Effect of Purple Sweet Potato Powder Substitution and Enzymatic Treatments on Bread Making Quality

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Specialty breads substituted with non-wheat flour like purple sweet potato have been attracting attention because of their added nutrients, flavor, and color. Although the addition of non-wheat flour to specialty breads often results in lower loaf volume, this can be improved by enzyme treatments. In this context, this study investigated the effects of purple sweet potato powder (PSPP) substitution and enzyme treatments using α-amylase and hemicellulase on gassing power (GP), gas retention of dough (GRD), color and specific loaf volume (SLV) of bread. Results showed that the addition of PSPP produces bread crumbs with light purple color but low GRD and SLV of bread. On the other hand, α-amylase and hemicellulase improved the GRD, SLV and GP of PSPP-substituted bread by degrading the damaged starch and hemicellulose. Thus, these improved properties indicate acceptable quality of the bread.

Keywords: purple sweet potato, bread making quality, α-amylase, hemicellulase, specialty bread

Introduction

Sweet potato is the sixth most important food crop in the world; more than 105 million metric tons is produced yearly (CIP¹). About 95% of its total production is from developing countries, with Asia as the largest producing region (Lu and Gao, 2011). Sweet potato is a good source of carbohydrates, dietary fiber, minerals and vitamins (Antonio et al. 2001). It is also a superior source of natural phytochemicals, such as phenolic acids, tocopherol, β-carotene and anthocyanin (Teow et al. 2007; Rumbaoa et al. 2009), which are responsible for the stable yellow, orange and purple colors of sweet potato varieties, making them a better alternative than synthetic colorants (Bovell-Benjamin, 2007). Furthermore, the stability of anthocyanin in purple-fleshed sweet potato has been confirmed at steaming and baking temperatures of 121°C and 200°C, respectively (Kim et al. 2012). Thus, purple sweet potato can be used as a natural colorant in beverages, confectioneries, and staple foods like bakery and noodle products (Hathorn et al. 2008; Montilla et al. 2011; Rosell, 2011).

Specially breads substituted with non-wheat flour have been attracting attention because of their added nutrients, flavor, and color not typically observed in plain wheat bread (Meuser et al. 1994; Brown, 1996; Brown, 1998; Dewettinck et al. 2008; Hathorn et al. 2008). However, the addition of non-wheat flour from rice, chickpea, potato, and sweet potato has resulted in inferior bread making quality due to the lack of gliadin and glutenin proteins, and the presence of damaged starch and fibers that weaken the gluten (Yamauchi et al. 2004a; Yamauchi et al. 2004b; Hathorn et al. 2008; Mohammed et al. 2012). Thus, the addition of dough enhancing ingredients or enzymes to improve bread making quality is necessary.

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Enzymes such as amylases and hemicellulases have become important in baking because they improve the quality of bread (Caballero et al. 2007). Previous studies reported that α-amylase and β-amylase catalyze the hydrolysis of amylase and amylopectin to fermentable sugars; the gas production resulting from the yeast-fermented sugars produces greater loaf volume (Macgregor et al. 2001; Gupta et al. 2003; Goesaert et al. 2009). On the other hand, hemicellulases such as xylanase have been reported to impart a slacker, softer and more viscous dough, which results in a greater bread volume because of their ability to degrade water insoluble hemicellulosins into water soluble forms and simple sugars (Jiang et al. 2005; Stojceska and Ainsworth, 2008; Schoenelechner et al. 2013).

In this study, the effect of purple sweet potato powder (PSPP) substitution and enzyme treatments using α-amylase and hemicellulase on bread making quality were examined. Furthermore, damaged starch, fiber, and ethanol-soluble sugar were analyzed in order to evaluate the relationship between these parameters and bread making quality.

Materials and Methods

Flour samples and enzymes used The commercial hard wheat flour (Camellia) and purple sweet potato powder (PSPP: Ayamurasaki Powder) used in this study were manufactured by Nissin Flour Milling Co., Ltd. (Tokyo, Japan) and Kumamoto Flour Milling Co., Ltd. (Kumamoto, Japan), respectively. Two commercial enzymes were used: α-amylase (Sumizyme AS) containing 1500 α-amylase U/g, and hemicellulase (Sumizyme SNX) containing 14,000 xylanase U/g, both manufactured by Shin Nihon Chemical Co., Ltd. (Anjo, Japan).

Dough preparation and bread making The bread-making tests were carried out using the no-time method and following the standard wheat bread formulation as the control, which is prepared from 200 g of wheat flour, 10 g of sugar (Nippon Beet Sugar Mfg. Co. Ltd., Tokyo, Japan), 10 g of shortening (Snowlight, Kaneka Corp., Osaka, Japan), 4 g of wet yeast (regular yeast, Nippon Beet Sugar Mfg. Co. Ltd., Tokyo, Japan), 4 g of deionized salt (The Salt Industry Center of Japan, Tokyo, Japan), 20 mg of ascorbic acid (Wako Pure Chemical Industries, Ltd., Osaka, Japan), and a suitable amount of water, as presented by Yamauchi et al. (2001). For the PSPP-substituted bread making treatments, 4 percent of the original wheat flour content of the control was replaced with PSPP, which is the minimum concentration that results in crumb color change. The bread treated with α-amylase and hemicellulase contained the optimum amount of 0.025 g and 0.05 g, respectively, which were determined from preliminary testing of the enzymes (data not shown). The optimal water absorption of each test was determined using a Farinograph at 500 BU according to the method used by the AACC (1991). The dough was mixed to just beyond the peak development, as indicated by the electric power curve of the mixing motor. Pieces of mixed dough (100 g and 20 g) were weighed, rounded, and incubated for 20 min (bench time) at 30°C and 75% relative humidity (RH) in a fermentation cabinet. Samples (100 g) were molded and rolled using a molding machine with 0.79 and 0.47 cm upper and lower roller clearance, respectively. The rolled doughs were panned in baking pan with 4.5x10 cm² and 6x13 cm² bottom and opening areas, respectively, and 5 cm height. The doughs were then proofed for 70 min at 38°C and 85% RH, and then baked at 180°C for 25 min. Meanwhile, 20 g samples were used for the analysis of gassing power (GP) and gas retention of dough (GRD).

Dough properties and bread evaluation GRD was evaluated by measuring the maximum expansion volume of 20 g of dough proofed at 38°C and 85% RH in a cylinder subjected to 0 to 75 cmHg as presented by Yamauchi et al. (2000). GP was measured at 30°C for 1, 2, and 3 h using a Fermograph II (ATTO Co. Ltd., Tokyo, Japan). The specific loaf volume (SLV) of bread cooled at room temperature for 1 h after baking was measured by the rapsseed-replacement method. Images of bread and bread crumb were recorded by a digital camera and a scanner, respectively. Color of the bread crust and crumb were determined using a colorimeter (CR-400; Konica Minolta Sensing, Inc., Tokyo, Japan). The moisture content of the bread crumb was measured based on the AOAC official method (AOAC, 2000).

Soluble sugar analysis Ethanol (80%)-soluble fractions of the breads were extracted to measure the sugar content and composition. The total saccharide content was determined by the phenol–sulfuric acid method as reported by Dubois et al. (1956). On the other hand, for the HPLC analysis of glucose, fructose, sucrose and maltose contents, 1 mL of the extract was diluted with an equal volume of acetonitrile, and filtered through a 0.45 µm membrane filter (Millipore Japan Co. Ltd., Tokyo, Japan). HPLC analyses of soluble sugars were performed using a Shodex Asahipak NH2P-50 4E (4.6 mm ID x 250 mm) column and RI-930 Intelligent RI detector (JASCO Corporation, Tokyo, Japan).

Fiber and damaged starch analysis Dough samples (100 g) after final proofing for 70 min at 38°C and 85% RH were divided into 90 g and 10 g portions, frozen at −40°C for 30 min using a blast freezer and stored in a freezer at −30°C until used for analysis of dough fiber and damaged starch (DS) content.

The dough samples were dried at 105°C and ground prior to fiber analysis. The neutral detergent fiber (NDF), an estimation of cellulose, hemicellulose and lignin content, and the acid detergent fiber (ADF), equivalent to the amount of cellulose and lignin, were analyzed using AOAC official methods (AOAC, 2000). Subsequently, crude hemicellulose content was estimated as the difference between NDF and ADF.

On the other hand, before DS analysis, water soluble sugars were removed by mixing 100 mg of dough with 8 mL of distilled water in a vortex mixer for 1 min and centrifuging at 2200 × g for 10 min at 20°C. Mixing and centrifugation were repeated twice, and the resulting precipitate was used for DS analysis using the

**Statistical analysis** All data except for water absorption, SLV and color values of bread were measured in triplicate. The SLV and color values of bread were measured 4 and 10 times, respectively. Bread making and physicochemical properties of dough and bread substituted with PSPP, and treated with α-amylase and hemicellulase were statistically analyzed using SPSS for Windows (ver. 17.0). ANOVA and Tukey’s multiple range test were performed to compare means at a 5% confidence level. Pearson’s bivariate test was used to evaluate the correlation of parameters.

**Results**

**Bread making quality of dough** The bread making quality of the control dough and doughs substituted with purple sweet potato powder (PSPP) and treated with α-amylase (AM) and hemicellulase (HC) is presented in Table 1. Results showed that the addition of PSPP significantly lowered GRD compared with the control and the enzyme treatments ($p < 0.05$), whereas the doughs with PSPP+AM and PSPP+HC showed similar GRD to the control. On the other hand, the PSPP+AM+HC dough had a significantly higher GRD among the bread making treatments ($p < 0.05$).

The tendency for GP to increase during the incubation of each dough varied among bread making treatments. After 1 hour of incubation, the dough with PSPP had the lowest GP. However, with increasing incubation time, the GP of the PSPP dough approached that of the control and the doughs with PSPP+AM and PSPP+HC. On the other hand, the dough with PSPP+AM+HC showed significantly higher GP than other treatments throughout all incubation periods ($p < 0.05$).

In terms of SLV, the PSPP bread was significantly lower than all other breads ($p < 0.05$).

**Bread crust and crumb properties** Table 2 summarizes the color and moisture content of breads; the results showed that the control bread crust had higher $L^*$, $a^*$ and $b^*$ values than those of other treatments except for PSPP. Similarly, $L^*$ and $b^*$ values of the control crumb were significantly higher than all bread crumbs containing PSPP. On the other hand, the $a^*$ value of the control crumb was significantly lower than the bread crumb of other treatments ($p < 0.05$).

The bread and bread crumb images are shown in Fig. 1. The PSPP bread with or without enzymes showed a darker external color compared to the control. Similarly, the crumbs of PSPP

<table>
<thead>
<tr>
<th>Bread Making Treatments</th>
<th>Water absorption (%</th>
<th>GRD</th>
<th>1h</th>
<th>2h</th>
<th>3h</th>
<th>SLV</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>68</td>
<td>95±4b</td>
<td>24.4±0.6ab</td>
<td>58.1±0.3a</td>
<td>90.9±0.4a</td>
<td>4.70±0.22b</td>
<td></td>
</tr>
<tr>
<td>+ PSPP</td>
<td>69</td>
<td>85±0a</td>
<td>23.7±0.5a</td>
<td>57.3±1.0a</td>
<td>91.7±1.3ab</td>
<td>4.09±0.17a</td>
<td></td>
</tr>
<tr>
<td>+ PSPP + AM</td>
<td>69</td>
<td>98±3b</td>
<td>24.7±0.3b</td>
<td>58.5±0.3a</td>
<td>92.1±0.3ab</td>
<td>4.65±0.18b</td>
<td></td>
</tr>
<tr>
<td>+ PSPP + HC</td>
<td>69</td>
<td>102±5b</td>
<td>24.6±0.1b</td>
<td>58.3±0.5a</td>
<td>93.2±0.6b</td>
<td>4.67±0.20b</td>
<td></td>
</tr>
<tr>
<td>+ PSPP + AM+HC</td>
<td>69</td>
<td>109±2c</td>
<td>26.5±0.2c</td>
<td>62.8±0.3b</td>
<td>99.5±0.4c</td>
<td>4.73±0.12b</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: GRD, gas retention of dough; GP, gassing power of dough; SLV, specific loaf volume; PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

$^{1}$/Each value, except for water absorption is the mean ± SD. The values followed by different letters within column are significantly different ($p < 0.05$).

<table>
<thead>
<tr>
<th>Bread Making Treatments</th>
<th>Bread crust color</th>
<th>Bread crumb color</th>
<th>Moisture Content of crumb$^{2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>44.42±0.95 c</td>
<td>15.84±0.15 c</td>
<td>28.23±0.92 d</td>
</tr>
<tr>
<td>+ PSPP</td>
<td>43.30±2.03bc</td>
<td>15.33±0.30bc</td>
<td>25.71±1.67cd</td>
</tr>
<tr>
<td>+ PSPP + AM</td>
<td>40.42±1.94ab</td>
<td>14.84±0.06ab</td>
<td>23.07±1.69bc</td>
</tr>
<tr>
<td>+ PSPP + HC</td>
<td>38.56±1.48 a</td>
<td>14.54±0.41 a</td>
<td>20.99±1.61ab</td>
</tr>
<tr>
<td>+ PSPP + AM+HC</td>
<td>37.70±2.14 a</td>
<td>14.38±0.53 a</td>
<td>19.67±2.44 a</td>
</tr>
</tbody>
</table>

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

$^{1}$/Each value is the mean ± SD. The values followed by different letters within column are significantly different

$^{2}$/Moisture content of crumb stored 1 day after baking.
breads had light purple color and differed from the white crumb of the control. The bread with PSPP alone appeared to be smaller than the control, whereas the breads with PSPP and enzyme treatments were either the same size or larger than the control.

**Bread soluble sugar content**

Table 3 shows the soluble sugar contents of breads. Significant differences in all treatments were observed among the means of glucose and fructose contents ($p < 0.05$). The bread with PSPP+AM+HC showed the highest glucose and fructose contents: $8.11 \pm 0.14$ mg/g bread and $12.61 \pm 0.10$ mg/g bread, respectively, whereas the control had the lowest

<table>
<thead>
<tr>
<th>Bread Making Treatments</th>
<th>Glucose (mg/g bread)</th>
<th>Fructose (mg/g bread)</th>
<th>Sucrose (mg/g bread)</th>
<th>Maltose (mg/g bread)</th>
<th>Total Sugar (mg/g bread)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5.01±0.11a</td>
<td>8.79±0.06 a</td>
<td>0.28±0.05 a</td>
<td>17.75±0.21 a</td>
<td>48.02±1.02 a</td>
</tr>
<tr>
<td>+ PSPP</td>
<td>6.13±0.13 b</td>
<td>9.79±0.18 b</td>
<td>0.46±0.05 b</td>
<td>23.66±0.14 b</td>
<td>62.35±0.80 b</td>
</tr>
<tr>
<td>+ PSPP+AM</td>
<td>6.82±0.11c</td>
<td>10.87±0.07 c</td>
<td>0.57±0.07 b</td>
<td>35.07±0.45 c</td>
<td>73.26±3.23 cd</td>
</tr>
<tr>
<td>+ PSPP+HC</td>
<td>7.28±0.15d</td>
<td>11.84±0.25d</td>
<td>0.49±0.04 b</td>
<td>35.56±0.58 c</td>
<td>68.90±0.70 c</td>
</tr>
<tr>
<td>+ PSPP+AM+HC</td>
<td>8.11±0.14e</td>
<td>12.61±0.10 e</td>
<td>0.61±0.06 b</td>
<td>41.81±0.11 d</td>
<td>77.02±1.13 d</td>
</tr>
</tbody>
</table>

Abbreviations: PSPP, purple sweet potato powder; AM, $\alpha$-amylase; HC, hemicellulase

1) Each value is the mean ± SD. The values followed by different letters within column are significantly different ($p < 0.05$).

**Table 4. Fiber and damaged starch content of doughs**

<table>
<thead>
<tr>
<th>Bread Making Treatments</th>
<th>NDF (%)</th>
<th>ADF (%)</th>
<th>NDF-ADF&lt;sup&gt;2)&lt;/sup&gt; (%)</th>
<th>DS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.94±0.08 ab</td>
<td>0.28±0.10</td>
<td>0.66±0.04 bc</td>
<td>3.96±0.03 c</td>
</tr>
<tr>
<td>+ PSPP</td>
<td>1.15±0.03 c</td>
<td>0.36±0.02</td>
<td>0.78±0.02 c</td>
<td>4.13±0.19 d</td>
</tr>
<tr>
<td>+ PSPP+AM</td>
<td>1.09±0.03bc</td>
<td>0.30±0.08</td>
<td>0.79±0.06 c</td>
<td>2.87±0.14 b</td>
</tr>
<tr>
<td>+ PSPP+HC</td>
<td>0.81±0.07 a</td>
<td>0.32±0.12</td>
<td>0.50±0.07 a</td>
<td>2.98±0.04 b</td>
</tr>
<tr>
<td>+ PSPP+AM+HC</td>
<td>0.94±0.05 ab</td>
<td>0.30±0.07</td>
<td>0.64±0.05 b</td>
<td>2.54±0.03 a</td>
</tr>
</tbody>
</table>

Abbreviations: NDF, neutral detergent fiber; ADF, acid detergent fiber; DS, damaged starch; PSPP, purple sweet potato powder; AM, $\alpha$-amylase; HC, hemicellulase

1) Each value is the mean ± SD. The values followed by different letters within column are significantly different ($p < 0.05$).

<sup>2</sup>NDF-ADF: crude hemicellulose content
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(\( p < 0.05 \)). Moreover, the control contained the lowest sucrose content of 0.28 ± 0.05 mg/g bread among all treatments.

In terms of maltose, the control had a significantly lower content of 17.75 ± 0.21 mg/g bread than all other treatments. Bread with PSPP had 23.66 ± 0.14 mg/g bread, which is higher than the control but lower than the enzyme-treated breads. Breads with PSPP+AM and PSPP+HC had 35.07 ± 0.45 and 35.56 ± 0.58 mg/g bread, respectively. The highest maltose content was observed in the PSPP+AM+HC bread at 41.81 ± 0.11 mg/g bread.

For total sugars, the PSPP bread had higher content than the control. Enzyme treatment of the PSPP bread further increased the total sugar content. The PSPP+AM+HC bread had a higher total sugar content than the PSPP+HC bread but was not significantly different from PSPP+AM at \( p < 0.05 \).

Fiber and starch damage contents of dough Table 4 shows the fiber composition and damaged starch content of doughs from different treatments. Results showed that the neutral detergent fiber (NDF) and crude hemicellulose (NDF-ADF) contents of PSPP and PSPP+AM doughs were significantly higher than the control, PSPP+HC and PSPP+AM+HC doughs. Meanwhile, the ADF content of the doughs from all treatments did not significantly differ.

The dough treated with PSPP+AM+HC had the lowest DS at 2.54 ± 0.03%. The DS of PSPP+AM and PSPP+HC doughs was significantly lower than the control and PSPP doughs. The control had a lower DS of 3.96 ± 0.03% than the PSPP dough (4.13 ± 0.19%), but was significantly higher than the enzyme-treated doughs (\( p < 0.05 \)).

Discussion

Bread making quality of dough The low GRD and SLV of bread with PSPP can be attributed to the lack of gluten protein and relatively higher fiber and damaged starch contents (Tables 1, 4 and Fig. 1). These properties of PSPP disrupt formation of the gluten network, resulting in a weaker gluten network for bread containing sweet potato flour (Hathorn et al. 2008). The improved GRD and SLV of the PSPP+AM bread in comparison with the PSPP bread can be explained by the \( \alpha \)-amylase hydrolysis of damaged and gelatinized starch to maltose and dextrin, as evidenced by the increased maltose content of the PSPP+AM bread (Table 3). These results agree with the report of Kim et al. (2006) wherein SLV decreased when the bread was substituted with polished wheat flour high in fiber and damaged starch contents; SLV increased upon the addition of \( \alpha \)-amylase. A similar observation was reported by Patel et al. (2012) on the improvement in specific volume of chemically leavened bread treated with fungal \( \alpha \)-amylase.

Likewise, hemicellulase catalyzes the degradation of polysaccharides including glucans, galactans, mannans, pentosans and xylans, into mono-sugars and short chain saccharides such as glucose, galactose, mannose, arabinose, xylose, xylobiose and xylotriose, which do not disturb the gluten network formation (Jiang et al. 2005). This catalytic activity may have caused the higher GRD and SLV of the bread with PSPP+HC compared to the PSPP bread. The same improvement in SLV after adding xylanase, a kind of hemicellulase enzyme, to whole wheat and millet/wheat composite breads was observed by Shah et al. (2006) and Schoenlechner et al. (2013), respectively.

A significant increase in GRD of PSPP+AM+HC over other treatments, including the control, was due to the decreased content of damaged starch and hemicellulose by the combined catalytic activity of \( \alpha \)-amylase and hemicellulase (Tables 1 and 4). The increase in mono-sugars from the \( \alpha \)-amylase and hemicellulase hydrolytic activities, as reported by Goesaert et al. (2009) and Jiang et al. (2005), respectively, promotes yeast fermentation and may have resulted in significant improvement in GP of the PSPP+AM+HC dough in all incubation periods (Tables 1 and 3).

Ultimately, the GP of doughs at all incubation periods was significantly correlated (\( p < 0.05 \)) with GRD; the Pearson’s correlation coefficients ranged from 0.749- 0.817. This suggests that an increase in GP results in an increase in GRD. Similarly, GRD and SLV were significantly correlated (\( r = 0.772 \)).

Bread color and appearance The addition of PSPP resulted in a darker bread crust compared with the control. Likewise, individual and combined treatments of \( \alpha \)-amylase and hemicellulase also resulted in a darker color compared with the control and PSPP, evidenced by the lower L* values and images (Table 2 and Fig. 1, respectively). Similarly, the addition of enzymes decreased the values of redness and yellowness, indicated by the lower a* and b* values shown in Table 2. These color changes can be attributed to the increased concentration of reducing sugars, i.e., glucose, fructose, and maltose (Table 3), which promote the Maillard reaction, resulting in the intensification of bread flavor and browning (Goesaert et al. 2009).

The darker bread crumb color with PSPP addition can be attributed to the natural dark purple color of the anthocyanin pigments (Kano et al. 2005; Montilla et al. 2011; Ray et al. 2011). Similarly, the purple color of PSPP also influences the change in crumb color from white to light purple, as verified by the increase in redness and the decrease in yellowness.

Bread soluble sugar content Higher glucose, fructose and total sugar contents of the PSPP bread compared with the control can be associated with the inherent sugar content of purple sweet potato powder (Antonio et al. 2011). On the other hand, the additional glucose, fructose and total sugar contents in the breads treated with enzymes may have resulted from the catalytic activity of \( \alpha \)-amylase and hemicellulase (Caballero et al. 2007; Goesaert et al. 2009). In addition, the invertase enzyme of yeast may have catalyzed the conversion of sucrose in PSPP to glucose and fructose (Caballero et al. 2007). Moreover, sucrose, which is the most abundant sugar in raw sweet potato, contributed to the increase in sugar content of the PSPP bread with or without
enzymes (Antonio et al. 2011).

On the other hand, the high maltose content of the PSPP bread could be caused by the catalytic activity of β-amylase, which is naturally present in wheat flour and sweet potato and results in hydrolysis of damaged or gelatinized starch to maltose and glucose (Lu and Gao, 2011). Moreover, the high maltose content observed in the PSPP+AM and PSPP+AM+HC breads may have been caused by the catalytic activity of α-amylase, which hydrolyzes gelatinized starch to maltose and dextrins (Goesaert et al. 2009). Likewise, the high maltose content of the PSPP+HC bread can be attributed to the amylase activity of the crude hemicellulase used in this study.

Fiber and damaged starch contents of dough The total fiber content of the control bread originated from the wheat flour used for baking. The high NDF and crude hemicellulose (NDF-ADF) contents of doughs from PSPP and PSPP+AM treatments (Table 4) can be attributed to the inherent fiber content of sweet potato, which generally contains about 3% dietary fiber (Antonio et al. 2011). On the other hand, the xylanase activity of the hemicellulase used, which catalyzes the hydrolysis of hemicelluloses like xylan, arabinoxylan to xylobiose and xylose (Jiang et al. 2005), may have resulted in the low NDF and crude hemicellulose (NDF-ADF) contents of PSPP+HC and PSPP+AM+HC doughs.

The DS content of the control dough can be associated with the DS contained in the wheat flour after milling. The higher DS of the PSPP dough compared with the control was brought about by the high level of damaged starch of 54% (data not shown) contained in PSPP, which is an indication of damage caused by heat treatment during preparation.

In contrast, the lower DS of the PSPP+AM and PSPP+HC doughs compared with PSPP and control in Table 4 seems to be the result of the amylase activity. Moreover, the combined activity of crude α-amylase and hemicellulase in the PSSP+AM+HC dough produced a significantly lower DS than PSPP+AM and PSPP+HC doughs (Table 4). The α-amylases in these crude enzymes catalyze the degradation of damaged and gelatinized starch to soluble sugars, as verified by the increase in glucose, maltose and total sugar contents of breads, which were inversely correlated with DS (correlation coefficients of $-0.850$, $-0.938$ and $-0.826$, respectively, at $p < 0.05$).

Finally, the NDF of the dough was inversely correlated with SLV ($r = -0.695$) and GRD ($r = -0.657$) at $p < 0.05$. Similarly, the DS of dough was inversely correlated with SLV ($r = -0.634$), GRD ($r = -0.845$) and GP at all incubation periods ($r = -0.762$ to $-0.689$). These findings indicate that the decrease in fiber and damaged starch contents improves GP, GRD and SLV of the bread treated with α-amylase and hemicellulase.

Conclusion Substitution with PSPP in bread results in light purple color, attributable to the intrinsic anthocyanin content. However, this also results in low GRD and SLV, making the bread inferior to pure wheat bread, and is related to the lack of gluten protein as well as high damaged starch and fiber contents of PSPP.

On the other hand, the addition of α-amylase and hemicellulase to the PSPP dough improved the GRD, GP and SLV of the resultant bread. These improvements were mainly brought about by the degradation of damaged starch and hemicellulose into mono-, di- and oligo-saccharides, which do not interfere with formation of the gluten network during bread dough development. Thus, PSPP substitution and enzyme treatments result in bread with light purple color and of acceptable quality. However, direct effects of α-amylase and xylanase in the crude hemicellulose on gluten-starch and gluten-pentosan interaction were not investigated in this study.

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