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Empirical and Fundamental Rheological Properties of Wheat Flour Dough as Affected by Different Climatic Conditions

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ABSTRACT

The aim of this study was to evaluate the capability of the empirical (large scale) and fundamental (small scale) rheological tests to differentiate between wheat flours of different harvest years. In order to provide flours affected by different climatic conditions, harvest years 2004 and 2005 characterized by high temperatures and large amounts of rainfall were chosen. Moreover, a control wheat flour sample was also tested. In order to simulate the baking process, both rheological measurements at constant low temperatures (30°C) and those that involved heating (30-100°C) were employed. Empirical and fundamental rheological parameters related to gluten strength were in great accordance and the flour strength decreased in the following order: control wheat flour> wheat flour of 2005> wheat flour of 2004. However, parameters related to starch pasting, such as peak viscosity, expressed different order when measured in suspension (Amylograph, Falling number) and dough (Mixolab, Rheometer) due to different amounts of available water.

Keywords: Climatic conditions, Harvest year, Rheology, Wheat flour.

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INTRODUCTION

Wheat yield and end-use quality depend on the variety, environment, and their interaction, and, thus, they reflect the interregional and year-to-year differences and the climatic conditions (Peterson *et al*., 1998; Corbellini *et al*., 1998; Singh *et al*., 2001). Najafian *et al*. (2010) as well as Sanjari Pireivatlou and Yazdansepas (2008) showed that drought and moisture stresses are the major factors causing low wheat productivity. However, the milling industry requires uniform wheat lots for the particular processing of interest and, therefore, the wheat parameter standardization is of the utmost importance. In order to evaluate the wheat utilization, the following quality characteristics are mainly determined: flour extraction (milling yield), flour protein content, and dough handling characteristics, i.e. rheological properties (Renzi *et al*., 2005).

Understanding of the rheological behavior of wheat dough is of great importance. Rheological measurements are generally employed to obtain a quantitative description of the materials' mechanical properties, to get information related to the molecular structure and composition of the material, and to characterize and simulate the material's performance during processing and for quality control. Dough rheological analyses have been used to attempt to predict final product quality such as mixing behavior, baking performance, and to optimize dough formulation (Ross *et al*., 2004). Although dough rheology has long been investigated, there remains a significant lack of understanding. This lack of progress is due to the fact that bread dough, and particularly wheat dough, is

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probably the most dynamic and complicated rheological system (Masi *et al*., 2001). This complexity is not restricted to chemical composition of dough, but also includes its physical (rheological) properties.

There are many test methods used to measure rheological properties. They are commonly categorized according to the type of strain imposed: e.g. compression, extension, shear, torsion; or relative magnitude of the imposed deformation, e.g. small or large deformation (Dobraszczyk and Morgenstern, 2003). The main techniques used for measuring cereal properties have traditionally been divided into empirical (descriptive) and fundamental (basic) (Bloksma and Bushuk, 1988). Similar to the baking process, rheological techniques can be divided into those that monitor dough behavior at constant low temperatures (in order to describe their rheological properties during the processing stage) and the studies that involve heating (in order to describe dough behavior during the baking phase) (Weipert, 1990). Devices for descriptive empirical measurements of rheological properties, such as the Farinograph, Extensograph, Amylograph, and Alveograph have been extensively used within the cereals laboratories. The benefits of using empirical tests are the following: they are easy to perform and are often used in practical processing situations; the instruments do not require highly skilled or technically trained personnel; and, finally, they have provided a great deal of information on the quality and performance of cereal products such as consistency, hardness, texture, viscosity, etc., and thus are used in flour quality control (Dobraszczyk and Morgenstern, 2003). They also reported that empirical tests are purely descriptive and dependent on the type of instrument, size and geometry of the test sample and the specific conditions under which the test was performed. Namely, empirical test methods employ large deformation force (i.e. large strains) to develop and, subsequently, destroy dough structure (Farinograph, Mixolab) or to stretch the dough (Extensograph, Alveograph). Moreover, only one deformation force is used, which results in a single-point measurements. The results of the measurements are expressed in arbitrary, relative units (Weipert, 1990). However, dough will normally experience different mechanical stresses during processing and baking. During dough mixing and development, the mechanical deformation is presumed to be larger than at the proofing stages or at oven raise. Therefore, the great advantage of fundamental rheological tests is that they are capable of describing the physical properties of a material over a wide range of strains. It produces not only a single-point viscosity value, but also a stress-strain curve (multiple-point measurement) (Weipert, 1990). Besides the possibility of continuous measurement throughout a simulated baking process and flexibility in the choice of the level of deforming force, the benefits of using the fundamental rheology include exact, defined measurements of stress and strain; results in absolute physical SI units (i.e. Pa), which allows direct comparison of results obtained by various instruments and researchers; ability to use an extremely small sample, and use of the same instrument for several applications. Problems encountered with fundamental tests are: complex instrumentation, which is expensive, require high levels of technical skill, and difficulty in interpretation of results.

The present study was performed with the aim to characterize the rheological properties of wheat flour dough from different harvest years, and to evaluate the capability of the fundamental and empirical rheological measurements to differentiate between wheat flour samples that were obtained in harvest years different by temperatures and amounts of rainfall during the harvest period. The obtained flour samples from these harvest years were compared to the control flour sample obtained in the harvest year not affected by extreme climatic conditions.

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MATERIALS AND METHODS

Analyzed wheat samples from the wheat-growing regions of Serbia were of the same cultivar and were obtained from the same location, but from two wheat harvest years: year 2004 characterized by extremely high temperatures during the grain filling phase from May to July (WF2004), and year 2005 characterized by high amount of rainfall during the harvest (WF2005). Weather conditions during June and July 2004 are shown in Table1. The third sample – the control wheat flour (CWF), was obtained from the harvest year that was not affected by extreme climatic conditions (Table1). The conditions were the following: mean temperature and rainfall in June 19°C and 90 mm; and in July 21°C and 70 mm. The wheat samples were milled on a Bühler laboratory mill. Before being milled, the samples were conditioned to 15.0% moisture for 2 hours. Moisture, protein, and ash content, as well as wet gluten content, gluten index (GI), and Hagberg falling number of wheat flour, were determined according to standard ICC methods (ICC, 1996).

Empirical Rheological Measurements

Wheat flour samples were analyzed using the following empirical rheological methods:

Brabender Farinograph was performed according to modified ICC 115/1. The parameters obtained from the recorded curve were: water absorption (WA, %); dough development time (DDT, min); stability (min), and degree of softening (DS, BU).

Brabender Extensograph was performed following the ICC 114/1. The following parameters were determined: resistance to extension (R_{50}, BU); extensibility (E, mm); energy (A, cm^2), ratio of resistance to extensibility (R_{50}/E).

Brabender Amylograph was conducted following the ICC 126/1. The parameter determined was: peak viscosity (AU).

Chopin Alveograph was performed using the ICC 121. The following parameters were recorded by a computer software program: tenacity or resistance to extension (P, mm H_2O); extensibility (L, mm); deformation energy (W, 10^{-4} J), curve configuration ratio (P/L).

Moreover, Chopin Mixolab was conducted using ICC 173 method. Since this is a relatively new method, its parameters will be briefly described.

The parameters obtained from Mixolab measurements were: water absorption (WA, %)or the percentage of water required for the dough to produce a torque of 1.1±0.05 Nm; dough development time (DDT, min) or the time to reach the maximum torque at 30°C; stability (min) or time until the loss of consistency is lower than 11% of the maximum consistency reached during the mixing; initial maximum consistency (C_1, Nm), used to determine the water absorption; mechanical weakening ($C_{1.2}$, Nm) , the torque difference between the maximum torque at 30°C and the torque at the end of the holding time at 30°C; minimum torque (C_2, Nm), the minimum value of torque produced by dough passage while being subjected to mechanical and thermal constraints; peak torque (C_3, Nm), the maximum torque produced during the heating stage, which represents the measure of starch gelatinization; minimum torque

Table 1. Weather conditions for different wheat samples.

	WF2004		WF2005		CWF	
	June	July	June	July	June	July
Mean temperature (°C)	19.2	21	18.9	21	19	21
Maximum temperature (°C)	≥ 30	35-39	25.2	27.5	-	-
Total rainfall (mm)	85	65	140	125	90	70

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reached during cooling to 50°C (C_4, Nm) , the measure of starch paste (cooking) stability and α-amylase activity; final torque or starch gelling (C_5, Nm), which is related to the retrogradation of starch molecules. All the tests were performed in triplicates, and the average results were reported.

Fundamental Rheological Measurements

Fundamental rheological tests: small deformation (frequency sweep dynamic oscillation), large deformation (creep-recovery) and temperature sweep dynamic oscillation rheological measurements were performed on Haake Mars rheometer (Thermo Scientific, Germany). The rheometer was equipped with 35 mm diameter serrated parallel plates (1 mm gap) that were maintained at 30°C. The dough samples for fundamental rheological measurements were prepared by mixing at Mixolab water absorption, on 14% moisture in Mixolab bowl during 7 minutes. The dough was rested for 10 minutes in a closed plastic bag at room temperature. Subsequently, a small piece of dough was taken and loaded between rheometer plates. The excess edges of the sample were trimmed and coated with mineral oil to prevent drying; and then rested for 10 minutes before testing, in order to allow relaxation of the stress imparted during sample handling.

Stress Sweeps

These were performed at a frequency of 1 Hz for all samples to determine the linear viscoelastic region, which varied between 10 and 15 Pa depending on tested dough sample. Frequency sweep tests, at a target stress of 1 Pa in the linear viscoelastic region, were performed from 1 to 10 Hz. Data obtained were storage (elastic) modulus (G') and phase angle ($\tan \delta = G''/G'$).

Creep-recovery Tests

The tests were conducted immediately after frequency sweep measurements on the same dough sample. Creep was measured at a shear stress of 50 Pa for 300 seconds, followed by a recovery phase of 900 seconds at a stress of 0 Pa. The parameters obtained were: maximum creep compliance (J_{max}), elastic part of maximum creep compliance (J_e) and relative elastic part of maximum creep compliance $(J_e/J_{max})\times 100$.

Temperature Sweep Dynamic Oscillation Measurements

These were performed by increasing the temperature from 30 to 100°C at 7 °C min^{-1}. Measurements were performed at a constant frequency of 1 Hz and a constant deformation of 0.1. To prevent dehydration of the sample during the test, a solvent trap (Teflon cover) was put over the entire plate. The parameters obtained were the minimum and maximum *G'*.

Reported values for the fundamental rheological parameters are the average of three independent replicates, where each replicate represents separately prepared dough on Mixolab.

Statistical Analysis

A one-way analysis of variance and Tukey's test was used to determine differences between wheat harvest year means. The analyses were performed using Statistica 7.0 (Statsoft, Tulsa, USA). Harvest year means were considered significantly different at $P \leq 0.05$.

RESULTS AND DISCUSSION

Moisture, protein, and ash content of the examined wheat flour samples were 11, 11.8, and 0.5% for WF2004; 11.4, 10.7 and 0.51%, for WF2005; 12.7, 11.6, and 0.49%

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for CWF, respectively. The mean values for rheological analysis of three samples during the cold stage, which comprises Farinograph, Extensograph, Alveograph, dynamic oscillatory, creep and recovery and part of Mixolab measurements are shown in Table 2. Since Mixolab has the ability to monitor the properties of dough during the both stages (cold and hot), the results obtained by Mixolab were divided into two Tables. The wet gluten content and gluten index values are also summarized in Table 2.

Observing Farinograph, Extensograph, and Alveograph parameters, the following differences between flour samples can be noticed. Degree of softening, which represents susceptibility of dough to the destructive effect of mixing (Miś *et al.*, 2012) was significantly higher ($P> 0.05$) for both WF2004 and WF2005 samples. Moreover, degree of softening was much higher for WF2004 in comparison to other investigated flour samples, which implicates poor technological quality of flour protein during mixing of WF2004 sample. Extensograph parameters such as energy and ratio between resistance and extensibility

Table 2. Rheological properties of dough during the cold processing stage, wet gluten content and gluten index values of the control and flours from harvest years 2004 and 2005[a].

	CWF	WF2004	WF2005
Farinograph			
WA (%)	54.6^a	57.9^b	58.1^b
DDT (Min)	2.0^a	3.0^b	1.8^a
Stability (Min)	2.0^a	3.5^b	2.0^a
DS (BU)	58.5^a	136.7^c	91.7^b
Extensograph			
R_{50} (BU)	465.0^c	46.7^a	351.7^b
E (mm)	125.0^b	111.7^a	127.3^b
A (cm^2)	100.3^c	7.3^a	72.7^b
R_{50}/E	3.7^c	0.4^a	2.8^b
Alveograph			
P (mm H_2O)	66.7^b	44.7^a	88.0^c
L (mm)	76.7^c	57.7^a	61.0^b
W (10^{-4} J)	193.0^b	70.7^a	202.3^b
P/L	0.87^b	0.80^a	1.42^c
Mixolab			
WA (%)	57.1^a	57.2^b	57.6^c
DDT (Min)	1.58^b	4.02^c	1.3^a
Stability (Min)	10.93^c	5.26^b	2.64^a
$C_{1.2}$ (Nm)	0.10^a	0.29^c	0.18^b
Dynamic oscillatory[b]			
G' (Pa)	34494^c	10592^a	22678^b
$\tan \delta$	0.308^a	0.399^b	0.319^a
Creep and recovery			
J_{max} (10^{-5} Pa^{-1})	40.7^a	168.4^c	55.8^b
J_e (10^{-5} Pa^{-1})	23.6^a	89.1^b	33.8^a
J_e/J_{max} (%)	58.17^b	52.92^a	60.56^b
Wet gluten content (%)	26.7^a	31.0^b	30.3^b
Gluten index			
GI (%)	97.3^b	86.0^a	97.7^b

[a] Values followed by the same letter in the row are not significantly different at $P> 0.05$.

[b] Parameters of dynamic oscillatory test are the means of the values that were within the given frequency range.

(R_{50}/E) as well as Alveograph deformation energy value (W) were much higher for CWF and WF2005 flour samples in comparison to WF2004. In contribution to the assumption that WF2004 sample is characterized by lower protein rheological quality was also $C_{1.2}$ Mixolab parameter. The obtained results showed the same trend between Farinograph *DS* and Mixolab $C_{1.2}$ value. Namely, although WF2004 had the highest wet gluten content, it was also characterized with lowest gluten index value, indicating the poorer technological quality of WF2004 than the other analyzed flour samples. According to Jamieson *et al.* (2001), conditions that shorten grain filling, such as high temperature or drought, affect the balance of protein fractions. Moreover, wheat flour, dough, and baking quality parameters could be altered in response to a short period of heat stress (Blumenthal *et al.*, 1993) and, according to Blumenthal *et al.* (1991), some of these effects have been linked to an increased gliadins-glutenin ratio, which could have, therefore, resulted in decrease in the proportion of the larger molecular size glutenins (Wardlaw *et al.*, 2002). On the contrary, gluten index value was not significantly different ($P< 0.05$) between CWF and WF2005. Similar trend was observed for Alveograph W parameter which was practically the same for CWF and WF2005 and was lower for WF2004 sample. However, Farinograph and Mixolab parameters, which refer to dough stability, were not in accordance for control sample. This was probably due to different interpretation of dough stability in these two tests. According to ICC 115/1 farinograph stability is defined as the difference in time between the point in which the top of the curve first intercepts the 500 BU line and the point at which the top of the curve leaves 500 BU line. On the contrary, Mixolab stability is the time until the loss of consistency is lower than 11% of the maximum consistency. In both tests control dough curve rapidly deviated from the maximum consistency line. However, that drop was less than 11%, which was detected by Mixolab as increased stability.

According to dynamic oscillatory measurements conducted in linear viscoelastic region, WF2004 showed the lowest *G´* and the highest *tan δ* values in comparison to CWF and WF2005. This was in agreement with Khatkar *et al.* (2002), Janssen *et al.* (1996), and Tronsmo *et al.* (2003) who stated that gluten from poor quality wheat is rheologically characterized as less elastic and more viscous in comparison to good quality wheat's gluten. According to Abang Zaidel *et al.* (2010), material characterized with higher degree of cross-linking is expected to have lower tan δ values. Therefore, the obtained results proved weaker viscoelastic properties of WF2004 in comparison to CWF and WF2005. However, the storage modulus for all tested doughs were higher than the loss modulus, which was in accordance with numerous research articles (Tronsmo *et al.* 2003; Amemiya and Menjivar 1992) that reported that dough system exhibited solid like behavior. Observing the extensograph parameter R_{50} and parameter *G´*, similar trend between tested flour samples could be noticed, i.e. CWF, which was characterized with the highest R_{50} values, had the highest *G´* and WF2004, which had the smallest R_{50} values, expressed the lowest elastic modulus. Moreover, flour sample with the smallest Farinograph *DS* as well as Mixolab $C_{1.2}$ parameter showed the most pronounced elastic properties and one with the highest *DS* had the lowest *G'*. Additionally, opposite trend behavior for different flour samples could be observed for extensograph R_{50}/E ratio and *tan δ* values. CWF was characterized with the highest R_{50}/E value and had the lowest tanδ value (higher elastic properties and stronger gluten network).

Concerning creep and recovery measurements the obtained parameters of maximum creep compliance (J_{max}) had similar trend with *tan δ*, Farinograph degree of softening and Mixolab $C_{1.2}$ value i.e. the WF2004 sample expressed the highest J_{max}

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and *tan δ*, degree of softening and $C_{1.2}$ values and CWF had the lowest previously mentioned parameters. According to Edwards *et al*. (1999), measured J_{max} is related to both relative, intrinsic strength and extensibility of dough samples. Moreover, Day *et al*. (2005) revealed that greater values of J_{max} indicated greater softness and better flow of the materials. Additionally, WF2004 sample that showed the smallest Extensograph *A* and Alveograph *W* values as well as *GI* value had the highest J_{max} values. It was in accordance with the results of Edwards *et al*. (1999) who found strong negative correlation between J_{max} and deformation energy values. Also, elastic part of maximum compliance, which represents system recovery after removal of load, was highest for WF2004 sample, which was characterized with poor protein quality. The obtained results are similar to investigation of Janssen *et al*. (1996) who found that weak wheat flours had higher recovery than strong flour. However, percentage of recovery was smallest for WF2004 sample.

The mean values for rheological analysis of three samples during the hot stage, which comprises Amylograph and Falling number values as well as temperature sweep dynamic oscillation measurements and part of Mixolab measurements, are shown in Table 3.

The obtained results indicated similar trend for both Amylograph peak viscosity and Falling number values. Namely, CWF that was characterized with the most appropriate starch properties and α-amylase activity (Kaluđerski and Filipović, 1998) had the highest values for the previously mentioned parameters and, consequently, WF2005 sample was characterized with poorest starch properties and *α*-amylase activity in comparison to CWF and WF2004 samples. According to Morris and Paulsen (1985), rain conditions, as in harvest year 2005 during the ripening stage of the crop, increased sprouting and thus *α*-amylase activity resulted in low peak viscosity and Hagberg Falling number value. Both Amylograph and Hagberg Falling number measurements are performed by heating flour-water suspension differing in concentration and detecting the changes in viscosities. The correlations between these two techniques were reported earlier (D'Appolonia *et al*., 1982). However, according to Weipert (1990), starch gelatinization does not take place under the

Table 3. Rheological properties of the control and flours from different harvest years (2004 and 2005) during heating ^{a}.

	CWF	WF2004	WF2005
Amylograph			
Peak viscosity (AU)	418^{c}	333^{b}	170^{a}
Hagberg falling number (s)	331.3^{c}	310^{b}	239.7^{a}
Mixolab$^{(a)}$			
C_2 (Nm)	0.53^{c}	0.35^{a}	0.40^{b}
C_2 temperature (°C)	54.1^{a}	55.1^{a}	53.9^{a}
C_3 (Nm)	2.20^{c}	1.67^{a}	1.80^{b}
C_3 temperature (°C)	76.6^{a}	81.6^{b}	76.0^{a}
C_4 (Nm)	1.89^{c}	1.49^{b}	1.13^{a}
C_5 (Nm)	2.56^{c}	2.11^{b}	1.50^{a}
Temperature sweep$^{(a)}$			
Minimum *G'* (Pa)	3868^{c}	1074^{a}	2480^{b}
Minimum *T* (°C)	56.6^{a}	55.5^{a}	55.6^{a}
Maximum *G'* (Pa)	56350^{c}	35707^{a}	45790^{b}
Maximum *T* (°C)	82.7^{a}	84.6^{b}	81.5^{a}

^{a} Values followed by the same letter in the row are not significantly different at $P > 0.05$.

same conditions in a suspension as it does in dough, which is characterized with reduced amount of available water. Therefore, Mixolab and temperature sweep dynamic oscillation measurements conducted in real dough systems may give better explanations of the phenomena that occur during the heating phase i.e. baking. He also observed that, during dynamic oscillatory techniques, constant small strains are applied during sample heating and cooling and the obtained values can be useful in characterization of the changes that occur in the fermentation and baking process.

Both Mixolab C_2 and Minimum G' parameters refer to gluten weakening induced by shearing and heating increase. WF2004, with the poorest protein quality in comparison to CWF and WF2005, expressed the lowest C_2 and minimum G' values, indicating that their protein network was less resistant to shear and heat. CWF, as a control flour with good protein quality, had stronger and more resistant protein network, as proved by C_2 and Minimum G'values.

Mixolab C_3 parameter and Maximum G', which are mainly influenced by starch gelatinization properties as well as *α*-amylase activity, were highest for CWF sample, while WF2004 had the lowest values for the above mentioned parameters. The obtained results of Mixolab C_3 and Maximum G' values did not follow the trend of Amylograph peak viscosity and Hagberg falling number entirely. Concerning Amylograph and Falling number measurements, starch from flour was in the form of a suspension and, thus, it could gelatinize freely upon heating. It is possible that the starch in flour suspension achieved its maximum gelatinization capacity. However, in a dough system, as in Mixolab and in temperature sweep dynamic oscillation measurements, starch gelatinization was influenced by the amount of free water as well as the amount of the water released from protein network upon heating.

Temperatures that refer to protein weakening, beginning of starch gelatinization/pasting (C_2 temperature), and peak occurrence (C_3 temperature) in both Mixolab and temperature sweep tests were also in harmony due to similarity of the systems (dough instead of flour suspension).

The last part of Mixolab curve, which refers to changes in dough consistency on cooling, has revealed that WF2005 sample had the lowest values of minimum (C_4) and final (C_5) torques. According to investigations performed by Stoenescu and Sorina Ionescu (2011) and Codina *et al.* (2012), parameters C_4 and C_5 were found to be lower in samples with high doses of additives containing α-amylase and high positive correlation was found between C_4 parameter and Falling number value. The results obtained in this study were in agreement with the above mentioned investigations and the sample WF2005, which showed the lowest torque values, was also characterized with the lowest Hagberg Fallling number and Amylograph peak viscosity values, reflecting the consequence of high amount of rainfall during grain filling.

CONCLUSIONS

Empirical and fundamental rheological parameters related to dough strength e.g. resistance to deformation during mixing or extension, were in great harmony with each other and with gluten index values. An increase in Farinograph *DS*, Mixolab $C_{1.2}$, *tan δ*, maximum creep and recovery values were followed by Extensograph *R* and A and frequency sweep G' decrease.

However, parameters from fundamental rheological tests, such as *tan δ*, recovery value from creep and recovery measurements as well as Alveograph *W* were not statistically different for CWF and WF2005. Since *GI* also did not differentiate between these two samples, it can be concluded that tan δ and recovery values gave better prediction of gluten quality than other parameters related to gluten strength.

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Concerning dough behavior upon heating, the lowest Amylograph peak viscosity and Falling number values of the flour with lower starch quality was not followed by the lowest Mixolab peak viscosity and temperature sweep storage modulus values. This difference may be attributed to the difference in the examined system: starch suspension (Amylograph, Falling number) *vs.* dough (Mixolab, Rheometer) as water limited system.

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خواص خمیره شناسی تجربی و بنیادی خمیر آرد گندم تحت اثر شرایط آب وهوایی گوناگون

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چکیده

هدف تحقیق حاضر ارزیابی توانایی آزمون های خمیره شناسی تجربی (کلان مقیاس) و بنیادی(خرد مقیاس) در تمیز دادن میان آرد گندم برداشت شده در سال های مختلف بود.برای تامین آرد گندمی که تحت تاثیر شرایط آب وهوایی گوناگون تولید شده است ، محصول سال های ۲۰۰۴ و۲۰۰۵ که مشخصه آن ها درجه حرارت بالا و بارندگی زیاد بود انتخاب شد. افزون بر این، یک نمونه شاهد از آرد نیز

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آزمون شد. به منظور شبیه سازی فرایند پخت، اندازه گیری های خمیره شناسی در هر دوشرایط حرارت ثابت کم (۳۰ درجه سانتی گراد) و حرارت بالا (۳۰ تا ۱۰۰ سانتی گراد) انجام شد. پارامتر های خمیره شناسی بنیادی و تجربی مربوط به قوام گلوتن با هم هماهنگ بود وقوام آرد به ترتیب زیر کم می شد: شاهد>آرد گندم سال ۲۰۰۵>آرد گندم سال ۲۰۰۴. با این همه، پارامتر های مربوط به خمیری شدن نشاسته مانند بیشینه گرانروی(ویسکوزیته) که در شناوری (تعلیق) (آمیلاز نگار و عدد سقوط) و خمیر(درMixolabو Rheometer) اندازه گیری شدند، به علت مقادیر متفاوت آب موجود، ترتیب دیگری را نشان می داد.