VARIATION OF FARINOGRAPHIC PARAMETERS OF DOUGHS OBTAINED FROM WHEAT AND RYE FLOUR MIXTURES DURING KNEADING

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În lucrare se prezintă rezultatele unor cercetări experimentale privind caracteristicile reologice ale aluaturilor din amestecuri de făină de grâu FA-480 cu făină de secară în procente diferite (0; 10; 20; 30 şi 40%), achiziţionată din comerţ. Determinările au fost realizate în laborator cu ajutorul farinografului electronic Brabender, şi a unui frământător cu braţ spiral planetar prevăzut cu traductor de moment de torsiune şi punte tensometrică adecvată. Achiziţia datelor şi trasarea curbelor variaţiei momentului rezistent la arborele frământătorului s-a efectuat pe calculator, printr-un sistem de achiziţie special. Au fost analizaţi parametrii farinografici rezultaţi din curbele farinografice pentru cele cinci tipuri de aluat experimentate, precum şi alura curbelor şi parametrii acestora pentru variaţia momentului la arborele frământătorului planetar. S-a constatat că pentru aluaturi cu până la 30% făină de secară, alura şi parametrii farinografici nu prezintă variaţii semnificative, în schimb pentru aluatul cu 40% făină de secară momentul rezistent şi alura curbelor s-a modificat esenţial.

The present paper shows the results of some experimental research on the rheological characteristics of the doughs obtained from FA-480 wheat flour and rye flour mixtures in different ratios (0, 10, 20, 30 and 40%), purchased from regular stores The measurements were made in laboratory conditions, using an electronic Brabender farinograph and a kneader with a planetary spiral arm equipped with a torque transducer and a proper strain gauge. The data acquisition and plotting of torque variation at the resistant shaft of the kneader was performed on the computer, using a special data acquisition system. The farinograph parameters given by the obtained curves were then analyzed for the five types of dough, as well as the shape of the curves and the parameters for the torque variation at the shaft. It has been found that, for doughs having up to 30% rye flour, the shape and farinograph parameters do not show significant variations, while, for the dough with 40% rye flour, the resistant torque and the shape of the curves have changed significantly.

Keywords: wheat flour, rye flour, dough mixer, farinographic characteristics, development time, stability, flour quality

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1. Introduction and review

The bread dough structure and rheological properties are obtained by physical, colloidal and biochemical processes during the kneading operation.

The kneading process differs from a regular mixing process due to the different characteristics of the mixture components, mainly flour and water which are the basic components of bakery dough. Only the first stage of kneading can be considered a mixing of the components, until the flour particles begin to hydrate, swell and form wet conglomerates. Dough linking occurs with the release of hydration heat, which is around 113 Joules for a gram of dry substance in the flour, rising the dough temperature [1].

Dough formation is achieved by merging the clusters of hydrated flour particles and by the relative movements of those, under the action of the kneaders working bodies, finally forming a compact and homogeneous mass. The elastic properties and rheological characteristics of bakery dough are obtained during the third stage of kneading, when the linked dough is subjected to deeper mechanical actions; then the dough easily comes off the tank walls and gains a smooth and glazed surface. The dough optimal development occurs within a certain range of time (2-20 min), depending on the flour quality, amount of added water, speed of kneader bodies (namely, kneader arm and bowl) [2].

The period of rheological characteristics retention during kneading, after dough formation, under the deformations caused by the speed gradients imprinted by the working bodies, depends on the flour quality. This is the stability phase of the dough. At this stage, the mechanical action of working bodies can improve the rheological properties of the dough, by accelerating the hydration of all the flour particles and the formation of the dough gluten frame. From this point onward, by further kneading, in the softening stage, the dough rheological characteristics change since the former becomes soft, expandable, loses its cohesion, begins to stick to the tank walls and looks like a viscous liquid.

Therefore, the gluten matrix, which keeps the dough bound and with proper rheological characteristics, manifests itself differently over time under the action of the kneading arm mechanical stresses. It is essential to estimate the completion of the kneading operation, in order to obtain a dough with the best features, both for further processing during the technological process (dough dividing and shaping) and for the final fermentation and ripening stages, since the gluten network formed at kneading is responsible for maintaining the dough shape, having the capacity to retain the fermentation gases which will give the bread crumb its porosity.

Dough formation stages can be highlighted by plotting farinograph curves, most often using standard kneaders, called farinographs.

Although the shape and profile of farinograph curves are similar, they show variations depending on the characteristics of the flour, the amount of added water, type of kneading body and the adopted kneading procedure, the quantity and quality of the ingredients added to improve the dough and finished product qualities, etc., the rheological behavior of the dough during kneading being nonlinear, [3,4]. Characteristic of wheat, it is the flour gliadin and glutenin (about 10-12% dry substance) that participate in the formation of the three-dimensional network of protein films forming wet gluten (22-30% in commercial Romanian wheat flour, with a minimum protein content of 7 -10.5%), [5]. These two proteins exist in sufficient quantities to form extensible (attribute of gliadin) and elastic (attribute of glutenin) doughs.

Rye flour bread has a fine flavour and can be preserved longer, but the nature of rye flour is completely different from that of wheat flour, which is the reason why the production of rye bread needs special procedures, applied only to rye. If the proportion of rye flour in bread is low (up to 40-50%) it can be considered that the bread is mainly made of wheat with added rye, [6].

Although rye flour has glutelin (a protein similar to glutenin) and gliadin, it also contains pentosans, which prevent the formation of the gluten network, which is why the gluten is of lower quality and in a smaller quantity; rye bread has always a denser structure than wheat bread. The pentosans absorb more water and compete with glutelin and gliadin in retaining moisture, also being fragile and easy to destroy, making the dough become very sticky and difficult to form. This is why the dough must be thoroughly kneaded at low speed.

Several papers have presented and analyzed various models for the rheological characterization of wheat flour doughs. Thus, in [7] the Lathersich rheological model is analyzed and justified by experiments, particularly used to describe the relaxation of the shear tension in wheat flour dough. It is considered that the developed model could help to clarify the relations between the technological baking parameters and the viscoelastic properties of the dough, which, although considered essential, are often non-quantifiable.

The most common method of determining the rheological properties of the dough is the farinograph test (ICC no.115/1; ISO 5530-1; AACC 54-21).

In paper [8] experimental measurements were made on the farinograph characteristics of several types of white bakery flour made from Romanian wheat, but also determinations of the energy consumed during kneading, based on the surface under the farinograph curves, determined by planimetry. It was found that the power at the Brabender kneader shaft ranged between 26.8-31.9 W, which corresponds to a specific power of 336.3-386.6 W/kg dough and a kneading specific energy of 67.5-73.1 J/kg dough.

In paper [9], Voicu et al. also presents the results of some comparative experimental research on the kneading behavior of three types of wheat flour from

2008 production (FA-480 FA-650 and FN-Graham), at SC Spicul SA Rosiori factory and FA-650 wheat flour in addition with salt (from 0.4% to 2%). It was observed that with the increased percentage of added salt, the amount of water needed to hydrate the flour and salt particles decreased. At the same time, the dough stability and kneading power, assessed by FQN farinograph index, increased approximately exponentially with the increase in salt content, while the development time, although it became longer, didn't show any significant variations after changing the percentage of added salt.

For wheat flours with different ash contents (0.48-1.25%), data are presented on the variation of rheological parameters of doughs, obtained by measurements using Chopin alveograph, but also the test results or falling index or gluten content, in paper [4]. It was found that the ash content does not significantly influence the shape of alveographic curves, thus there were samples with similar gluten content, but the alveographic index P/L was significantly different. It was also found that the gluten was of a very different quality, which was not influenced by the flour ash content.

This paper presents some theoretical and experimental comparative research on the behavior of wheat and rye flour mixtures during kneading, depending on the content of the rye flour added (from 10% to 40% compared to wheat flour), using both the Brabender farinograph and a regular bakery kneader equipped with a torque transducer.

2. Theoretical considerations

During the kneading operation, the resistant moment at the shaft of the kneading arm presents an increasing variation; at first, during dough formation and development, reaching a maximum value beyond the normal consistency, and then it remains approximately constant for some time (stability phase) depending on the flour characteristics. In the final phase of kneading (wetting phase) the torque variation slightly decreases as the kneading time is extended and the flour quality is lower.

The torque at the kneading arm shaft appreciates the consistency of the dough, recorded in farinograph units (1 FU ≈ daN·m 10^{-3} = 10 N·mm); a normal consistency is considered when the dough kneading requires a maximum torque of 500 FU, [1, 2].

Thus, the dough consistency is a complex rheological characteristic, resulting from the combined effect of the fundamental properties of viscosity, plasticity, elasticity, which influence the efficiency of the technological bakery process. The dough consistency varies with the moisture content, temperature and kneading time, with the proportion of dough phases (solid - liquid - gas), with the biochemical composition of the flour and other factors mentioned before.

The variation in time of the resistant torque moment at the kneading arm of a farinograph (standard kneader) is described by the curve in Figure 1, [8].

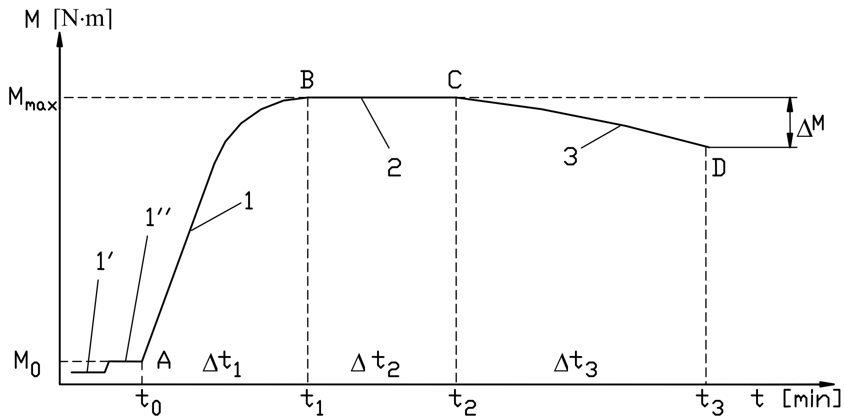

Fig.1. Variation of torque in time at farinograph shaft (farinogram profile), [8]

On the profile of the torque variation curve, the following characteristic parts are distinguished: 1' – idling torque; 1" – torque after the introduction of flour in bowl; AB – torque post beginning of the hydration water and flour; BC – torque during the kneading of the dough (maximum torque); CD – torque in the softening phase if the dough kneading is prolonged. Also, the process characteristic time intervals are: Δt_1 – period formation (development) of the dough; Δt_2 – period of stability; Δt_3 – softening period.

Given the general relationship to calculate the power required to drive the shaft of the kneading arm at a known revolution n (r/min), it can be written:

$$P_{\max} = M_{\max} \frac{\pi . n}{30}; \quad P_m = M_m \frac{\pi . n}{30} \tag{1}$$

where: M_{max}, M_m (daN·m) are resistant torques at the shaft, maximum, respectively average, n (min^{-1}) – kneading arm speed, and P_{max}, P_m (W) – corresponding powers of these torques, [8].

From the graph shown in Figure 1, knowing the surface area under the curve of variation S (N·m·min), obtained by integrating equation of the curve or by planimetry and kneading time t_f, the average resistant torque at the shaft of kneading arm can be determined:

$$M_m = \frac{S}{t_f} \tag{2}$$

where: $t_f = \Delta t_1 + \Delta t_2$ – kneading time (corresponding to the end phase of stability).

Based on relations (1) and (2), the energy consumed in the process of kneading (E_f) is given by the following relation:

$$E_f = P_m t_f = \frac{S \cdot n}{9{,}55} \text{ (N·m)} \tag{3}$$

For a constant speed revolution n, the consumed energy depends only on the surface area under the curve $E_f = f(S)$, being directly proportional to this.

Specific kneading energy ε is determined as ratio between energy consumption E_f and mass of dough to knead w_d:

$$\varepsilon = \frac{E_f}{w_d} \quad \text{(J/kg)} \tag{4}$$

As stated before, kneading curves may vary depending on the amount of added water, flour quality, auxiliary added materials and the kneading equipment (fig.2).

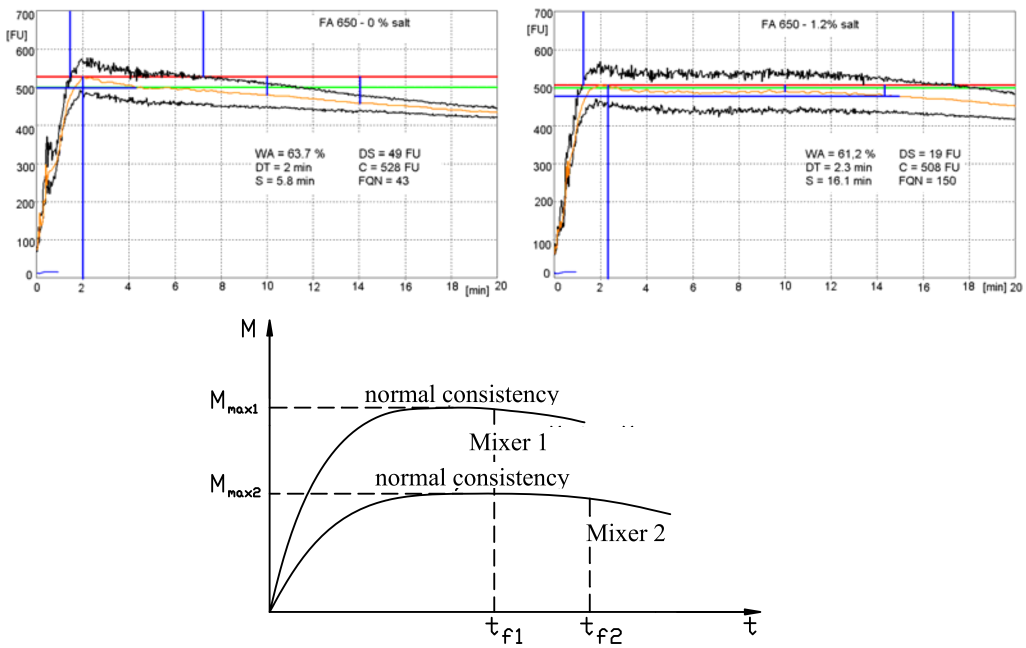

Fig.2. Influence of some process factors on the profile and the relative position of kneading curves, [9]; WA(%) - hydration capacity of flour; DT – development time; S – time stability; DS – degree of softening after 12 minutes to achieve maximum moment; C – consistency; FQN – farinograph index

The consistency coefficient, that makes the correlation between the value of consistency and the resistant torque at the shaft of the kneader arm, can be determined from the following relation, [8]:

$$k = \frac{5}{M_{\max}} \tag{5}$$

where: 5 is normal consistency, in N·m and M_{max} – maximum resistant torque expressed in the same measurement units.

Thus, for two different kneaders, a kneader may have coefficient k_1, while another kneader may have a different value for normal consistency coefficient k_2:

$$k_1 = \frac{5}{M_{max.1}}; \qquad k_2 = \frac{5}{M_{max.2}} \tag{6}$$

Papers [8, 9] specify the elements that asses the farinograph curves, their reading and interpretation.

3. Materials and methods

Experimental measurements to evaluate the quality of flour in the kneading process were performed using a Brabender farinograph, version E, with data acquisition on computer, in 2011, at the Department of Biotechnical Systems from ‘Politehnica’ University of Bucharest. For the laboratory experiments, the device was set to a speed of 63 min^{-1}.

The farinograph has a capacity of 300 g of flour (450-500 g dough) and the water temperature in the recirculation bath was maintained at 30 +1 º C. The flour used for experiments was FA-480 type, purchased from the bread factory Spicul SA Rosiori de Vede, Romania, from the 2010 wheat production, mixed with different percentages of rye flour purchased from the market, from10% to 40% compared to the wheat flour. The experimental methodology is in accordance with AACC 54-21 method for farinograph experiments, AACC 54-50 method for determining the flour absorption capacity and the technical instructions of the device.

The FA-480 wheat flour has an ash content of about 0.48%, being particularly intended for pastry products, but is also used in baking, when trying to obtain products with special qualities. On determining the moisture of the wheat flour and rye flour with a Partner MAC-110 thermo-balance at a temperature of 105 °C, the moisture content was found to be of about 12±0.12%.

Index tests were performed on Fall FA-480 wheat flour and its values fell within the limits of 384-393 seconds, but for the rye flour, the results are inconclusive. The dough was kneaded for 20 minutes, interval during which the variations of the farinograph curves, to be interpreted by computer software, were recorded. Then, for the same types of flour, we conducted tests on a Dito Sama BE5 bakery kneader, having a spiral kneading arm, with planetary motion [10] and fixed bowl with a capacity of 5 l, to determine the changes in the resistant torque variation at the kneader’s arm. To this effect, on the input shaft in the box of the hypocycloidal drive mechanism of the kneading arm, we fitted a torque transducer, connected to a Wheatstone bridge with strain gauges glued onto the drive wheel, connected to a data acquisition system, in order to record real-time signal changes (acquired torque). The Wheatstone bridge was calibrated for a 10 N force acting at a distance of 200 mm from the center of rotation, so that, for the output signal of 5.6V, the calculated value of the transformation constant was 714.28 N·mm/V.

During the farinograph tests, we used a quantity of 1 kg flour (the same percentage of the mixture as measured by the farinograph) and water at the absorption capacity indicated by the Brabender device during the farinograph tests. The water temperature was 30 ± 2°C in correlation with the temperature of the water recirculated at the farinograph. The kneading time was of about 11 minutes, slightly higher than the real kneading time of the bread dough for such a kneader, and the speed of the spiral arm was set to the same value as the one of the farinograph arms, i.e. 63 rev/min, but the speed of the drive wheel was slightly higher due to the hypocycloidal drive mechanism (about 110 rev/min).

4. Results and discussions

The farinograph curves obtained from the experiments with the Brabender device for the flour mixtures mentioned are presented in Fig.3, while the curves of the torque variation at the Dito Sama BE5 kneader's arm/shaft are shown in Fig.4.

From the farinograph curves we extracted the values of the kneading parameters (rheological characteristics of formed dough) for the dough development time - DT (min), the stability - S (min), the degree of softening - DS (FU), consistency - C (FU), flour absorption capacity - WA (%), index of dough farinograph FQN. The values of these parameters are presented in Table 1.

As for the flour hydrating capacity, it is important that the Brabender device makes corrections, related both to this and to the estimation and proper interpretation of other parameters. Also, the dough softening degree is presented on the farinograph curves and in the table of data for a kneading period of 10 minutes and respectively, for a kneading time of 12 minutes (using the ICC).

The analysis of the farinograph curves shows that there is a slightly increasing trend in the dough development time with the increased percentage of the rye flour added, but the differences are insignificant. As for the stability of the dough during kneading, this decreases slightly for 10% and 20% rye flour, increases a little more for doughs with 30% and 40% rye flour, and there is a more than double increase for the dough containing 40% rye flour compared to the one which has 30%. As stated in the literature, the softening degree (at least, on the curves plotted using the Brabender farinograph) shows a decreasing trend with the increased percentage of the rye flour added, but it must be mentioned that, by becoming stickier, the dough hardly comes off the walls of bowl (as shown by the curves of variation of the resistant torque at the kneading arm in Fig.4).

As for the power of the flour, valued by FQN farinograph index, (i.e. how soft it gets at battering - which is a flour quality index), from the analysis of the farinograph curves and the synthetic data presented in Table 1, it can be seen that it becomes higher by increasing the percentage of the rye flour added, even doubling when changing from 30% to 40% rye flour mixed with wheat flour, to the amount of 50-100.

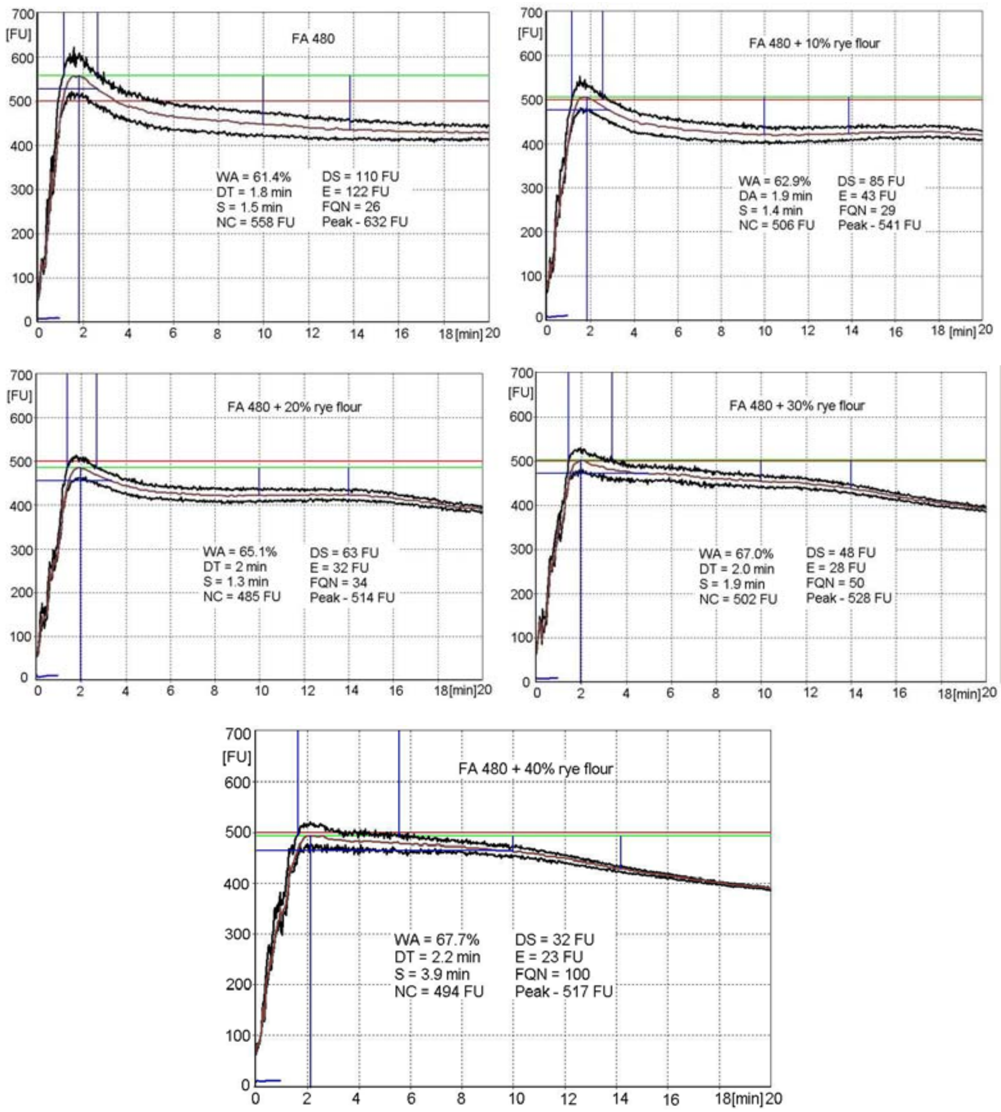

Fig.3. Farinograph curves obtained from experimental determinations with Brabender farinograph

Regarding the consistency of the dough, its value is correlated with the amount of added water, being around 500 FU, but the peak of the curve is more pronounced in doughs containing less rye flour with smaller and smaller decreases as the latter grows.

Thus, for the dough without any rye flour (wheat flour only), the peak is around 600 FU, but, for this sample, the amount of water added was slightly below the absorption capacity of the flour (as shown on the graphs and in Table 1). For the dough with 10% and 20% rye flour, the peak was located around 530 FU, respectively 510 FU. It should be noted that, if the quantity of added water is a little over the absorption capacity of the flour, the peak is more pronounced, and this may affect the development time and stability of the dough.

Table 1

Farinograph parameters of dough from wheat flour mixed with FA-480 rye flour

	At the Brabender farinograph					At Dito Sama BE5 mixer				
	0% rye flour	10% rye flour	20% rye flour	30% rye flour	40% rye flour	0% rye flour	10% rye flour	20% rye flour	30% rye flour	*40% rye flour
Development time, min	1.8	1.9	2.0	2.0	2.2	1.4	1.6	1.4	1.2	3.1
Stability, min	1.5	1.4	1.3	1.9	3.9	2.2	1.9	2.2	2.0	6.5
Degree of softening, FU	110	85	63	48	32	32	40	36	47	24
Degree of softening, ICC method (12 min after max.)	122	83	63	65	65	-	-	-	-	-
Farinograph number FQN	26	29	34	50	100	-	-	-	-	-
Consistency (normal), FU	558	506	485	502	494	176	145	153	150	255
Moment peak, FU	632	541	514	528	517	213	171	176	171	325
Added water, %	60.0	62.8	65.5	67.0	67.7	61.4	62.9	65.1	67.0	67.5
Water absorption (corrected for 500 FU)	61.4	62.9	65.1	67.0	67.5	-	-	-	-	-
Elasticity, FU (after 10 min)	52	43	32	28	23	40	26	33	39	32
Consistency coefficient k_F	0.89	0.93	0.94	0.95	0.96	0.82	0.84	0.86	0.87	0.90

** Due to unevenness of the curve of variation values shown are approximate*

Therefore, in the establishment of the adopted working regime at kneading, we should take into account many factors that could influence the quality of the dough and, eventually, the quality of the bread.

Although the computer program does not provide any information on the dough elasticity, however, from the analysis of the farinograph curves, this can be estimated by the width of the variation of consistency (or resistant torque), at some point. It can be read 10 min after the initiation of the kneading process or 12 minutes after the maximum torque has been achieved, but in order to make a comparison with that obtained on the spiral kneading arm, we read it 10 minutes after the kneading has begun. On the five farinograph curves we analyzed, elasticity has the values shown in Table 1. It appears that elasticity decreases with the increased percentage of rye flour added, reaching a value of 23 FU for 40% rye flour added to the dough compared to 50 FU without any rye flour and 43 FU for 10% rye flour.

According to relations (5) and (6), the consistency coefficient of the farinograph was calculated for the analyzed types of dough, and the values are presented in Table 1. An upward trend was found for both the farinograph tests and for the tests carried out on a real spiral kneader with planetary motion, its values ranging within the limits of 0.89 - 0.96.

As for the torque variation at the shaft of Dito Sama BE5 kneader, this is presented in the graphs in Fig.4.

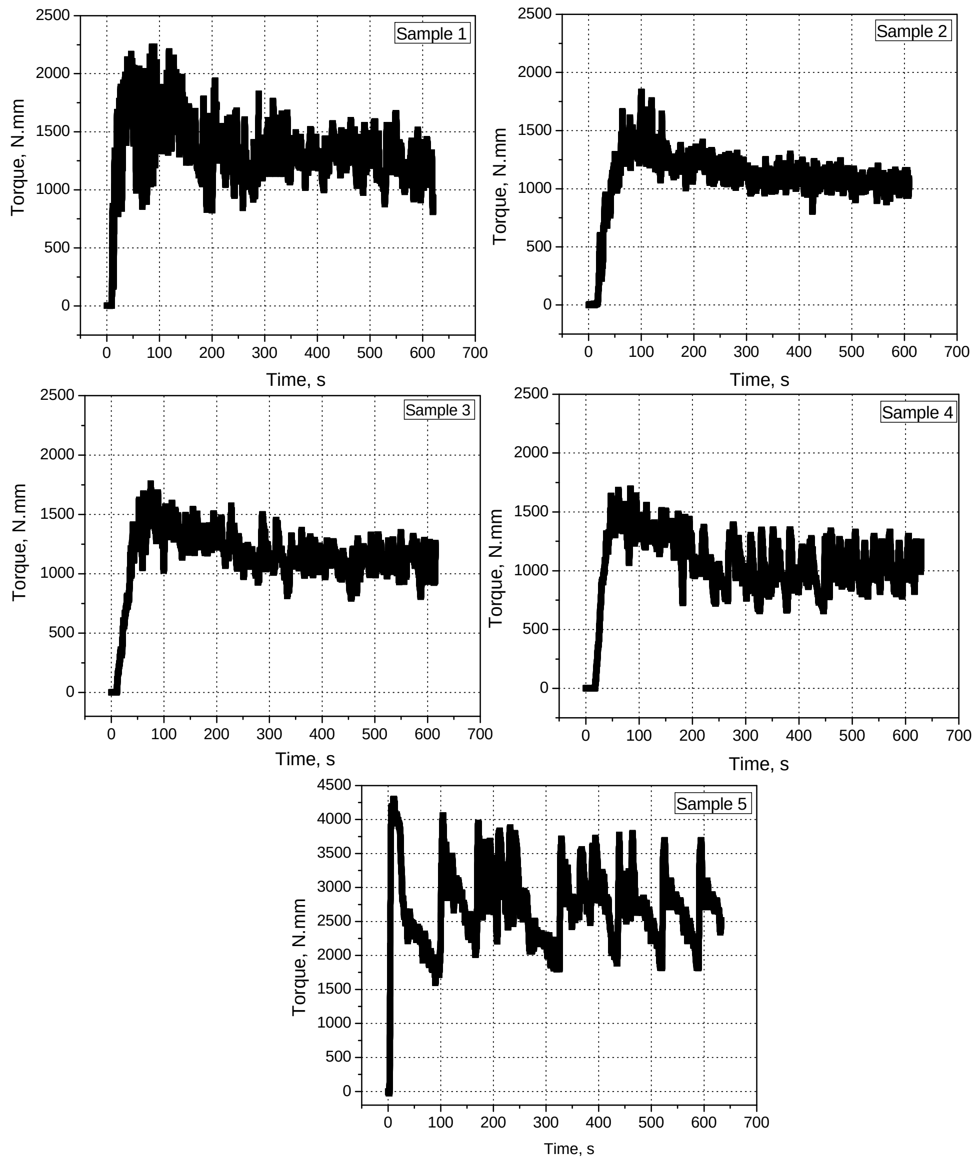

Fig. 4. Torque moment curves obtained from experimental determinations with Dito Sama mixer

The analysis of these graphs indicates a strong similarity of the resistant torque variation with the profile of the curve shown in Figure 1, but also with the farinograph curves obtained using the Brabender device. After a detailed analysis, even the width of the variation bands can be considered in conjunction with the width of the farinograph curve band; however, these curves show significant leaps because the spiral kneading arm has a planetary motion and the kneading area inside the bowl (at least theoretically) is smaller than the bowl diameter, while the moved dough is not always the same and in the same amount. It can be observed that these leaps are becoming more pronounced and more rare for a higher proportion of rye flour, due to the dough sticking to the sides of the bowl and to the different stresses for its separation.

To estimate the same parameters presented by a farinograph curve, on the obtained variation curves, envelope curves were drawn on the outer and the inner profile of the curves given by the kneader, as well as the mean curve between the two envelope curves. Then we measured (at graph scale, on the horizontal and vertical axis) the parameters shown by the farinograph curve: development time, stability, maximum torque, dough consistency, elasticity and degree of softening (that was determined six minutes after the start of kneading).

The values of these rheological parameters, together with the consistency index calculated using the same relationship (1) for the planetary kneader are also presented in Table 1. For the Dito Sama planetary spiral arm kneader tested in the laboratory with the same types of flour mixtures, although the shapes of curves were similar, there were, however, some very significant differences. To be able to make the estimations of torque in the same measurement units as for the Brabender farinograph, it was taken into account that 1 FU ≅ 10 N·mm and the dough elasticity was approximated due to the torque jumps on the variation curve (Fig.5). With reference to the development time and the stability of the bread dough, we can only establish a partial correlation with the values obtained from the farinograph, because the amounts were different, even though the flour/water ratio was the same. However, we should notice the important time jump from the dough with 30% to the one with 40% rye flour, which has the same trend shown by the farinograph measurements, both for development time and for stability time. The order of magnitude for the dough consistency and for the peak torque is about the same as for the farinograph, but the ratio between the kneader values and the farinograph values is about 1:3, both for normal consistency and maximum torque. It is also found that the size of the consistency coefficient, calculated as the ratio of the normal consistency and maximum resistant torque, is approximately the same, with even the same upward trend for the two devices used for measurements.

Fig. 5 presents the variation of the consistency coefficient with the rye flour content, the experimental data being fitted with the allometric regression function. We found a good correlation between those parameters, appreciated by the R^2 values.

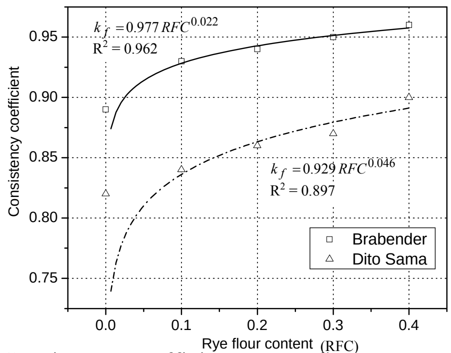

Fig.5. Consistency coefficient vs. rye flour content (RFC) for the two analyzed devices

Regarding the softening degree, expressed in FU, we can notice that the values given for the planetary mixer are 2-3 times smaller than those of the kneader, for which the plateau trend of resistant torque for doughs with higher rye flour was evident, while for the planetary mixer this trend was decreasing. Also, the dough elasticity, indicated by farinographs and by the torque curves of the planetary mixer falls approximately in the same range, with slight deviations that could have occurred due to the way of reading the values on the graphs in Fig.5.

No estimations were made on the values of the FQN flour quality index for the planetary mixer, since a method for measuring it should be proposed, at least in correlation with the Brabender farinograph. However, it is our intention to realize that in the future.

5. Conclusions

The measurements made on the variation of the kneading torque by two different modalities, using an electronic Brabender farinograph and an experimental plant with a torque transducer mounted on the spiral arm of a planetary kneader, have indicated the same shape of the variation curves, with slight deviations from one device to another.

We have found a tendency of change in the physical characteristics of the doughs obtained from wheat flour mixed with rye flour, with the increase in the proportion of rye flour in the mixture. We have also noticed a downward trend in the softening degree of the dough with a higher content of rye flour and in its elasticity, even if there were some deviations in the laboratory plant with a planetary mixer.

As the content of rye flour grows, the dough loses some of its elasticity, becomes stickier and harder to fall off/remove from the bowl walls, showing significant leaps of torques, and this is more obvious in the kneading machine with a planetary mixer due to the hypocycloidal drive mechanism.

Although it can be said that the values of the normal dough consistency have been estimated for the two plants used in this experiment, the ratio of the values from the two devices was about 1:3; yet, the consistency coefficient values were approximately the same for both devices. The results presented in this paper can be starting points for future research and can be of real interest and help to the specialists in the bakery industry.

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