ASPECTS REGARDING THE REPRESENTATION OF FARINOGRAPHIC CURVE TO ASSESS WHEAT FLOUR DOUGH BY MATHEMATICAL EQUATIONS
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ASPECTE PRIVIND REPREZENTAREA CURBEI FARINOGRAFICE DE APRECIERE A ALUATURILOR PE BAZĂ DE FĂINĂ DE GRÂU PRIN ECUAȚII MATEMATICE

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ABSTRACT

The Brabender farinograph is a device with which important indications for baking are obtained, namely: dough development time (DDT), water absorption (WA), dough stability time (DST), softening degree (SD), Farinograph Quality Number (FQN), important parameters for determining flour mixtures. These parameters are represented on the farinographic curve drawn during the farinograph test. Dough development or formation (formation of gluten) is represented by the ascending branch of the farinographic curve, which has a steep ascending slope, because time (expressed in minutes), fixed on the abscissa of the diagram, has relatively low values (about 1.2–3 min for regular flours), while consistency, fixed on the ordinate of the diagram, reaches the maximum value (peak time) of the dough. In comparison, the descending branch of the farinogram, which starts from the maximum value of the dough consistency (peak time), has a slow descending slope, because the kneading time is extended up to 20 minutes, and the consistency decreases relatively little. The paper presents the appreciation of this branch of the farinogram by mathematical equations for several types of doughs from wheat flour mixed with different percentages of salt.

REZUMAT

Farinograful Brabender este un aparat cu ajutorul căruia se obțin indicații importante pentru panificație și anume: timpul de dezvoltare a aluatului (DDT), capacitate de absorbție a apei (WA), timpul de stabilitate a aluatului (DST), gradul de înmuiere (SD), Indicele de calitate farinografic (FQN), parametri importanți pentru stabilirea amestecurilor de făină. Acești parametri sunt reprezentați pe curbă farinografică trasată în timpul testului cu farinograful. Dezvoltarea sau formarea aluatului este reprezentată de ramura ascendentă a curbei farinografice, care prezintă o pantă crescătoare abruptă, deoarece timpul (exprimat în minute), fixat pe abscisa diagramei, are valori relativ mici (circa 1.2–3 min pentru făinuri obișnuite), în timp ce consistența, fixată pe ordonata diagramei, atinge valoarea maximă a aluatului. Comparativ, ramura descendentă a farinogramei, care pornește de la valoarea maximă a consistenței aluatului, prezintă o pantă descrescătoare lentă, deoarece timpul de frământare se prelungește până la 20 minute, iar consistența scade relativ puțin. Lucrarea prezintă aprecierea acestei ramuri a farinogramei prin ecuații matematice pentru câteva tipuri de aluaturi din făină de grâu în amestec cu diferite procente de sare.

INTRODUCTION

Farinographic parameters (dough development time, absorption capacity, softening degree, farinograph quality number, dough stability) are widely used to predict the functionality of flour and dough. They can be easily identified by reading the farinographic curve drawn in farinograph experiments (figure 1).

According to the water absorption characteristic, the flour is classified as having a good and very good capacity when the absorbed water is between 57 and 62% and the dough development time is between 1.5-3 minutes. By the methodology of the response surface, the authors *Temea (Moroi) et al., (2016*), established that the optimal conditions for the maturation process of wheat flour type FA-650 (0.65% medium ash content) should be: storage temperature 28°C, storage time 21 days, environmental humidity 68-70%.

For these conditions, farinographic records showed that water absorption increased by about 0.5% compared to the initial flour (immediately after grinding), the stability time of the dough increases by ~20%, and the degree of softening of the dough is reduced by 27-30%.

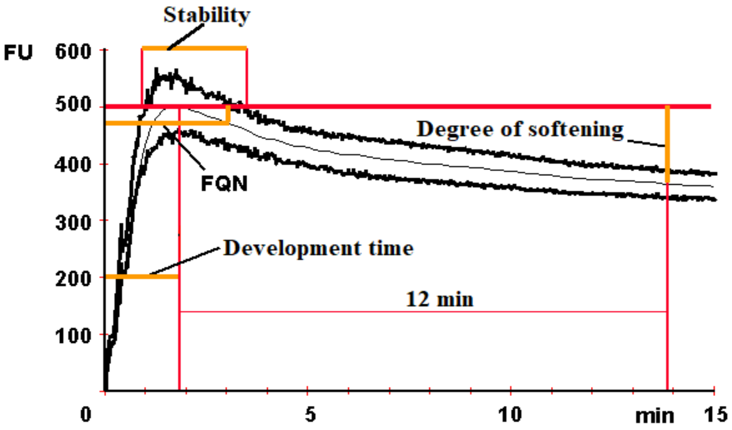

Fig. 1 - Example of a farinographic curve and how to interpret it

It is known that there is a significant correlation between the volume of bread and the characteristics of the flours used in its preparation (protein content, Zeleny sedimentation index, dough development time, absorption capacity, softening degree, farinograph quality number, dough stability, the last five parameters being indicated in farinograph tests). Dough development time (peak time) shows the quality of wheat proteins. *Aydogan, et al., (2015*) found values of this parameter within the limits 1.35-12.17 min, with an average value of 4.22 min for 111 Turkish grains. The absorption capacity of flour, determined by the authors, was within the limits of 54.8-68.4% (average value 61.76%). Positive and significant correlations were found between the volume of bread, on the one hand, and dough development time, farinograph quality number, dough stability, flour absorption capacity, on the other hand, respectively a significant negative correlation between the volume of the bread and the degree of dough softening at 12 minutes of kneading.

Dough development time, its stability to kneading and farinograph quality number, are indicators of flour resistance, higher values suggesting stronger doughs. A high water absorption capacity, combined with a low degree of softening indicates a good quality flour, while a high water absorption combined with a high degree of softening indicates a poor quality flour.

The salt added to the dough has the main role of flavouring the bread, but beyond that it also contributes to the improvement of the gluten network. Naturally, the proteins that make up gluten (gliadin and glutenin) reject each other, but salt helps them get over this trend, practically forcing them to join in gluten strings faster and better. However, salt in food should be reduced for better human health, so as to achieve a maximum salt intake of 5 g per day in adults. A high dietary intake of sodium leads to increased blood pressure and the occurrence of chronic cardiovascular disease. Bread is thus a major source of sodium in the daily intake of the population and, therefore, various strategies are undertaken to reduce the consumption of salt in bakery products. Research has been done on the characterization of bread dough prepared with low-sodium sea salt or dry wheat flour dough, *Voinea et al. (2020*), as substitutes for sodium chloride on the basis of rheological properties obtained with different apparatus, including the farinograph. Thus, the optimal quantities found by the authors were 1.396 g of sea salt and 2.683 g of dry dough, both per 100 g of wheat flour. For these values, the absorption capacity was 60.01%, the development time 1.59 min, the stability of the dough 1.33 min, the softening degree 88.0 UB. It has been found, however, that during mixing and spreading, sea salt strengthens the wheat flour dough, while the dry dough weakens it.

Supplementing wheat flour with other types of flour changes, in general, the rheological characteristics of the obtained doughs but also of the finished products. Usually the final recipes, which give the best properties to both the dough and the finished product, are obtained through several tests and research in the laboratory and on the production flow. Such research has been done in the past and does not stop being done today. In this respect, supplementation with Chinese yam for the preparation of noodles has led to changes in their chemical attributes, texture, cooking, rheology and microstructure. Moreover, the addition of Chinese yam also affects the structure of starch granules, as well as the sensory characteristics of noodles, and it is not recommended to substitute wheat flour with more than 30% yam in industrial applications (*Sun, et al., 2019; Li, et al., 2020*).

It is known that wheat bread with bran is obtained by adding them to the kneading of the dough, after its development in the kneader, and not by using flour mixed from the beginning with bran. Eating bran bread significantly suppresses appetite, causing a feeling of fullness, also having a beneficial effect on the microflora of the digestive tract. Brans have the ability to absorb toxins and harmful substances, helping to remove them from the body, increasing immunity and iron content in the blood, but also bring benefits to the human body.

Cardone, et al., (2020) discussed the addition of sprouted wheat bran to wheat flour doughs. It has been shown that the sprouting process reduces phytic acid by about 20%, insoluble dietary fibre by about 11% and water retention by about 8%, but leads to increased simple sugars and enzymatic activities in dough processing. Changes in the interactions between fibre and gluten have also been observed, with sprouted wheat bran leading to a worsening of the mixing properties (on the farinogram the stability is much shorter and the degree of softening is much more pronounced) and fermentation, but does not significantly affect the extensibility of the dough. The volume of bread, on the other hand, increases by about 10% compared to the use of un-sprouted wheat bran, and their use could be useful to produce fibre-rich bread with improved characteristics.

It should be noted that the use of potato starch in the preparation of wheat flour doughs leads to changes in the water absorption characteristics of the flour mixture, decreasing significantly with increasing potato starch content, while the stability of the dough, determined by farinograph, increases significantly with the increase of this content. At the same time, it was found that additions of up to 5% potato starch do not significantly affect the flour drop rate, the results being applicable to certain wheat-based foods, such as noodles, bread, and biscuits (*Sarker et al., 2008*).

Slukova et al., (2017), studied the characteristics of wheat flour (with gluten) and buckwheat (gluten free) doughs in order to evaluate changes in protein structure during dough formation. It has been shown that the mixing time significantly affects the structures of the three-dimensional gluten networks in wheat and buckwheat doughs, which can ultimately influence the quality of the dough baking. At the same time, there were pronounced differences between undeveloped, optimally developed and overmixed wheat dough, but no significant differences were observed between the structures of undeveloped, optimally developed and overmixed buckwheat doughs.

The characteristics of mixtures of wheat flour and buckwheat were also studied by *Stefan et al., (2018*). The addition of whole buckwheat flour to wheat flour influenced the technological and rheological parameters of the flour mixtures. Thus, the increase in the amount of whole buckwheat flour (from 10% to 40%) leads to a decrease in the fall time (from 411 s to 234 s) and the sedimentation index (from 28 ml of wheat flour to 18 ml). Also, the increase of the buckwheat flour content, leads to the increase of the amount of water absorbed at mixing from 58.6% to 79.9%, as well as the development time of the dough from 2.2 min. at 8.7 min., but the stability of the dough decreases significantly. Farinograph quality number also had significant changes.

Based on the farinographic curves obtained for eight wheat flours of different varieties, a mathematical model was developed to simulate the middle curve of the farinograms. The model consisted of five common first- and second-order differential equations that describe the dynamic behaviour of state variables using four kinetic parameters to estimate the mean curve of the farinogram (*Hermannseder et al., 2016*).

The expression of the farinographic curve by mathematical functions is generally cumbersome because it has at least two variations along it, namely a steep increase on its first portion, followed by a portion of the curve decreasing slowly, possibly with sinusoidal variations, depending on the type of flour and the additions to change its quality. An attempt at mathematical expression of the farinographic curve is presented in the paper (*Mis et al., 2017*), the authors presenting the differences obtained between farinographic curves for plain flour and supplemented flour with eight types of botanical fibres from the market.

The results presented by the authors showed differences between farinograms, their shape being strongly influenced by the supplements introduced, in the sense that two peaks appeared along it. The presence of these peaks allowed the distinction of two types of rheological activity of each fibre supplement, namely the weakening or strengthening of the consistency of the bread dough during its development. If the carrot, oat, cranberry and cocoa fibres predominantly showed an action of strengthening the consistency of the dough, the fibres of chokeberry, carob, apple and flax had mainly an action of weakening its consistency. The mathematical equation proposed in the mentioned paper has two terms, one for each visible portion of the farinographic curve.

The paper presents the variation of the farinographic curves after reaching the point of maximum consistency and the equations that represent the respective curves, for the farinograms obtained in experiments with wheat flour in which different percentages of salt were added (between 0-2%), as well as the differences obtained between them. The curves were obtained by regression analysis using the experimental data obtained in the MS Office Excel program for plotting consistency farinographic curves using the Brabender electronic farinograph.

MATERIALS AND METHODS

The authors of this paper have previously performed farinographic determinations on a series of different flours, with different percentages of added salt (*Voicu et al., 2016*), different percentages of other types of flours (*Voicu et al., 2012; Stefan et al., 2018; Munteanu et al., 2015*) or different amounts of water added (*Voicu et al., 2017*).

Research in the field continued to find a method for estimating the farinographic curve by mathematical relations, including how to change the parameters of the equations used in regression analysis depending on the type of flour used to prepare the dough.

The farinographic curve, together with its parameters, shows the evolution of the structure and consistency of the dough during kneading and some basic rheological characteristics of it. The two branches of the farinographic curve can be expressed relatively easily by mathematical equations, although not much is known in this regard.

Voicu et al., (2016) have tried to identify the main Eulerian mathematical functions that can assess the development and formation of the dough (the ascending part of the farinogram) until reaching maximum consistency, for wheat flour dough with different percentages of added salt. Weibull function, lognormal function, hyperbolic function, exponential function and gamma function were tested, the most appropriate degree of correlation being given by the gamma function. ($R^2 \geq 0.967$), and the present paper represents a continuation of the investigations carried out in the above-mentioned paper.

Moreover, *Mis et al., (2017)*, tested a composite sigmoid function (with two basic components) to describe how the dough consistency of wheat flour dough mixed with eight types of dietary fibre.

The E-Brabender farinograph used for making the determinations has the vat capacity of 300 g of flour (450-500 g of dough), and the possibility of maintaining a constant temperature (30+1ºC). The farinograph software records the measurement data, evaluates them according to standard methods (AACC, ICC) and prints the farinographic curve together with some data related to the properties of flour and dough.

For the experimental research were used samples of flour type FA-650 with an average moisture content of 11%, mixed with salt in percent from 0.4% to 2%, compared to flour. The flour used was procured from the S.C. Spicul S.A. Roșiorii de Vede, from the wheat production in the southern part of Romania in 2008. The methodology of the experiments complies with the AACC 54–21 method, for farinographic experiments and with the AACC 54–50 method for determining the flour absorption capacity and with the instructions in the technical book of the apparatus.

The determinations were performed in June 2009, in the specialized laboratory of the Department of Biotechnical Systems of the Polytechnic University of Bucharest.

The absorption capacity of the flour was determined according to the moisture content of the flour, previously determined with a MAC-110 thermobalance, with heating with halogen lamps, at a drying temperature of 105°C and the type of flour. It had values between 60.2 - 63.7%.

Based on the experimental data obtained in the farinographic experiments, the correlation of the values of the experimental points on the descending branch of the curve with two known mathematical functions was tested:

[a]. exponential type: $$y = a\, e^{-bx} \tag{1}$$

[b]. power type: $$y = a\, x^{b} \tag{2}$$

The aim of the paper is not to present the characteristics of wheat flour dough with different percentages of salt, but rather to present the possibility of identifying the farinographic curve with an exponential or power mathematical function, as well as how it varies the coefficients of the equation with the parameters of the dough.

RESULTS

Table 1 shows the values of the parameters of the farinograms obtained in experiments with FA-650 flour, by adding salt in different percentages.

Table 1

Parameters of flour dough farinograms with different salt contents, recorded in experiments

Salt (%)	WA (%)	DT (min)	S (min)	DS (f.u.)	C_{max} (f.u.)	FQN
0%	63.7	2.0	5.8	49	528	43
0.4%	61.4	2.8	13.5	18	477	148
0.8%	61.8	2.5	15.6	9	470	165
1.2%	61.2	2.3	16.1	19	508	150
1.6%	60.6	2.5	18.7	16	484	185
2.0%	60.2	2.3	18.7	11	490	200

WA – water absorption, DT – development time, S – stability, DS – degree of softening, Cmax – maximum consistency, FQN – farinographic index; f.u. – farinographic units

The results of the regression analysis regarding the variation of the descending part of the farinographic curves for the maximum curve, the average curve, respectively the minimum curve, of the farinogram are presented in fig.2 and Table 2.

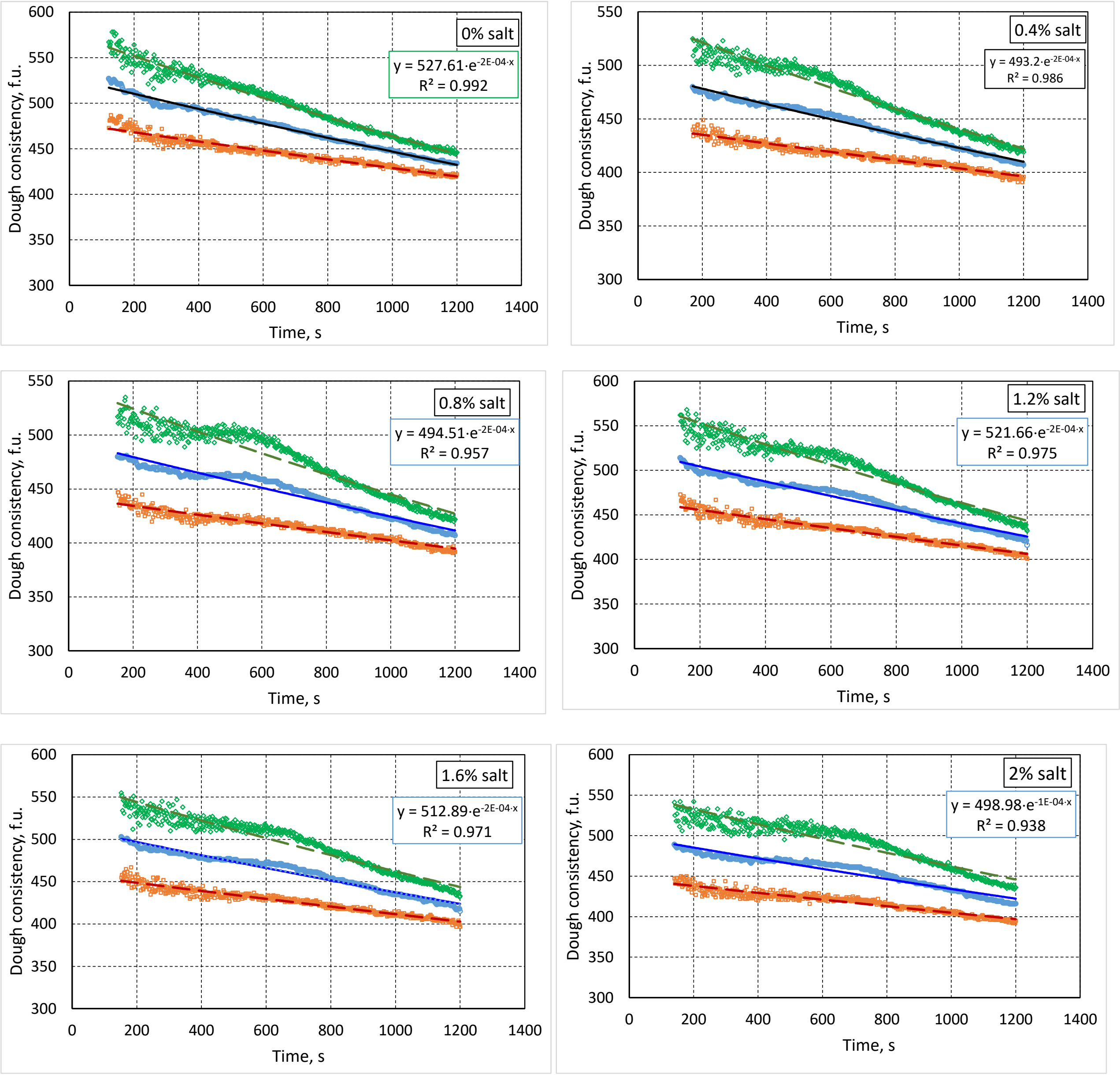

Fig. 2 – Curves obtained by regression analysis for the stability and softening phase of the dough

Note: the regression function is presented only for the median curve of the farinogram

The analysis of the data presented in Table 1 shows that the increase of the salt content in the dough leads to the hardening of the dough, a phenomenon observable by the values of the degree of softening, which decreases in principle with the added salt content, but especially by the values of the farinographic index FQN which gives an appreciation of the power of the flour when mixing (the values of FQN increase constantly with the increase of the salt content).

The analysis also shows that, for values of the amount of salt greater than or equal to 0.4%, the amount of water absorbed by the flour shows values of approx. 61.04 ±0.5% for a 95% confidence interval, while the degree of softening of the dough obtained has average values of 14.6 ±3.4 f.u., for the same confidence interval, and the maximum consistency of the dough does not reach the threshold of 500 f.u. which means less water added to the kneading (consistency had average values of 485.8 ±11.3 f.u. at a confidence interval of 95%).

Table 2

The values of the coefficients of the regression equations and of the correlation coefficient R^2, for regression analysis of flour dough farinograms with different salt contents

	$C = a \cdot \exp(-b \cdot x)$			$C = a \cdot x^b$		
Salt (%)	a	b	R^2	a	b	R^2
0%	527.61	$2 \cdot 10^{-4}$	0.992	813.90	-0.086	0.933
0.4%	493.20	$2 \cdot 10^{-4}$	0.986	762.95	-0.084	0.891
0.8%	494.51	$2 \cdot 10^{-4}$	0.957	742.89	-0.080	0.831
1.2%	521.66	$2 \cdot 10^{-4}$	0.975	813.80	-0.088	0.863
1.6%	512.89	$2 \cdot 10^{-4}$	0.971	787.44	-0.084	0.860
2.0%	498.98	$1 \cdot 10^{-4}$	0.938	711.94	-0.070	0.796

From the analysis of the drawn regression curves, in relation to the experimental points, as well as from the analysis of the values of the correlation coefficient R^2 presented in Table 2, the concordance of the proposed mathematical laws with the experimental data is ascertained. However, the values of the correlation coefficient R^2 shows a better correspondence of the experimental data with the exponential law, which has values in the range 0.938-0.992 for this function, while for the power type function its values R^2 were in the range 0.796-0.933.

We must also note that the salt added to the dough gives the farinographic curves visible undulatory variations especially on the maximum curves, where they are further away from the regression curve, but also on the minimum curves, respectively on the median curve of the farinogram. The farinographic curve for salt-free dough (compared to which we refer) is smoother and has fewer ripples, which makes the regression function have a higher value of the regression coefficient.

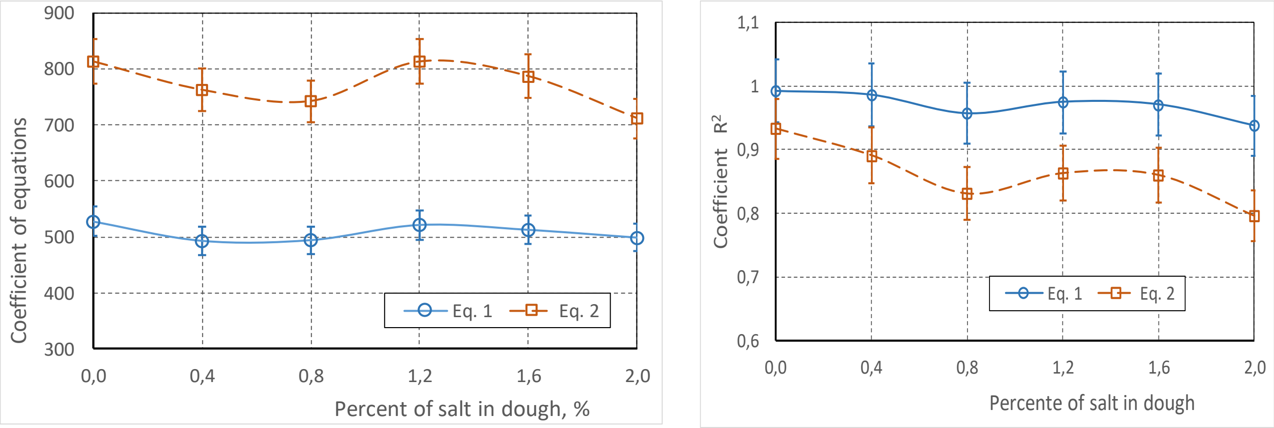

Fig. 3 – Variation of the values of the coefficients of the exponential and power regression equations

left – coefficient of equations (1) and (2); right – correlation coefficient R^2 for eq.(1) and eq.(2)

We find that, both for the exponential function and for the power function, the coefficients and exponents of the mathematical relations have relatively close values, with small variations depending on the percentage of salt added to the kneading. Thus, for the exponential law, the coefficient of the mathematical relationship shows a sudden decrease in value with the addition of salt to the dough, but increases as the percentage of salt increases, but does not reach the value it has for dough without salt. However, for salt percentages above 1.6% the values of this coefficient show a decreasing trend (figure 3).

The values of this coefficient fall within the limits 508.14 ±10.72, for a 95% confidence interval, and the correlation coefficient obtained in the regression analysis is $R^2 = 0.970$ with an average of deviations ±0.014.

The same mode of variation, relatively identical, is presented by the power function coefficient. Here, its values are on average 772.15 ±29.72 within the 95% confidence interval, but the correlation coefficient has much lower values, i.e. $R^2 = 0.862 \pm 0.035$ in the same confidence interval, with a standard deviation ±0.042.

Regarding the values of the exponents of the mathematical relations used in the regression analysis, they are very close, regardless of the percentage of salt added to the dough.

If we compare the values of the coefficient of the exponential relationship with those of the maximum consistency of the dough obtained at kneading, we find that these values are relatively close, which may lead to the conclusion that this coefficient could be set at the average maximum consistency values (with deviations previously), but in this case the values of the exponent of the relationship could be different from those obtained previously.

In the case of the power type relationship, the values of the relationship coefficient are very different from those of the maximum consistency of the dough, and the comparative analysis between the two categories of values does not have a physical significance in the kneading process.

CONCLUSIONS

Farinographic curves are used for the rheological assessment of doughs obtained mainly from wheat flour to which various quantities of other cereal flours may be added. This curve can provide important information for workers in the bakery technology flow, both in terms of flour and dough parameters and in terms of material balance (with reference to the amount of water added, the percentage of salt or the quantities of other food flours).

Being a curve with two slopes, one steep ascending and one descending with a smooth slope, the farinographic curve could be represented by mathematical functions that express as confidently as possible the curve obtained with the help of the Brabender electronic farinograph.

Both the ascending part of the farinographic curve and its descending part can be appreciated by exponential or power type mathematical functions (but also by other types of functions), with a greater or lesser degree of correlation.

It is necessary to identify that mathematical relationship that is as close as possible to the curve obtained experimentally, so that through other mathematical artifices can obtain additional information about the physical and rheological characteristics of the dough and flours used.

The authors of this paper discussed the use of exponential and power mathematical functions to describe the farinographic curve of an FA-650 flour with different percentages of added salt. In addition to the information that the farinographic curve initially transmits, the parameters of the mathematical relations (coefficients and exponents) and the R^2 correlation coefficient were identified. Correlation coefficient shows the degree of proximity or distance of the mathematical functions of the real farinographic curve. For the second part of the curve (the downward slope with a smooth slope), it was found that this coefficient has values $R^2 = 0.970 \pm 0.014$ for the exponential mathematical function (for a 95% confidence interval), which shows a relatively high degree of correlation.

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