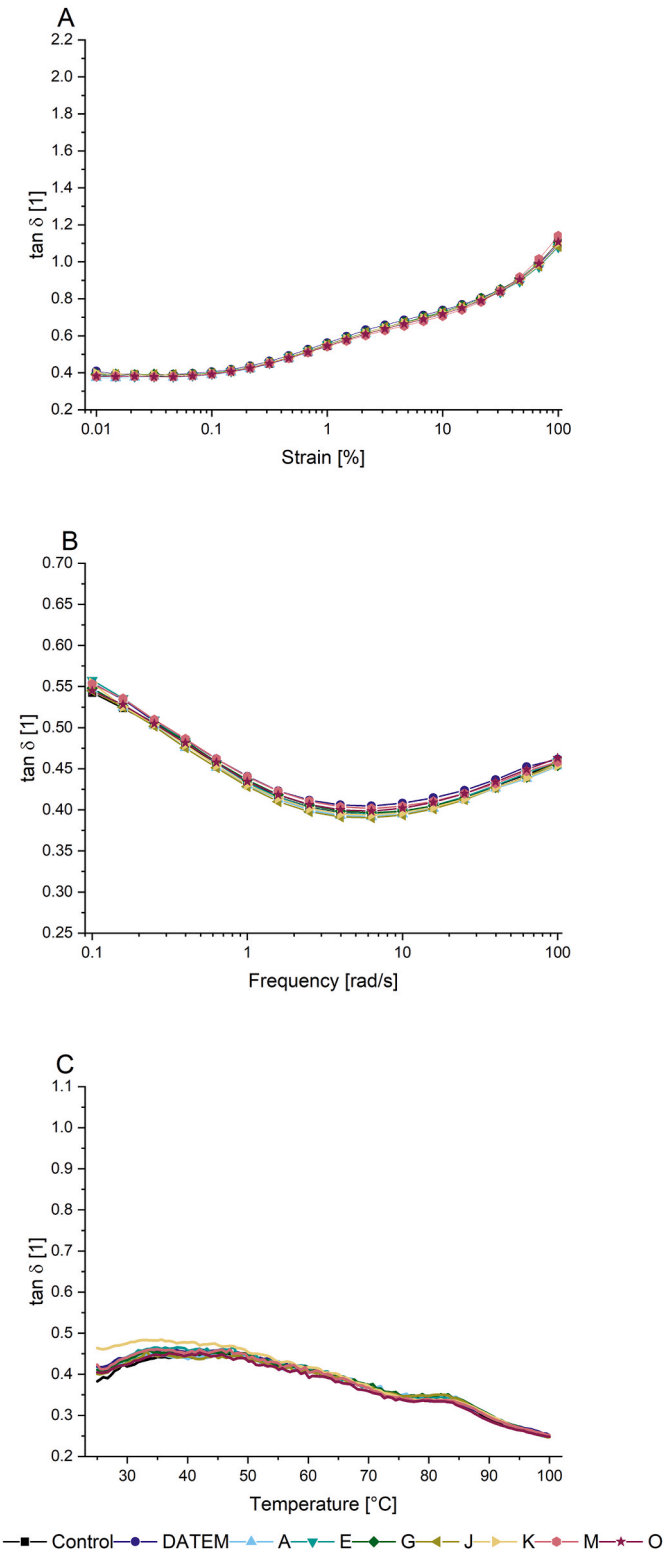

Fig. 4. Rheological characterisation of brioche batters. Amplitude sweep (A), frequency sweep (B), and temperature sweep (C). All curves represent the average of three (amplitude sweep and frequency sweep) and two measurements (temperature sweep), respectively. Control: sample without addition of improver; DATEM: sample with addition of DATEM; A–O: sample with addition of the respective lipase.

density after addition of lipases to a low-fat cake with eggs. For brioche, no improver led to a significant change of batter density. Brioche also contains eggs, albeit to a lesser extent than PC (5.8% instead of 24.9%). The lecithins might therefore also be a cause for the lack of effects in brioche. This observation is in accordance with the results from previous studies which also showed a diminishment of lipase-induced effects in cakes when eggs are part of the recipe (Stemler & Scherf, 2022b). Concerning the resulting products, there is no direct correlation of cake batter density and the corresponding product density (Stemler & Scherf, 2022b). The improving effects on batter density in BC are not sustained during baking, probably because the gas bubbles are lost during baking. To sum up, both the cake recipe (presence or absence of inherent emulsifiers) and the chosen lipase influence the reduction of cake batter density.

Lipases are known to reduce the stickiness of bread dough (Colakoglu & Özkaya, 2012). The underlying mechanisms have not yet been conclusively clarified, but might be related to the co-oxidation products from lipid oxidation processes, which are enhanced when lipases are used (Colakoglu & Özkaya, 2012) or due to the gluten network, which is strengthened when polar lipids are introduced (Köhler, 2001). The influence of specific ingredients has not been analysed so far. A significant reduction of stickiness was only achieved by the lipases A, G and J in BC for the cake batters in this study. Similar to the results for batter density, no improvement of batter properties occurred if eggs were included in the recipe. Comparable effects as for the batter stickiness were already observed by Stemler and Scherf (2022b) for the cake resilience of the same recipes with the same range of lipases. There, the gluten network and thus the resilience was influenced most strongly by lipases A, G and J in BC and less by the other lipases and in the other recipes. This supports the assumption that the gluten network is an important factor for cake batter stickiness.

During the rheological characterisation of the batters, the overall effects of lipase addition were greatest in BC, smaller in PC and smallest in brioche. As discussed for the density, the lecithins in PC might explain the smaller extent within PC. Brioche however contains less lecithins than PC (0.1% instead of 0.5%) and was still less affected by improvers. Similar effects were already described in our earlier study (Stemler & Scherf, 2022b). Possible causes are a potential shear-sensitivity of the lipases, the limitation of their reaction time to mixing and inhibiting by-products produced by yeast. However, the preparation of brioche batters slightly differs from our previous recipe, as no yeast was included and the lipase was added to the final batter, not the pre-batter. Besides the possible inhibition of lipase activity, the reduced dosage as recommended by the manufacturers might be a cause for the lack of effects. Further investigations upon this topic are needed to clarify the phenomenon.

In the amplitude sweep, the lipases A, G, J and K had the greatest effects on the cake batters. All led to a liquefaction of the batters, as visible with higher tan δ at high strains, lower G′ at the end of the LVE and lower CP. A lower degree of system structuring and concomitant liquefaction of cake batters after addition of lipases were also reported by Rodríguez-García et al. (2014). Those results are in contrast to the effects of emulsifiers, which increase G' and therefore stiffen cake batters (Jyotsna et al., 2004; Rodríguez-García et al., 2014). For emulsifiers the authors named their water-binding capacity or further interactions between the emulsifier and other ingredients as possible causes for their stiffening effect. Furthermore, the liquefaction could also be due to the alteration of lipids in the cake batter. A decreasing fat content has been described to cause a more liquid-like behaviour of cake batter similar to the change of fat type (Hesso et al., 2015). The properties of the lipid phase in cake batter are changed when lipases hydrolyse triacylglycerols. It is possible that in this case, the remaining lipid phase is the decisive factor for the changed properties of the batter, not the released polar lipids. Another factor influencing the rheological properties is the gluten network. Gluten is known to stiffen bread dough (Gallagher et al., 2004). A decrease in gluten extensibility by lipases as described by Melis

et al. (2017) supports the assumption of an altered gluten network in the batters linked to a higher liquefaction. This assumption is further proven by corresponding effects in the resulting cakes, especially the reduction of resilience caused by interactions with the gluten network. The difference between the various lipases can be explained by their different reactivity patterns as suggested by Stemler and Scherf (2022b).

The liquefaction of cake batters was also visible during the frequency sweeps. Again, the lipases A, G, J and K had the greatest effect on both BC and PC while brioche was not affected. All batters showed only a mild dependence on frequency and remained solid-like ($\tan \delta < 1$) during the whole measurement. There is only scarce data on the time-dependent behaviour of cake batters. Other studies reported increasing tan δ with increasing frequencies (Andrade et al., 2018; Saghafi et al., 2019) for untreated batters. The three recipes analysed in this work all had the lowest values for tan δ between 3 and 4 rad/s. It is unclear what this difference between our results and other studies is due to. Similar batter compositions as for PC were used in literature.

Baking of the batters was imitated during the temperature sweeps. Cake batter temperature sweeps include three characteristic phases: (i) an increase of tan δ at the beginning of the sweep, due to melting of fat, (ii) a second increase of tan δ between 40 °C and 70 °C, due to decreased interactions between the ingredients and the release of CO_2, (iii) the decrease of tan δ at temperatures above 75 °C, due to protein denaturation and starch gelatinization (Andrade et al., 2018; Christaki et al., 2017; Hesso et al., 2015; Salvador et al., 2006). Those phases were identified in the temperature sweep for PC. In case of BC, tan δ decreased between 45 °C and 70 °C, showing an early stiffening of the batter. The explanation for phase (ii) therefore needs further clarification, as BC contains baking powder and should thus release CO_2. A similar curve as for BC has already been reported by Migliori et al. (2011) for Yorkshire Pudding batter. For their batter formulation, they used neither sugar nor fat. BC contains 8.1% of sugar, compared to 24.9% for PC. Sugar is known to increase the gelatinization temperature of starch (Allan et al., 2018) and this offers a possible explanation for the different curve shapes. For brioche, maximum values for tan δ occurred around 45 °C and decreased afterwards. Brioche also contains only about 5.8% of sugar and therefore starch gelatinization occurs at lower temperatures.

One of the effects of lipases in BC seems to be the hindrance of fat melting. The curves for the batters treated with the lipases A, G and J are more equalized than from the control batter. This effect has already been described for the isolated reaction of lipases with milk fat (Omar et al., 2016). Besides the hindrance of fat melting, the resulting products with lipases A, G and J in BC have higher tan δ and are thus more liquid-like than the other products. This corresponds to improved baking properties for those combinations as described by Stemler and Scherf (2022b). In PC, the improvers led to more liquid batters and shifted the maximum peak heights. The maximum of tan δ is linked to the structure setting of the batter (Christaki et al., 2017). Lower temperatures for the maximum of tan δ correspond to earlier structure setting. The batters treated with lipases O, A, G, J and K as well as the DATEM-treated batter all had earlier structure setting. This might enable a reduction of the baking temperature needed, leading to reduced energy costs and reduced by-products of the heating process, namely e.g. acrylamide. However, an early structure setting corresponds to less time for bubble expansion and could cause lower product volumes. Studies upon this matter show that the volumes of lipase-treated PC did not differ significantly from control PC (Stemler & Scherf, 2022b). A similar effect has also been described by Rodríguez-García et al. (2014). As expected, the improvers did not exert effects on tan δ during heating in brioche.

Overall, the results are in good accordance with the analysis of the improvement of cake baking properties by lipases (Stemler & Scherf, 2022b): The presence of intrinsic emulsifiers in the cake recipe impairs effects caused by lipases as shown for PC, lipase specificities are decisive for the extent of improvement and most likely, the gluten network is affected by the addition of lipases.

5. Conclusions

The influence of seven baking lipases and the traditional emulsifier DATEM on the batter properties of three different cake recipes was assessed for the first time. Three lipases had an improving effect on the density, stickiness and the rheological properties of the batters. Both the chosen lipase and the cake recipe had an influence on the extent of the effects. Especially the three lipases A, G and J showed a great potential to ease the machinability of batters by, e.g., reducing their stickiness. The effects of all lipases were comparable to or exceeded the ones of the traditional emulsifier DATEM. The study also highlighted the importance of the cake formulation. If intrinsic emulsifiers like lecithins from egg are part of the recipe, the extent of improvement by lipases is limited.

Our hypothesis that baking lipases can improve the batter quality of cakes was hereby confirmed. We identified possible uses for baking lipases in cake batter manufacturing, especially in combination with known beneficial effects on the baking properties while maintaining the original sensory characteristics. To ease the predictability whether a lipase is suited for the use in cakes, molecular insights into their specific reactions are still missing. A limitation of our study is that we have not identified possible mechanisms yet. Therefore, further studies are needed which focus on the reactions on the molecular level leading to the improvement of batter and baking quality improvement, especially on the lipidomic profiles.

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Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

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Charlotte Dorothea Stemler: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft. **Katharina Anne Scherf:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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