New Approach to the Study of Dough Mixing Processes

Zdenka MUCHOVÁ and Boris ŽITNÝ

Department of Storing and Processing of Plant Products, Faculty of Biotechnology and Food Sciences, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

Abstract

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The importance of the dough mixing, knowledge of the requirements of individual types of flour in the mixing, and achieving the proper quality with respect to the final dough properties are still actual problems. This study describes the changes in consistency, extensographic energy, and temperature progress in connection with the mechanical energy flow into the dough during mixing on Diosna SP12 kneader. The results of the mixing tests on the first gear indicate that different energy inputs caused different changes in consistency, the development time, and temperature increase of mixed dough. By the alteration of the mixing energy is it probably possible to utilise this energy achieving, dough with a better quality, despite the fact that this was not proved statistically. However, it was proved that energy consumption was more effective in the experimental regimes in comparison to the standard regime. The experimental regimes required a lower energy input, while the achieved consistency level was similar and durability of the positive consistency changes was higher. The temperature increase was significantly higher when the standard regime was used.

Keywords: mixing; kneading; dough rheology; wheat dough

The mixing process is the crucial operation in bakery industry by which the wheat flour, water, and additional ingredients are changed through the mechanical energy flow to coherent dough. The dough properties are strongly influenced by the way of their mixing (Gras *et al.* 2000; Zheng *et al.* 2000; Wilson *et al.* 2001).

For achieving the proper dough development, two basic requirements must be satisfied. The imparted mixing energy or work input must be higher than the critical limit of energy needed for protein formation, and the mixing intensity must be above the critical level for the dough development (Kilborne & Tipples 1972). These requirements vary with the flour properties and the type of mixer used (Frazier *et al.* 1975; Oliver & Allen 1992). The dough development is a dynamic process where the viscoelastic properties are continuously changing. The dough consistency increases with mixing speed. At higher energy input levels, higher peak consistencies of the dough were achieved, however, the increased speed of mixing resulted in the loss of the mixed mass stability as similarly referred in assays with Farinograph-E (Zounis & Quail 1997). The complexity of the changes caused by mixing motions during the mixing process must be considered for each mixing apparatus individually, because it was proven by many previous studies that, besides the speed of mixing, the type of mixing forces applied

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(*z* – blade, spiral blade, pin mixer) and energy flow are factors with major influence on the final dough consistency (Hwang & Gunasekaran 2001; Haraszi *et al.* 2008). The mixer parameters present the external factors of mixing, which can be possibly adjusted to flour mixing requirements coming out from the inner composition of wheat flour (Weegels *et al.* 1996; Aussenac *et al.* 2001; Tronsmo *et al.* 2002; Don *et al.* 2005). The difficulties in the determination of an exact model for energy flow to the arising dough system and thus defining the mixing requirements of flours with a defined composition (mainly in starch and protein characters) reside in the complexity and variability of emergent mixing forces inside the dough during its deformation (shear, stress, extension, creep), where each mixer type imparts mixing energy by a dissimilar way and its processing profile is in view of this entirely incomparable (Mani *et al.* 1992; Haraszi *et al.* 2008). Consequently, this causes very low correlations between the dough rheological parameters (development time, stability of dough, breakdown, and others) obtained from different mixers. Furthermore, the lab mixing devices like Farinograph or Mixograph do not exert identical mixing actions not only between them but also in comparison with industrial mixers. The dimensions of the mixing space and quantity of the mixed dough play an important role in the dough formation and influence the dough properties (Hwang & Gunasekaran 2001). Even so some values exist which can be correlated well. Farinograph stability is well correlated to the mixing requirements of dough (Willson *et al.* 1997) while the Mixograph development time is well correlated to the bakery mixing time (Zounis & Quail 1997). Due to the dissimilarities in the nature of the applied forces, the devices with unlike moving apparatuses obtaining rheologic data are probably based on different physical fundaments. Therefore the evaluating parameters obtained from these measurements (such as the dough development, energy or stability) can not be exploited for the modelling of dough processing and dough mixing profiles directly on industrial mixers. This presumption is supported by the works evaluating the extent of changes in protein composition during mixing where the unextractable polymeric proteins (UPP) are studied in the dependence on the way of dough mixing (Aussenac *et al.* 2001; Kuktaite *et al.* 2004). The contents of UPP with the same flour sample were significantly different at the peak dough development in the dependence on the mixer type used (Haraszi *et al.* 2008). The results concerning the size distribution of proteins are apparently opposite in the claims for the increase/decrease of UPP during the dough formation in comparison to their content in flour. This seems to be influenced by the extracting method and flour used. The concentration of UPP increases from the start to the peak development and decreases after the maximum consistency peak has been achieved. The amount of UPP is in positive correlation with the dough strength while the content of extractable polymeric proteins together with the fraction of omega gliadins is related to the extensional properties of dough (Weegels *et al.* 1996; Skerrit *et al.* 1999a, b). The extent of protein formation and the concentrations of their individual fractions are affected by the mixing action as well as by mixing speed which considerably changes the mixing energy requirements. The energy requirements of common laboratory devices for the achievement of the dough development to the maximum consistency peak are lower due to the more intensive mixing action as compared to the mixers used on the industrial scale. Anderssen *et al.* (1998) suggested a more accurate assessment of the moving action of mixing can be rather achieved by the expression of the number of revolutions to reach the peak dough development than by the time value, because the reaching of the peak dough development seems to be a rate – independent event. This statement was formulated on the basis of examinations carried out on Mixograph. The findings of Haraszi *et al.* (2008) confirmed that the achieved dough consistency and development time were different with each mixed flour sample, but the number of revolutions required for reaching the peak dough development on Mixograph was quite similar for each mixing speed in the speed range of 60 to 140 revolutions per minute (rpm). Wilson *et al.* (2001) used a MDD 125 mixer and found that the blade revolutions are not clearly rate – independent over all mixing speeds. The number of revolutions for achieving the dough development point was higher at lower speeds (below 150 rpm for weak flour and 200 rpm for strong flour), but in the upper range (above 150 rpm – weak flour or 200 rpm – strong flour) the number of revolutions was steadily rate – independent. Apparently, the rate – independence of mixing is the function of both the mixer type and flour quality.

From the industrial view, the requirements for the mixing process can be formulated as a cost effective way for processing of dough with proper quality. The requirements of the doughs for the mixing energy are related to the dough strength, therefore the costs of the end-products of mixing are different. Different industrial mixers can be evaluated through their efficiency (Wooding *et al.* 1999). The energy consumption (work input) for the dough formation at the peak resistance depends on the flour used, mixer speed, and mixer type. During mixing, the energy flow and the hydration processes are accompanied with a temperature increase. The temperature growth is dependent on the speed of mixing (Wilson *et al.* 2001), but it is assumed that heating of dough during mixing is influenced by the type of the flour used and also by the type of mixer.

Through the determination of the proper energy input, optimal changes during mixing can be probably achieved (in the case of one type of mixer). It is possible in this way to manage the process of dough developing.

This study is focused on the evaluation of changes evoked by the mixing motion at different mixing speeds on Diosna SP12 mixer (Diosna Dierks and Söhne, Osnabrűck, Germany). This device was constructed by Diosna company as an experimental mixer for the purpose of optimising the mixing requirements of industrial Diosna mixers. The changes caused by different dough compositions were studied using Amylograph-E, Farinograph-E, and Extensograph-E (Brabender GmbH & Co. KG, Duisburg, Germany). For the purpose of monitoring the role of water during the dough formation, water activity was measured.

MATERIALS AND METHODS

The changes taking place during the mixing process were observed using flour type T512 (MPC Cessi joint-stock company, Spišská Nová Ves, Slovakia) with defined properties. The samples of the flour were evaluated according to the described methods. Determined were:

The contents of ash (ICC Standard 104/1:1990), nitrogenous components (STN ISO 1871:1997 – Common conditions for determination of organic nitrogen according to Kjeldahl method), moisture (ICC Standard 110/1:1976 – Determination of moisture content of cereals and cereal products), wet gluten (ICC Standard No. 106/2:1984 – Working method for the determination of wet gluten in wheat flour), and starch (STN EN ISO 10520:2002 – Native starch, Determination of starch content – Ewers polarimetric method). Further the falling number (ICC Standard 107/1:1995 – Determination of the “Falling Number” according to Hagberg-Perten as a measure of the degree of alpha-amylase activity in grain and flour), extensibility of gluten (STN 46 101-9:1997 – Examination methods for the testing of cereals, legumes and oilipherous plants), and Zeleny index (ICC Standard 115/1:1994 – Determination of sedimentation value (ac. to Zeleny) as an approximate measure of baking quality).

The characterisation of the rheological properties was performed by means of the Farinograph-E (Brabender GmbH & Co. KG, Duisburg, Germany) (ICC Standard 115/1:1997 – Method for Using the Brabender Farinograph), Extensograph-E (Brabender GmbH & Co. KG) (ICC Standard 114/1:1992 – Method for using the Brabender extensograph), and Amylograph-E (Brabender GmbH & Co. KG) (ICC Standard 126/1:1992 – Method for using the Brabender Amylograph). The falling number characteristic was determined by Falling number 1500 Perten (ICC Standard 107/1:1995).

Dough was prepared with the addition of 2.23% NaCl (db) and with distilled water. The flour samples were mixed according to the various regimes of mixing by Diosna SP12 with the evaluation of the following parameters: the temperature increase (with the use of an electronic thermal test probe Pt 100), number of revolutions of the mixing spiral, mixing speed as the revolution frequency per second at constant rounds of the mixing bowl, and energy consumption on the rotor (energy requirement). The finished dough was subsequently evaluated by rheological methods according to the modified methodologies. The changes in water mobility of the water phase in the dough were evaluated by the water activity value measured by the Novasina LabMaster a_w (Novasina AG, Lachen, Swiss). The samples for the water activity assays were separated from the dough after each individual test of the mixing regime on Diosna SP12 in four 6 g specimens. These specimens were equally embedded into the testing dose (the measurement dose is provided with LabMaster as accessory) and covered with plastic lids. Then the samples were placed inside the LabMaster (the lid of the dose had been uncovered) and the water activity measurement was started according to manufacturers method.

Modifications of the laboratory Diosna SP12 mixer. The construction of the mixer is designed with the aim of possible simulation of industrial conditions of the mixing process on laboratory scale. The results obtained from this laboratory mixer can be applied to industrial mixing equipment manufactured by Diosna company.

The standard regime (1st gear: 25 Hz for 2 min, 2nd gear: 50 Hz for 5 min) is predominantly used on industrial scale for the mixing action in east Europe for the Diosna kneaders. The experimental regimes were designed on the basis of the presumption that the main changes are evoked when the dough system begins to rise to the dough mass, that is in the plateau region area before achieving the maximum development peak.

Diosna SP12 consists of two moving parts: the mixing dose and mixing spiral with an individual power drive each; and of static parts: the control panel and the main skeleton of the device. On the vertical axis of the mixing dose, perpendicular to the base of the dose, is placed the electronic thermometer probe Pt 100. The signal from the Pt 100 probe is connected directly to the control panel. The work input and the measuring of the mixing spiral rotations are regulated by an integrated electronic control panel as an organic part of the control software made by Diosna. The speed of the mixing dose can be changed by an electric frequency converter independently from the speed of the mixing spiral. The mixing spiral is driven by an independent engine with independent energy consumption measurement. The energy requirements are expressed directly in Wh. The temperature of the dough can be monitored continuously during the mixing. The rotation of the mixing spiral is evaluated in rounds per mixing period.

Modifications of the rheological methods. The modification of the classical methodology resides in the use of Farinograph-E for the rheological characterisation of the dough prepared with Diosna SP12 kneader. The calculated amount of the dough sample mixed in Diosna SP12 under controlled conditions was put inside the mixing space of Farinograph-E. The consistency was evaluated from the farinogram curve precisely in the fourth minute, after the farinograph assay started,

The modification of the extensographic method resides in changes of the resting time intervals (15 min and 30 min). The dough prepared with Diosna SP12, being mixed according to the suggested regimes (Table 1) or using the first gear only was measured twice, i.e. immediately at the end of mixing and after 30 min from the end of mixing on both devices (Farinograph-E and Extensograph-E). The modification of the Amylograph-E method resides in the measurement of the dough sample instead of that of flour, which had been homogenised with the mixer ETA (ETA, Hlinsko, Czech Republic) during an interval of 120 s (1800 rounds of blade per minute). Water was added to the calculated amount of the dough, in order to have equal amounts of dry base under the modified and standard ICC methods.

Measurements of the evolving consistency flow on Diosna SP12. Diosna SP12 mixer is not equipped with a load cell for the monitoring of the torque resulting from the dough mixing. Therefore, the consistency of the dough emerging from Diosna SP12 was monitored by means of the Farinograph-E. The samples of doughs were removed from the mixing bowl 5 min after the mixing was done for the purpose of the consistency and stress – strain evaluations with Extensograph-E. The samples were removed in one piece each with a defined weight

Table 1. Setting of individual (self-contained) regimes

Self-contained mixing regime		Abbreviations for figures	1st gear speed (Hz)	Work time on 1st gear (s)	2nd gear speed (Hz)	Work time on 2nd gear (s)
Standard regime		str	25	120	50	300
Self-contained regime	1	scr1	70	120	25	300
	2	scr2	60	120	25	300
	3	scr3	50	120	25	300
	4	scr4	40	120	25	300
	5	scr5	30	120	25	300

Table 2. Chemical composition of flour sample

Sample of flour	Moisture content	Ash content in dry matter	Wet gluten content in dry matter	Extensibility of gluten (cm)	Falling Number (s)	Content of N × 5.7 (%)	Content of starch in dry matter (%)	Zeleny index (cm^3)
	(%)							
T 512	12.8	0.55	24	12	261	11.9	71.5	35

(the pieces extracted from a bigger dough mass as undivided pieces). The weight of each extracted piece of the dough sample was determined so as the dry weight of each piece should be equal. The water absorption capacity of the flour samples was the same during the tests. The measurements of the consistency flows (torque) at the first gear of mixing were pursued individually for each time point (90 s, 120 s, 150 s, 180 s, 240 s, 300 s).

Statistical analysis. For the formulation of the data variances in the measurements of temperature differences and power consumption was used the Kruskal-Wallis one way analysis of variance with the depiction in the box plot graph. This statistical method was used for the expression of all variances among the data group including the same logical group. For the expression of the relation between consistency and the speed of mixing as well between the extensographic energy and mixing regime, *t*-test for pairs of data was used.

RESULTS AND DISCUSSION

The basic characteristics of the flour sample (Tables 2 and 3) showed that the flour sample quality equals those of flours with middle baking quality (if we consider the quality of flours in Eastern Europe). The results in the tables are the averages of three independent measurements.

Determination of the reproducibility of the measurements in association with modified methodologies

During the evaluation of the changes in the dough, which had been prepared with Diosna SP12, modified methodologies for Amylograph-E and Farinograph-E were used. Similar modifications of these methodologies were not found and neither were the sources describing the measurements of dough prepared with Diosna SP12. The verification of these methods showed that Farinograph-E achieved reproducibility with the deviation of up to 4% between the values in parallel assays in respect to the standard method. Amylograph-E achieved deviations of up to 5% (reproducibility assumes parallel measurements). The reproducibility of the modified methods depends on the accurate conditions during the dough preparation with Diosna SP12.

Consistency Changes of dough at the first mixing speed

In accordance with the actual concept of the dough development process introduced by more studies (Walker & Hanzelton 1996; Graybosch *et al.* 1999), changes with a major impact take place during the initial periods of mixing to the peak dough development, which considerably differ between the individual flours and mixers. Probably,

Table 3. Rheological parameters of flour sample

Rheological parameter	Evaluation
Maximum consistency (FU)	504
Water absorb 500 FU (%)	54.8
Water absorb corrected for 14% humidity of flour sample (%)	54.2
Development time (min)	1.7
Stability [min]	9.4
Degree of softening (5 min) (FU)	32
Degree of softening (12 min) (FU)	59
Farinograph quality number FQN (s)	97
Begin of gelatinization (°C)	62.6
Maximum of gelatinisation (AU)	465
Temperature of gelatinization max. (°C)	82

FU – farinograph units. Unit comonly used for evaluation of rheologic consistency in bakery practice. It was defined by Brabender company. The physical equation is Nm – 100 FU = 1 Nm; AU – amylograph units. Unit comonly used for evaluation of rheologic consistency in bakery practice. It was defined by Brabender company. The physical equation is Nm – 100 AU = 0.1 Nm

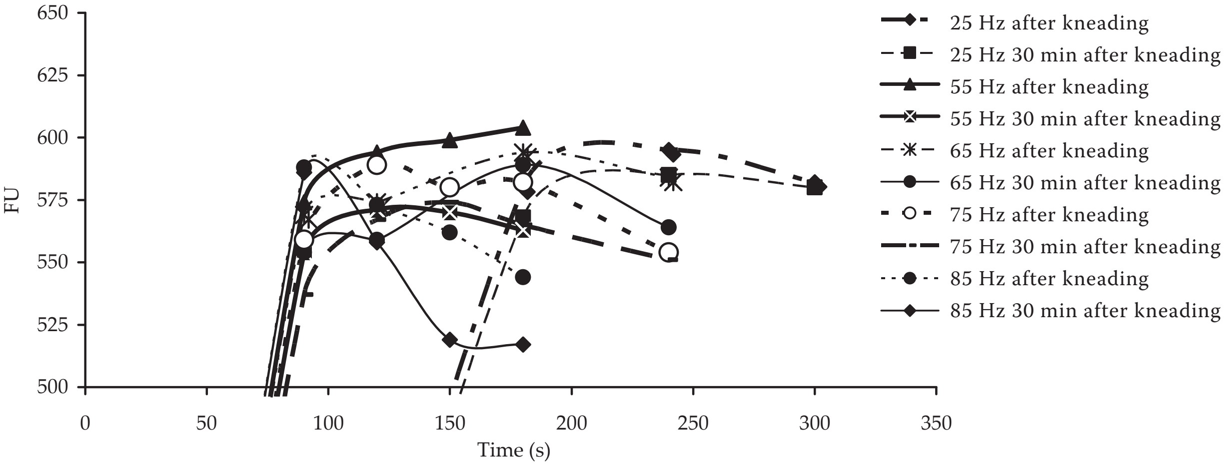


Figure 1. Consistency of doughs prepared under various mixing regimes on Diosna SP12 – Consistency progress of doughs prepared under various mixing regimes on the first gear (all tests together in one graph area express the variable behaviour of arised doughs which were achieved by changing the mixing speed on the first gear)

by using one mixer type, the dough development can be influenced by the mixing speed, imparted energy input, and reciprocal mixing motion of the moving parts (in case if it is possible to change the reciprocal motion of the moving parts; presumably, when the reciprocal motion of the mixing parts is changed, the mixing forces and resulting dough properties are changed). Considering these facts, the stage of mixing to the maximum peak is the processing area where the dough development can

Table 4. The evaluation of *P*-values for achieved dough consistencies (without resting and 30 min resting)

PCT	25 Hz 180 s	25 Hz 240 s	25 Hz 300 s	–	–
ΔC	25c0	25c1	25c2	–	–
P-value	0.0266	0.0154	0.3899	–	–
PCT	55 Hz 90 s	55 hz 120 s	55 hz 150 s	55 hz 180 s	
ΔC	55c0	55c1	55c2	55c3	–
P-value	0.0025	0.0258	0.0433	0.0156	–
PCT	65 Hz 90 s	65 Hz 120 s	65 Hz 180 s	65 Hz 240 s	–
ΔC	65c0	65c1	65c2	65c3	–
P-value	0.0165	0.0322	0.1188	0.0495	–
PCT	75 Hz 90 s	75 Hz 120 s	75 Hz 150 s	75 Hz 180 s	75 Hz 240 s
ΔC	75c0	75c1	75c2	75c3	75c4
P-value	0.0797	0.1088	0.3063	0.1255	0.1334
PCT	85 Hz 90 s	85 Hz 120 s	85 Hz 150 s	85 Hz 180 s	–
ΔC	85c0	85c1	85c2	85c3	–
P-value	0.0076	0.2725	0.0129	0.0183	–

PCT – mixing intensity/the time point – at which the comparison of consistencies for doughs (with and without resting) was evaluated; ΔC – the time point at which the *P*-value evaluation for exact consistency level was done (for example point 25c0 expreses *P*-value for the difference in measured consistencies among first gear for dough with and without resting). The 25 (Hz) signifies the speed intensity of mixing and c0 means the time point at which consistency of doughs is compared; *P*-value – statistical data value

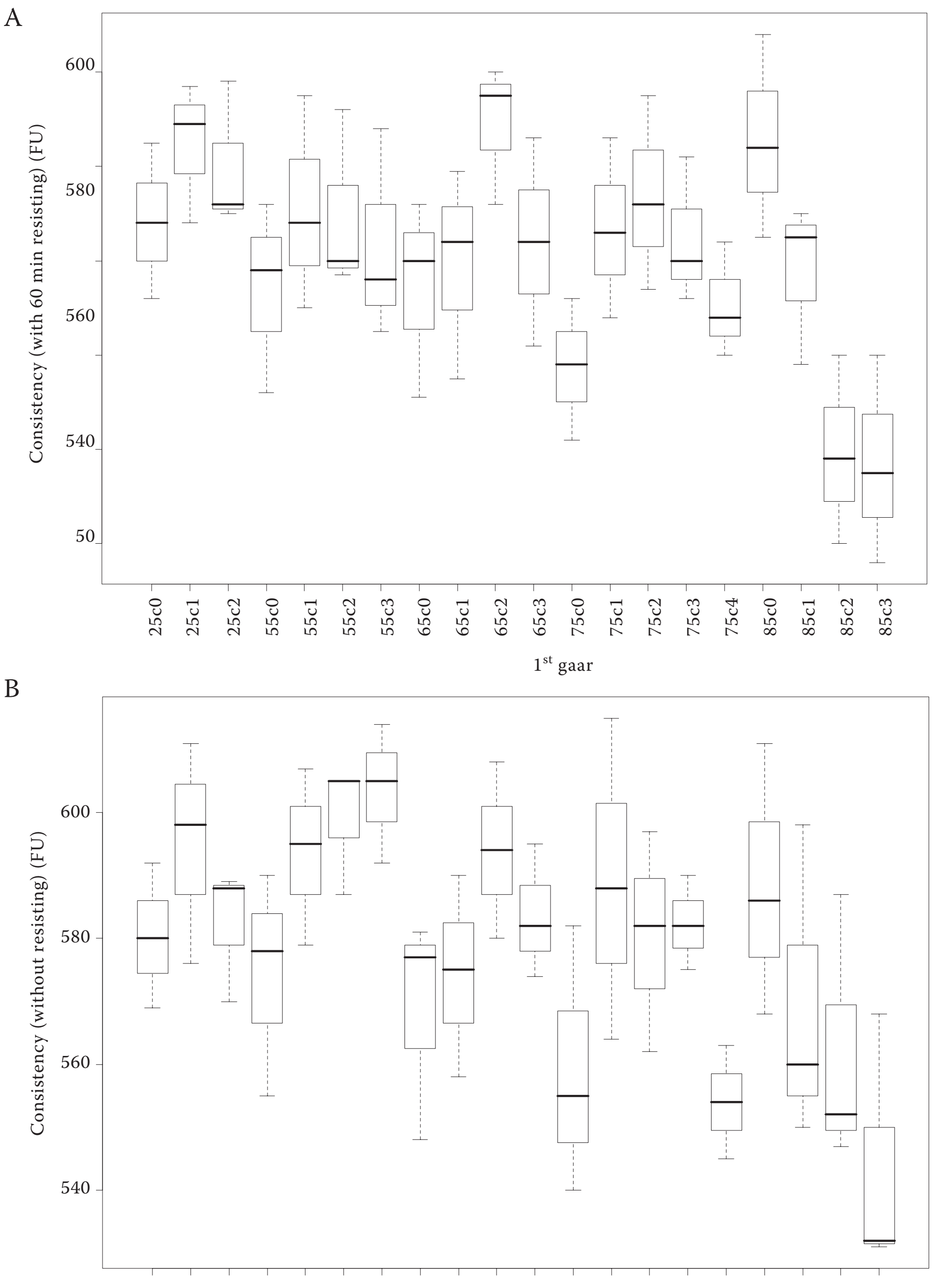


Figure 2. Consistency of doughs prepared under various first gears of mixing in Diosna SP12 – statistical evaluation in box plot: A – consistency of doughs with 30 min resting, B – consistency of doughs without resting (the marking of x axis for the Figure 2(A) and 2(B) is same as data marking in Table 4)

be fundamentally modified. Based on this presumption, the changes in consistency and temperature during the initial stage of mixing were monitored (Figure 1). The evaluation of the consistency of each dough sample prepared at defined mixing speed was carried out immediately at the end of the mixing process and subsequently after 30 min, in order to determine the durability of the possible changes caused by the alteration in the mixing speed. The decrease in the consistency of rested doughs with each mixing speed was significant (Figure 2 and Table 4), this being consistent with the claims of former authors. In the case of the 75c0 consistency difference point, *P*-value showed a slight decrease after the resting period. The decreasing consistency after resting is attributed

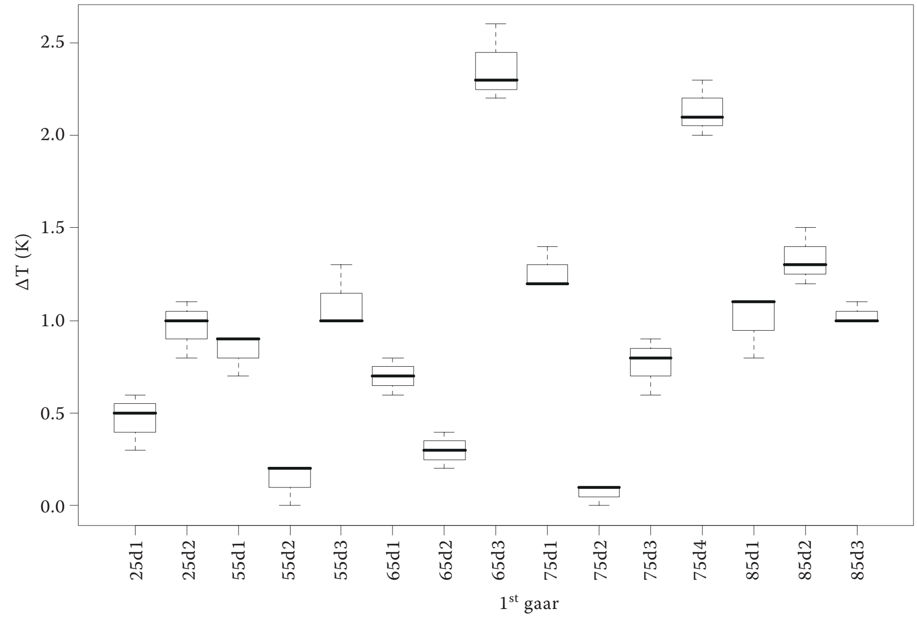


Figure 3. Temperature increase – data variances by Kruskal-Wallis one-way analysis caption for the Figure 3 is given in Table 5B

to the compensation of the stress – strain forces at the molecular level between protein polymers (Singh & MacRitchie 2001). The decrease in consistency after 30 min of resting expressed in brabender units was high with the dough prepared under a mixing speed of 85 Hz. Maximal consistency points were reached faster in such instances when the dough was mixed more intensively as referred equally in previous works (Frazier *et al.* 1975; Zheng *et al.* 2000), and therefore it seems

Table 5. The temperature growth (ΔT) during the dough mixing at first gear. Issued for the range of speeds from 25 Hz to 85 Hz

Mixing speed	Mixing time (s)					
	90	120	150	180	240	300
A. temperature increase during mixing (stepwise from the time point to time point)						
85 Hz	0	1.0	1.3	1.2	–	–
75 Hz	0	1.3	0.1	0.8	2.1	–
65 Hz	0	0.7	0.3	2.4	–	–
55 Hz	0	0.8	0.1	1.1	–	–
25 Hz	0	0.0	0.0	0.0	0.5	1.0
B. capture to the x axis of Figure 3						
85 Hz	0	85d1	85d2	85d3	–	–
75 Hz	0	75d1	75d2	75d3	75d4	–
65 Hz	0	65d1	65d2	65d3	–	–
55 Hz	0	55d1	55d2	55d3	–	–
25 Hz	0	0	0	0	25d1	25d2

ΔT – temperature increase in K from the time point to past time point in one same mixing process for the same mixing speed (e.g. temperature increase for the speed 85 Hz during mixing of dough from the mixing time point 120 s to the mixing time point 150 s is stated as 85d2 which value is 1.3 K)

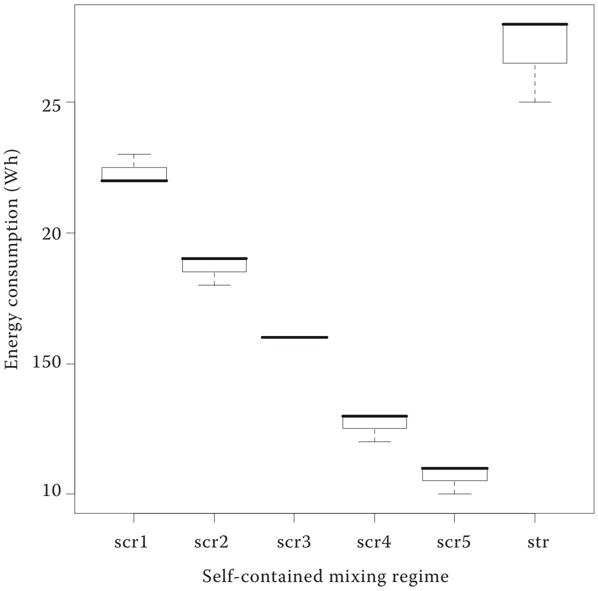


Figure 4. Energy consumption variances for mixing in individual self-contained regimes by Kruskal-Wallis one-way statistical analysis (caption to the *x* axis of Figure 4 is given in Table 1)

to be similar for all types of mixers. The speed gradation affected the increase of consistency while the dough stability decreased with the speed gradation. The temperature increase is not linear during the dough formation. From the start of mixing, the temperature rises progressively, but close to the plateau region (before reaching maximum consistency), the temperature increase is very low or none. After reaching the peak dough development, the temperature increase proceeds faster. The temperature growth in later stages of mixing beyond the peak dough development is not presented in this study. Probably, in the determined area of mixing, the energy supplied into the system is exploited rather for the creation of the bonds between newly formed macromolecules of dough than for the dissipation of energy in the form of heat (Table 5 and Figure 3). Conjecturally, the temperature behaviour during mixing should depended on the method of mixing (mixing action), because it is activated by inner rubbing between molecules and by particles hydrating. The speed of mixing, work input, and flour type play significantly important roles in the temperature increase during mixing (Wilson *et al*. 2000).

Dough mixing during self-contained regimes (where the 1st and the 2nd gear are applied subsequently)

The standard regime chosen for the comparison with experimental regimes was the same mixing regime which is used for the industrial mixing in bakeries (1st gear: 25 Hz per 2 min, 2nd gear: 50 Hz per 5 min).

The results obtained with various mixing regimes showed (Table 6 and Figure 4) that the imparted energy and rotation are higher under the standard regime in comparison with the experimental regimes, but the final consistency of the dough is approximately equal for all regimes, which is supported by *P*-values higher than *P* = 0.05 (Fig-

Table 6. Evaluation of self-contained mixing regime parameters

Mixing regime		P (Wh)	U	U/P	Consistency immediately after mixing (FU)	Consistency 30 min after mixing (FU)	A	B
Standard regime		26.5	1232.5	46.5	510.5	487	23.5	4.6
Self-contained regime	1	22	1079.7	49.1	507.5	490.5	17	3.4
	2	18.5	1000.5	54.1	500.5	488.5	12	2.4
	3	16	918.5	57.4	501	489	12	2.4
	4	12.7	841.3	66.4	502.3	490	12.3	2.5
	5	10.5	756.5	72	515	502	13	2.5

P – power output consumption of Diosna SP12 kneader during mixing regime (measured for both speeds of one regime together); U – number of spins of mixing spiral per mixing period (measured for 1st and 2nd mixing speed together); U/P – divide between power output consumption of Diosna SP12 kneader and total spins of spiral per period of mixing; A – difference in consistency between 0 min and 30 min after mixing, expressed in FU; B – difference in consistency between 0 min and 30 min after mixing, expressed in %

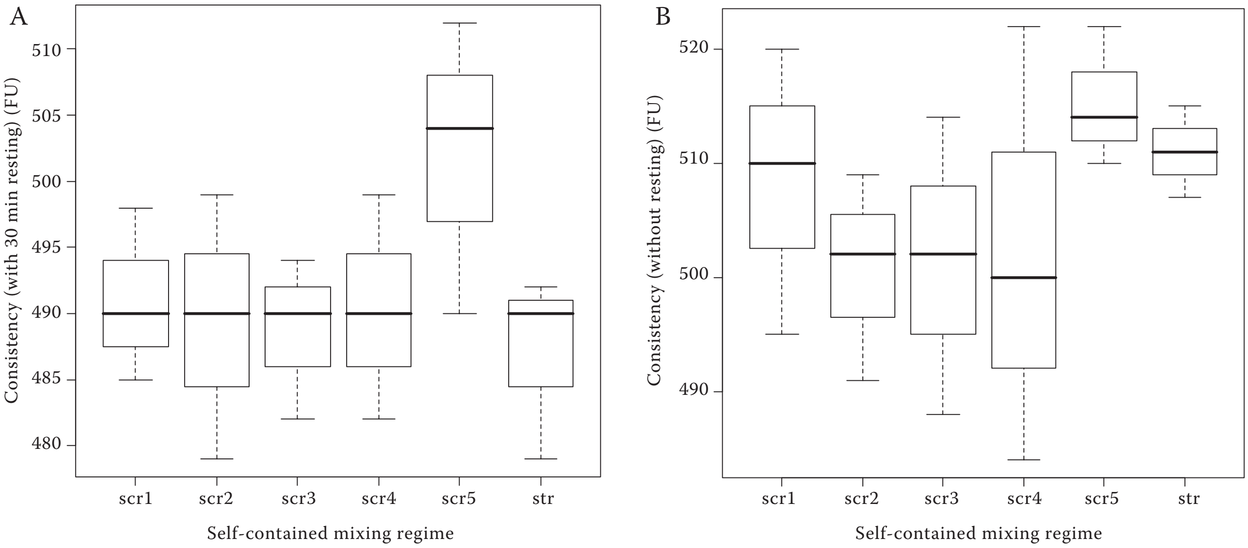


Figure 5. Consistency variances for mixing in individual self-contained regimes: A – Consistency data variances for dough with 30 min resting; B – Consistency data variances for dough without resting (caption to the *x* axis of Figure 5 is given in Table 1)

ure 5). The consistency of dough after 30 min resting in self-contained regimes did not change significantly, however, the decrease in consistency in the standard regime changed significantly. This could indicate that the changes taking place at molecular level during the mixing action on Diosna SP12 are more durable if the energy is imparted by a more intensive action at the stage before the dough peak development, which is in disagreement with the standard regime conception. According to Larsson *et al.* (2005), the formation of dough macro-polymers is significantly influenced by the mixing regime, especially during the phase of the 3D molecular structure development. Similar conclusions have been stated in many previous works focused on developmental rheology in relation to protein behaviour (Weegels *et al.* 1996; Skerritt *et al.* 1999a; Kuktaite *et al.* 2004; Haraszi *et al.* 2008). This indicates that it is probably possible to modulate the rheologic properties of the final dough by a proper energy input. The impact of this event for the use on industrial scale might be momentous, especially in the case when the mixers can be optimised by the type of flour used. On the basis of the assays made with Diosna SP12, experimental regimes proved to be more energy efficient in comparison to the standard regimes (Figure 4). The reasoning behind the above statement is that

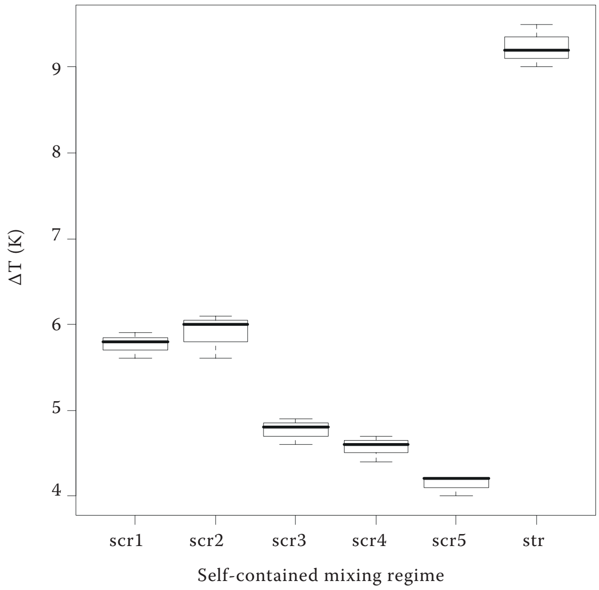
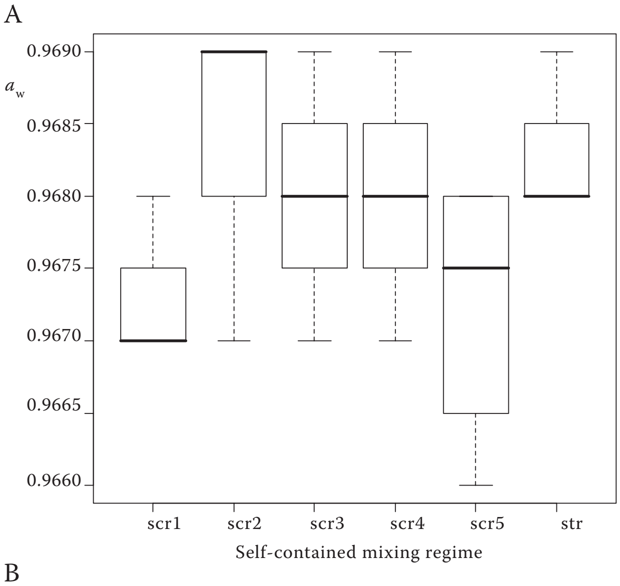


Figure 6. Comparison of temperature increase during mixing process: ΔT – temperature difference between the begining and end of the mixing period for the particular mixing regimes; B – evaluation of data variances for the measurements of temperature increase by Kruskal-Wallis one-way statistical analysis (caption to the *x* axis of Figure 6 is given in Table 1)

the experimental regimes require lower energy levels, which are more effectively utilised by and transferred into the mixed mass during the mixing process. Probably, the increase in the temperature of dough while using the experimental regimes was therefore lower than the increase recorded when using the standard regime (Figure 6). The dough mixed more intensively was finished sooner than the doughs with which the initial mixing speed used was lower. As shown (Figure 2), maximal consistency was achieved with the 1st gear at speeds of around 65 Hz. Despite the 1st gear embodying only a partial phase of mixing, it is assumed that consistency declines during the later phases, it is therefore sufficient to observe maximal consistency levels at the 1st gear only (to reaching the maximal consistency). ZHENG *et al.* (2000) showed that the apparent viscosity of dough in relation to the work input increased to the peak dough development, and further work input resulted in a lower apparent viscosity. Further study should elucidate the existence of the discrete interval of the imparted energy (represented by the speed and moving action of the mixer), in which the dough elements have the maximum ability to absorb and utilise the supplied energy for the formation of optimal dough structure. Probably, the imparted energy (mixing requirements) will be different for each flour quality class. From another point of view, we could also consider this as the rate of imparted mechanical energy, which is still utilisable from the perspective of optimal dough formation. The questions of intensity and timing of energy input should be considered together with the qualitative and quantitative parameters of the input materials, which is consistent with former findings provided



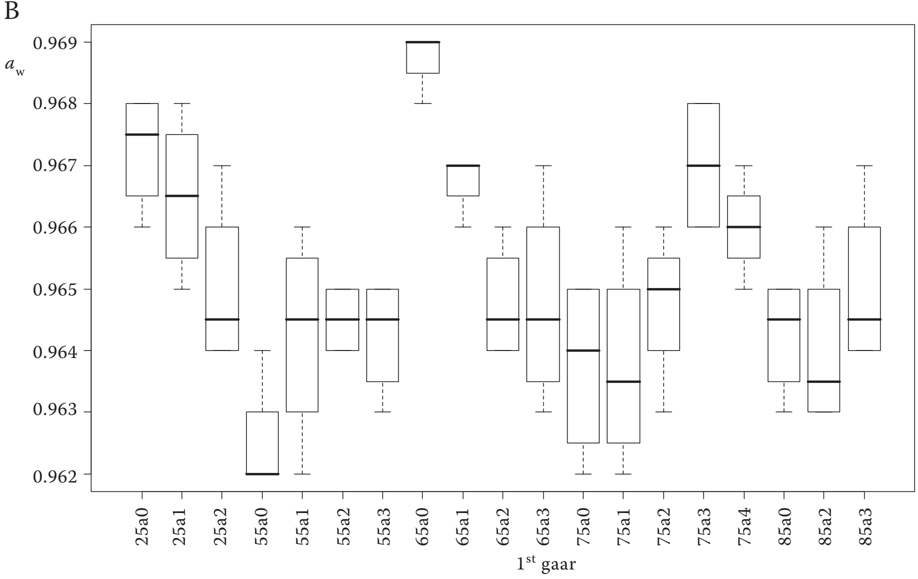


Figure 7. Influence of changes in mixing speed on a_w values: A – for self-contained regimes mixed on the Diosna SP12; B – for the dough samples mixed on the 1st gear on Diosna SP12

by means of other mixer types (Rao *et al.* 2000; Hwang & Gunasekaran 2001).

Evaluation of the water activity changes in relation to the mixing regime

The consistency of dough is predetermined by the water to the solid components ratio and by the quality of the flour components, mainly proteins. The values of a_w in the finished dough indicate whether the change in consistency of the dough has been caused either by the change in the affinity of water to the inner structures of dough or by the change in consistency due to the changes in dough proteins conformation. The assumption is that the changes in the consistency of the finished dough can be attributed to either proteins or affinity, or both. As the assays showed, water activity value (a_w) did not change in the dependence on various mixing speeds or mixing regimes (Figure 7). Dough is a complex colloidal system containing many hydrophilic chains. These substances probably bind the free water molecules during their migration from the system, so if we consider this, then the water activity method is of minor importance for the dough system. Despite the fact that between several data from a_w statistical evaluation significant differences occur, the deviation of the method is greater or the same as the differences between the data obtained from a_w measurements. Referring to the previous, the changes in the consistency of dough observable in relation to the mixing regime probably relate to the changes in the structure formation of proteins.

Amylographic measurements according to the modified method

The results obtained from amylographic measurements did not reveal any significant differences between the dough samples prepared under different mixing regimes.

Extensographic measurements according to the modified method

The comparison of the mixing actions by using the Extensographic energy parameter ascertains that, for the doughs mixed to the peak dough development on Farinograph-E, the area under the Extensograph log was smaller (extensograph

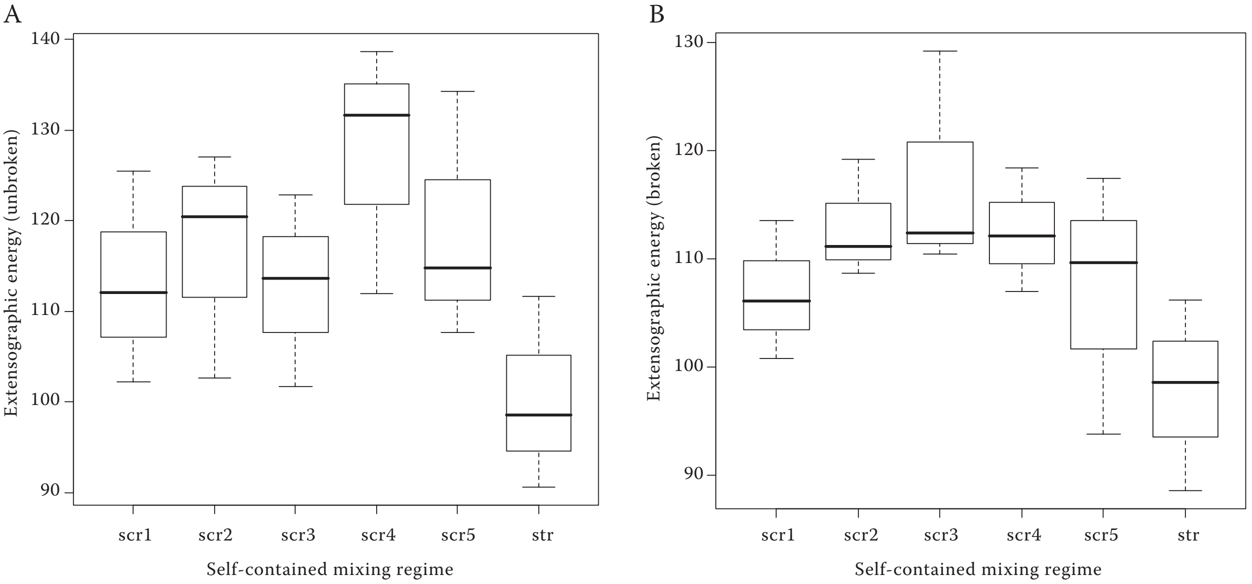


Figure 8. Extensographic energy of doughs prepared by individual (self-contained) mixing regimes: A – evaluation of extensogrphic energy in box plots by Kruskal-Wallis one-way statistical analysis for doughs mixed by individual mixing regimes which was not broken before extensographic measurement; B – evaluation of extensographic energy in box plots by Kruskal-Wallis one-way statistical analysis for doughs mixed by individual mixing regimes, which had been broken before extensographic measurement

energy was low) in comparison to Diosna SP12. The Extensographic energy value expresses the resistance ability of dough against the deformation forces and correlates well with the gas retention capacity of dough and the volume of the end product after baking. This finding is valid for the extensographic curves where the ratio between resistance and relative extension does not fall out of the common range. No significant differences were proved between the extensographic properties of the dough samples mixed according to the experimental regimes and the standard regime. Anyway, there is a strong indication that the consistency of the dough mixed under the experimental regimes is more favourable than that of dough made by the use of the standard regime. Temperature increase was lower in the experimental regimes than in the standard regime (Figure 6). The measured extensographic energy of the dough samples indicates a tendency towards technologically better values in the experimental regimes (Figure 8).

CONCLUSIONS

Preliminary conclusions of this paper are:

– The increase in the intensity of speed on the 1st gear without proceeding to the subsequent gear indicates a tendency towards an increase in the consistency level of the dough developed by using Diosna SP12 mixer. No significant difference between the consistency of high and low speed mixing (energy input) was proved (*P*-value was higher than $P = 0.05$). Maximal consistency was achieved with mixing at a speed of 65 Hz, however, the difference was not proven to be significant. By increasing the intensity of mixing on Diosna SP12, the duration of the dough preparation from flour sample was shorter, but the stability of the final dough was lower.

– The energy requirements of the mixing process on Diosna SP12 are significantly more efficient where the experimental regimes are used for flour-water-salt dough system development (*P*-value perceptibly less than 0.05 using of the pair *t*-test).

– The values of extensographic energy and mechanical properties of dough are technologically more favourable under the proposed experimental regimes as compared to the standard regimes of dough mixing, but statistical significance of this claim has not been proved. Anyway, the results of the measurements explicitly support this reasoning. This claim is open for the further argumentation. The yields in the dough consistency in the standard and experimental regimes are comparable, and this applies so far to the dough consistency after 30 min resting. On the other hand, significant differences were proven in the consistency decrease between the standard and experimental regimes. The changes in dough viscosity were more durable with the experimental regime doughs. Water affinity to the structural components of the dough did not significantly change due to the mixing action on Diosna SP12. The significantly higher temperature increase in the doughs mixed under the standard regime as compared to the experimental regimes is presumably related to a worse energy utilisation resulting from non-satisfying the energy requirements of the arising dough structures during the developing stage up to reaching maximum consistency. All evaluations are strictly related to the mixing process on Diosna SP12 and partly on Farinograph-E. For this study, only major trends were indicated by using only one flour sample. For further work, more flour samples of different baking quality will be used for the comparison of the changes occurring during mixing.

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Corresponding author:

Ing. Boris Žitný, Slovenská poľnohospodárska univerzita v Nitre, Fakulta biotechnológie a potravinárstva,
Katedra skladovania a spracovania rastlinných produktov, Tr. A. Hlinku 2, 949 01 Nitra, Slovenská republika
tel.: + 421 376 414 421, e-mail: zitnyb@t-zone.sk