Yeast leavened banana-bread: Formulation, processing, colour and texture analysis

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**A B S T R A C T**

Banana powder (BP) was added to hard-red spring wheat (HRSW) flour intended for yeast-leavened bread formulation. Five different formulations containing 10%, 15%, 20%, 25%, and 30% BP were prepared with varying amounts of base flour, while vital gluten was maintained at 25% in all blends. Based on the added BP amounts only, the prepared bread could deliver 42.87–128.6 mg potassium/30 g of bread (one regular slice) and 0.33–1.00 g of fibre. Although the dough water absorption was increased, due to BP addition, the dough mixing tolerance (MTI) decreased. The bread loaf volume was significantly higher than the control except for the 30% blend, where the loaf volume was similar to the control. Bread staling increased with BP levels due to the high sugar content but, this effect was limited to the first two days of storage. Blends exhibited darker colour due to the high sugar and protein, while the 25% and 30% blends had the lowest percent of freezable water. The amounts of acetic acid extractable proteins from the dry blends and the dough decreased with increase in BP. The linear rheological properties of the control, 10%, and 30% blends exhibited similar viscoelastic solid behaviour, where both G' and G'' had plateaus (G' > G'') and they were parallel to each other over three decades of the frequency. Blends showed higher moduli values than the control.

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**1. Introduction**

The addition of pre-hydrated plant fibre has been reported to improve dough water absorption and also to increase the loaf volume of high-fibre bread as well (Sosulski & Wu, 1988; Pomeranz, Shogren, Finney, and Bechtel (1977) reported that the addition of various dry fibres to bread formulations increased dough water absorption, the mixing time, and decreased bread loaf volume. Addition of brewer's spent grain, a solid material remaining after absorption, the mixing time, and decreased bread loaf volume. The change in formulation was demonstrated to influence bread thermal properties. This was clearly established by differential scanning calorimetry (DSC), where the addition of soluble fibre was found to increase the melting temperature of ice in frozen bread (Mohamed et al., 2008; Vodovotz, Hallberg, & Chinachoti, 1996). A significant increase in loaf volume and specific loaf volume was observed upon the addition of water soluble non-starch polysaccharides (Rao, Manohar, & Muralikrishna, 2007). The dynamic mechanical analysis (DMA) testing of bread at very low temperatures (−70 °C) revealed various changes in viscoelastic properties (Hallberg & Chinachoti, 1992; Vittadini & Vodovotz, 2003). Freeze-dried banana pulp showed a marked cholesterol-lowering effect when incorporated into a diet at the level of 300 or 500 g/kg. The soluble and insoluble components of dietary fibre participate in the hypcholesterolaemic effect of banana pulp (Horigome, Sakaguchi, & Kishimoto 1992).
potassium-rich fruits along with raisins, orange juice, and potato skin (Young, Lin, & McCabe 1995). In 2004, the Food and Nutrition Board of the Institute of Medicine established an adequate intake level for potassium based on intake levels that have been found to lower blood pressure, reduce salt sensitivity, and minimize the risk of kidney stones. These levels were 3800 (mg/day) for children, 4700 for adults and pregnant women, and 5100 for breast-feeding (Food & Institute of Medicine. Potassium., 2004).

The objectives of this research were to develop yeast-fermented bread formulations with high banana powder content without compromising bread quality characteristics such as loaf volume, taste, and length of storage time. The possible interactions between the components of the formulation will be addressed. This product will assist consumers in meeting their daily recommended potassium intake by consuming bread.

2. Materials and methods

2.1. Materials

Freeze-dried banana (in 1/4” diced pieces) obtained from Van Drunen Farms (Momence, IL) was ground in a food processor for 5 min and sieved through 80 mesh before use. Hard-red spring wheat (HRSW) flour (Miller’s Choice) was obtained from North Dakota State Mill (Grand Forks, ND). Vital wheat gluten was obtained from Midwest Grain (Pekin, IL). Ascorbic acid was obtained from Spectrum Chemical Mfg. Corp. (Gardena, CA), α-amylase (Doh-tone) was obtained from American Ingredients (St. Louis, MO), and instant dry yeast was obtained from Fleischmann’s Yeast (Chesterfield, MO). Other bread ingredients (non-fat dry milk and Crisco shortening) were obtained from a local supermarket. The banana powder proximate analysis as described in the certificate of analysis provided by the supplier were: 4% moisture; 4.09% protein; 87.19 carbohydrates (68.9% sugars, 7.5 other carbohydrates, and 10.9% dietary fibre); 1.33 g potassium; 0.089 g magnesium. Five blends with the same amount of vital gluten were used in this research: Control (100% HRS wheat flour); 10% (10% banana, 65% flour, 25% gluten); 15% (15% banana, 60% flour, 25% gluten); 20% (20% banana, 55% flour, 25% gluten); 25% (25% banana, 50% flour, 25% gluten); and 30% (30% banana, 45% flour, 25% gluten).

2.2. Methods

2.2.1. Farinograph testing

The HRSW flour and the five blends (0%, 10%, 15%, 20%, and 30% banana powder) were tested using the Farinograph according to AACCI (2000) method No. 54–21, while moisture was determined as stated by AACCI (2000) method No. 39–06. The 10 g mixing bowl was used under standard conditions (60% absorption, 14% moisture, 500 FU consistency, and 20 min run time). The dough water absorption, mixing tolerance index (MTI), and stability parameters were calculated.

2.2.2. Baking procedure

The baking procedure was based on the modified AACCI (2000) method (10-09). The ingredients for the 35 g loaf used here were a mix of solutions and dry blends. Two solutions were prepared; 350 mg ascorbic acid in 100 ml water and α-amylase solution (105 mg α-amylase (Doh-tone) in 100 ml water). The dry ingredients were prepared by combining the following: 35 g flour (or flour/banana blend); 0.875 g (2.5%) instant dry yeast; 2.1 g (6%) shortening; 1.4 g (4%) non-fat dry milk. To the dry ingredients; 5 ml ascorbic acid solution (500 ppm) and 1 ml α-amylase solution were added. The blend was mixed in a Micro mixer (National Manufacturing, Lincoln, NE).

The water absorption, as determined by mixing and feeling the dough, was as follows: Control (100% HRSW flour) = 17.5 ml; 30% = 20 ml; 25% = 21 ml; 20% = 21 ml; 15% = 22 ml; 10% = 22 ml. These amounts were added plus the 5 ml ascorbic acid and 1 ml amylase solutions added to all samples equally. Mixing times were 6 min for the control and the 10% banana, 7 min for the 15%, 20%, and the 25% banana, while the 30% banana required 8 min mixing. During initial testing, it was found that addition of the sugar/salt solution (as specified in the AACC method) to the blends containing banana caused little or no dough development (gluten-network development) due to the elevated amount of sugar in the powdered banana (68% w/w) used in the blend. Therefore, sugar and salt were eliminated in the final formulations. The method was further modified to maximize loaf volume as follows: After dough-mixing, the different formulations were proofed for 1.5 h in baking pan without punching, rather than proofing in bowls first and punched and finally in baking pans. Formulations were baked in pre-heated oven at 425 °F for 18 min. Baking performance was done in triplicate and loaf volume was recorded according to AACCI (2000) method number 10-05.

2.2.3. Bread firmness

Bread samples were tested using TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). Although the Texture Analyzer was used, this method was based on the AACCI (2000) method number 74-09 with a 35 mm aluminum plunger and 20 mm bread-slices. Firmness testing was performed on bread loaves that were stored at 25, 4, and −20 °C for 2, 5, and 7 days using 5 kg load cell and a 6 mm cylinder probe as described by the texture analyzer manufacturer. The bread macro available in the applications software of the texture analyzer was used without modifications. The testing was performed in triplicate, and the force recorded in grams.

2.2.4. Colour analysis

After baking, bread samples were cooled and stored at room temperature in Double Zipper, Ziploc® Brand (SC Johnson, Racine, WI), for colour measurement at the same day. The L* (Lightness), a* (Redness), and b* (Yellowness) values of the crust and the crumb were measured utilizing a HunterLab LabScan XE Spectrophotometer with a D65 light source (Hunter Associates Laboratory, Inc., Reston, VA) in triplicate.

2.2.5. Differential scanning calorimetry (DSC) and freezable water

Bread samples were analyzed using a Q2000 DSC (TA Instruments, New Castle, DE). Samples (12–16 mg) were placed in hermetically-sealed aluminum pans and cooled to −80 °C using the refrigeration system connected to the DSC. The samples were then heated from −80 to 110 °C at a rate of 5 °C/min. The onset and peak temperatures were determined by the tangent method utilized by the instrument software, which minimizes error committed by the operator in determining the onset temperature. The amount of freezable water was determined from the DSC data according to the method of Vittadini and Vodovotz (2003).

2.2.6. Acetic acid protein extraction and HPLC

Doughs were ground using a coffee grinder (Coffee Grinder GX4100-11, Oceanside, NY). The grinding was done gradually with occasional stops so that to prevent temperature rise due to friction. Dry control and blends, and their ground dough samples (4 g) were dispersed in 40 ml 0.1 M acetic acid. In order to extract the acetic acid-soluble proteins from dry blends, samples were shaken for 1 h, while dough samples were shaken overnight (−14 h) using a 32-WBS-40 shaker (John-Sam, Boocheon, NJ). After extraction (shaking), samples were centrifuged at 6000×g for 30 min at 10 °C. The supernatant and the precipitate were freeze-dried sepa-
rately. The protein content of the dried precipitate and the liquid supernatant was determined using FP-528 Nitrogen Protein Analyzer (LECO, St. Joseph, MI) (Mohamed et al., 2008). The protein content was determined by multiplying the total nitrogen by a factor of 6.25.

Supernatant of acetic-acid extracted samples were filtered through a 0.45 μm syringe filter and analyzed using size exclusion HPLC (SE-HPLC HP) 1100 system (Hewlett Packard, Ramsey, MN) with automatic injection. Samples were injected (20 μl) on a Bio-Sep-SEC-S4000 column and detected at 214 nm. The eluting solvent was acetonitrile and water (1:1, v/v) containing 0.1% trifluoroacetic acid (TFA) at a flow rate of 0.5 ml/min for 60 min (Batey, Gupta, & MacRitchie, 1991).

2.2.7. Rheological measurements

Although all formulations were baked, only three out of the six blends were used for rheological testing, the control (100% HRS wheat flour); 10% (10% banana, 65% flour, 25% gluten); and 30% (30% banana, 45% flour, 25% gluten), where testing was done on 20% (wt%) suspensions. Samples were dispersed in a 0.05 M sodium phosphate buffer, pH 7.0 (25 °C) (Xu, Bietz, Felker, Carriere, & Wirtz, 2001) using Polytron PT10-35 homogenizer with a “low-foam” mixing head PTA 20TS (Kinematika AG, Switzerland). A duplicate of each sample were well dispersed and stored at 4 °C and used within 2 days. Rheological properties of the suspensions were measured using Rheometrics ARES strain-controlled fluids rheometer (TA Instruments Inc., New Castle, DE) equipped with 50 mm diameter cone-plate geometry (Xu et al., 2001). The angle of the cone was 0.04 radians. The sample chamber was placed in a humidity-controlled chamber to prevent moisture loss during runs, while the temperature was set at 25 ± 0.1 °C and controlled via a water circulation system. Prior to dynamic rheological parameter measurements, a strain-sweep experiment was conducted to confirm the linear viscoelastic range throughout the experiment. Linear viscoelasticity indicates that the measured parameters are independent of shear strains. Below 0.3% of strain, all measured materials in this study were in the linear range. Small-amplitude oscillatory shear experiments (shear strain = 0.1%) were conducted over a frequency (ω) range of 0.1–500 rad/sec, yielding the shear storage G’ and the loss G” moduli. The storage modulus represents the non-dissipative component of mechanical properties. The viscoelastic solid or “rubber-like” behavior is suggested if the G’ spectrum is independent of frequency and greater than the loss modulus over a certain range of frequency. The loss modulus represents the dissipative component of the mechanical properties and is characteristic of viscous flow. The phase shift (δ) is defined by δ = tan⁻¹(G”/G’), and indicates whether a material is solid (δ = 0), or liquid (δ = 90°), or somewhere in between. Non-linear rheological measurements were conducted as steady shear in the range of shear rate of 0.01–400s⁻¹. Each measurement was repeated at least two times with different samples, where the relative errors were all within the range of ±12%.

2.2.8. Dynamic mechanical analysis (DMA)

Samples were weighed in 25.4 x 50.8 x 3 mm stainless steel windows and put in carver press at room temperature for 10 min and 2000 lbs force (8886.5 N). The samples were removed and cut into strips and placed in torsion rectangular fixture for the TA ARES LS2 controlled strain rheometer. Each sample had different dimensions, which were recorded before testing. The samples were clamped in the fixtures using a torque wrench set at 20 cN.m. The bread samples were cooled to −60 °C and measured to as high as possible temperature before samples slipped out of grips due to change in dimensions. The temperature ramps were 2 °C/min, 0.1% strain and 1 rad/s. Storage, loss modulus, and tan δ were characterized, and the storage modulus was fitted into the Fermi Equation.

2.2.9. Statistics

The statistical analysis of the bread samples data was carried out using PROC GLM in SAS Version 8.2 for PC Windows. A completely random design (CRD) was used to compare the texture data of the control and the blends stored for 2, 5 and 7 days at 25, 4, and −20 °C. From the ANOVA, F-test value was obtained and a multiple comparison test was performed on the means, using Duncan’s Multiple Range Test at 0.05 levels.

3. Results and discussion

3.1. Farinograph testing

The presence of banana fibre dictated the addition of supplemental vital gluten intended for maintaining dough viscoelasticity. In general, fibre dilutes wheat gluten functionality for two reasons; due to its high water holding capacity as well as lack of viscoelasticity. Mixing flour and water for dough development is the most critical step of dough formation that requires exact mixing time and enough available water. The importance of dough mixing is evident in the disulphide bond formation between gluten (wheat proteins) fractions, where gluten film is formed, which is required for holding dough components together, thus forming a viscoelastic mass. Farinograph was used to determine the effect of powdered banana on the water absorption of the control flour and the mechanical properties of the formed dough. The water required for dough maximum consistency in the Farinograph was different from that needed for the dough used for baking. That is due to the presence of other ingredients beside the water and the different type of mixing used relative to the Farinograph mixing. Despite the difference in the amount of water required for dough formation, the Farinograph is an appropriate tool to test the effect of dried banana on the mechanical rheology of wheat flour. The presence of banana powder increased the Farinograph water absorption of the control by 5.2, 7.5, 10.3, 12.5, and 15.2% for the 10, 15, 20, 25, and 30% banana added, respectively. The dough mixing tolerance index (MTI) is the difference in Brabender Units (BU) between the top of the Farinograph-profile peak and 5 min later, where larger differences indicate increasing banana powder influence on the control. MTI of wheat flour had decreased in the presence of the banana powder, where MTI of the 15% banana was 37% lower than the control (46 versus 29 BU). Further increase in banana content resulted in additional decrease in MTI of the control but, there was little difference between 10 and 15% blends, in addition to insignificant differences between the 20 and 25% blends. Dough stability was reduced by 22.3% (control 21.1 min and blends 16.4 min) in the presence of banana powder. Dough stability is the difference in min between the time when the top of the curve reaches 500 BU and the time where it leaves the 500 BU. The increase in the banana content in the blends didn’t have further influence on the dough stability. The effect of the banana on the Farinograph profile of the control could be attributed to the presence of fibre and the sugars as well as the electrolytes such as potassium. The influence of these components on MTI and dough stability is due to their ability to compete with gluten for water as well as weakening the gluten network needed for dough formation. The purpose of adding vital gluten to the blends was to manage the negative influence of the banana on the dough rheology. This way, the quality of the final product, such as loaf volume and crumb quality, will be maintained. The arrival time is also one of the dough quality parameters obtained from the Farinograph testing. It is the time needed for the curve to reach the
The 30% blend loaf volume was similar to the control (Fig. 1a). The final product.

One of the good measures of wheat flour quality as well as the effect of added ingredients on the final bread quality characteristics is the bread loaf volume. Although, the addition of vital gluten to banana blends will increase cost, it was necessary to maintain bread quality. Among other components, banana powder contained around 11% fibre, 69% sugars, 4% proteins, and 1.5% fat. Due to their structure, sugars and the fibre absorb a large amount of water, consequently interfering with gluten development during dough mixing. Lack of fully developed gluten has a direct effect on dough formation, mixing time, and bread quality. The 10%, 15%, 20%, and 25% blends exhibited significantly (p < 0.05) higher loaf volume compared to the control (Fig. 1a), keep in mind that all blends had the same amount of vital gluten added to the control (25%). Therefore, blends with less banana powder showed higher loaf volume indicating positive effect of vital gluten. The 30% blend appeared to be the most comparable to the control. It is worth mentioning here, because of the high sugar content of the banana powder, sugar was eliminated from the baking formulation of the blend while it was added to the control. The presence of higher sugar content, instigated competition with vital gluten for available water, which delayed gluten development. Another reason for eliminating sugars was their effect on the colour (high sugar darker colour), texture, and taste of the final product.

3.2. Bread staling

Bread staling is one of the important characteristic of stored bread, where bread aroma becomes less desired by consumers. Staling can be quantified by determining bread texture. Amylose and amylopectin retrogradation are believed to be the main cause of staling. Monoacylglycerols complexation with amylose was found to be effective in reducing staling (Willhoft, 1971). In order to determine the effect of storage time and temperature on bread, firmness testing was done at 25, 40, and −20 °C for 2, 5, and 7 days. The time and temperature were selected to imitate supermarket’s storage conditions. The control (0% banana) exhibited higher firmness compared to the blends at all temperatures and storage time (Table 1). In addition to the increase in firmness with time, the lower temperature reduced the firmness at all storage time. The data in Table 1 also showed that higher banana powder content increased bread firmness due to the high sugar content. Elevated amounts of sugar had direct effect on water migration from other bread components, such as protein and gelatinized starch, thus causing bread stiffness. This moisture distribution and trapping by the sugars are the cause of higher firmness. Bread enriched with soluble fiber is one of the popular products in the baking industry. High soluble fibre and protein content, were found to have reduced bread firmness (Mohamed et al., 2008). The amount of banana powder added had a significant effect on bread firmness after storage, where most blends were significantly different from each other, within each temperature, except 25% and 30% blends (Table 1). Samples stored for two days at room temperature showed significantly lower firmness compared to the control, where samples with lower banana powder content exhibited lower firmness. After 5 and 7 days storage at room temperature, no significant difference in firmness was observed between blends, except the 10%, regardless of the amount of banana powder added (Table 1). At 4 °C storage, banana powder content seemed to have significant effect specially, after 5 and 7 days storage. Storage at −20 °C showed a pattern, where the 10% and 15% blends had similar firmness values, while the 20%, 25%, and 30% blends exhibited similar firmness (Table 1). The 10% blend stored at −20 °C showed the least firmness, while the greatest firmness recorded was the control stored at room temperature for 5 or 7 days.

Table 1

Bread firmness, after storage for 2, 5, and 7 days at 25, 4, and −20 °C.

<table>
<thead>
<tr>
<th>Banana (%)</th>
<th>2</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1563.0 ± 52.0 a</td>
<td>2614.0 ± 87.0 a</td>
<td>2871.0 ± 86.0 a</td>
</tr>
<tr>
<td>10</td>
<td>375.1 ± 35.1 d</td>
<td>954.9 ± 24.7 b</td>
<td>1085.0 ± 21.3 a</td>
</tr>
<tr>
<td>15</td>
<td>502.4 ± 22.3 cd</td>
<td>1016.0 ± 20.1 b</td>
<td>1266.0 ± 30.7 b</td>
</tr>
<tr>
<td>20</td>
<td>742.2 ± 28.5 bc</td>
<td>1392.0 ± 31.0 b</td>
<td>1617.0 ± 47.8 b</td>
</tr>
<tr>
<td>25</td>
<td>871.5 ± 24.6 b</td>
<td>1413.4 ± 16.3 b</td>
<td>1724.6 ± 19.5 b</td>
</tr>
<tr>
<td>30</td>
<td>887.8 ± 19.4 b</td>
<td>1530.3 ± 20.8 a</td>
<td>1754.8 ± 20.2 b</td>
</tr>
<tr>
<td>4 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1002.6 ± 89.0 a</td>
<td>1143.8 ± 23.4 a</td>
<td>1202.9 ± 18.9 a</td>
</tr>
<tr>
<td>10</td>
<td>305.1 ± 51.0 c</td>
<td>450.7 ± 9.7 d</td>
<td>484.0 ± 51.1 d</td>
</tr>
<tr>
<td>15</td>
<td>421.1 ± 81.8 c</td>
<td>580.0 ± 13.8 cd</td>
<td>629.8 ± 82.6 cd</td>
</tr>
<tr>
<td>20</td>
<td>652.3 ± 15.6 b</td>
<td>814.5 ± 26.8 bc</td>
<td>855.2 ± 26.1 bc</td>
</tr>
<tr>
<td>25</td>
<td>763.6 ± 20.4 b</td>
<td>869.3 ± 12.1</td>
<td>1007 ± 29.8 ab</td>
</tr>
<tr>
<td>30</td>
<td>821.3 ± 18.8 ab</td>
<td>996.7 ± 29.5 ab</td>
<td>1032.1 ± 30.6 ab</td>
</tr>
<tr>
<td>−20 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>275.7 ± 94.4 a</td>
<td>269.8 ± 78 a</td>
<td>300.0 ± 80.0 a</td>
</tr>
<tr>
<td>10</td>
<td>70.7 ± 19.8 b</td>
<td>79.7 ± 16.4 b</td>
<td>84.7 ± 14.4 b</td>
</tr>
<tr>
<td>15</td>
<td>101.6 ± 36.8 b</td>
<td>106.8 ± 25.9 b</td>
<td>120.3 ± 39.7 b</td>
</tr>
<tr>
<td>20</td>
<td>211.9 ± 56.7 a</td>
<td>228.5 ± 36.4 a</td>
<td>263.1 ± 65.8 ab</td>
</tr>
<tr>
<td>25</td>
<td>253.8 ± 83.0 a</td>
<td>283.9 ± 63.6 a</td>
<td>320.8 ± 86.0 a</td>
</tr>
<tr>
<td>30</td>
<td>276.1 ± 65.7 a</td>
<td>295.6 ± 62.6 a</td>
<td>332.0 ± 63.0 a</td>
</tr>
</tbody>
</table>

Predicted mean values followed by the same letter within temperature and column are not significantly different based on overlap of the 95% confidence intervals.
3.3. Colour analysis

Considering the high protein content of the blends, due to the additional vital gluten, it was expected they will be darker than the control (lower \( L^* \) value). Similarly, samples with more banana powder will be darker, due to the excess sugar in the banana powder. The bread crust data in Table 2 showed just that, where the \( L^* \) value decreased significantly and in accordance to the banana powder content, where the 30% blend was the darkest and the 10% was the least. The crust showed similar pattern with less significant differences between blends. The darkness of both, the crust and crumb, is a product of the Maillard Reaction between reducing sugars and proteins. The redness (\( a^* \)) and yellowness (\( b^* \)) of the crust was also significantly different between all samples. The redness values of the crumb significantly increased relative to the banana content, while the yellowness was not significantly different, where the 10% and 15% blends were significantly lower than the remaining blends including the control (Table 2). Unlike in the crust, this indicated the difficulty in locating regions on the crumb with major colour contrast compared to the control.

3.4. Freezable water

The percent freezable water (FW) was calculated according to Vittadini and Vodovotz (2003). The method is based on DSC analysis of bread by dividing the peak enthalpy of the water in the bread sample by the latent heat of fusion of ice. The initial moisture content of the tested bread samples was directly associated with the FW (Fig. 1b). As expected, the amount of banana powder in blends influenced the moisture content and consequently altered the %FW. The %FW value of the control was in the middle of those of the blends, despite the lower amounts of water added to the control initially during dough mixing. The 25% and the 30% blends showed the lowest %FW, while the 10% and 15%, and 20% blends were the highest (Fig. 1b). It is interesting to see the differences between samples with the same amounts of water during dough mixing display different %FW values as in blends 10% and 15% as well as 25% and 30%. The effect of the banana powder on %FW was obvious in Fig. 1b. Although, the initial excess amounts of water added to the blends compared to the control managed to increase %FW as in blends 10, 15, and 20, the increase in the amounts of banana powder brought it down as shown in blends 25% and 30% (Fig. 1b). The high sugar content of the added banana powder have interacted with the water and lowered the quantity of free water hence reducing the overall %FW of the bread. The peak temperature data of ice melting gathered from DSC profile reflected similarities between the samples, where the 10% blend as well as the control melted at \(-2^\circ C\) and the 30% blend at \(-7^\circ C\). This trend was not apparent, neither on the moisture content and the %FW nor in the bread firmness.

3.5. Acetic acid protein extraction and HPLC

Protein extractability can be used as a measure of interaction, where low extractability indicates protein interaction with other ingredients used in the formulation. A representative sample of wheat proteins can be extracted using 0.1 M acetic acid (Mohamed et al., 2008) because wheat gluten is partially soluble in acetic acid. Additionally, it is important to determine the effect of mixing on protein extractability by extracting proteins from both, dry mixes as well as dough. The amounts of proteins extracted from both, dry mixes or dough, decreased as the banana powder increased in the formulation, even though the ratio of protein:non-protein in the dry mix was kept the same by adding extra gluten. The amount of protein in the supernatant was determined and plotted against the amount of banana powder in the blends. A linear regression of the plotted data was used to show the linearity of the amount of proteins extracted from the dry mix and the dough as a function of banana powder content. The decrease in the extractable protein from the dry mixes followed a strait line with a good fit \( Y = 36.9 X - 0.68 \) \((R^2 = 0.97)\), whereas the dough had a poor fit with \( R^2 = 0.40 \) and \( Y = 39.7 X - 0.83 \). This difference could be attributed to the formation of water-insoluble aggregates as part of the gluten-network formed during mixing while gluten transformed into a viscoelastic material. Considering the extra protein added to the blends one might expect the amount of extractable protein from control to be lower than the blends, but the data presented here showed otherwise. Except for the 10 and the 15% blends, the extractable protein from the remaining blends was lower than the control.

In an attempt to show changes in protein-fractions size, the extracted proteins were analyzed using a SE-HPLC. The dough profile showed a typical wheat protein profile with different peak intensity according to the amount of protein in each sample. The first peak around 11.5 min represents the high MW glutenins followed by the low MW glutenins and finally the gliadins (Fig. 2). The SE-HPLC profile of the blends showed similar trends regarding the type of protein extracted. Although, there is similarity in the type of the extracted protein, some fractions showed more glutenins

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Table 2

<table>
<thead>
<tr>
<th>Banana (%)</th>
<th>( L^* )</th>
<th>( a^* )</th>
<th>( b^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crust</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>56.51 ± 3.7°a</td>
<td>14.83 ± 1.2 c</td>
<td>36.36 ± 1.2 a</td>
</tr>
<tr>
<td>10</td>
<td>37.85 ± 2.6 b</td>
<td>16.42 ± 0.37 a</td>
<td>27.77 ± 1.4 b</td>
</tr>
<tr>
<td>15</td>
<td>32.39 ± 2.9 c</td>
<td>15.55 ± 0.8 b</td>
<td>22.10 ± 1.9 c</td>
</tr>
<tr>
<td>20</td>
<td>28.51 ± 1.4 cd</td>
<td>13.45 ± 0.4 c</td>
<td>16.87 ± 0.6 d</td>
</tr>
<tr>
<td>25</td>
<td>25.79 ± 0.8 de</td>
<td>11.68 ± 0.3 d</td>
<td>13.20 ± 0.2 e</td>
</tr>
<tr>
<td>30</td>
<td>22.86 ± 0.3 e</td>
<td>9.27 ± 0.8 e</td>
<td>9.66 ± 0.9 f</td>
</tr>
<tr>
<td>Crumb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>66.21 ± 2.3 a</td>
<td>1.30 ± 0.7 d</td>
<td>19.88 ± 1.3 a</td>
</tr>
<tr>
<td>10</td>
<td>60.39 ± 0.5 b</td>
<td>1.28 ± 0.2 d</td>
<td>16.46 ± 0.1 b</td>
</tr>
<tr>
<td>15</td>
<td>57.91 ± 2.9 bc</td>
<td>2.14 ± 0.3 c</td>
<td>17.72 ± 0.3 b</td>
</tr>
<tr>
<td>20</td>
<td>54.40 ± 4.1 c</td>
<td>3.10 ± 0.8 b</td>
<td>19.48 ± 1.2 a</td>
</tr>
<tr>
<td>25</td>
<td>53.52 ± 3.7 c</td>
<td>3.71 ± 0.2 ab</td>
<td>19.78 ± 0.7 a</td>
</tr>
<tr>
<td>30</td>
<td>56.83 ± 1.6 bc</td>
<td>3.94 ± 0.3 a</td>
<td>20.55 ± 0.8 a</td>
</tr>
</tbody>
</table>

\( ^a L^* = \) lightness, higher values indicate lighter colour.

\( ^b a^* = \) redness.

\( ^c b^* = \) yellowness; higher colour intensity is indicated by higher values.

\( ^d \) Predicted mean values followed by the same letter within a column are not significantly different based on overlap of the 95% confidence intervals.

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Fig. 2. SE-HPLC of acetic acid extractable proteins from doughs of control and blends.
than low MW glutenins (Fig. 2). The dry mixes extraction profile did not show sharp glutenins peak, instead, a broad peak appeared (data in not shown) between 12 and 16 min and another peak with higher intensity, compared to the dough profile. The presence of the broad peak could be due to the fact that, glutenins interacted with the banana powder while in the dough, glutenins formed aggregates, which allowed easy extraction, and thus the sharp peak was present.

3.6. Rheological measurements

The profile of the strain-sweep measurements at 1 rad/s frequency for the control (0% banana), 10%, and the 30% banana, where the linear range of control was less than 1% and the linear range of the 10% and 30% suspensions was less than 0.3% as well as the remaining blends. The elastic or storage modulus ($G'$) for the 30% blend was the highest among the three blends. Although all samples had the amount of added vital gluten (25%), the high banana content of the 30% blend and the higher amount of gluten in the 10% blends are possibly the cause of the high $G'$ relative to the control. The 30% blend contains higher fibre content, while the 10% blend was higher in gluten content due to the higher wheat flour in the blend. Therefore, the high fibre content facilitated the formation of a more solid like suspension, while gluten is known to have high elasticity than the other components in the flour causing higher $G'$ of the two blends than the control. The linear rheological properties of the control, 10%, and 30% blends exhibited similar viscoelastic solid behavior (Ferry, 1980), where both $G'$ and $G''$ had plateaus ($G' > G''$) and there were parallel to each other over three decades of the experimental frequency. Blends showed higher moduli values than the control. The storage or elastic moduli ($G'$) and the phase shifts (δ) for the control were in a range of 20 to 90 Pa and 15 to 32°, respectively. The elastic moduli ($G'$) and the phase shifts (δ) for the 10% blend were in a range of 99 to 437 Pa and 15 to 31°, respectively, while the 30% blend exhibited a 212–851 Pa elastic moduli ($G'$) and the (δ) between 11 and 23° (Fig. 3a). The $G'$ and the δ values of the remaining blends (10%, 15%, and 25%) were in between the 20% and 30% blend (data not shown). These results indicated that blends exhibited stronger viscoelastic solid properties than the control, suggesting that blends should have better baking quality than the control. However, the stronger viscoelastic solid-behaviour of the blends, partially caused by the fibre in the banana, may not have the same effect on the dough system and the baking process. Therefore, blends and the control flour might have similar baking quality despite their differences in the dynamic rheology testing. This is due to the difference between the suspension system tested here and the dough system used for baking, where the solid content of the dough system is much higher than the suspension used for dynamic rheology analysis.

The non-linear shear behavior of the control and the 10% as well as 30% blends showed shear-thinning behavior (Fig. 3a). The viscosity of the blends was higher than the control, whereas the viscosity of the 30% blend was highest (Fig. 3a). The remaining blends exhibited the same shear-thinning with values between the 10% and the 30% blends (data not shown), indicating that all blends has similar viscosities but, slightly higher than the control. Because the actual industrial processing shear rates are in the range of 1 to 100 s⁻¹ (Bloksma, 1988), we could predict that, processing the control flour will require less mixing-energy than the blends due to the lower viscosities and should be easily processed. Although there were differences between the control and the blends in their rheological properties, it is reasonable to consider these differences being not substantial enough to cause changes in the final bread quality. Especially, if we consider the nutritional benefits due to the high potassium and fibre of the blends.

3.7. Dynamic mechanical analysis (DMA)

The storage moduli ($G'$) obtained from DMA measurements of the bread made from the control flour and its various blends were fitted in the glass transitions model proposed by Peleg (1993, 1994). The model equation can be written as:

$$R(T) = 1 / \{1 + \exp[(T - Tc)/a]\}$$

where $R(T)$ is stiffness ratio, $T$ is temperature, $Tc$ is temperature level which characterizes the transition region and is the inflection point of the stiffness, and a is indicator of the steepness of the curve of $R(T)$ vs. $T$ (Fig. 3b). In our cases, $R(T)$ can be expressed as $R(T) = G'/G''$ ($-30$ °C). The fitting results are shown in Table 3, where all $R^2$ of the fitting results were above 0.71. The lower $Tc$ value of the control bread relative to the blends signify slight shift of transition region to lower temperatures. The gradual drop in $G'$ of the control might imply grater heterogeneity of the control compared to the blends. Overall, the variations in stiffness between the control and the blends were minimal according to the model fit, which indicated that the properties for these breads were similar around the glass transitions region.
Table 3: Storage moduli (G') obtained from DMA testing of control bread and blends.

<table>
<thead>
<tr>
<th>Banana in bread (%)</th>
<th>Tc (°C) a</th>
<th>a (°C) b</th>
<th>Tc - a (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>−13.1 ± 0.1</td>
<td>5.0 ± 0.1</td>
<td>0.85</td>
</tr>
<tr>
<td>30</td>
<td>−15.0 ± 0.2</td>
<td>4.4 ± 0.2</td>
<td>0.80</td>
</tr>
<tr>
<td>25</td>
<td>−15.9 ± 0.3</td>
<td>4.1 ± 0.3</td>
<td>0.71</td>
</tr>
<tr>
<td>20</td>
<td>−16.3 ± 0.3</td>
<td>4.0 ± 0.2</td>
<td>0.72</td>
</tr>
<tr>
<td>15</td>
<td>−17.3 ± 0.2</td>
<td>3.8 ± 0.1</td>
<td>0.80</td>
</tr>
<tr>
<td>10</td>
<td>−18.4 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>0.81</td>
</tr>
</tbody>
</table>

a = the temperature level which characterizes the transition region and is the inflection point of the stiffness. 

b = is a indicator of the steepness of the curve of R(T) vs. T. R(T) is stiffness ratio; T is temperature.

4. Conclusions

Although it is considered specialty bread, by replacing up to 30% of the wheat flour, the final bread loaf volume was as good as or better than the control. The presence of BP increased the un-freezable water, which was reflected on the 50% reduction on bread staling as indicated by bread hardness. The rheological properties of the blends represented by Farinograph and the dynamic rheology showed that mechanical properties (Farinograph) are better predictor of the blends baking performance than dynamic rheology. This bread is a readily obtainable source for the daily recommended potassium intake per bread serving. This bread is also low in carbohydrates and higher in fibre relative to conventional bread.

Acknowledgements

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References


