THE EFFECT OF WATER HARDNESS ON RHEOLOGICAL BEHAVIOR OF DOUGH

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Abstract: Flour and water are basic components in dough formation process. The water quality affects the whole breadmaking process and the quality and retention period of bakery products. In bakery, an important role is played by the hardness of water; are preferred water having a hardness by 5 - 10º D (German degrees) and, in some cases, are preferred the waters with 10 – 20º D, depending on the characteristics of gluten. For the experimental determination, presented in this paper, were used samples of FA 650 flour type (white flour) and four kinds of water with different hardness values. To determine the dough rheological characteristics were made measurements according to AACC 54-21 standard method, using the Brabender Farinograph-E model (300 g mixer capacity).

The paper presents the study of rheological characteristics variation of wheat flour dough, depending on the water hardness used in mixing and formation process.

Keywords: flour, water hardness, dough, farinograph, rheological characteristics

1. INTRODUCTION

The flour dough is formed in the mixing process of its components. In the dough formation process, the flour and the water are the basic components. Without water, the dough forming would not possible, it is the responsibility of hydration and formation of gluten flour, [1-3]. The dough formation intermolecular reactions occur. Gluten formation process is complex and runs gradually in dough. Thus, in the presence of water and under the mechanical action of the mixers blades, the gluten proteins swell and coalesce into a compact mass, homogeneous, with elastic-plastic properties, called gluten. Gluten is that, during the baking of bakery products, form their protein skeleton. The protein substances gluten generating absorb the largest amount of water used in the mixing process, while the starch absorb a smaller amount of water (30-35% dry weight), swelling into a slight measure. The wheat flour dough is built up from a continuous gluten phase in which wet starch granules are incorporated [4-6].

Dough mixing is conducted in three stages, with some overlapping between them: simple mixing of the components; hydration of flour particles with the forming and the development of dough; tensioning the bound dough by use the speed gradient (differential movement of kneading arms and bowl).

It is known that for breadmaking potable water should be used. The quality of water affect whole the breadmaking process and the quality and retention period of bakery products (crumb porosity, crust soft, shiny and aesthetically pleasing) [7]. Thus, the water affects the consistency and temperature of dough; water dissolves salt and sugar products; in fermentation process, the water helps stimulate the activity of yeast (due to the minerals content); if the dough formation using alkaline water (pH > 7.5), the baking time is greater [8]. The alkaline water has a negative effect on gluten formation (does not present elastic property) [8]. Yeast is most active when is used water with values of pH ranged between 4 and 5 [7].

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In the breadmaking, an important role is water hardness. [1, 2]. Water hardness is given by the content of calcium (Ca) and magnesium (Mg) salts. Water hardness is of three types: temporary hardness - contain Ca and Mg bicarbonates, removing by boiling; permanent hardness – contain sulfate (SO₄) and Ca and Mg salts which remain dissolved by boiling; total hardness – concentration of Ca and Mg salts in water.

Water hardness is expressed in German degree (1°D is 1 mg CaO (or 0.719 mg MgO) dissolved in 100 ml of water), French degree (1°F is 1 mg CaCO₃ dissolved in 100 ml of water) or English degree (1°E is 1 g CaCO₃ dissolved in 700 ml of water) [5]. Water with hardness of 0 and 5° D is regarded as soft water; if the hardness is between 5 and 12° D, then the water is weak hard; for the hardness of 12 – 30° D, water is hard and over 30° D water is very hard [5, 7].

In breadmaking are preferred the waters with 5-10° D hardness and, sometimes, are preferred waters with 10 – 20° D hardness, depending on gluten characteristics [1].

The paper presents the study of rheological characteristics variation of wheat flour dough, depending on the water hardness used in mixing and formation process.

2. EXPERIMENTAL SETUP

The behavior of dough during mixing process can be tracked by farinograph curve (farinogram). An example of farinogram and its interpretation are presented in Figure 1.

With farinograph curve can be estimated following mixing characteristic of dough: dough development time (formation of gluten); dough stability; degree of softening; Farinograph Quality Number index (FQN). The same method can be used to determine the flour water absorption, which is the amount of water necessary to form a standard dough consistency – 500 FU or UB (1 BU ≈ 10⁻³ daN·m) [3, 4, 8-10].

Development time of dough (dough formation) is the period of time that the gluten network is formed and the normal consistency of dough reaches 500 BU.

Dough stability is the period of time that the dough keeps the normal consistency with the continuation of mixing process (see Figure 1).

Degree of softening of dough is the difference between the standard consistency (500 BU) and the consistency that touch the curve after 12 minutes (or more) of achieving standard consistency (see Figure 1).

Farinograph Quality Number index (FQN) measure the so-called ‘strength of flour’, which establishes the quality of flour (weak flour or strong flour).
On the farinogram can be read dough elasticity, as the difference in BU between the maximum values curve and minimum values curve, 10 minutes after reaching maximum consistency or 15 minutes after the start of the kneading process.

So, to determine the dough rheological characteristics was used the Brabender Farinograph-E model (300 g mixer capacity). The Brabender Farinograph and the determination experimental methodology (standard for testing flour quality AACC 54-21, ICC 115/1) was presented in the papers [9, 11].

For the experiments were used samples of FA 650 flour type (white flour), produced by the mill SC ILSA SA, Calarași, Romania. The properties of the flour FA 650 are presented in Table 1.

Table 1. Characteristics of FA 650.

<table>
<thead>
<tr>
<th>Moisture content, (%)</th>
<th>13.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash content, (%) s.u.</td>
<td>0.65</td>
</tr>
<tr>
<td>Protein content, (%) s.u.</td>
<td>11</td>
</tr>
<tr>
<td>Wet gluten, (%)</td>
<td>26.8</td>
</tr>
<tr>
<td>Gluten deformation (mm)</td>
<td>4</td>
</tr>
<tr>
<td>Acidity, (grade)</td>
<td>1.8</td>
</tr>
<tr>
<td>Gluten deformation index</td>
<td>2</td>
</tr>
<tr>
<td>Falling Number, (sec)</td>
<td>350</td>
</tr>
</tbody>
</table>

For this type of flour measurements were made according to AACC 54-21 standard method, using four kinds of water. The values of hardness and pH are presented in Table 2. According to the standard method, the distilled water is used for determination of dough rheological characteristics. The first three types of water (distilled water, Borsec and Saguaro) belong to types of soft water. Borsec and Saguaro are type of commercial water consumption. Gradistea water type is taken from a fountain with a depth of 11 m, in North-Eastern Ilfov, Gradistea city.

Table 2. Values of hardness degree and pH for water types used in experiments.

<table>
<thead>
<tr>
<th>Type of water</th>
<th>Hardness (°D)</th>
<th>pH</th>
<th>Salts content* (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distilled water (DW)</td>
<td>1.01</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>Borsec (B)</td>
<td>4.7</td>
<td>7.42</td>
<td>235</td>
</tr>
<tr>
<td>Saguaro (S)</td>
<td>5</td>
<td>5.87</td>
<td>244</td>
</tr>
<tr>
<td>Gradistea - Ilfov (G)</td>
<td>48</td>
<td>6.7</td>
<td>1120</td>
</tr>
</tbody>
</table>

Drinking water has TDS (Total dissolved solids) range in 150-250 ppm.

3. RESULTS AND DISCUSSION

For all types of water were made two determinations (with farinograph). The farinograph curves obtained are presented in Figure 2. The parameters of farinograph curves for all types of dough made of four types of water are presented in Table 3 (the mean value of two determination for each type of water).

Should be noted that for the water absorption of flour, the Brabender device makes a correction, such as the parameter values registered will be for the 500 FU consistency (make their own interpretation of the parameters).

The value of dough consistency is correlated with the amount of added water. From farinograph curve and Table 3, it is observed that the dough softening degree have two values, for two kneading periods: a period of 10 minutes after beginning of hydration process and a period of 12 minutes, after reaching the normal consistency (according to the ICC method).

Table 3. Rheological parameters for FA 650 flour with all four types of water.

<table>
<thead>
<tr>
<th>Rheological parameters</th>
<th>Type of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorption (%) / Correction for 500 FU</td>
<td>Distilled water</td>
</tr>
<tr>
<td>60.5 / 60.6</td>
<td>61.6 / 62.3</td>
</tr>
<tr>
<td>Development time (min)</td>
<td>2.2</td>
</tr>
<tr>
<td>Stability (min)</td>
<td>6.5</td>
</tr>
<tr>
<td>Degree of softening (10 min after beginning) (FU)</td>
<td>52</td>
</tr>
</tbody>
</table>
The analysis of the farinograph curves shows that they have a similar allure. A slight difference occurs in the farinograph curve obtained with Gradistea water: compared with the other three curves, it conveys that the dough flour is stronger, but the softening occurs faster than when using other types of water. Water hardness provides greater stability of the dough (standard consistency), but, with increasing of the mixing time, the degree of softening is higher.

| Degree of softening (ICC/12 min after max.) (FU) | 75 | 77 | 63 | 56 |
| Farinograph Quality Number (FQN) | 45 | 56 | 55 | 86 |

Following the data in Table 3 and farinograms in Figure 2, it can be seen that the development time of the dough does not present major differences for the four water types (increased slightly with increasing water hard). However, in terms of dough stability time, is very clear observed that the increase of water hardness caused increase its value.

While for the dough made from distilled water, the stability time is 6.5 min, then for the dough with water commercial water (hardness of 4.7° D and 5°D respectively), the stability time increase to 7.1° D and 7.7° D, respectively. But for the dough with hard water, the stability time increase much more, reached the value of 9.4 min (for Gradistea water). In fact, this is graphically represented in Figure 3.

It is found that up to a water hardness of 5° D, dough stability time variation is very pronounced, rapidly increasing, after which, from the hardness of 5° D to 48° D, the variation (although linear) is much slower. Overall, the linear variation of dough stability presents a correlation coefficient of water hardness of $R^2 = 0.894$.

Making linear regression analysis of the first three points of dough stability graph, it is found that the slope is changed from 0.24 (for this area of the graph) to 0.04 for the second area of the graph. The whole slope is 0.053 (the regression was done separately on two distinct areas).
Fig. 3. Variation of Development time (DT) and Stability (S) depending on the hardness.

As regards the dough degree of softening (read on the farinogram and Table 2), it is found that that is changed decreasing by increasing the water hardness. Also, the variation is approximately linear. For hard water, the dough degree of softening is 52 FU and decrease to 49 FU, and 44 FU, respectively, for water hardness of 4.7° D, 5° D, respectively. For water hardness of 48° D, the dough degree of softening is 35 FU (Figure 4).

Fig. 4. Variation of Degree of softening (SD) and Farinograph Quality Number (FQN) depending on the hardness.

From the graph of variation (Figure 5), it is observed that the general slope of the regression line is about -0.31, the correlation coefficient being on the whole value of $R^2 = 0.852$. Similarly as in the case of variation of dough stability, it is found that up to 5° D water hardness, variation is more pronounced with a slope of -1.5, after which the variation is much slower, the slope having value of -0.2. FQN index variation depending on water hardness is increased, similarly as in the case of dough stability. Values of FQN are presented in Table 3. It is found a slope of regression linear equal with about 0.7, and the correlation coefficient has a high value - $R^2 = 0.959$. On the firs area of graph (the first three experimental points, see Figure 4), the slope is much abruptly (about 2.7), and while on the second area (from 5° D to 48° D) the slope of the variation is much slower (about 0.72).

Fig. 5. Variation of FQN depending on the hardness.
Analyzes performed and data presented in this paper indicates that the water hardness affects all parameters of farinograph curves, and, therefore, the rheological characteristics of the dough. So, are affected both the stability time (sensitive affected), which increases with increasing water hardness, and degree of softening, regardless of time reading it. However, it is observed that the most affected parameter is Farinograph Quality Number (FQN), which increases very much with increasing water hardness.

4. CONCLUSIONS

The hardness water influence on the rheological parameters of the flour dough, on the mixing behavior of dough, especially on the stability of dough and FQN index. Thus, we can say that water hardness affect the power mixing of flour and total energy consumption, the mixing time extending very much.

The dough that was made from water with a hardness increasingly higher keeps standard consistency for a longer period of time (value of stability is higher – from 6.5 min to 9.4 min).

We can say that the degree of softening is inversely related to increasing water hardness. FQN increase with increasing of water hardness, so the dough keeps longer the normal consistency. For a hardness between 5 – 48 o D, the degree of softening decreases with 7 – 20 units and FQN index increases from 56 to 86 FU. Also, it is found that could be highlighted a correlation between water pH and farinograph parameter values.

The information referring to the effects of hardness water on the rheological characteristics of wheat flour and dough flour, can be used in technological bakery process, to establish the technological parameters of the bakery, in order to achieve quality finished products.

REFERENCES