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Research Article

A new micro-baking method for determination of crumb firmness properties in fresh bread and bread made from frozen dough

Entwicklung eines Mikrobackversuches zur Evaluierung der Krumeneigenschaften von frischen Broten und Broten aus vorgegarten Tiefkühlteiglingen

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Summary

In general, micro-baking tests are used to determine the baking quality when only low amounts of test flour are available, for example, in grain breeding. Several micro-methods are described in literature, but none of them allows the determination of bread crumb texture parameters. Therefore, a micro-baking procedure that offers this option was developed, and it was also evaluated for bread made from pre-fermented frozen doughs. In this procedure, Rapid Visco Analyser (RVA) sample cans were used as baking pans. To examine the capability of this procedure, three wheat flours with different starch properties were chosen. The obtained breads were analyzed with respect to specific loaf volume, crust color and bread crumb firmness. Additionally, a storage test (0-5 days) was performed to determine the crumb firming parameters by kinetics of the Avrami equation. The obtained specific bread volumes revealed significant differences between the flours and the coefficients of variation ranged between 4.2 and 5.5%. Crumb firmness measurement was able to identify significant differences within the samples. The obtained data on firming kinetics reflected the expected properties of samples with different starch properties. Overall, this work demonstrated the feasibility of crumb property measurement on breads on a micro-scale.

Keywords: bread staling, wheat quality, Avrami, bread crumb properties, Rapid Visco Analyser

Zusammenfassung

Mikrobackversuche werden zur Bestimmung der Backqualität bei Vorliegen von nur geringen Mehlmengen angewendet. In der Literatur sind dazu bereits mehrere Methoden beschrieben, jedoch bietet keine die Möglichkeit, Texturparameter der Brotkrume zu erfassen. Darum wurde in dieser Arbeit eine Methode entwickelt, die dies ermöglicht. Es wurde auch eine Methode für Brot aus vorgegarten Tiefkühlteiglingen definiert. Als Backformen kamen Probenbehälter des Rapid Visco Analysers (RVA) zum Einsatz. Um die Differenzierungsfähigkeit dieser Prozedur zu bestimmen, wurden drei Weizenmehle mit verschiedenen Stärkeeigenschaften dem Test unterzogen. Von allen Broten wurde das spezifische Volumen, die Krustenfarbe und die Krumenfestigkeit bestimmt. Außerdem wurde ein Lagertest (0-5 Tage) durchgeführt, um basierend auf der Avrami-Gleichung die kinetischen Parameter des Altbackenwerdens zu ermitteln. Die spezifischen Volumina der einzelnen Brote unterschieden sich signifikant voneinander, wobei die Variationskoeffizienten der einzelnen Versuche zwischen 4.2 und 5.5 % lagen. Auch bei der Messung der Krumenfestigkeit konnten signifikante Unterschiede zwischen den einzelnen Mehlen identifiziert werden. Die kinetischen Kennzahlen zur Beschreibung des Altbackenwerdens spiegelten wie erwartet die unterschiedlichen Stärkeeigenschaften der einzelnen Proben wieder. In der vorliegenden Arbeit konnte erfolgreich die Durchführbarkeit der Bestimmung von Krumeneigenschaften im Mikrobackversuch demonstriert werden.

Schlagworte: Altbackenwerden, Weizenqualität, Avrami, Brotkrume, Rapid Visco Analyser

1. Introduction

Today, extensive numbers of analytical parameters are used to describe wheat and wheat-flour quality, but accurate and reliable predictions of end-use qualities for bakery-use are still highly challenging (Békés, 2012a). Furthermore, the sample sizes in early generation grain-breeding and testing of newly tailored baking additives are limited. Therefore, micro-methods are used to determine the quality characteristics (Belitz et al., 1978; Kaur et al., 2004).
Several down-scaled versions of the common wheat-analyzing tools, such as Extensograph and Farinograph, have been developed (Kieffer et al., 1998; Kaur et al., 2004). Nevertheless, baking tests are still the best quality-prediction tool to determine baking properties of wheat flour. Therefore, various micro-baking tests have been established (Sedlácek and Horćićka, 2011). Baking tests aim to reflect the local bread-making practice; hence, many different standardized procedures exist (Meppelink, 1981). For instance miniaturized versions of the German Rapid-Mix-Test (Pelshenke et al., 2007) are described by several authors (Kieffer et al., 1993; Sedlácek and Horćićka, 2011) and have been used extensively in recent studies (Schaffarczyk et al., 2014; Thanhaeuser et al., 2014). It was demonstrated that the results of these micro-measurements are highly associated with the conventional sized versions and are immensely valuable in evaluating the dough and bread characteristics (Békés, 2012b).
The available micro-baking methods are limited to determination of bread volume, since analyzing the crumb and crust properties is difficult to implement (Doekes and Belderok, 1976). However, bread crumb and crust characteristics are essential for end-use quality and consumer acceptance of bread (Angioloni and Collar, 2009). Use of wheat varieties with different starch pasting properties can influence the crumb firmness significantly; also, different surfactants can have substantial effects on the crumb properties (Goesaert et al., 2005). To screen the effects of these factors on bread crumb properties at small scale, we developed a micro-baking test, which offers the opportunity to measure the crumb properties and bread firming kinetics. This micro-baking test used 15 g dough for one bread and it was developed for fresh bread, but also for bread made from pre-fermented frozen dough. To assess the discrimination power and general feasibility of this test, three wheat flours with differing starch pasting properties were selected. These flours underwent a standardized dough preparation and baking procedure. After a storage time of up to 5 days, the bread volume, crumb firmness, crumb elasticity and crust color were measured and evaluated.

2. Materials and Methods

2.1 Materials

Three different wheat cultivars have been used in this study: bread making cv. Midas (A), waxy cvs. Waxydie (B) and Waximum (C). The seed samples were provided by Saatzucht Donau (Probstdorf, Austria), Dieckmann Seeds (Rinteln, Germany) and BOKU Plant Breeding Division (Tulln, Austria), respectively. Samples were milled on a laboratory roller mill (E8, Haubelt Laborgeräte GmbH, Berlin, Germany) and flour was sieved with 180 μm sieves. Flours were stored for two weeks at 4°C in paper bags, before baking experiments were carried out. Salt (iodized) and dry yeast (saf-instant, Lesaffre Group, France) were obtained locally.

2.2 Micro-Baking procedure

A schematic overview of the bread making process is shown in Figure 1. For baking pans, unused Rapid Visco Analyzer (RVA) sample canisters (h = 67.7 mm, d = 38 mm, wall thickness 0.45 mm) were applied. Usually, these aluminum canisters are exclusively used for viscosity measurements by the RVA device (Perten Instruments, Hägersten, Sweden). On the bottom of each pan, two holes (d = 3 mm) were drilled for easier depanning of breads after baking (shown in Figure 2). The baking formula included 100 g flour (14% moisture basis), 2% salt, 2% dry yeast and 63 ml water. All dry ingredients were equilibrated at room temperature before use. The water amount was kept constant for all flours in this experiment, as changes would have had substantial effects on crumb firmness of bread (Yi et al., 2009). All ingredients were mixed in a Flourgraph E6 (Haubelt Laborgeräte GmbH, Berlin, Germany) for 5 minutes. Water was pre-warmed to 30°C and added at the beginning of the mixing. The mixing bowl of Flourgraph E6 was tempered to 30°C, whereby a final dough temperature between 29 and 30°C was reached (and the dough temperature was monitored). The dough was removed by hand, rounded and placed into a fermentation cabinet (G66W, Manz Backtechnik GmbH, Creglingen, Germany). After proofing for 30 min at 30°C and 85% RH (relative humidity), the dough was divided into 15±0.5 g portions. Each piece was rounded by hand for 10 s and placed into an RVA canister, which was greased carefully with baking spray

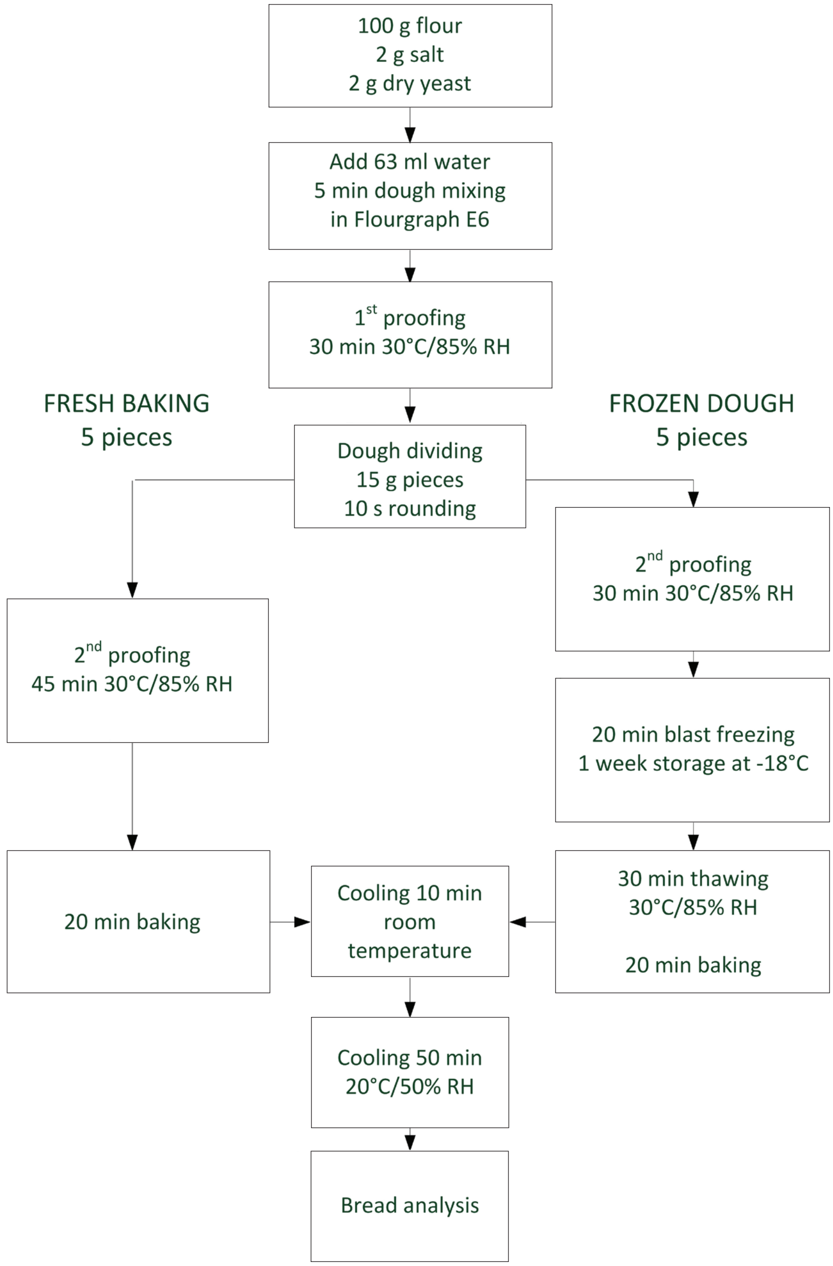


Figure 1. Micro-baking procedure flow diagram
Abbildung 1. Fließdiagramm des Mikrobackversuchs

(Boeson-Trennwachs, CSM Deutschland GmbH, Bingen, Germany) prior to use.

One part of such prepared dough pieces underwent a second proofing step of 45 min (30°C/85% RH) for fresh bread production, followed by the baking process. For the production of frozen dough pieces, another part of the dough pieces was submitted to a reduced second proofing step of 30 min (30°C/85% RH) followed by freezing in a blast freezer (IF101L, Sagi S.p.a., Ascoli Piceno, Italy) at an ambient temperature of –36°C. The freezing duration of 20 min was experimentally determined before, as a core temperature of –15°C was reached by these settings. Then, the dough pieces were taken out of the cans, packed in airtight plastic bags, sealed and stored for 1 week at –18°C. After that, the frozen storage doughs were placed into baking pans again, and thawed in the fermentation chamber for 30 min (30°C/85% RH). Fresh and frozen dough were baked under same conditions. First the baking oven (60/3 W, Manz Backtechnik GmbH, Creglingen, Germany) was pre-heated to 230°C, top and bottom heat. Five bread pans were placed in the oven, evenly distributed inside the oven. Subsequently, the top temperature was reduced to 200°C and bottom temperature to 180°C; the breads were baked for 20 min. After baking, the breads were cooled at room temperature within the pans for 10 min; then, the breads were removed from the pans and were cooled for further 50 min in a controlled atmosphere (20°C/50% RH). The baking trials were done in dupli-

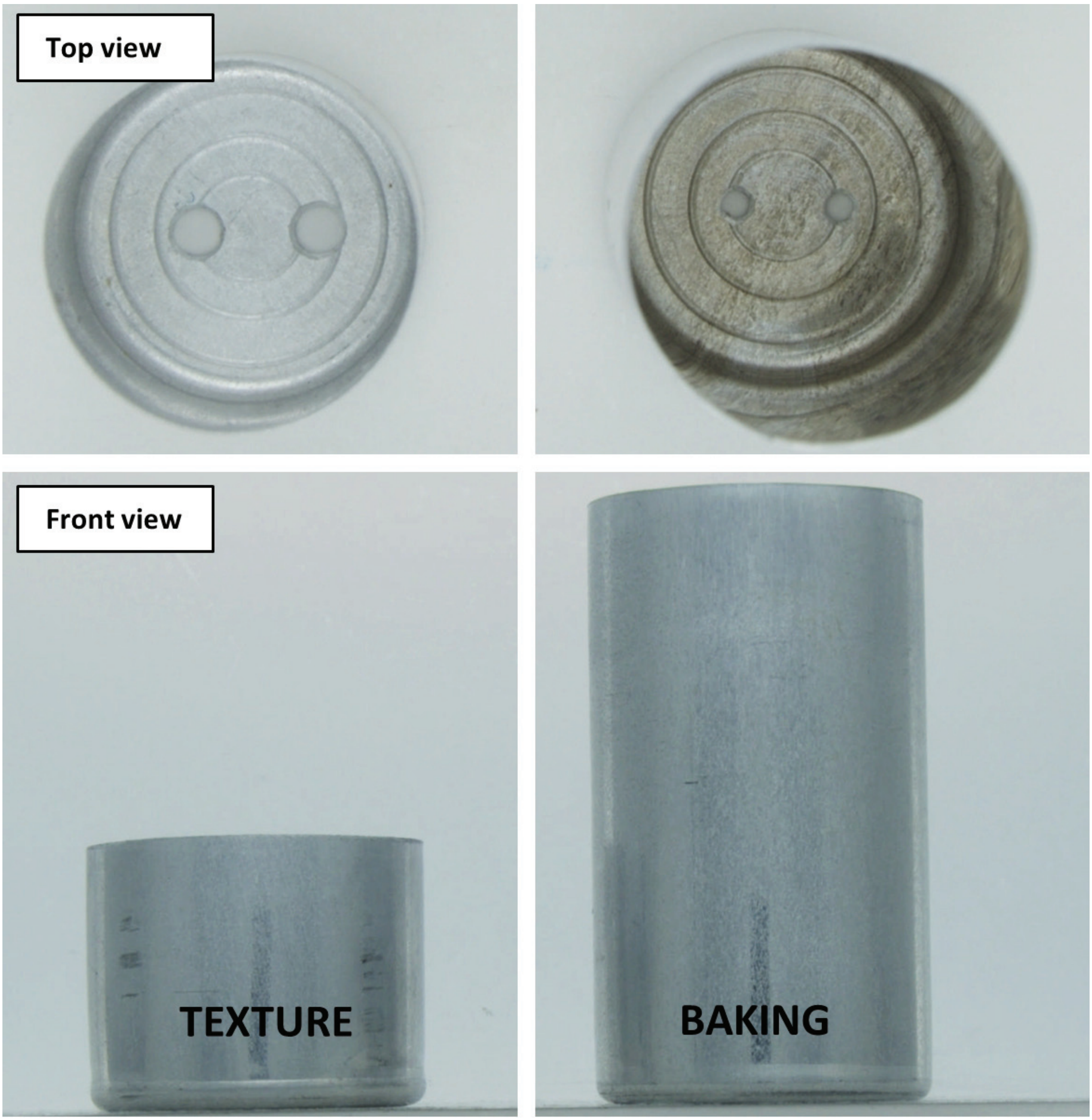


Figure 2. Modified RVA cans used for micro-baking (right) and crumb texture determination (left)
Abbildung 2. Bearbeitete RVA Probenbehälter zur Verwendung als Backform (rechts) und als Halterung für die Texturmessung (links)

cate, resulting in 10 fresh breads and 10 breads from frozen dough for each flour. Specific loaf volume and crust color was measured for all breads. Bread crumb properties were determined from 6 breads on the day of baking. The other four breads were used for determination of firming kinetics. For the storage study, breads were packed into plastic bags and stored at 20°C. After 24, 48, 72 and 96 hours of storage, one bread per sample was analyzed on each day.

2.3 Determination of bread properties

2.3.1 Specific loaf volume and crust color

Bread volume was measured twice for each loaf by rapeseed displacement, as described by AACC method 10-05. After weight measurements, the specific loaf volume was expressed as cm³/100 g bread.

The determination of bread crust color was performed with the DigiEye system (VeriVide Limited, Leicester, GB). From top view, the bread images at controlled illumination were taken, the crust color was measured with DigiPix Software (VeriVide Limited, Leicester, GB) and expressed according to CIELAB color space.

2.3.2 Bread crumb firmness and relative elasticity (REL)

Crumb firmness was measured by TA-XT2i texture analyzer (Stable Micro Systems™ Co., Godalming, GB) using the SMS P/0-5 probe and 5 kg load cell. Data were evaluated using the Texture Expert Software (Stable Micro Systems™ Co., Godalming, UK). Breads were cut with a sharp saw at 2 cm height from the bottom. The lower parts were put into a tailor-made RVA can (Figure 2, left) with 3 cm height and 2 holes (d = 5 mm) on the bottom, for easier handling. The RVA can with the bread was placed in the middle of the texture analyzer instrument platform and a uni-axial compression test was applied with the following test conditions: pre-test speed 5.0 mm/s, test speed 0.5 mm/s, holding time 120 s and test distance 7 mm (corresponding to 35% deformation,). The resulting peak force of compression was reported as crumb firmness (F_{max}). Relative crumb elasticity (F_{REL}, %) was calculated as a percentage ratio of F_{max} to F_{120} (force after 120 s test time).

2.4 Statistical Analysis

Mean values, standard deviations and coefficients of variation were calculated using Microsoft Office Excel 2016 (Microsoft, Redmond, USA). One-way ANOVA was performed by using SPSS 21 for Windows (SPSS Inc., Chicago, IL, USA) to analyze the significance of flour type on bread properties. To determine the individual differences between groups, the Tukey test was performed at $p < 0.05$. Bread staling parameters (k and n) were fitted to the Avrami equation by using the website www.mycurvefit.com (accessed 16th December 2016):

$$\frac{(F_\infty - F_t)}{(F_\infty - F_0)} = e^{-k*t^n}$$

where F_∞ and F_0 were the measured crumb firmness at the beginning and final stage of bread staling and F_t corresponds to firmness at time t (Cornford et al., 1964).

3. Results & Discussion

The physical properties of breads produced by the micro-baking procedure are summarized in Table 1. For each flour and procedure, the photos of two exemplary breads are presented in Figure 3.

3.1 Bread Volume

Specific loaf volumes obtained by the micro-baking procedure varied between 330 and 425 cm³/100 g for fresh bread and from 236 to 331 cm³/100 g for the frozen dough procedure. The highest volume for fresh bread was achieved by flour C, while for frozen dough bread, flour B reached the highest volume. Specific volumes of waxy wheat flours (B and C) were not significantly different or even higher as compared to the volume of the standard bread wheat (A). These results are likely to be related to a higher loaf expansion of waxy wheat breads during baking (Blake et al., 2015).

Guenzel (1981) argued that the baking process in micro-baking is hardly comparable with standard baking tests, because a very low oven rise occurs, and additionally, the dough can shore up more at the walls of the baking pans than in standard sizes. This could be critical in this baking procedure, as the geometry of the RVA canisters supports this disadvantage. For instance, flours B and C show surprisingly high loaf volume for waxy wheat. Figure 3 demonstrates that breads obtained from these flours have a rather flat top in comparison to the standard bread wheat (A). This occurred due to the weak structure of the

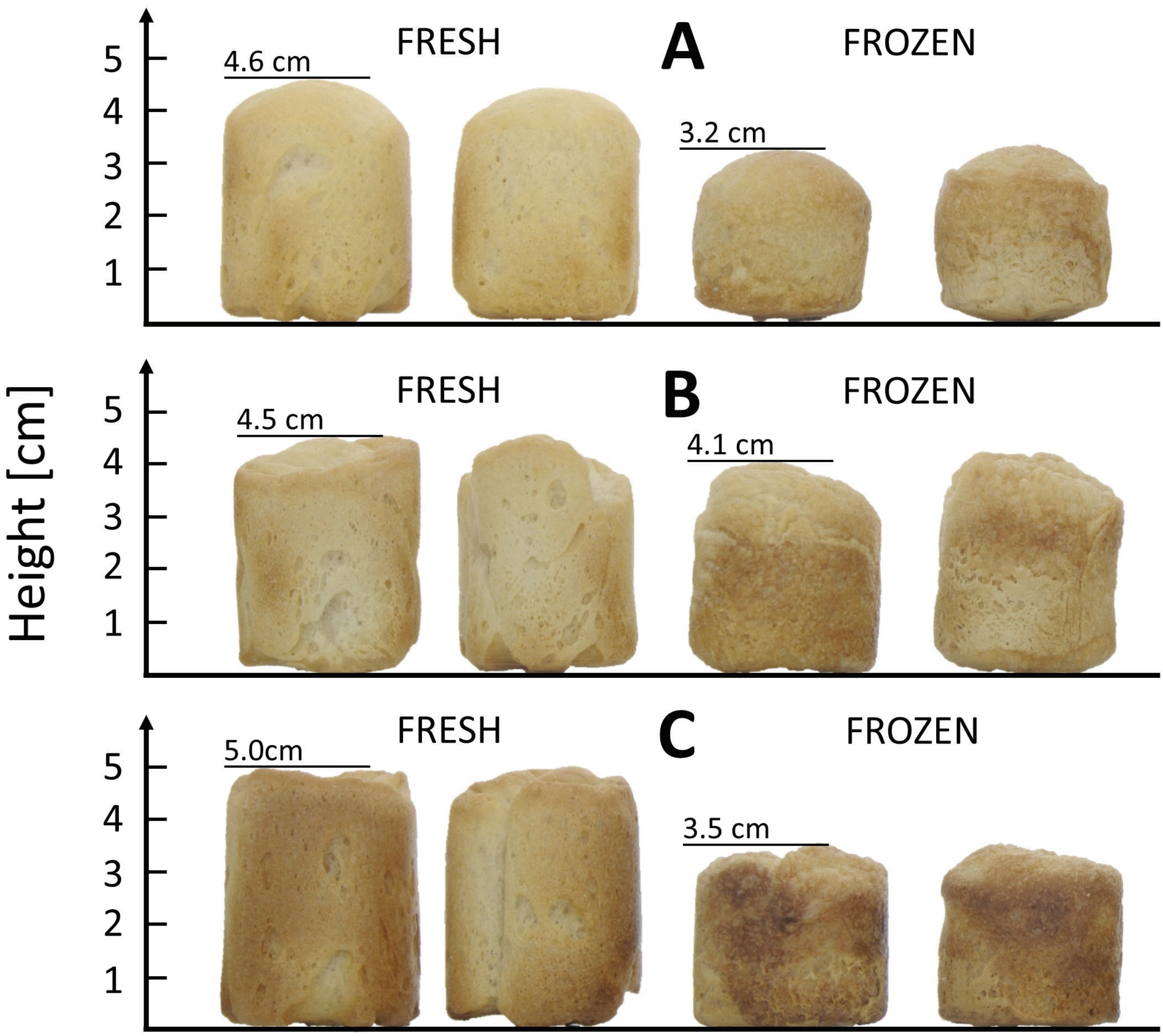


Figure 3. Exemplary front view images of breads obtained by micro baking procedure out of wheat flours A, B and C.
Abbildung 3. Beispielhafte Fotos von Broten hergestellt mittels Mikrobackversuch aus Mehlen A, B und C

waxy wheat doughs, which allows a high oven rise, but during baking, the dough partly collapses again. This effect would be higher when the bread is baked without pans or in standardized pans with relatively larger base area and lower height, as they are used in the ICC standard method 131, for example. However, within the used micro-pans, the shearing of the dough at the walls is higher, thus the collapse of the dough was probably diminished. Therefore, the specific loaf volume could be higher in micro-pans than in standard sized baking experiments.

The coefficients of variation were similar for each flour and bread making procedure. Values were comparable to data shown by Kieffer et al. (1998) for the micro-Rapid-Mix-Test. Other studies (Sedlácek and Horćićka, 2011; Thanhaeuser et al., 2014) reported extremely low (<0.5%) coefficients of variation for micro-baking tests. However, in this study, significant differences among wheat flours could be detected.

In Figure 3, it is visualized that height measurements of micro-baking breads would only roughly describe the volume,

Table 1. Specific volume, crumb firmness, crumb elasticity and crust color of breads made by micro-baking procedure
Tabelle 1. Spezifisches Volumen, Krumenfestigkeit, Krumenelastizität und Krustenfarbe der im Mikrobackversuch hergestellten Brote

Parameter		Fresh bread (n = 10)			Frozen dough bread (n = 10)		
		A	B	C	A	B	C
Specific loaf volume, cm³/100g							
	Mean	359^{a}	330^{ab}	425^{c}	236^{d}	331^{ab}	317^{b}
	Standard deviation	15	18	19	11	18	14
	Coefficient of variation	4.2	5.5	4.5	4.7	5.4	4.3
F_{max} [a], N							
	Mean	2.4^{a}	0.9^{b}	1.0^{b}	5.9^{c}	0.8^{b}	1.0^{b}
	Standard deviation	0.2	0.1	0.1	1.3	0.1	0.2
	Coefficient of variation	7.5	9.5	10.3	21.3	11.7	15.8
FREL [a], %							
	Mean	49.7^{a}	37.6^{b}	30.0^{c}	59.3^{d}	39.9^{b}	40.5^{b}
	Standard deviation	1.6	1.5	1.6	3.4	2.8	2.4
	Coefficient of variation	3.3	4.0	5.2	5.8	6.9	6.0
Color L*							
	Mean	80.8^{a}	72.7^{b}	63.1^{d}	65.3^{cd}	67.3^{c}	57.5^{e}
	Standard deviation	1.2	1.1	1.5	1.0	1.8	2.2
	Coefficient of variation	1.4	1.6	2.3	1.6	2.6	3.8
Color a*							
	Mean	11.1^{ab}	10.6^{a}	15.8^{c}	15.1^{c}	12.8^{b}	16.7^{c}
	Standard deviation	0.6	0.9	0.9	0.6	1.2	0.9
	Coefficient of variation	5.8	8.8	5.4	4.0	9.3	5.4
Color b*							
	Mean	37.5^{a}	34.3^{bcd}	35.3^{bc}	35.8^{b}	34.1^{cd}	33.3^{d}
	Standard deviation	0.5	1.1	1.1	0.2	0.9	0.8
	Coefficient of variation	1.2	3.4	3.1	0.5	2.6	2.3

[a] n = 6
Within row, values with the same following letter do not differ significantly from each other ($p > 0.05$)

as the bread volume increase does not occur evenly. For example, a comparison between fresh breads produced by flour C to frozen dough breads by flour A reveals on one hand a "rectangular" shape, flat top and flat bottom (flour A), and on the other hand a rather "circular" shape, round top (higher rise in the middle part of the bread) and sometimes also round bottom (flour C).

3.2 Bread Firmness

The texture properties of the bread crumb were measured by a compression test which describes the viscous and the elastic deformation (represented by F_{REL}). Coefficients of variation for maximum firmness (F_{max}) ranged between 7.5 and 21.3% and were higher for the frozen dough procedure. For F_{REL} all coefficients of variation were lower than 7%. Significant differences between flours and bread making procedure were found for both parameters. Maximum firmness (F_{max}) of breads made from waxy wheat flours (B, C) were significantly lower than from breads made with standard bread wheat (A), which is a typical quality characteristic of waxy wheat flours (Bhattacharya et al., 2002). Moreover, there was no difference between the firmness of fresh and frozen dough bread made by waxy wheats. Standard bread wheat (A) showed substantial increase in firmness with the frozen dough procedure, following the results of numerous frozen dough studies (Rosell and Gómez, 2007).
Results of relative elasticity (F_{REL}) showed diverse effects, flour A and C showed an increase after the freezing pro-

cedure, whereas flour B F_{REL} did not significantly change. Crumb elasticity does not only affect the mouthfeel, but also the cutting ability and therefore, it is an important quality parameter in industrial bread production (Wassermann, 1973).

3.3 Bread Color

To observe the repeatability of the baking procedure, color is also a noteworthy parameter. For the measurements expressed as CIELAB parameters, only the top of the bread, which was not in direct contact with the baking pan surface, was used. The color of the sidewalls can be seen on exemplary breads in Figure 3. For the parameter lightness (L*), the coefficient of variation was 1.4 and 3.8%, for redness (a*) 4.0 to 8.8% and for yellowness (b*) 0.5 to 3.4%. Bread made from frozen dough had a significantly lower L*-value than fresh bread with the same flour, this resulted in a darker color, as shown in Figure 3. For all color parameters, significant differences between flours and bread making procedure were identified.

3.4 Bread firming during storage

The increase in F_{max} of bread crumb, due to retrogradation during 5 days of controlled storage is shown in Figure 4. For both procedures, irrespective of the storage duration, highest firmness was achieved with the standard bread flour (A). Waxy wheat breads (B, C) showed similar behavior and only very little increase of firmness in the first 48 hours.

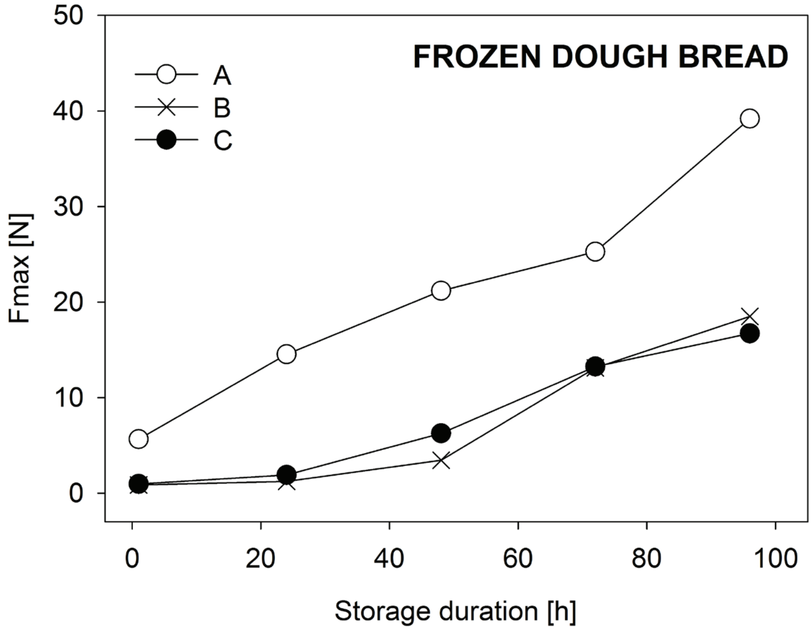
The kinetics of bread crumb firming can be described by measuring crumb firmness after different storage periods; this mechanism is following the model of Avrami equation (Armero and Collar, 1998). The Avrami parameters determined by curve fitting are presented in Table 2. The parameter *k* is the firming rate and defines the initial stage of firming. The Avrami exponent *n* indicates the nucleation type and describes the behavioral approach to reach the final state of staling (Amigo et al., 2016). Both parameters revealed big differences between waxy wheat and standard bread wheat. This behavior was expected, as slower retrogradation for breads with the addition of waxy wheat has been shown by Bhattacharya et al. (2002) previously.

4. Conclusions

The main goal of the current study was to set up a micro-baking procedure, which allows the measurement of bread crumb texture parameters. The repeatability of this easy-to-use baking test was sufficient to identify differences among specific loaf volume, crust color and crumb firmness of different wheat flours. An additional strength of this test is that we also defined a procedure for bread made from frozen dough, which is an important product today. This study has also shown that it is possible to evaluate staling kinetics of bread on a micro-scale. Notwithstanding the relatively limited sample, this method has the potential to be used in further research on bakery ingredients, to understand their influence on staling kinetics. Because of the use of RVA cans as baking pans and as a crumb

Table 2. Staling kinetic parameters according to the Avrami equation
Tabelle 2. Kinetische Parameter des Altbackenwerdens laut Avrami-Gleichung

Bread type	Avrami equation parameters		
	n	k	R^2
Fresh bread			
Flour A	1.85	0.184	0.934
Flour B	3.42	0.030	0.998
Flour C	5.66	0.002	0.999
Frozen dough bread			
Flour A	0.95	0.314	0.999
Flour B	4.92	0.005	0.999
Flour C	3.14	0.048	0.999



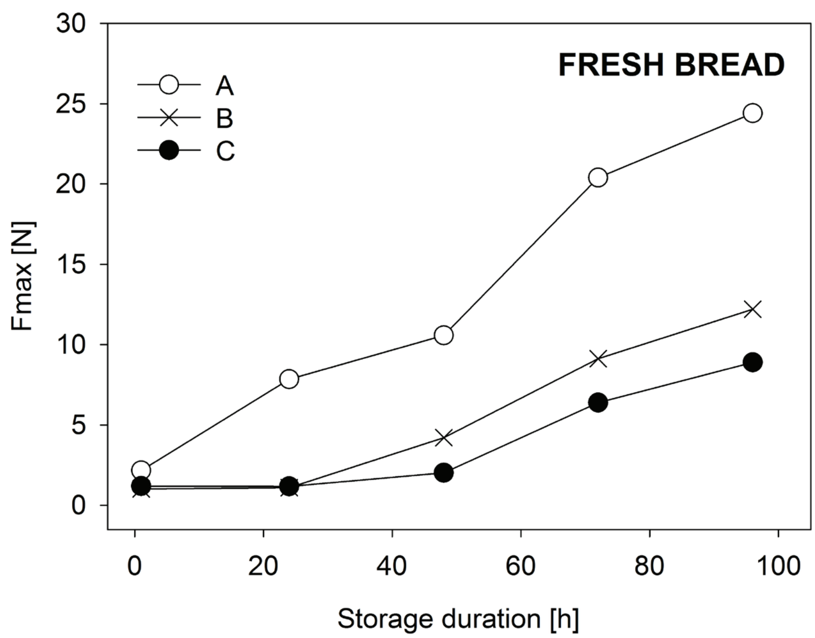


Figure 4. Changes of bread crumb firmness during storage at 20°C, 50% relative humidity
Abbildung 4. Veränderungen der Krumenfestigkeit während der Lagerung bei 20°C, 50 % relative Luftfeuchtigkeit

measuring stand, this method offers simple handling and easily accessible materials. If this method owns enough selectivity for determination of differences in gluten qualities remains unclear, as this work is aimed at using flours with different starch compositions. Another aspect is that the mixing process of dough has not really been performed on micro scale yet. In pre-trials, the Promylograph E3 (Apparatebau Egger, St. Blasen, Austria) was tested for dough preparation, which uses only 10 g of flour for mixing. The resulting doughs were satisfactory, but it is only possible to perform one dough/bread from one batch in this way. As the main aim of this study was the determination of crumb firming during storage of more breads from one batch, therefore it was decided to switch to a larger dough mixing equipment. Another reason to apply mixing on a rather medium scale was that it was intended to implement a two-step fermentation process, which includes first a fermentation, then a dividing step and then a second fermentation, in order to simulate as close as possible to the usual baking practices. We are aware that 100 g is still not a suitable sample size for, for example, early generation grain breeding.

Since this was the first approach to determine the texture properties of bread crumb on a micro-scale with only 15 g of dough, further studies should be performed to evaluate correlations with standard-sized procedures.

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