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Improvement of maize bread quality through modification of dough rheological properties by lactic acid bacteria fermentation

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ABSTRACT

This work investigated how sourdough fermentation improves maize bread quality. Maize sourdoughs were made by fermenting maize flour with multiple strains starter culture and with *Lactobacillus plantarum*. Sourdough fermentation of maize dough brought about a 25–26% increase in loaf volume of maize bread. Confocal laser scanning microscopy revealed a cohesive dough structure in the sourdoughs. Larger cells were also observed in maize breads with maize sourdough. Differential Scanning Calorimetry showed that maize sourdough had a slightly lower endothermic peak temperature and higher endothermic peak enthalpy than straight maize dough. Rheological analysis showed that maize sourdoughs had a shorter relaxation time. Strain sweep analysis suggested that maize sourdoughs had the lowest elastic modulus, all indicating a softer and less elastic dough. Temperature sweep analysis showed an initial less elastic dough and a final high tan delta, suggesting that the maize dough could withstand gas expansion pressure during baking without crumbling. It appears that improvement in maize bread quality by sourdough fermentation is primarily due to starch granule modification which makes the dough more cohesive, soft and less elastic and improves its ability to trap and withstand the pressure of the expanding carbon dioxide during fermentation and baking.

1. Introduction

Due to the high cost of wheat importation in countries where the climatic conditions do not favour its cultivation, for example tropical and sub-tropical Africa, alternative sources of bread making flour such as maize are required (reviewed by Goodall et al. (2012)). According to FAOSTAT (2012), maize is by far the most important crop produced in Africa (about 69.6 million tons). However, the challenge is to produce bread from maize that will imitate closely the desirable qualities (high loaf volume and open crumb structure) that make wheat bread acceptable by consumers. Wheat gluten is the only protein with the proper functionality to produce high-quality breads (reviewed by Mejia et al. (2012)). This is attributed to its unique property of forming strong viscoelastic dough when hydrated (reviewed by Goodall et al. (2012)).

The use of maize in wheat-free and gluten-free bread making is not common. The few investigations have included additives such as egg and maize starch (Sanni et al., 1997), improver (S500 Actiplus, Puratos) (Brites et al., 2010), soybean flour and ascorbic acid (Edema, 2011), hydroxy propyl methyl cellulose (De la Hera et al., 2013) to aid the final quality of maize bread. The use of additives increases the cost of the final wheat-free bread (reviewed by Moroni et al. (2009)), a critical issue where consumers are food insecure. Sourdough fermentation seems to be a promising alternative to the use of additives since it is a natural and inexpensive process (reviewed by Moroni et al. (2009)). Sourdough is a mixture of flour and water that is fermented by naturally occurring lactic acid bacteria (LAB) and yeast (Hammes and Gänzle, 1998). Success has been reported in the use of sourdough fermentation on the improvement of the quality of wheat bread and some wheat-free breads (reviewed by Arendt et al. (2007), Edema et al. (2013)).

The positive effects of sourdough on the quality of wheat breads may be attributed to the direct influence of low pH on structure forming dough components such as gluten, starch and arabinoxylans (reviewed by Schober et al. (2003)). Although maize does not contain gluten, gluten-like functionality of zein (maize prolamin) dough as a result of acidification with lactic acid and acetic acid has been reported (Sly et al., 2014). The lactic acid bacteria fermentation process also acts on the other major structural component in dough, namely starch (Petrofsky and Hoseney, 1995). Edema et al.

Abbreviations: tan δ, tan delta; cfu, Colony forming units; CLSM, Confocal laser scanning microscopy; DSC, Differential Scanning Calorimetry.

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(2013) attributed the improvement in fonio dough and bread brought about by the use of a sourdough to starch modification (slight granule swelling and probably some leaching of starch molecules) to the activities of endogenous amylases from the sourdough microorganism whose activities were favoured at low pH. This present work will focus on how a sourdough fermentation process, which has proven to be effective in improving the quality of fonio bread (Edema et al., 2013), improves the quality of maize bread with particular attention to its effect on the rheological properties of maize dough.

2. Experimental

2.1. Materials

Refined maize meal (Impala Special Maize Meal, Premier Foods, Isando, South Africa) with a protein content 8.6 g/100 g (db) and a fat content 2.7 g/100 g (db) was milled into a flour using a laboratory hammer grinder (Mikro-Feinmuhle-Culatti MFC grinder, Janke and Kunkel, Staufen, Germany) fitted with a 0.5 mm opening screen. A *Lactobacillus plantarum* culture (B411) was obtained from the Council for Scientific and Industrial Research, Pretoria, South Africa.

2.2. Methods

2.2.1. Preparation of the sourdoughs and chemically acidified dough

L. plantarum sourdough was prepared by mixing maize flour (75 g) with sterile distilled water (75 ml) containing *L. plantarum* cells (9.3×10^{10} cfu/ml) in a ratio of 1:1 (w/v). The mixture was fermented at 30 °C to a pH range of 3.3–3.6 (approx. 24 h). Multiple strains starter culture fermented maize sourdough was prepared by mixing maize flour (75 g) with sterile distilled water (75 ml). The maize dough was left to ferment for 72–96 h at ambient temperature (22 °C). A portion of the fermented maize dough was used as a starter (backslopping) for a fresh mixture of maize flour and water. The mixture was fermented at 30 °C to a pH range of 3.4–3.7 (approx. 48 h). The final cell count of the *L. plantarum* fermented maize sourdough and the multiple strains starter culture fermented maize dough ('wild' sourdough) was 6.4 × 10 10 cfu/g and 8.6 × 10 10 cfu/g respectively. Chemically acidified maize dough was prepared by adding 0.1% lactic acid to the mixture of maize flour and water to pH 3.4.

2.2.2. Maize bread making and quality analysis

This was performed as described by Edema et al. (2013) with some modifications. The remaining baking ingredients per 100 g of flour were: sugar (10 g), salt (1.5 g), soft margarine (5 g) and instant dried yeast (2 g) and water (15 ml). These were added to the sourdoughs and the chemically acidified doughs and mixed together. First proofing was at 30 °C for 20 min. The maize bread dough was remixed and scooped into silicone pans (70 mm top diam and 58 mm bottom diam) to half full (47 g dough). The second proof was at 30 °C for 15 min. Baking was at 200 °C for 20 min. Bread volume was determined. Crumb structure was measured by scanning cut surfaces of the bread using a flatbed scanner. The number and size of cells was determined by using Image J software 1.42 q/Java 1.6.0_10 (32-bit), Wayne Rasband, National Institutes of Health, Bethesda, Maryland. Bread firmness was determined by using a TA-XT2 texture analyser (Stable Micro Systems, Godalming, UK) with a 20 mm radius cylinder probe (P/20 L). Pre-Test speed was 1.0 mm/s, test speed 1.7 mm/s to 40% strain.

2.2.3. Stress relaxation of the maize dough treatments

Stress relaxation was measured using a texture analyser (EZ-L, Shimadzu, Kyoto, Japan). A plastic rod (43 mm diam and 10 mm height) was used at a 25% strain to compress the maize dough for 5 s, after which the dough was allowed to relax over a period of 180 s. Relaxation time was calculated as the time required for the maximum force of compression to drop to 36.8% of its value, as described by Singh et al. (2006).

2.2.4. Maize dough rheology during baking

Strain sweep analysis was performed using a Physica MCR 101 Rheometer with Rheoplus software (Anton Paar, Ostfildern, Germany) to determine the linear viscoelastic region of the maize dough treatments prior to the temperature sweep test. Parallel plate geometry with a 25 mm diam probe and 2 mm gap between the top and bottom plate was used. The strain measured ranged from 0.01 to 100% at constant frequency of 6.3 rad/s (1 Hz) measured at 4 °C. Excess dough was removed with a spatula and paraffin oil was put at the edges of the dough to prevent it drying. Temperature sweep analysis was performed to estimate the changes that would occur in dough properties during baking. This analysis was done within the linear viscoelastic range (0.1%) of the maize dough as determined earlier by strain sweep analysis. Frequency was kept constant at 6.3 rad/s (1 Hz) and the temperature range was from 25 to 150 °C for 20 min at a heating rate of 6.25 °C/min. Excess dough was scraped off but no paraffin oil was added to the edges because it caused a bubbling effect at higher temperatures.

2.2.5. Structural properties of the maize dough treatments and maize bread

Confocal laser scanning microscopy (CLSM) (Zeiss 510 META system, Jena, Germany) with a Plan-Neofluar 10 × 0.3 objective under natural fluorescence at an excitation wavelength of 405 nm was used. Dough (<1 g) or maize bread (1 mm thick slice) was attached to a slide with double sided tape. Samples were stained with 0.5% acid magneta dye (Maeda et al., 2013). The stained samples were dried in an oven at 60 °C for 1 min. Dried samples were mounted on the stage of the CLSM and viewed. Images were captured using a micro- and macro-photography ultra-high resolution digital camera.

2.2.6. Thermal properties of the maize doughs

These were determined by Differential Scanning Calorimetry (DSC) with STARe software (HPDSC-827, Mettler Toledo, Schwerzenbach, Switzerland). Maize dough treatments were prepared as for baking but without yeast. Maize dough (45–50 mg) was weighed into a 100 µl aluminium DSC pan. Scanning was from 30 to 120 °C at a rate of 10 °C/min. Nitrogen, at normal air pressure and 50 ml/min flow rate was used. Onset (T_o), peak (T_p), conclusion gelatinization (T_c) temperatures were measured and enthalpy (ΔH) was calculated.

2.3. Statistical analyses

All experiments were performed at least twice. Results were analysed using one-way analysis of variance (ANOVA). Fisher's Least Significant Difference Test (LSD) was used to determine significant differences between the treatments at $p = 0.05$.

3. Results and discussion

3.1. Maize bread quality

Loaf height, loaf volumes and specific volume of maize breads made with sourdoughs: *L. plantarum* fermented maize sourdough or multiple strains starter culture fermented maize sourdough were significantly ($p < 0.05$) higher (by 25–26%) than maize bread