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A normalized texture profile analysis approach to evaluate firming kinetics of bread crumbs independent from its initial texture

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ABSTRACT

Firming kinetics of bread crumbs are a major quality-determining factor. In literature, dough variations are often related to crumb firming behaviors. It is hypothesized, that this is often a spurious correlation based on methodological effects due to changes of the crumb void fraction. Thus, the study investigated different initial crumb textures with equal solid materials and a normalized TPA methodology with adapted cylinder probe sizes. The results showed a clear methodological impact of the standard TPA approach. The normalized TPA methodology showed weak or no significant correlations between the crumb void fraction and firmness, the firmness and the firming rate, as well as the void fraction and the firming rate. This proves that mostly changes of the bread volume influence the firming behavior of bread crumbs with equal solid materials. The findings of the current study have to be considered for the interpretation of the firming behavior of bread crumbs.

1. Introduction

The thermal phase transition of the cereal biopolymers during baking restructures the flexible foam dough with closed cells to a flexible open-cell foam or cellular solid. This crumb composed of connected air cells and a solid matrix is mainly based on polymerized gluten molecules and a disordered starch gel network. During storage the bread undergoes quality determining changes, the so-called staling, which is assumed to be responsible for one of the most important sources of food waste. Staling of bread consists of a loss of flavor and taste as well as textural changes of the bread crumb. The loss of flavor and taste is based on a) volatile flavor compounds and its evaporation to the surrounding medium and on b) inclusion effects of the flavor active compounds with the biopolymers of bread, such as gelatinized starch and proteins. However, the most important change of crumb quality during storage is the increase in crumb hardness (firming). Firming is well described in the literature (Amigo et al., 2016; Beck et al., 2012; Chen and Opara, 2013; Fadda et al., 2014; Le-Bail et al., 2009; Monteau et al., 2017). One main mechanistic background is the redistribution of moisture between the dry crust (0.05–0.10 g moisture/100 g product) and relatively moist crumb (0.4 g moisture/100 g product) (Chhanwal and Anandharamakrishnan, 2014), even having a balanced mass equilibrium. Thus, the crumb is losing moisture over storage time and its firmness increases. However, firming of the crumb also occurs with removed crust (after baking) (Baik and Chinachoti, 2000). Consequently, the loss of moisture of the crumb to the crust and the surrounding medium are not the only effects causing the firming. This leads to another well-described effect of the firming, the (re-)crystallization of starch. During storage of heated starch-water based products (such as bread) amylopectin molecules change from an amorphous to a crystalline phase. Amylose crystallizes during the first hours (cooling of bread), whereas amylopectin recrystallizes slowly during several days of storage (Goesaert et al., 2009; Hug-Iten et al., 2003). During the recrystallization of amylopectin, B-type amylopectin crystals are formed which include more water than the A-type of native starch. Furthermore, water is withdrawn from gluten to the starch network during storage resulting in a not fully hydrated and firmer gluten network (Bosmans et al., 2013b). In general, a strong association between the firming of the bread crumb with the recrystallization behavior of starch is an accepted fact (Bosmans et al., 2013b; Lagrain et al., 2012; León et al., 1997; Ribotta and Le Bail, 2007), even if some experimental designs could not confirm a relation (Beck et al., 2012).

In general, the standard procedure of firmness and thus firming

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measurement of bread crumbs is the usage of a Texture Profile Analyzer (TPA) with a standard cylinder probe diameter of 36 mm (AACC International, 1999). A wide range of studies uses this standard or a slightly adapted version. All have in common, that a bread crumb (slice or cut out cylinder) of a specific height (standard 25 mm) is compressed by a cylinder probe (standard 36 mm). The compression is set to 40% deformation in the standard methodology, some studies also varied this between 30 up to 50% or to a fixed height, causing slightly differed results. Some other parameters of the method, such as the applied force, the test speed, and the trigger force influence the absolute measures, too. Further, it has to be mentioned, that the firmness is not a rheological measure and not a material constant (such as the young's modulus would be). However, since the firmness is commonly used for textural analysis of foods and is additionally related to sensory analysis, the method is used by most studies, which aimed to prevent the firming of bread crumbs. Some suggested approaches were the use of enzymes, hydrocolloids, pre-processed flour, process parameters, and more. However, these studies often correlated directly the changed variables with the firming rate, which must not be interpreted as a causal relation between these effects. This fact is underlined by studies showing a relation between the bread volume and the firming behavior (Beck et al., 2012; Bosmans et al., 2013a; Cornford et al., 1964; Fearn and Russell, 1982; Jekle and Becker, 2012a). These relations are even valid although some of the studies applied slightly varied texture analysis methodologies, since all are based on the same deformation approach and thus the only limitation should be that the absolute values are not comparable. Just few studies analyzed this effect quantitatively in a larger experimental setup and revealed significant correlations between the bread volume and the firming values (Axford et al., 1968; Jekle and Becker, 2012c). Therefore, the results of the above mentioned studies, which showed an effect between recipe or process variations and the firming rate, may be interpreted at least in some extent as a spurious relationship. Thus, the question arises, if the relation between dough formulation or process parameters and the firming rate has just a mathematical or really a mechanistic basis. In this context, the measurement of the firming of bread via texture profile analysis has to be considered.

Since bread is a porous material, its textural properties are dependent on the pore wall solid material as well as its three dimensional structure of the cellular solid. Changes in dough composition and process parameters often lead to a variation in the gas forming and holding kinetics of dough and thus to a varied gas ratio in the crumb. During the TPA analysis of the cellular solid crumb with a high gas (loaf) volume less solid material (crumb) is compressed under the cylinder probe (case 1, see Fig. 1) than at the TPA analysis of a product with a low gas volume (case 2, see Fig. 1). Assuming the same structural changes of the solid material during storage, the higher amount of solids in case 2 influences the TPA values to a higher extent during storage than in case 1. This simple methodological effect could influence the interpretation of the firming behavior of bread crumb during storage.

To confirm this hypothesis the current study aims to identify causal and/or spurious relations between the initial texture of the cellular solid bread, its total volume or void fraction, and its firming rate. Therefore, wheat breads with different void fractions and equal solid material properties (analyzed by DSC) were produced with chemical leavening agents to evaluate the effect of the bread volume on the firming rate, independent from dough composition and process variations. The mechanical properties (firmness) and its kinetics over storage time were analyzed by the standard TPA methodology and a normalized TPA methodology with adapted cylinder probe diameters.

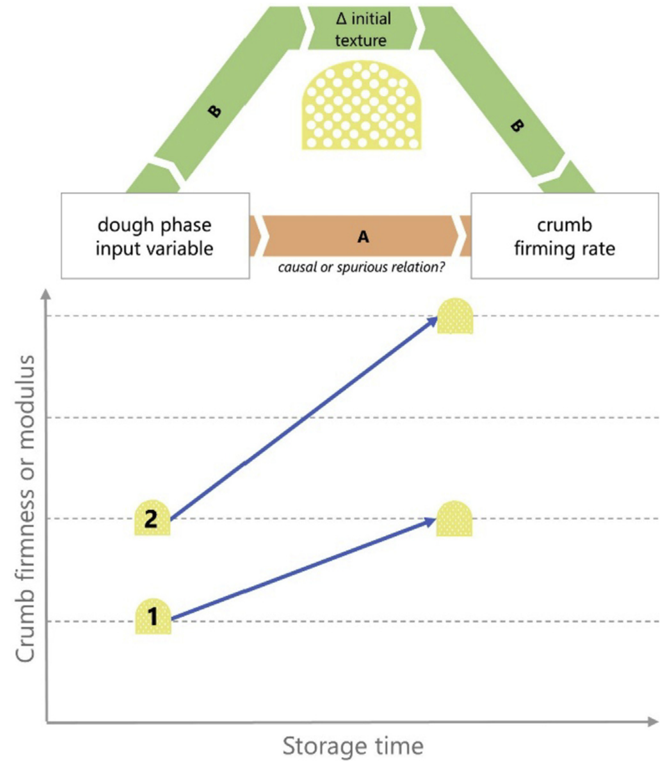

Fig. 1. Lower part: Schematic relation between initial bread crumb firmness or modulus and the change over storage time. The firmer the crumb after baking (case 2), the more intense the increase of firmness or modulus over storage. Upper part: Possible causal pathways of the relation between dough phase input variables and the firming rate of the crumb. Variation A) causal relation between dough variable and crumb firming rate and variation B) causal relation over the factor initial texture, which means variation A would be spurious.

2. Materials and methods

2.1. Materials

For the bread preparation wheat flour type 550 from Rosenmühle GmbH Landshut, Ergolding, Germany was used. Moisture content (13.7 ± 0.1 g 100 g^{-1} flour (n = 5)) and ash content (0.7 ± 0.0 g kg^{-1} flour (n = 3)) were determined according to the International Association for Cereal Science and Technology's (ICC) principles 110/1 and 104/1, respectively. The protein content (11.6 ± 0.2 g 100 g^{-1} flour d.m. (n = 2)) was analyzed using the Kjeldahl Method (EBC) with the conversion factor N x 5.7. Falling number was 382 ± 10 s (n = 5) (ICC 107/1). The following values were determined by ICC 155/1 (n = 3): Water absorption 60.2 ± 0.2%, dough development time 2.9 ± 0.5 min, dough stability 17.1 ± 1.4 min, and degree of softening 24.8 ± 6.8 BU. Rapeseed oil was obtained from REWE Markt GmbH, Cologne, Germany, sodium chloride (NaCl) from Südsalz GmbH, Heilbronn, Germany, calcium propionate from Sigma-Aldrich Chemie GmbH, Taufkirchen, Germany, and sodium hydrogen carbonate (Kaiser Natron) from Arnold Holste Wwe. GmbH & Co. KG, Bielefeld, Germany, respectively. Sodium acid pyrophosphate (SAPP10) was kindly provided from Chemische Fabrik Budenheim KG, Budenheim, Germany. The rate of reaction of the SAPP 10 was 10 and its neutralization value 72.2.

2.2. Bread sample preparation

For the preparation of the bread samples following components were used: wheat flour type 550, 62 g distilled water 100 g^{-1} flour,