GlutoPeak method improvement for gluten aggregation measurement of whole wheat flour

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\textbf{ABSTRACT}

A shear-based device, the GlutoPeak, was developed to measure the aggregation behavior of gluten. In this study, the GlutoPeak testing method was improved and applied for the gluten aggregation evaluation of whole wheat flour (WWF) of different particle size ranges. The sample/solvent weight ratio, mixing speed, and testing temperature were adjusted to different levels for obtaining more repeatable Peak Maximum Time (PMT) and Maximum Torque (MT) using two commercial WWF samples. The temperature had a greater effect on the repeatability of the PMT, while the sample/solvent weight ratio and mixing speed had lower impact on the repeatability of both PMT and MT. Another four commercial wheat samples were milled to WWFs of different particle size ranges. The gluten aggregation of the WWF was measured using the improved GlutoPeak parameters, which were 8-g WWF and 10-g 0.5 mol/L CaCl\textsubscript{2} solvent with a mixing speed of 3000 rpm and test temperature of 20°C. The PMT significantly decreased (with the exception of SW) and MT significantly increased with a decrease of WWF particle size. Compared to the Mixolab and Farinograph tests, the GlutoPeak method took less time and provided significantly different results for WWFs of different particle size ranges.

\textbf{1. Introduction}

Whole wheat flour (WWF) is milled from the whole grain kernel that contains bran, germ, and endosperm, thus, it provides a highly nutritious and inexpensive source of protein, carbohydrates, dietary fiber, and various minerals. Considerable scientific research has confirmed the positive effects of WWF products intake on human health (Liu, 2007; Okarter & Liu, 2010). United States Department of Agriculture (USDA) recommends that Americans should consume at least half of their grains as whole grains (USDA, 2015), and outlines the whole grain-rich criteria for national school meals (USDA, 2016). Along with the increasing health awareness of consumers and recommendations of scientists, a large market demand for various WWF-based products is expected in the near future (USDA, 2015; Zong, Gao, Hu, & Sun, 2016).

One of the major challenges of WWF application is the influence of wheat bran, which results in changes in dough rheological properties, and further affects the qualities of food products (Cai, Choi, Hyun, Jeong, & Baik, 2014; Niu, Hou, Lee, & Chen, 2014; Steglich, Bernin, Moldin, Toppgaard, & Langton, 2015; Wang, Hou, Kweon, & Lee, 2016). Many studies have been conducted to reduce the influence of bran in products by adding vital wheat gluten, enzymes, and adjusting the particle size of bran (Katina, Salmenkallio-Marttila, Partanen, Forsell, & Autio, 2006; Penella, Collar, & Haros, 2008). Compared to other methods, adjusting the particle size of bran is more natural and cost effective.

Several rheological instruments, such as the Mixograph, Mixolab and Farinograph, have been developed and applied to dough systems (Huang et al., 2010; Koksel, Kahraman, Sanal, Ozay, & Dubat, 2009; Manthey & Schorno, 2002; Vizitiu & Danciu, 2011). However, it is difficult for these instruments to detect meaningful differences in dough rheological properties for WWFs of different bran particle size ranges. Previous studies reported no significant effects of bran particle size regarding water absorption in the Farinograph (Noort, van Haaster, Hemery, Schols, & Hamer, 2010; Zhang & Moore, 1997), and dough development time in Mixograph (Cai et al., 2014) and Mixolab (Liu, Hou, Lee, Marquart, & Dubat, 2016) of WWFs.

Recently, a new technique has been investigated as a more efficient and rapid predictor of wheat flour functional quality (Chandi & Seetharaman, 2012; Marti, Cecchini, D’Egidio, Dreisoerner, & Pagani, 2014; Melnyk, Dreisoerner, Bonomi, Marcone, & Seetharaman, 2011).
The GlutoPeak is a rapid shear-based device that measures the aggregation behavior of gluten for evaluation of wheat flour quality. By mixing appropriate amounts of flour and solvent at a certain speed, gluten is separated by the paddle rotation, resulting in aggregation. At this point the gluten aggregate mass exerts a resistant force on the paddle resulting in the generation of a torque curve. The curve records the complexity of aggregation and breakdown of the gluten by providing Peak Maximum Time (PMT, in min) and the Maximum torque (MT, in Brabender equivalents, BE). High sensitivity, short analysis time and small sample testing requirements are key features that make the GlutoPeak method valuable to flour quality evaluation. In a recent study, GlutoPeak PMT was proposed as an alternative approach to mixograph and gluten index tests to evaluate the gluten strength of durum wheat (Sissons, 2016).

Various settings for the GlutoPeak test including the sample to solvent weight ratio (8 g/10 g–9.4 g/8.6 g), solvent type (water, CaCl₂), mixing speed (1900 to 3000 rpm), and testing temperature (35–45 °C) were used in previous researches (Marti, Augst, Cox, & Koehler, 2015; Melnyk, Dreisoerner, Marcone, & Seetharaman, 2012; Melnyk et al., 2011) for different varieties and protein contents of wheat flour. Melnyk et al. (2011) studied the influence of the Hofmeister series on gluten aggregation, and recommended calcium chloride (CaCl₂) as the solvent due to its significant reduction in time to gluten aggregation. Chandi and Seetharaman (2012) studied the gluten aggregation of refined and whole wheat flours (WWFs) by adjusting the testing parameters of the GlutoPeak and found a significant influence of flour–solvent interaction on MT. There was no significant influence of flour weight and mixing speed for WWFs. However, the relatively minor adjustments of the GlutoPeak testing parameters limited the opportunity to find a better setting. Also, there was no report on the repeatability of the test results, which could significantly influence the evaluation of the gluten aggregation properties of WWFs of different particle size ranges.

The objective of the current study was to improve the GlutoPeak method for detecting the gluten aggregation of WWFs of different particle size ranges. The influences of sample/solvent weight ratio, mixing speed, and test temperature on the repeatability (as judged by the coefficient of variation) of PMT and MT were examined and evaluated. The same set of WWF samples was also measured using the Mixolab and Farinograph for comparison with the measurement of the improved GlutoPeak method.

2. Materials and methods

2.1. Materials

Two commercial WWF samples: hard red spring (13.8 g/100 g protein, 1.6 g/100 g ash, and 32.1 g/100 g wet gluten content based on 14 g/100 g mb) was purchased from the Archer Daniels Midland Company (Chicago, IL, USA); ultrafine soft white (9.7 g/100 g protein, 1.5 g/100 g ash, and 21.6 g/100 g wet gluten content based on 14 g/100 g mb) was purchased from the Ardent Mills (Denver, CO, USA). Commercial grain samples of hard white (HW), hard red winter (HRW) and hard red spring (HRS) were described by Liu et al. (2016), and soft white (SW) was described by Wang et al. (2016).

2.2. Preparation of WWFs

The preparation procedures of HW-, HRS- and HRW-WWFs of different particle sizes were described by Liu et al. (2016), and SW-WWF of different particle sizes was outlined by Wang et al. (2016). Wheat samples were milled on a pilot-scale Maig Mulumat mill (Buhler, Inc. Braunschweig, Germany) to obtain straight-grade (SG) flours, and bran, shorts and red dog fractions. The attached flour from the bran and shorts fractions was dusted off by a laboratory bran finisher (Model MLU-302, Buhler, Inc., Braunschweig, Germany). The obtained clean bran and shorts fractions were separately ground 1 to 4 times using a Perten 3100 laboratory mill (Perten Instruments, Hagersten, Sweden). Since the particle sizes were similar for samples ground 3 and 4 times, the two were mixed as the 4th grinding pass sample. For the HW, HRS and HRW, bran and shorts of the 4th grinding pass were pre-ground in a blender (Vitamix Corporation, Cleveland, OH) prior to the 5th grinding to obtain finer particle sizes. The bran-dusted flour, short-dusted flour, red dog fraction, and SG flour were then blended with the non-ground, 1st, 2nd, 4th, and 5th (no 5th in SW) grind bran and shorts fractions, respectively, to make the WWF-0, 1, 2, 4 and 5 for HW, HRS and HRW, and WWF-0, 1, 2 and 4 for SW.

The particle size distribution of WWF was measured by a Ro-Tap testing sieve shaker (WS Tyler Incorporated, USA), and the median particle diameter was calculated as described in Penella et al. (2008).

2.3. Gluten aggregation testing in GlutoPeak

The gluten aggregation test was performed using the GlutoPeak (Brabender GmbH & Co. KG, Duisburg, Germany) equipped with a refrigeration and heating circulator (Julabo Inc, PA, USA). During operation, the testing chamber was first heated or cooled to a targeted temperature by the circulator. Weight of flour and solvent, test time (3 min) and mixing speed, and sample moisture content were entered into the parameter window of GlutoPeak program. WWF sample and solvent (0.5 mol/L CaCl₂ solution) were weighed separately and put together in the test cup, then mixed with the pre-defined mixing speed. The MT and PMT were recorded for evaluating the gluten aggregation of WWF sample.

As shown in Fig. 1, three stages of gluten aggregation testing of WWFs were conducted in this study. In the first stage, HW-, HRS-, HRW- and SW-WWF samples, which were prepared at the Wheat Marketing Center, were tested by using the recommended settings as reported by Chandi and Seetharaman (2012): 8.5-g WWF, 9.5-g 0.5 mol/L CaCl₂ solvent, 24 °C test temperature and 1900 rpm mixing speed. All measurements were conducted in three replicates in the first stage. In the second stage, two commercial WWFs (Hard Red Spring and Soft White) were selected for the improvement of the test parameters. Testing started with the following settings: 8-g WWF sample, 10-g solvent (0.5 mol/L CaCl₂), test temperature of 34 °C, and mixing speed of 1900 rpm. First, the test temperature was adjusted to 20, 25, 30 and 34 °C without changing the other parameters. Second, the test temperature that provided the most repeatable PMTs and MTs was selected, and the mixing speed was adjusted to 1,500, 1,900, 2500 and 3000 rpm without changing the flour/solvent weight ratio. With the confirmed appropriate test temperature and mixing speed, the flour/solvent weight ratio was adjusted to 7.5 g/10.5 g, 8 g/10 g and 8.5 g/9.5 g to identify the appropriate amount of flour and solvent. All measurements were conducted in five replicates in the second stage.

In the third stage, the MT and PMT of HW-, HRS-, HRW- and SW-WWF samples were measured following the improved parameters identified in the second stage. All measurements were conducted in three replicates in the third stage.

2.4. Measurement of WWF using the Mixolab and Farinograph

The rheological behaviors of WWF were measured using the Mixolab and Farinograph to compare with the gluten aggregation properties using the GlutoPeak. The test times of Mixolab and Farinograph are usually longer than 10 min. AACC International Approved Method 54–60.01 was used for the analyses of WWF in the Mixolab (Chopin Technologies, Villeneuve-la- Garenne, France). The CI time, which represents the time for the dough to reach the maximum torque, was recorded (Huang et al., 2010). A Farinograph E (C.W. Brabender Instrument Inc., South Hackensack, NJ, USA) equipped with a 50-g mixing bowl was used to measure the dough development time according to the AACC International Approved Method 54–21.02.
2.5. Statistical analyses

In this study, we were especially interested in obtaining repeatable results with selective parameter settings of GlutoPeak. Thus, coefficient of variation (CV) was used to compare with each other instead of using other optimization designs such as response surface methodology, which assumes the variation of each point is equal across the design space. The repeatability of PMT and BT in stages 2 and 3 was evaluated by comparing the CVs. ANOVA was used to analyze the effects of particle size on the gluten aggregation parameters from the GlutoPeak (in Stages 1 and 3) and dough rheological properties from the Mixolab and Farinograph. Tukey's HSD test was applied for pair-wise comparison of the effects of different particle sizes. The significance level P was set as 0.05. All statistical analyses were conducted using SPSS software (SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1. The median particle sizes of WWFs

The mass median particle size of WWFs of HW, HRS, and SW was significantly (p < 0.05) reduced with the increased number of grinding passes. From the non-ground to the 5th (WWF-0 to WWF-5) grinding pass (4th for SW), the median particle diameters for HW were 175.7 ± 1.5, 128.6 ± 0.4, 120.0 ± 0.7, 108.5 ± 1.1, and 102.4 ± 0.7 μm; for HRW were 173.7 ± 2.0, 133.6 ± 1.0, 124.3 ± 0.7, 110.8 ± 0.1, and 104.2 ± 0.2 μm; for HRS were 173.7 ± 0.9, 132.1 ± 0.8, 124.7 ± 0.3, 112.9 ± 0.6 and 106.3 ± 0.3 μm, and for SW were 172.4 ± 0.2, 120.2 ± 2.2, 103.4 ± 1.1 and 90.3 ± 0.3 μm, respectively. The median particle diameters of the commercial Hard Spring and Soft White WWFs were 157.1 ± 0.9 μm and 98.9 ± 0.7 μm, respectively.

3.2. The gluten aggregation properties measured by the first stage GlutoPeak method

The gluten aggregation properties of the four WWFs were measured using the recommended settings by Chandi and Seetharaman (2012). The decreasing trends of PMT and increasing trends of MT were observed for all samples (Fig. 2). However, the large deviations of PMT and MT resulted in no significant differences (p > 0.05) from WWF-1 to WWF-5 of HW, HRS and HRS, and WWF-0 to WWF-4 of SW. One possible explanation was that both the presence of wheat bran and its large particle size could influence the gluten aggregation and water absorption of the slurry (Goldstein, Ashrafi, & Seetharaman, 2010), which resulted in an unstable buildup in dough consistency. Therefore, it was impossible to use the GlutoPeak settings of Chandi and Seetharaman (2012) to evaluate differences in the gluten aggregation properties of WWFs of different particle sizes.

3.3. The gluten aggregation properties measured by the second stage GlutoPeak method

The effect of test temperature on the repeatability of gluten aggregation of the commercial hard red spring and soft white WWFs was first investigated. The mean values of PMT and MT indicated that both of them increased with the increased test temperature (Table 1). The aggregation of gluten proteins was strongly temperature dependent (Morel, Redl, & Guilbert, 2002). The higher the temperature, the more energy was added into the system, which resulted in a shorter time (PMT) for the aggregation of gluten. The coefficient of variation (CV) was used to evaluate the reproducibility of the results with different testing parameters (Wang, Dupuis, & Fu, 2017). The CV values indicated that the test temperature greatly influenced the repeatability of the PMT. The results of commercial hard red spring-WWF showed that the highest CV of PMT was 6.41% with the test temperature at 34 °C, while the lowest CV was 2.27% with the testing temperature at 20 °C. The CV of PMT at 30 °C was 4.41%, which was lower than 25 °C but still much higher than 20 °C. The CVs of MT ranged from 2.13% to 2.72%, thus, the test temperature had little influence on the repeatability of the MT. The results of commercial soft white WWF indicated that the CV of both PMT and MT was the highest at 34 °C, and the lowest at 20 °C. Therefore, a test temperature of 20 °C was appropriate for both hard red spring and soft white WWFs.

The effect of mixing speed was studied by increasing the mixing speed from 1500 to 3000 rpm with a test temperature of 20 °C and flour/solvent weight ratio of 8 g/10 g. As expected, increasing the mixing speed accelerated gluten aggregation and increased the resistance on the paddle, which manifested as decreased PMT and increased MT for both commercial hard red spring and soft white WWFs (Table 1). Similar results were found for two Canada Western Red Spring (Glenn and Unity) wheat flours (Wang et al., 2017). The highest CVs of both PMT and MT were observed at a mixing speed of 1500 rpm for the two commercial WWFs. All the CVs of PMT and MT at mixing speeds of 1,900, 2,500, and 3,000 rpm were relatively small, and no significant differences (p > 0.05) were found among them. One possible reason was that the increased mixing speed accelerated the mixing of bran, flour and solvent, which promoted a more uniform distribution. The increased uniformity contributed to the reduction of testing deviation that yielded more repeatable results. Thus, any of the three
Mixing speeds at 1,900, 2,500, and 3000 rpm is recommended to obtain repeatable results. From an efficiency point of view, the PMT exhibited the smallest value (i.e., shortest test time) at a testing speed of 3000 rpm, and this speed was selected for further research accordingly.

The effect of the flour/solvent weight ratio was studied by adjusting the weight of flour and CaCl₂ solution to 7.5 g:10.5 g, 8 g:10 g and 8.5 g:9.5 g with a fixed test temperature of 20 °C and a mixing speed of 3000 rpm as discussed above. By increasing the flour and decreasing the solvent (water and CaCl₂) weight, the PMT decreased and MT increased for the two commercial WWFs (Table 1). More flour and less solvent resulted in a higher concentration of gluten, which provided more material to develop a larger gluten aggregate. The flour/solvent ratio of 7.5 g:10.5 g for the commercial hard red spring WWF had the highest CV for PMT and lowest CV for MT. Thus, even though the MT result at 7.5 g:10.5 g was better than at other flour/solvent ratios, the high CV for PMT limited the application of this ratio. Similar low CVs for PMT and MT were found for flour/solvent ratios at 8 g:10 g and 8.5 g:9.5 g, thus both ratios were considered suitable for the

**Table 1**

Gluten aggregation of commercial hard red spring and soft white WWFs (five replicates) measured by GlutoPeak using different settings.a

<table>
<thead>
<tr>
<th>GlutoPeak Setting</th>
<th>Commercial Hard Red Spring Whole Wheat Flour</th>
<th>Commercial Soft White Whole Wheat Flour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PMT (s)</td>
<td>CV (%)</td>
</tr>
<tr>
<td>Temp (°C)</td>
<td>Speed (rpm)</td>
<td>Flour/CaCl₂ (g/g)</td>
</tr>
<tr>
<td>20</td>
<td>1900</td>
<td>8/10</td>
</tr>
<tr>
<td>25</td>
<td>1900</td>
<td>8/10</td>
</tr>
<tr>
<td>30</td>
<td>1900</td>
<td>8/10</td>
</tr>
<tr>
<td>34</td>
<td>1900</td>
<td>8/10</td>
</tr>
<tr>
<td>20</td>
<td>1500</td>
<td>8/10</td>
</tr>
<tr>
<td>20</td>
<td>1900</td>
<td>8/10</td>
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<tr>
<td>20</td>
<td>2500</td>
<td>8/10</td>
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<tr>
<td>20</td>
<td>3000</td>
<td>8/10</td>
</tr>
<tr>
<td>20</td>
<td>3000</td>
<td>7.5/10.5</td>
</tr>
<tr>
<td>20</td>
<td>3000</td>
<td>8/10</td>
</tr>
<tr>
<td>20</td>
<td>3000</td>
<td>8.5/9.5</td>
</tr>
</tbody>
</table>

a Abbreviations: PMT, Peak maximum time; MT, Maximum torque; BE, Brabender equivalents; CV, Coefficient of variation.
commercial hard red spring WWF. The CVs for PMT for the commercial soft white WWF had similar values for all three flour/solvent ratios. The MT had the highest CV for the flour/solvent ratio at 8.5 g:9.5 g; thus, the 8.5 g:9.5 g ratio was not suitable for MT determination. After comprehensively assessing the results of both commercial WWFs (one strong flour and one weak flour), the flour/solvent at 8 g:10 g was identified as the appropriate ratio for obtaining more repeatable PMT and MT results.

The influence of the flour/solvent ratio on gluten aggregation is complicated by a number of factors. A higher flour content provided more protein. Chandi, Lok, Jie, and Seetharaman (2015) and Marti, Ulrici, Foca, Quaglia, and Pagani (2015) reported that increasing protein content resulted in an increase of torque. Gliadin and glutenin are the two main proteins that are responsible for the viscoelastic network, and contribute to the elasticity and extensibility of dough, respectively. Marti, Augst, et al. (2015) studied the influence of gliadin and glutenin on gluten aggregation using GlutoPeak. The gliadin, which represents up to about 60% of the total protein has a significant correlation with the MT. The higher the gliadin content, the greater the viscosity mass which detected as MT in GlutoPeak (Marti, Augst, et al., 2015). Similar results were also found by Melnyk et al. (2012). The glutenin, on the other hand, has a high correlation with aggregation time. Preston (1984) reported that the solvent CaCl₂ would dissociate as chaotrope ions that are capable of unfolding glutenin, thus promoting the aggregation of gluten. Hence, both the increased quantity of flour and CaCl₂ had positive effects on the gluten aggregation. As for WWF, the presence of bran particles negatively influences gluten aggregation (Noort et al., 2010), which could make the gluten aggregation more complicated. Therefore, an appropriate flour/solvent ratio is required to achieve repeatable gluten aggregation properties for WWF.

3.4. The gluten aggregation properties measured by the third stage GlutoPeak method

With improved test parameters for the GlutoPeak, which were 8-g WWF, 10-g 0.5 mol/L CaCl₂ solvent with a mixing speed of 3000 rpm at 20 °C, the PMT and MT of four WWF samples of different median particle sizes were measured again. The PMTs of HW-, HRW- and HRS-WWFs were significantly decreased, and the MTs of HW-, HRW-, HRS- and SW-WWFs were significantly increased in response to decreasing particle size (Fig. 3). The deviations of the PMT and MT were much lower than using the stage 1 setting (Fig. 2). Thus, the improved test parameters largely improved the repeatability of gluten aggregation measurements of the WWFs by the GlutoPeak. The decreasing PMT and increasing MT with the decreased particle size indicated that finer particle sizes could promote gluten aggregation of WWF. Such results are in agreement with the finding of Niu et al. (2014), Steglich et al. (2015), and Wang et al. (2016) that the WWF of finer particles had a less destructive effect on the gluten aggregation in dough. One possible explanation is that larger bran particle size in WWFs contains more bran surface area which might allow for attachment to other bran particles. Such aggregated bran particles are stiffer and could damage the aggregation of gluten, while finer bran particles are more flexible and much easier to embed in the gluten matrix (Steglich et al., 2015). The trend of PMT for SW was not as obvious as the HW-, HRW- and HRS-WWFs, but we can still conclude that finer particle size had a positive effect on the gluten aggregation of SW-WWF based on the increased MT with decreasing particle size.
Table 2

PMT and dough development time of HW-, HRW-, HRS- and SW-WWFs (three replicates) of different particle sizes.

<table>
<thead>
<tr>
<th>Wheat class</th>
<th>WWF sample</th>
<th>GlutoPeak&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mixolab</th>
<th>Farinograph</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PMT (s)</td>
<td>CV (%)</td>
<td>C&lt;sub&gt;t&lt;/sub&gt; time (min)</td>
</tr>
<tr>
<td>HW</td>
<td>WWF-0</td>
<td>62.7 ± 0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.93</td>
<td>6.2 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>WWF-1</td>
<td>60.3 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.91</td>
<td>4.5 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>WWF-2</td>
<td>58.0 ± 1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.72</td>
<td>4.4 ± 1.0&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>WWF-4</td>
<td>56.3 ± 0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.03</td>
<td>4.8 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>WWF-5</td>
<td>53.0 ± 0.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00</td>
<td>4.7 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>HRW</td>
<td>WWF-0</td>
<td>92.3 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.63</td>
<td>7.7 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>WWF-1</td>
<td>77.3 ± 1.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.49</td>
<td>5.0 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>WWF-2</td>
<td>74.3 ± 1.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.05</td>
<td>4.8 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>WWF-4</td>
<td>72.3 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.60</td>
<td>4.6 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>WWF-5</td>
<td>70.0 ± 1.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.47</td>
<td>4.7 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>HRS</td>
<td>WWF-0</td>
<td>61.7 ± 1.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.48</td>
<td>7.6 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>WWF-1</td>
<td>57.7 ± 2.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.61</td>
<td>6.0 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>WWF-2</td>
<td>54.3 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.06</td>
<td>5.7 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>WWF-4</td>
<td>54.0 ± 1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.85</td>
<td>5.6 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>WWF-5</td>
<td>53.0 ± 1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.89</td>
<td>5.3 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>SW</td>
<td>WWF-0</td>
<td>41.3 ± 0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.40</td>
<td>6.9 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>WWF-1</td>
<td>43.3 ± 1.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.66</td>
<td>6.4 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>WWF-2</td>
<td>43.7 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.32</td>
<td>4.0 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>WWF-4</td>
<td>42.7 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.35</td>
<td>3.6 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Values with different letters in the same column and sample category are significantly different (P < 0.05).

<sup>b</sup> HW, Hard white; HRS, Hard red spring; HRW, Hard red winter; SW, Soft white.

<sup>c</sup> WWF, Whole wheat flour.

<sup>d</sup> PMT, Peak maximum time; CV, Coefficient of variation.

3.5. Dough development time in the Mixolab and Farinograph

Rheological behaviors of HW-, HRW-, HRS- and SW-WWF samples were determined using the Mixolab and Farinograph. Dough development time, which represents the time from adding water into flour sample to the development of the dough’s optimum viscoelastic properties (Vizitiu & Danciu, 2011), was obtained from the Mixolab and Farinograph tests, separately. The decreasing trends of dough development time of HRW-, HRS- and SW-WWFs were observed from the Mixolab test in response to the decreasing WWF particle size. Similar results were reported by Zhang and Moore (1997) showing that coarser wheat bran (609 μm) had a longer development time than fine (278 μm) wheat bran. Penella et al. (2008) reported that the water absorption was faster with smaller bran particle sizes, and this might result in shorter dough development time. However, for the dough development time measured by the Mixolab, no significant influence (p > 0.05) of WWF median particle size (except for WWF-0) was found for HW, HRW, HRS and SW samples; similarly, for the dough development time measured by the Farinograph, no significant influence (p > 0.05) of WWF particle size was found for all samples (Table 2). Therefore, Mixolab and Farinograph tests may not be sensitive enough to detect the differences in dough development time due to varied WWF particle size.

Compared to the dough development time from the Mixolab and Farinograph tests, the PMTs from the GlutoPeak were significantly different (p < 0.05) in response to the decreasing particle size of all WWFs. Meanwhile, the CV of the PMT ranged from 0.0 to 3.61% for all the tests, much lower than the CV from the Mixolab (1.8–21.6%) and the Farinograph (0.0–27.7%). Additionally, the overall test time of WWF samples in the GlutoPeak was about 1 min, much faster than the test time of the Mixolab (45 min) and Farinograph (10–20 min). More accurate and repeatable gluten aggregation properties of WWFs of different median particle sizes could be quickly measured by using the improved GlutoPeak method.

Previous studies have demonstrated that WWF particle size influenced the quality of different products (Cai et al., 2014; Niu et al., 2014; Steglich et al., 2015; Wang et al., 2016). The association of WWF gluten aggregation properties with end product quality provides valuable information in practice. This improved GlutoPeak method could efficiently and accurately measure the gluten aggregation of WWF of different particle sizes, and provide an effective tool to evaluate WWF in end product applications.

4. Conclusion

A novel shear-based device, commercially known as the GlutoPeak, was applied to detect the gluten aggregation of WWF of different median particle sizes. An improved GlutoPeak setting was obtained for WWF testing: 8-g WWF, 10-g 0.5 mol/L CaCl<sub>2</sub> solvent, mixing speed of 3000 rpm, and a test temperature of 20 °C. A decrease in WWF particle size resulted in a significant decrease in PMT (except for SW), and a significant increase in MT in HW, HRW, HRS and SW, which demonstrated that the finer the bran particle size of WWFs, the more efficiently gluten aggregate formation occurs. The improved GlutoPeak method yielded more sensitive and repeatable results in PMT and MT, and could serve as a starting point for an optimization study for WWF applications. These improved test features, combined with the shorter test time suggested that the GlutoPeak could be an efficient and valuable tool for the evaluation of the gluten aggregation of WWF.

References


US Department of Agriculture (2016). Whole grain resource for the national school lunch and school breakfast programs. Washington (DC): USDA.


