Influence of damaged starch on the quality parameters of wheat dough and bread

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Abstract

Introduction. A certain degree of damage to the starch granules is desirable but excessive level of starch damage can have deteriorating effect on the quality of the bakery products.

Materials and methods. The wheat flour with lower (3.15%) and higher degree of starch damage (6.13%) were produced by repeat grinding (two passes) in a laboratory mill. The rheological measurements of dough samples were conducted using Farinograph and Extensograph, and gelatinisation and pasting properties – differential scanning calorimetry and Micro Visco-Amylo-Graph. Texture profile analysis of bread samples were performed using a texture analyser, and specific volume by laser topography method.

Results and discussion. The dough mixing properties were generally better for the samples with a higher level of starch damage and the most significant improvement has been manifested in the increased water absorption, from 60.7% to 63.8%. Higher water absorption can be associated with the influence of starch damage but also with the effect of flour particle size because smaller particles have larger total surface area. The starch damage had no significant effect on most of the extensographic indicators, although a slight decrease in resistance and extensibility was observed. Samples with a higher degree of starch damage showed decreased gelatinisation power. The gelatinization enthalpy (ΔHg) decreased from 1.41 to 1.31 J/kg, and amylographic peak viscosity from 582.5 to 505.0 BU. This could be explained by the restricted swelling of damaged starch granules due to the loss of organised structure. There were no significant differences in the moisture content and water activity between samples with different damaged starch content. The starch damage had a significant impact on majority of the bread quality parameters but the hardness increase and specific volume were most pronounced. The hardness increased from (from 4.09 N to 5.25 N) and specific volume (from 4.04 cm3/g to 3.53 cm3/g) when flour with a higher degree of damaged starch was used.

Conclusions. The level of starch damage had a significant effect on the dough rheological properties, starch gelatinisation and pasting properties, as well as on the bread quality parameters.

Introduction

Although the name "damaged starch" may suggest that this is an undesirable phenomenon, a certain degree of damage to the starch granules has a favourable effect on the quality of the bakery products. Damaged starch is formed during milling of wheat due to mechanical shear between the mill rolls [1, 2]. The level of starch damage is affected by several parameters during milling: pressure and gap size between the reduction rolls, roll speed ratio, rolls diameter, milling time, wheat tempering conditions (or moisture of the wheat entering the milling process), and wheat hardness. The milling of soft wheat results in less damaged starch than the milling of hard wheat [3–6]. A higher degree of starch damage in flours can be also achieved by grinding wheat in multiple passages through mill rolls, or with more intensive grinding in a ball or disk mill, which is generally performed during laboratory testing.

Knowledge of the physical state of starch granules, as well as their size and shape, is very important for predicting the technological process conditions and manifestation of starch properties (e.g. water absorption, gelatinization properties, rheological characteristics ...) [7]. Damaged starch differs from intact in several important features: it is much more susceptible to enzymatic hydrolysis, has an increased ability to absorb water, and has modified gelatinisation and pasting properties [8]. Intact starch granules can absorb water up to 40% of their weight, while damaged ones absorb up to 300%. The benefits of increased water absorption are evident due to encashed dough mixing properties, while greater susceptibility to amylolytic enzymes results in increased maltose and dextrin production during fermentation. However, too much starch damage can cause production problems and lead to a decline in bread quality such as reduced volume, poor texture and cell structure, grey crumb and dark crust colour, etc. This deteriorating effect of excessive level of starch damage on the bakery products can be explained in a way that the higher water absorption of the damaged starch prevents the full development of gluten. Furthermore, during fermentation, the starch is degraded too much, which leads to excessive water release, and to decrease in the dough consistency and gas retention capacity [9, 10].

There are different methods for determining damaged starch, but today the enzymatic/spectrophotometric AACC method 76-31.01, and Chopin's SDmatic device which combined iodometric/amperometric methods (AACC International Method 76-33.01) are the most commonly used. Usually, degree of starch damage for wheat flours is in the range of 4–10%. Hard wheat flour may show higher values, and vice versa, soft wheat flour may have a lower degree of starch damage.

Therefore, the aim of this study was to investigate the effect of damaged starch on the quality parameters of wheat dough and bread using a wide variety of methods to gain insight into the mechanisms of damaged starch influence on the rheological properties of the dough, gelatinization and pasting properties of the starch, and on the qualitative parameters of bread.

Material and methods

Flour Samples

Commercial all-purpose plain white flour (Podravka d.d. Koprivnica, Croatia) was used in this study as a reference flour sample with the lower level of starch damage (DS1). According to the conducted composition analysis (ISO standard methods 712:2001; 20483:2006; 2171:2007), moisture, protein and ash content of this flour was 12.22%, 11.18%, and 0.54%, respectively [11]. Level of starch damage of DS1 sample was 3.15% (Megazyme kit, Ireland; AACC method 76-31.01) [12]. This flour was subjected to repeat grinding (two passes) in a laboratory mill MLU-202 (Bühler, Switzerland) with tightened reduction rolls to obtain more crashing force and pressure to the flour particles in order to get more damaged starch. This sample was marked as DS2, and showed higher degree of starch damage (6.13%).

Particle size analysis

The particle size distribution of the flour samples was tested by sieving on a laboratory vibrating shaker "Analysette 3" (Fritsch, Germany) using sieves with apertures of 0.125 mm, 0.100 mm, 0.075 mm and 0.050 mm. Three rubber balls were placed on each sieve for the purpose of cleaning and facilitating the flow of flour during testing. The sieving time was 10 minutes with an amplitude of 2 mm. The weight of each sieve was recorded before and after the analysis.

Geometric mean particle size (average size) of samples was calculated from the following equations [13, 14]:

$$\overline{d_i} = (d_i \times d_{i+1}) \quad (1)$$

$$d_{gw} = \log^{-1}\left[\frac{\sum(W_i \log \overline{d_i})}{\sum W_i}\right] \quad (2)$$

where:

d_i –sieve openings diameter of the ith sieve;
d_{i+1} – sieve openings diameter of the next larger sieve;
$\overline{d_i}$ – mean diameter of the openings of two adjacent sieves;
d_{gw} –geometric mean diameter;
W_i – weight of particular fraction.

Dough rheological characterisation

Rheological measurements of dough properties prepared from samples with different levels of starch damage (DS1 and DS2) were conducted using Farinograph and Extensograph (Brabender OHG, Duisburg, Germany). Farinograhic analyses were made using a 300-g mixing bowl according to an ISO standard method 5530-1 and the results were expressed according to the Hungarian national standard MSZ 6383. Extensograhic analyses were conducted according to an ISO standard method 5530-2 [11, 15].

Determination of starch gelatinisation and pasting properties

The differential scanning calorimeter (DSC822e, Mettler-Toledo, Switzerland) was used to determine the gelatinisation properties of dough samples. The measurements were carried out under ultrahigh-purity nitrogen atmosphere, and calibration was performed by measuring the thermal properties of indium. Samples of 10-15 mg of dough were weighed into standard aluminium pan (40 µL) immediately after mixing the dough in the farinograph mixing bowl. The pans were sealed and immediately analysed. Three measurements were performed for each sample. An empty, hermetically sealed pan was used as a reference. The samples were subjected to a heating program of 30-100 ºC, with a heating rate of 10 ºC/min. Gelatinisation parameters were extracted from the peak endotherm of thermogram: onset temperature (T_0), peak temperature (T_p), conclusion temperature (T_c), gelatinization temperature range (T_c-T_0), and the starch gelatinization enthalpy (ΔH_g) were determined.

The pasting properties of samples with different levels of starch damage were evaluated using Micro Visco-Amylo-Graph (MVA, Brabender, Germany). A suspension containing 15 g (14 % w. b.) of flour sample and 100 ml of distilled water was held under constant shear of 250 min^{-1}, heated from 30 to 92 °C at 5 °C/min rate, held at 92 °C for 5 min, cooled down to 50 °C at 5 °C/min rate and held at 50 °C for 1 min. The following data was recorded: pasting temperature (°C), peak viscosity (BU), peak temperature (°C), breakdown viscosity (BU) and setback viscosity (BU).

Baking tests

Bread loafs containing flour with different levels of starch damage were produced according to the ICC standard method 131 [16]. The dough was mixed in a laboratory mixer (Diosna, Germany) for 9 minutes (2 min at speed 1, and 7 min at speed 2). After mixing, the dough was divided into 250 g pieces and rested in proofer (30 °C and 85% RH), then moulded by hand and placed into the baking pans and proofed for another 60 min (30 °C and 85% RH). The samples were baked in an oven (Wiesheu Minimat Zibo, Wiesheu GmbH, Germany) for 20 min at 200 °C. Bread samples were prepared in triplicate batches.

Bread quality evaluation

Bread quality evaluation was conducted four hours after baking. Analysis of moisture content and water activity was performed separately for bread crumb and crust. Moisture was determined in accordance with the two-stage air oven method (AACC method 44-15.02) [12]. Water activity measurements were conducted using portable water activity meter (HygroPalm AW1, Rotronic, USA).

Texture profile analysis (TPA) of bread samples were performed using a TA.XT2i Texture Analyzer (Stable Microsystems Ltd., Surrey, England). The bread loafs were precisely sliced to obtain four uniform slices of 25 mm thickness. TPA test included double compression of slices to 40% of their thickness with a 25 mm aluminium cylindrical probe. The force-time curves were recorded at 1.7 mm s^{-1} crosshead speed with a trigger force of 5 g. The following parameters were quantified: hardness (N, the maximum force required to compress the sample), springiness (the ability of the sample to recover its original form after the deforming force was removed), resilience (the ratio of work returned by the sample when compressive strain is removed), cohesiveness (the extent to which the sample could be deformed prior to rupture), and chewiness (N, the force needed to chew a food product calculated as hardness x cohesiveness x springiness).

The specific volume of bread samples was calculated as ratio of bread volume and loaf weight. The volume was measured by laser topography method with the use of Volscan Profiler (Stable Microsystems Ltd., Surrey, UK).

Statistical data analysis

All the tests were performed in at least three replications. Obtained experimental data was analysed by an analysis of variance (ANOVA) and Fisher's least significant difference (LSD), with significance defined at $p<0.05$. A statistical analysis was carried out with Statistica ver. 12.0 software (Stat Soft Inc. Tulsa, OK, USA).

Results and discussion

The degree of starch damage is defined as the percentage of starch that is subject to enzymatic hydrolysis. The principle of AACC method 76-31.01 is based on the hydration and hydrolysis of damaged starch granules of the sample using fungal α-amylase at 40 °C for 10 minutes. These conditions allow for almost complete hydrolysis of damaged starch granules and minimal degradation of undamaged granules. Hydrolysis products are maltooligosaccharides and α-limit dextrins. Dextrins are converted to glucose by amyloglucosidase and, after reaction with oxidase/peroxidase reagent, the resulting colour is determined by spectrophotometer (AACC). In this research, in order to obtain two samples of wheat flour with the same chemical composition but with a different degree of starch damage, all-purpose plain flour was subjected to repeated grinding in a laboratory mill with tightened reduction rolls. As a result, sample flour with lower (3.15%) and higher starch damage (6.13%) was obtained. Furthermore, in addition to the increased starch damage, intensive grinding results in a significant reduction in the flour particle size (Table 1). Average size of flour particles were 88.11 µm and 63.55 µm, for the DS1 and DS2 sample, respectively.

Table 1

Particle size distribution of flour samples

Particle size (µm)	Distribution (weight, %)	
	DS1*	DS2**
>125	26.09	2.19
100-125	29.09	17.28
75-100	22.50	35.09
50-75	10.48	24.81
<50	11.84	20.63
In total	100.00	100.00
Average size (µm)	88.11	63.55

*DS1 – wheat flour with 3.15% of damaged starch
**DS2 – wheat flour with 6.13% of damaged starch

The results on the effect of starch damage on the rheological characteristics of dough are presented in Table 2. The dough mixing properties were generally better for the samples with higher level of starch damage (DS2). The most significant improvement (p<0.05) has been manifested in the increased water absorption, 60.7% for DS1 to 63.8% for DS2. Higher water absorption can be associated with the influence of starch damage but also with the effect of flour particle size because smaller particles have larger total surface area. Development time and stability, and consequently quality number, were also improved with the higher degree of starch damage. This is in accordance with the results of other researches [17–19].

The starch damage had no significant effect on most of the extensographic indicators, although a slight decrease in resistance and extensibility could be observed. This resulted in a reduction in energy required for dough sample extension.

A differential scanning calorimetry (DSC) was used to monitor the process of the starch gelatinisation. As the temperature increased, an endotherm appeared in the thermogram of the test sample. The thermogram peak corresponds to the gelatinization process of the amorphous starch phase (starch gelatinization endotherm) [8, 20]. The thermal parameters of starch gelatinization are shown in Table 3.

Table 2

Effect of starch damage on rheological characteristics

	DS1*	DS2**
Farinograph		
Water absorption (%)	60.7 ± 1.9b	63.8 ± 1.1a
Dough development time (min)	1.7 ± 0.2b	2.1 ± 0.1a
Stability (min)	1.7 ± 0.1b	2.0 ± 0.2a
Degree of softening (BU)	61.9 ± 3.1a	62.5 ± 4.3a
Quality number	60.2 ± 2.1b	66.9 ± 3.5a
Quality group	B1	B1
Extensograph		
Energy (cm^2)	101.1 ± 4.1a	92.7 ± 3.9b
$Resistance_{50\ mm}$ (BU)	353.2 ± 13.2a	338.1 ± 15.1a
Extensibility (mm)	174.1 ± 6.6a	160.9 ± 6.1a
$R_{50\ mm}/E$ ratio (BU/mm)	2.0 ± 0.1a	2.1 ± 0.2a

*DS1 – wheat flour with 3.15% of damaged starch
**DS2 – wheat flour with 6.13% of damaged starch
Values are means of three replications ± SD.
Values in the same row with different superscripts (a-b) are significantly different (p<0.05).

Table 3

Effect of starch damage on gelatinisation and pasting properties

	DS1*	DS2**
Differential scanning calorimetry (DSC)		
T_0 (°C)	59.98 ± 0.06^a	60.36 ± 0.31^a
T_p (°C)	69.12 ± 0.29^a	69.51 ± 0.21^a
T_c (°C)	78.18 ± 0.13^a	78.80 ± 0.51^a
T_c - T_0 (°C)	18.21 ± 0.19^a	18.44 ± 0.82^a
ΔH_g (J/g)	1.41 ± 0.04^a	1.31 ± 0.03^b
Micro Visco-Amylo-Graph (MVA)		
Pasting temperature (°C)	63.1 ± 0.4^a	62.7 ± 0.6^a
Peak viscosity (BU)	582.5±8.5^a	505.0 ± 9.9^b
Peak temperature (°C)	89.1 ± 0.4^a	88.9 ± 0.3^a
Breakdown viscosity (BU)	142.5 ± 2,6^a	117.5 ± 3.5^b
Setback (BU)	503.5 ± 5.5^a	464.5 ± 7.8^b
Resistant starch (%)	1.35 ± 0.06^a	1.18 ± 0.01^b

*DS1 – wheat flour with 3.15% of damaged starch
**DS2 – wheat flour with 6.13% of damaged starch
Values are means of at least three replications ± SD. Values in the same row with different superscripts (a-b) are significantly different (p<0.05).

There were no differences in the gelatinisation temperatures (pasting, peak and conclusion temperature, and gelatinisation range (T_0, T_p, T_c, T_c - T_0) between samples with different levels of starch damage. In contrast, the gelatinization enthalpy (ΔH_g) were significantly influenced (p<0.05) by damaged starch content, 1.41 J/g for DS1 and 1.31 J/g for DS2 sample. Samples with increased level of damaged starch showed lower thermogram peaks, because gelatinisation process is more pronounced when higher amount of native and intact granules are present in the system [21].

Similar results were obtained when the Micro Visco-Amylo-Graph (MVA) was used to monitor pasting properties of flour samples. Pasting and peak temperatures were not affected by the degree of starch damage but peak viscosity was significantly decreased (p<0.05) with a higher degree of starch damage.

Furthermore, breakdown and setback also decreased when degree of damaged starch increased. This could be explained by the restricted swelling of damaged starch granules due to the loss of organised structure and decrease of their gelatinisation power [5]. On the other hand, decreased gelatinisation power could be also explained with a greater susceptibility of damaged starch granules to amylolytic enzymes (as illustrated on Figure 1), which results in an increased maltose and dextrin production during fermentation.

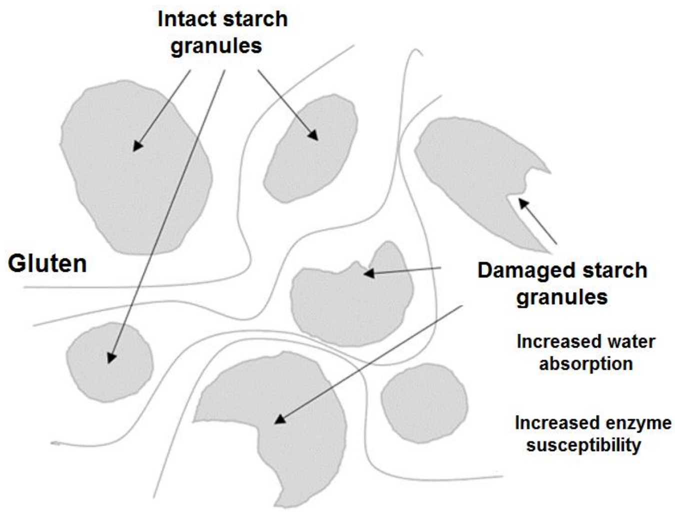

Figure 1. The effect of damaged starch on water absorption and enzyme susceptibility

The effect of the degree of starch damage on bread quality parameters are presented in Tables 4 and 5. There were no significant differences in the moisture content and water activity between samples with different damaged starch content. Despite the increased water absorption during mixing, the bread samples produced from flour with higher level of damaged starch did not have a higher moisture or water activity. This can be also explained by the increased amylolytic activity during fermentation when starch hydrolysis occurs, resulting in excessive release of water that becomes more mobile, and therefore more susceptible to evaporation during baking.

Table 4

Moisture content and water activity of bread samples with different levels of starch damage

	DS1*	**DS2****
Moisture content (%)		
Crumb	41.8 ± 0.3[a]	41.7 ± 0.2[a]
Crust	24.6 ± 0.2[a]	24.8 ± 0.2[a]
Water activity		
Crumb	0.974 ± 0.003[a]	0.960 ± 0.002[a]
Crust	0.889 ± 0.002[a]	0.891 ± 0.002[a]

*DS1 – wheat flour with 3.15% of damaged starch
**DS2 – wheat flour with 6.13% of damaged starch
Values are means of three replications ± SD. Values in the same row with different superscripts (a-b) are significantly different (p<0.05).

Table 5

Effect of starch damage on textural properties and specific volume of bread

	DS1*	**DS2****
Texture profile analysis (TPA)		
Hardness (N)	4.09 ± 0.55[b]	5.25 ± 1.04[a]
Springiness	0.95 ± 0.01[a]	0.92 ± 0.02[b]
Resilience	0.28 ± 0.04[a]	0.27 ± 0.01[a]
Cohesiveness	0.73 ± 0.03[b]	0.79 ± 0.02[a]
Chewiness (N)	2.84 ± 0.23[b]	3.82 ± 0.46[a]
Specific volume (cm^3/g)	4.04 ± 0.09[a]	3.53 ± 0.11[b]

*DS1 – wheat flour with 3.15% of damaged starch
**DS2 – wheat flour with 6.13% of damaged starch
Values are means of three replications ± SD. Values in the same row with different superscripts (a-b) are significantly different (p<0.05).

Data on the textural properties of bread samples is presented in Table 5. The starch damage had a significant impact (p<0.05) on majority of the textural parameters, but the hardness increase was most pronounced, from 4.09 N for DS1 to 5.25 N for DS2. One possible explanation for the increase in bread hardness is the starch-gluten interactions and the increased dough strength that prevents normal expansion during fermentation [10, 22], resulting in a more compact cell structure of finished product. Consequently, there is also a decrease in a specific volume of bread samples with a higher damaged starch content (Figure 2). Specific volume decreased from 4.04 cm^3/g for DS1 to 3.53 cm^3/g for DS2. In addition to increased hardness and decreased specific volume, the cohesiveness and the force needed to chew the bread were also increased. For this reason, some researchers advise that a higher protein content must be ensured when using flour with high degree of starch damage.

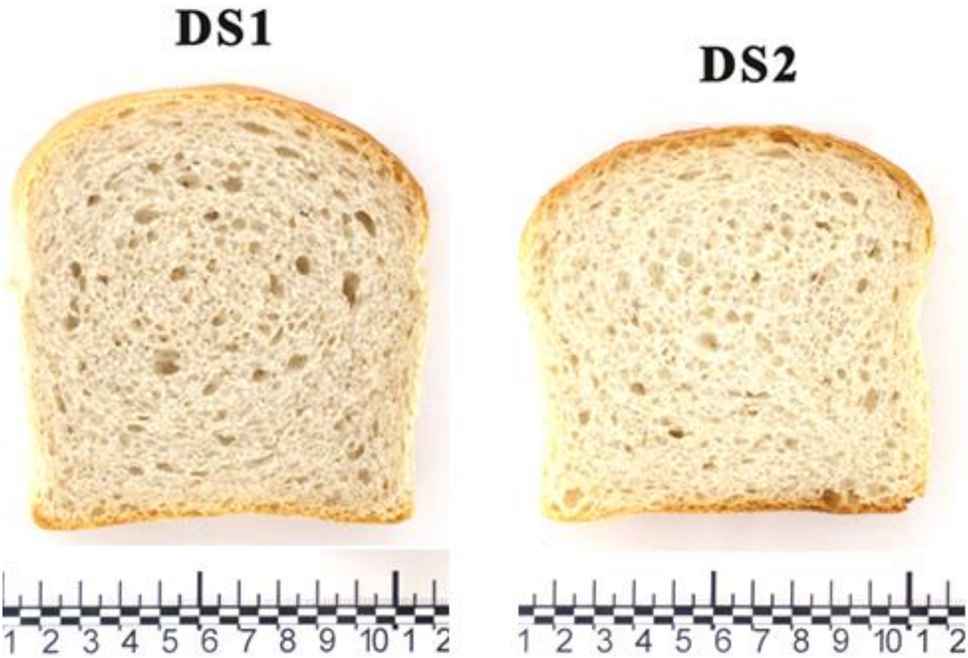

Figure 2. Bread samples made from the wheat flour with 3.15% (DS1) and 6.13% starch damage (DS2)

Conclusion

The results of this research has demonstrated that the level of starch damage had a significant effect on the dough rheological properties, starch gelatinisation and pasting properties, as well as on the bread quality parameters. The benefits of increased content of damaged starch are evident due to an improved dough mixing properties, but too much starch damage can cause production problems and lead to a decline in bread quality. Therefore, it can be concluded that the degree of starch damage in flour is an important factor to consider when producing bakery products.

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