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Optimization of beta-glucan and water content in fortified wheat bread using Response Surface Methodology according to staling kinetics

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A B S T R A C T

The aim of our research is to optimize the BG and water content to obtain bread with high-quality attributes and then examine it in terms of staling, comparing it to a control wheat bread. To find the behavior of variables by means of surface plots, the models created in this study were utilized for modeling purposes, using point prediction post analysis to optimize the BG and water content in the bread, which could be stored, while maintaining high-quality traits. Using the central composite rotational design, we developed an optimal BG addition of 1.24% with 63.48% water to achieve a final product with minimum firmness value and maximum porosity, springiness, and beta-glucan content. The analysis of the staling kinetics of bread fortified with BG revealed this optimized content could prevent staling in enthalpy and firmness of bread, even up to 7 days of storage.

1. Introduction

Cereal products could be one of the most important sources of bioactive compounds, which could make food functional (Fares et al., 2015). One of the bioactive ingredients in cereal products is dietary fiber. The role of dietary fiber in the improvement of human health has gained significant interest as a research subject over the last few years (Ronda, Perez-Quirce, Lazaridou, & Biliaderis, 2015). Dietary fiber could be divided into two types, insoluble and soluble. Most research is devoted to soluble dietary fiber, i.e., beta-glucan (BG). BG has a proven effect on lowering glycemic and insulin responses, lowering lipid metabolism, and lowering blood cholesterol levels (Piwińska, Wyrwisz, Kurek, & Wierzbicka, 2016).

Despite BG mainly being a soluble type of dietary fiber, usually, it forms hydrocolloids and is soluble up to 1% solutions (Moschakis, Lazaridou, & Biliaderis, 2014). Previous studies focus on adding BG to bread or bakery products (Kurek, Wyrwisz, & Wierzbicka, 2015a; Lazaridou, Duta, Papageorgiou, Belc, & Biliaderis, 2007; Moriartey, Temelli, & Vasanthan, 2011). However, many researchers claim that adding BG could cause bread quality to deteriorate in various aspects (i.e., loaf volume, porosity, firmness) due to competing with gluten in terms of water during mixing. Due to the water-holding abilities of BG, it could be an anti-staling agent. It is not fully explained how staling occurs in bread, but according to one theory, staling is mainly influenced by the retrogradation of starch during storage (Ziobro, Korus, Juszczak, & Witczak, 2013). Retrogradation is a process that takes place as a function of time and depends on the crystalline structure re-association (Li et al., 2016). This process could be slowed down by maintaining the ratio of water to starch (Mariotti, Sinelli, Catenacci, Pagani, & Lucisano, 2009). Because of the water-holding capacity of BG, it could be a reservoir for water in bread to maintain this ratio.

Optimizing bread recipes is done mainly by using Response Surface Methodology, an effective tool for such tasks (Kittisuban, Ritthiruangdej, & Suphantharika, 2014; Kurek, Wyrwisz, Piwińska, & Wierzbicka, 2015; Pourfarzad, Mahdavian-Mehr, & Sedaghat, 2013). The resulting ability to design a proper experiment is among its main advantages as a statistical method. After optimization, the analysis of variance of predicted and measured values is the routine element that validates this method.

The optimized recipe should be examined and compared to control samples. The addition of BG could be an effective way to delay staling in bread. Staling kinetics are described mainly by the Avrami model (Limanond, Castell-Perez, & Moreira, 2002), a model of the crystallization process in a restricted solid matrix and the

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fraction of crystallization, which still must occur in the matrix as a function of time.

The worldwide consumption of bread justifies the continuous need to conduct research on its quality. Despite many publications, staling is still a problem for the bread industry. Increasing consumer awareness means artificial emulsifiers in bread are no longer acceptable (McDonagh, 2012, pp. 162–174). BG is one of the promising replacements for currently used anti-staling agents. Few research papers consider optimizing the water content when adding BG to slow the staling of bread and maintain the high quality of bread during storage. Therefore, the aim of our research is to optimize the BG and water content to obtain bread with high-quality attributes and then examine it in terms of staling, comparing it to a control wheat bread.

2. Material and methods

2.1. Material

2.1.1. Raw materials

Wheat flour from the local supplier was used (Polskie Młyny, Inc., Poland). The composition of wheat flour was 13.70% moisture content, 10.86% protein, 0.49% ash, and 27.4% gluten. The composition of the flour was measured with near-infrared spectroscopy (NIRFlex N-500, Buchi, Switzerland). The fiber preparation comprised 44% dietary fiber (23% soluble and 21% insoluble) and contained 16 g of oat β-(1.3–1.4) glucan per 100 g (Microstructure, Inc. Poland).

2.1.2. Bread production

The wheat bread was made according to the method from the previous study (Kurek et al., 2015). Briefly, wheat flour and BG powder were mixed with water, fresh yeast, and salt for 6 min at 200 rpm in a TRQ-42 RM Spiral mixer (Gastro, Poland). The amounts of wheat flour and dietary fiber have been set out in Table 1, where each combination of wheat flour/BG preparation mixture and water content constitutes a single run of the experiment.

Preliminary fermentation was conducted at 37 °C and 80% relative humidity for 1 h. The mixing bowl was turned once after 30 min, and the dough was divided into pieces of 350 g each. Each piece was placed into pans, where the proofing process took place until reaching oven maturity (37 °C, 80% relative humidity). The direct, single-phase method was used to bake the bread. Baking was conducted in a convection oven (CPE 110, Kuppersbuch, Germany) for 25 min at 180 °C.

Table 1
Runs of the experiment and the composition of wheat flour/BG mixture used in the study.

Run	A: BG (%)	B:Water (%)	C:Day
1	1	55	0
2	1	65	0
3	1	60	1
4	0	55	1
5	0	65	1
6	2	60	3
7	2	65	1
8	1	60	1
9	0	60	0
10	0	60	3
11	1	60	1
12	1	65	3
13	1	55	3
14	2	55	1
15	2	60	0
16	1	60	1
17	1	60	1

2.2. Methods

2.2.1. Rheology

The rheology parameters of the dough were examined using dough prepared without yeast. The measurements were done using the Rheo-Test RT-20 (Haake, Germany), with parallel serrated plate geometry of 20 mm in diameter and a 2 mm gap. The temperature was regulated using a circulating bath at 25 °C. The dough was loaded onto the plate, where it rested for 15 min before the measurements. The tests were performed with a strain sweep test in the range of 0.01–100% of 1 Hz frequency (Lazaridou et al., 2007). The results were presented as storage (G') and loss (G") moduli in Pa. The measurements were done in triplicate.

2.2.2. DSC measurement

The DSC measurement was performed on bread, using a differential scanning calorimeter DSC 1 (Mettler Toledo, OH, USA). A 10 mg bread sample was hermetically sealed in a 40-μl aluminum pan the 1st, 2nd, and 3rd day after baking. Then, heat effect registration was performed using the temperature program (10 °C – 2 min of static stage, 10°–200 °C with a heating rate of −5 °C/min). The peak reaction enthalpy was collected from each measurement. The measurements were conducted in triplicate. The reference sample was the empty 40-μl aluminum pan.

2.2.3. Texture profile analysis

The texture profile analysis (TPA) was performed using the universal testing machine, Instron 5965 (Instron, Tulsa, USA). A breadcrumb cube (2 cm square) was cut from the loaf on the 1st, 2nd, and 3rd day after baking and examined using a double compression test, with up to 50% of compression with maximal load 500 N. The pace of displacement of test probe was 120 mm/min. The result was presented as firmness (N), known as the first compression force, and springiness (–) as the ratio of first and second peak of force needed to compress the sample.

2.2.4. Porosity measurement

Computer image analysis of TIFF images was used to estimate porosity as previously described (Kurek, Wyrwisz, & Wierzbicka, 2015b). The loaf was cut into 2.5 cm thick slices. The slices were digitally photographed, using lighting from lamps with the color temperature at 5400 K. The measurement of porosity involved archiving the images of the sample using a digital camera (Micro Publisher 5.0 RTV, QImaging, BC, Canada), equipped with a linear polarizing filter of 46 mm (Keiser, CA, USA), and a lighting system (RB-5004-HF, Kaiser, CA, USA) with 4 fluorescent lamps (Dulux L 36 W/954, AC 230 V/50 Hz, Osram GmbH, Munich, Germany), with a color temperature of 5400 K. Pictures were taken at a resolution of 2560 × 1920 pixels. The digital camera was connected to a PC computer with Image Pro Plus 7.0 software (Media Cybernetics Inc., MD, USA). The results were presented as medium pore size (mm^2) and porosity as a percentage of pore area and total area of the slice.

2.3. Statistics

The responses obtained for the assays were subject to the central composite rotational design (CCRD), used to study the effects of the variables – BG content, water content, and day of storage. These were analyzed using the Design Expert software version 9 (Stat-Ease, Inc., USA). The response or dependent variables were the dough (G', G") and bread characteristics (peak enthalpy, firmness, springiness, porosity). The significant terms in this model were