



# Prediction of rye flour baking quality based on parameters of swelling curve

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## Abstract

The objective of this work was to use the swelling curve test for the evaluation of the baking value of rye flours commonly used for bread production. Ten rye flours obtained from industrial mills were used for investigations. The parameters characterized the flour properties such as protein content, ash content, pentosans content, falling number, amylograph peak viscosity and water absorption were determined. Besides, the swelling curve test and the baking test were performed. The results showed significant relations between flour properties and bread quality. Especially, all viscosity parameters obtained on the basis of swelling curve could be used for rye flour baking quality evaluation. Especially, the logarithmic decrease of viscosity was negatively correlated with crumb bread hardness after 1 and 4 days after baking ( $r = -0.802$  and  $-0.789$ , respectively). Besides, the breads with the lowest volume were obtained from flour with low amylograph peak viscosity and low logarithmic decrease of viscosity. In summary, the swelling curve test can be used as a useful tool for the evaluation of baking quality of rye flour.

**Keywords** Rye flour · Baking quality · Pentosans · Swelling curve · Bread

## Introduction

Rye (*Secale cereale* L.) is in addition to wheat the major bread grain in Europe. Rye is mainly produced and consumed as bread in northern Europe; the major producers being Russia, Poland, Germany, Belarus and Ukraine. Rye bread is often made using sourdough, a process influencing both nutritional quality and taste of rye bread [1]. Starch is the most important constituent of rye flour which plays a major role in the crumb texture of rye bread. It is known, that baking properties of starch depend mostly on its swelling and gelatinization. Besides, starch, pentosans

and pentosans-degradation enzymes affect the baking value of rye flour [2]. Research carried out by Gräber [3] revealed that pentosans play mainly role in created properties of dough with temperature below 45 °C while starch is responsible for create crumb structure in temperature above 45 °C. Pentosans are important component of rye flour. They bind water and contribute to the formation of viscous dough [4]. They are located mainly in outer parts of rye grain and divided into water extractable and water unextractable [5–7]. Low extraction flour is rich in starch and poor in pentosans content but has higher proportion water extractable pentosans in compared to high extraction flour. Rye flour with good baking value should be characterized by high pentosans content and also high proportion water extractable pentosans [8]. In bread making parts of water unextractable pentosans are converted in water extractable [9–11]. The hydrolysis of water unextractable pentosans changes their solubility and causes an increase dough viscosity and reduction of water binding capacity [12]. These changes caused an increase in bread volume and decrease crumb hardness [13, 14]. One method use to determined properties of dough association with pentosans content and activity cell wall degradation enzymes is the swelling curve

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test [15]. A lot of authors studied the swelling curve test, but mainly for wholemeal flours [16–18]. However there are no papers concerning possibility the use of swelling curve test for the evaluation of the baking quality of rye flour from milling industry. Therefore, the aim of this work was to evaluate the possibility using the swelling curve test for the evaluation of the baking value of rye flours commonly used for bread production.

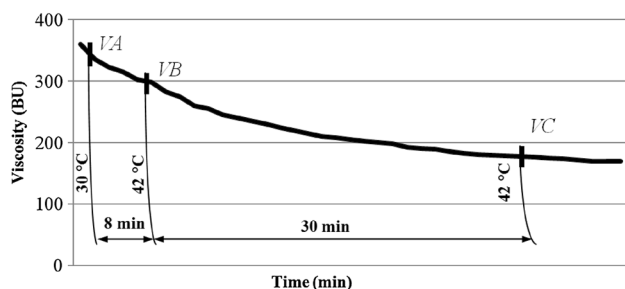
## Materials and methods

### Flour properties

Ten rye flour samples (type 1400) obtained from different milling companies located in Poland were use for this study. The protein content (Nx625), ash content, the falling number and amylograph peak viscosity were determined according to ICC approved method no: 105/2, 104/1, 107/1 and 126/1, respectively [19]. For the evaluation degree of flour comminution the flour was separated with the held mechanical sifter using sieves with size 95  $\mu\text{m}$ . Pentosans content was determined according to Hashimoto et al. [20]. Flours were evaluated for water absorption at 300 FU with the Brabender farinograph on 50 g samples according to ICC 115/1 [19].

### Test swelling curve

Test swelling curve test was performed according to Drews [21]. A slurry made from 120 g rye flour, 410 ml water and 47 ml sodium phosphate buffer solution (pH = 5.0) was heated from 30 °C to 42 °C (heating rate 1.5 °C/min) in a Viscograph (Brabender, Germany) bowl under constant stirring and held at 42 °C for 30 min. The viscosity of the slurry was measured in Brabender unit (BU). A typical swelling curve was shown in Fig. 1. There are three parameters used for evaluation of the swelling curve. The first parameter (VA) represents initial viscosity at 30 °C. The second parameter (VB) indicate viscosity after reaching



**Fig. 1** The typical swelling curve; VA—initial viscosity at 30 °C, VB—viscosity when the sample reaching 42 °C, VC—final viscosity after holding suspension at 42 °C for 30 min

temperature 42 °C. The third parameters (VC) indicate the final viscosity after holding suspension at 42 °C for 30 min. The logarithmic decrease of viscosity VB and VC was also calculated ( $\log VB - \log VC$ ). This parameter characterizes indirectly the intensity of enzymatic processes during the first phase of baking.

### Bread preparation

High extraction rye pan breads were produced from rye flour samples in the laboratory baking trials. Breads were made with sourdough to reflect the usual production process utilized in Polish bakeries. The formulation used in the tests was given in Table 1. The amount of water addition was adjusted to standard moisture of flour [14% wet basis (wb)].

The dough was prepared with sourdough. A part flour from recipe was soured in a one-stage sourdough process. Sourdough procedure: 350 g of rye flour type 1400 was mixed with 3.5 g of starter (SAF Levain LV2 from Lesafire) and with 525  $\text{cm}^3$  of water (35–36 °C) to get homogeneous dough of soft consistency (yield 250) and temperature of about 30 °C. Sourdough fermentation was performed in fermentation chamber for 16 h at 30 °C and 75% relative humidity. The final dough procedure was as follow: the mature sourdough was combined with recipe's ingredients (Table 1) and water in amount corresponding to farinograph absorption (300 FU), decreased by the water contained in the sourdough. Dough kneading was performed using Turbo-mix-6,5 spiral mixer (HOMMEL) for 10 min on low speed. Desired dough temperature was 30–32 °C. After a resting time of 10 min in fermentation cabinet dough was divided into five pieces of 350 g weight. The dough pieces were manually moulded, putted into the pans and proofed in fermentation cabinet at 35 °C and 75% relative humidity until they reached the normal level of proofing. The proofing time ranged from 20 to 25 min. The end of proofing was signalled by the first cracks on the dough surface. The first phase of baking was performed at temperature 260 °C with steaming (1 min) at the beginning of the baking in the

**Table 1** Used dough recipe

Ingredient	Weight (g)
Flour	1000*
Salt	17
Yeast	10
Starter culture LV2	3.5
Water	Up to adequate consistency**

\*Moisture of flour (14% wb)

\*\*The amount of added water was initially established for the consistency of dough equal 300 FU, during dough kneading if the dough was too dense the adequate correction of water was made

decking oven (Piccolo, producer Wachtel, Germany). The temperature was decreased to 220 °C after 10 min of baking. The total time of baking was 40 min. After baking the loaves were brushed with water, cooling and stored at ambient room temperature in polyethylene bags. The yield of dough (YD) was calculated on the basis of the total mass of dough ( $a$ ) and mass of using flour ( $m$ ) (14% moisture wb) according to the equation:

$$YD = \frac{100a}{m} \quad (\%) \quad (1)$$

The bread yield (YB), representing the amount of bread obtained from 100 g of flour, was calculated as follows:

$$YB = \frac{c \cdot YD}{a}, \quad (2)$$

where  $a$  is a weight of dough portion before baking,  $c$  is the mass of bread after cooling and YD is a dough yield.

## Bread properties

Physico-chemical evaluation of obtained breads was carried out 1 day after baking. Additionally, the crumb bread hardness was measured also 4 days after baking in case of assay the changes of crumb texture during staling. The loaf volume was measured by rapeseed displacement method [22]. The crumb bread hardness was assessed using texture analyser (Instron 1140). Two bread loaves were cut to obtain 35-mm thick slices. Two slices were taken from the center of each loaf and were used to evaluate crumb hardness. The test was performed at a speed of 50 mm min<sup>-1</sup> and load cell 500 N. The crumb was pressed by 50% by aluminium sampler with a diameter 35 mm at center place of prepared bread slices. Hardness was expressed as the force (in N) required to achieve a predetermined deformation of the crumb breads,

and was determined on the basis of the graph (the maximum peak height). The crumb moisture was measured using the oven drying method (10 g of crumb was dried in an oven for 1 h at 130 °C).

## Statistical analysis

All tests were performed in four replicates. The results were statistically analyzed in the Statistica 10. One-way analysis of variance (ANOVA) was made with significance level  $\alpha=0.05$ . The homogenous groups were determined by Tukey's test. Besides, and the Pearson's correlation coefficients for relationships between various flour properties were calculated and a statistical differences at  $p<0.05$  and  $p<0.01$  were considered to be significant. Principal component analysis (PCA), which is a multivariable approach designed for multicorrelated data, was also performed on the whole data set.

## Result and discussion

### Flour properties

The basic quality parameters characterized the rye flour were presented in Table 2. The protein content ranged from 8.2% dry mass (dm) (F1) to 11.1% dm (F7) and the ash content changed from 0.75% dm (F1) to 1.52% dm (F6). According to Gleń [23] the rye dough obtained from rye flour with the protein content above 10.5% dm shows high plasticity and viscosity, which negatively influence on dough shaping. The flour samples F4 and F7–F10 were characterized by protein content above 10.5% dm, which can indicate the lower baking quality of these flours. The results showed significant correlations between protein content and ash content

**Table 2** Quality parameters of rye flour

Rye flour	PC (% dm)	AC (% sm)	FPS (%)	FN (s)	APV (BU)	WA (%)
F1	8.2 <sup>a</sup> ± 0.01	0.75 <sup>a</sup> ± 0.01	75.3 <sup>j</sup> ± 0.1	290 <sup>h</sup> ± 6	630 <sup>g</sup> ± 7	60.8 <sup>c</sup> ± 0.4
F2	9.5 <sup>b</sup> ± 0.08	1.38 <sup>d</sup> ± 0.01	37.6 <sup>g</sup> ± 0.3	212 <sup>c</sup> ± 4	370 <sup>c</sup> ± 3	58.3 <sup>b</sup> ± 0.1
F3	9.4 <sup>b</sup> ± 0.06	1.37 <sup>d</sup> ± 0.01	35.3 <sup>e</sup> ± 0.1	182 <sup>a</sup> ± 6	360 <sup>b</sup> ± 4	58.4 <sup>b</sup> ± 0.1
F4	10.6 <sup>c</sup> ± 0.02	1.50 <sup>f</sup> ± 0.02	25.2 <sup>a</sup> ± 0.1	232 <sup>e</sup> ± 3	280 <sup>a</sup> ± 7	54.2 <sup>a</sup> ± 0.6
F5	9.4 <sup>b</sup> ± 0.05	1.34 <sup>c</sup> ± 0.01	36.3 <sup>f</sup> ± 0.1	187 <sup>a</sup> ± 4	350 <sup>b</sup> ± 11	58.2 <sup>b</sup> ± 0.1
F6	10.5 <sup>bc</sup> ± 0.07	1.52 <sup>f</sup> ± 0.01	29.4 <sup>c</sup> ± 0.1	201 <sup>b</sup> ± 4	290 <sup>a</sup> ± 7	54.0 <sup>a</sup> ± 0.1
F7	11.1 <sup>e</sup> ± 0.01	1.24 <sup>b</sup> ± 0.01	38.4 <sup>h</sup> ± 0.6	239 <sup>e</sup> ± 6	460 <sup>d</sup> ± 4	63.6 <sup>d</sup> ± 0.1
F8	10.6 <sup>c</sup> ± 0.03	1.43 <sup>e</sup> ± 0.02	40.0 <sup>i</sup> ± 0.9	222 <sup>d</sup> ± 3	450 <sup>d</sup> ± 14	64.8 <sup>e</sup> ± 0.3
F9	10.6 <sup>c</sup> ± 0.01	1.31 <sup>c</sup> ± 0.01	34.3 <sup>d</sup> ± 0.1	274 <sup>g</sup> ± 6	510 <sup>f</sup> ± 7	66.1 <sup>f</sup> ± 0.8
F10	10.8 <sup>d</sup> ± 0.03	1.32 <sup>c</sup> ± 0.02	26.2 <sup>b</sup> ± 0.3	254 <sup>f</sup> ± 3	480 <sup>e</sup> ± 4	66.7 <sup>f</sup> ± 0.4

The values designated by the different letter in the columns of table are statistically significantly different ( $\alpha=0.05$ )

PC protein content, AC ash content, FPS the mass fraction of flour pass through sieve of 0.95 mm, FN falling number, APV amylograph peak viscosity, WA water absorption

( $r=0.645$ ,  $p<0.05$ , Table 6). It is in agreement with the results of Michalska and Zielińska [24] and Gómeza et al. [25]. The water absorption of flour changed from 54.0% (F6) to 66.7% (F10). Obtained flours had different granulometric compositions established by evaluating the pass through the sieve of 95 mesh test. The highest amount of particles below 95  $\mu\text{m}$  was found in the flour F1, whereas the coarse flour (the lowest mass fraction of particles above 95  $\mu\text{m}$ ) was obtained for F4 sample. The rye flours significantly differ according to the falling number (FN), and amylograph peak viscosity of flour (APV). These parameters are very important for the evaluation of susceptibility of starch on enzyme degradation and starch ability to swelling and gelatinization [26–28]. The results of FN ranged from 183 s (F3) to 290 s (F1), whereas the APV changed from 280 BU (F4) to 630 BU (F1). The results showed significant and positive correlation between the FN and APV ( $r=0.811$ ,  $p<0.01$ , Table 6). Similar correlation was found by the others authors [29, 30].

Table 3 presents the results of pentosans evaluation in the rye flour. The total pentosans content ranged from 7.9 dm (F2) to 9.8 dm (F10). The pentosans content significantly correlated with water absorption of flour ( $r=0.698$ ,  $p<0.05$ , Table 6). Similar tendencies were observed by other authors [2, 31–33]. Tokar et al. [34] found that, the highest influence on ability to bind water by the pentosans has their molecular weight. Increase the molecular weight of pentosans causes increase in water absorption. In this work, flour sample F1 was characterized by similar total pentosans content such as samples F4 and F5 but had statistically higher water absorption. It is caused probably due to differences in molecular weight of pentosans. The highest content of water extractable pentosans (4.3% dm) was found in the sample F7 and the lowest (2.6% dm) in the flour F5. The water extractable pentosans content significantly correlated with FN and APV

**Table 3** The content of pentosans in rye flour

Rye flour	TPC (% dm)	WEP (% dm)	WUP (% dm)	%WEP
F1	8.5 <sup>b</sup> ±0.07	4.1 <sup>d</sup> ±0.16	4.4 <sup>b</sup> ±0.08	48 <sup>d</sup> ±1
F2	7.9 <sup>a</sup> ±0.22	2.7 <sup>a</sup> ±0.13	5.2 <sup>c</sup> ±0.09	35 <sup>b</sup> ±2
F3	8.4 <sup>b</sup> ±0.08	3.0 <sup>b</sup> ±0.13	5.4 <sup>cd</sup> ±0.05	36 <sup>b</sup> ±1
F4	8.5 <sup>b</sup> ±0.14	3.2 <sup>b</sup> ±0.10	5.3 <sup>c</sup> ±0.04	38 <sup>bc</sup> ±1
F5	8.5 <sup>b</sup> ±0.08	2.6 <sup>a</sup> ±0.11	5.9 <sup>e</sup> ±0.03	31 <sup>a</sup> ±1
F6	9.1 <sup>c</sup> ±0.12	3.6 <sup>c</sup> ±0.14	5.5 <sup>d</sup> ±0.02	40 <sup>c</sup> ±1
F7	9.3 <sup>cd</sup> ±0.07	4.3 <sup>d</sup> ±0.11	4.0 <sup>a</sup> ±0.09	46 <sup>e</sup> ±1
F8	9.4 <sup>d</sup> ±0.11	3.3 <sup>b</sup> ±0.13	6.1 <sup>e</sup> ±0.24	35 <sup>b</sup> ±2
F9	9.5 <sup>d</sup> ±0.18	4.1 <sup>d</sup> ±0.17	5.5 <sup>d</sup> ±0.06	43 <sup>d</sup> ±1
F10	9.8 <sup>e</sup> ±0.14	3.7 <sup>c</sup> ±0.08	6.1 <sup>e</sup> ±0.05	38 <sup>bc</sup> ±4

The values designated by the different letter in the columns of table are statistically significantly different ( $\alpha=0.05$ )

TPC total pentosans content, WEP water extractable pentosans content, WUP water unextractable pentosans content, % WEP percent of pentosans soluble in water from the total of pentosans

( $r=0.759$ ,  $p<0.05$  and  $r=0.632$ ,  $p<0.05$ , respectively, Table 6). The water unextractable pentosans content ranged from 4.4% dm (F1) to 6.1% dm (F8) and was positively correlated with FPS ( $r=-0.661$ ,  $p<0.05$ , Table 6). %WEP was in the range from 31% (F5) to 48% (F1) and was positively related with FN and APV [ $r=0.745$ ,  $p<0.05$  and  $r=0.619$ ,  $p<0.05$ , respectively (Table 6)].

## Results of swelling curve test

The results of parameters obtained on the basis of swelling curves were significantly different between individual flour samples (Table 4). The changes of these parameters are related to the changes during dough mixing, fermentation and during the first phase of baking. Rasmussen et al. [35] showed that the optimal conditions for enzymes which degradation of pentosans is pH in the range 3.8–5.3 and temperature 40 °C. Therefore, the conditions during swelling curve test are optimal for enzymatic degradation of pentosans. The initial viscosity (VA), which reflect the amount of water-binding material present in rye flour, ranged from 175 BU (F4) to 845 BU (F9) while the viscosity when the sample reaching temperature 42 °C (VB) changed from 175 BU (F4) to 675 BU (F9). The final viscosity (VC), which depends on the amount of swelling substances, the swelling or hydration properties of these substances and the degree of enzymatic degradation during test, was in the range from 165 BU (F2) to 355 BU (samples F7, F9, F10). The results showed significant correlations between all viscosity parameters obtained on the basis of swelling curve and FN (Table 6). Our results clearly show that the values of viscosity parameters obtained on the basis of swelling curve were positively and significantly correlated with the water extractable pentosans content and their share in the total pentosans

**Table 4** The swelling curves parameters

Rye flour	VA (BU)	VB (BU)	VC (BU)	logVB – logVC
F1	685 <sup>g</sup> ±21	560 <sup>f</sup> ±18	280 <sup>e</sup> ±25	301 <sup>f</sup> ±25
F2	205 <sup>bc</sup> ±7	190 <sup>b</sup> ±7	165 <sup>a</sup> ±7	61 <sup>c</sup> ±35
F3	195 <sup>b</sup> ±4	190 <sup>b</sup> ±7	185 <sup>b</sup> ±7	12 <sup>b</sup> ±1
F4	175 <sup>a</sup> ±7	175 <sup>a</sup> ±7	215 <sup>c</sup> ±7	–89 <sup>a</sup> ±3
F5	215 <sup>c</sup> ±7	200 <sup>c</sup> ±3	175 <sup>ab</sup> ±11	58 <sup>c</sup> ±26
F6	280 <sup>d</sup> ±14	290 <sup>d</sup> ±7	280 <sup>e</sup> ±7	15 <sup>b</sup> ±2
F7	510 <sup>e</sup> ±21	505 <sup>e</sup> ±18	355 <sup>f</sup> ±21	153 <sup>d</sup> ±11
F8	280 <sup>d</sup> ±11	275 <sup>d</sup> ±14	245 <sup>d</sup> ±21	50 <sup>c</sup> ±15
F9	845 <sup>h</sup> ±14	675 <sup>g</sup> ±25	355 <sup>f</sup> ±18	279 <sup>f</sup> ±6
F10	630 <sup>f</sup> ±18	565 <sup>f</sup> ±21	355 <sup>f</sup> ±28	202 <sup>e</sup> ±18

The values designated by the different letter in the columns of table are statistically significantly different ( $\alpha=0.05$ )

VA initial viscosity at 30 °C, VB viscosity when the sample reaching 42 °C, VC viscosity after holding at 42 °C for 30 min, logVB – logVC logarithmic decrease of viscosity at 42 °C

content (Table 6). The most of tested flour samples were characterized by the decrease of viscosity after heating the samples from 30 to 42 °C. It is caused by the degradation of water extractable pentosans up to the compounds with lower molecular weight [10]. Only in the case of F6 sample the slight increase of viscosity was observed after heating this sample from 30 to 42 °C. It is probably caused by the transformation of water unextractable pentosans up to soluble forms up to the moment when the degradation of extractable pentosans caused a decrease of viscosity [12]. The values of logarithmic decrease of viscosity during holding a slurry at 42 °C, ranged from –89 (F4) to 301 (F1). This parameter informs indirectly about activity of enzymes hydrolyzed pentosans (EHP). The negative value of this parameter for F4 sample indicates about very low activity of EHP. In the case of very low EHP transformation of water unextractable pentosans into soluble form during baking is very limited. It causes that starch has low level of water for gelatinization and that negatively influences on bread properties [36]. The optimum level of pentosans depolymerization exchange the dough elasticity, which increase the ability of dough to keep carbon dioxide and obtained bread is characterized by increased volume, and softer crumb. To excessive hydrolysis of pentosans causes a decrease of dough ability to keep the carbon dioxide and it has negative influence on bread volume [37, 38]. The results showed significant relation between the logarithmic decrease of viscosity and the amylograph peak viscosity and FN ( $r=0.921$ ,  $p<0.01$  and  $r=0.792$ ,  $p<0.01$ , respectively, Table 6).

## Bread properties

Table 5 presents the results of dough yield and quality parameters of bread. The dough yield changed from 168% (F2 and F5) to 176% (F10). This parameter was positively

correlated with water absorption of flour and with the all viscosity parameters obtained on the basis of swelling curve (Table 6). The bread volume changed from 170 cm<sup>3</sup>/100 g (F6) to 249 cm<sup>3</sup>/100 g (F1). Generally, the breads with the lowest volume were obtained from flour with high protein content, more coarse flour, higher ash content, low amylograph peak viscosity and low logarithmic decrease of viscosity. The bread yield ranged from 135% (F2) to 149% (F7). The bread yield was positively correlated with viscosity parameters: VA and VC ( $r=0.649$ ,  $p<0.05$ ,  $r=0.819$ ,  $p<0.01$ , respectively, Table 7). Beside this, the total pentosans content and the water extractable pentosans content positively influenced on bread volume ( $r=0.797$ ,  $p<0.01$ , and  $r=0.758$ ,  $p<0.05$ , respectively) (Table 7).

The crumb hardness in one of the most important bread texture parameters [2]. The lowest hardness after 1 and 4 days bread storage was found in the bread obtained from flour F1 (19.1 and 28.4 N, respectively), whereas the highest values of this parameter were found for bread crumb from F4 sample (89.5 and 160.4 N, respectively). Most importantly, the logarithmic decrease of viscosity was negatively correlated with crumb bread hardness after 1 and 4 days storage of bread ( $r=-0.802$ ,  $r=-0.789$ , respectively, Table 7). The crumb moisture changed from 44.0% (F5) to 50.4% (F6) and was positively correlated with water extractable pentosans and total pentosans content ( $r=0.761$ ,  $p<0.05$  and  $r=0.793$ ,  $p<0.01$ , respectively, Table 7). Beside this, bread moisture content was positively correlated with VA and VC parameters obtained on the basis of swelling curve ( $r=0.674$ ,  $p<0.05$  and  $r=0.805$ ,  $p<0.01$ , respectively, Table 7).

The results of principal component analysis (PCA) were presented on Fig. 2. Using PCA, it was possible to reduce the dimension of the raw data and identify several correlations between various flour properties. The properties whose

**Table 5** Yield of dough and quality parameters of obtained breads

Rye flour	YD (%)	BV (cm <sup>3</sup> /100 g)	YB (%)	CH1 (N)	CH4 (N)	HI (N)	CM (%)
F1	173	249 <sup>e</sup> ± 8	147 <sup>de</sup> ± 1	19.1 <sup>a</sup> ± 1.0	28.4 <sup>a</sup> ± 0.3	9.3 <sup>a</sup> ± 1.3	49.2 <sup>cd</sup> ± 0.6
F2	168	199 <sup>d</sup> ± 3	135 <sup>a</sup> ± 1	43.4 <sup>e</sup> ± 5.4	83.4 <sup>e</sup> ± 1.6	40.0 <sup>h</sup> ± 6.9	45.2 <sup>ab</sup> ± 0.6
F3	173	179 <sup>b</sup> ± 8	143 <sup>b</sup> ± 0	39.2 <sup>d</sup> ± 1.0	60.3 <sup>d</sup> ± 1.1	21.1 <sup>d</sup> ± 0.1	48.4 <sup>c</sup> ± 0.6
F4	170	171 <sup>a</sup> ± 1	138 <sup>b</sup> ± 1	89.5 <sup>h</sup> ± 1.8	160.4 <sup>g</sup> ± 0.6	70.9 <sup>i</sup> ± 1.3	46.4 <sup>b</sup> ± 0.9
F5	168	194 <sup>e</sup> ± 7	141 <sup>b</sup> ± 1	52.5 <sup>f</sup> ± 1.1	89.3 <sup>f</sup> ± 2.0	36.8 <sup>g</sup> ± 3.1	44.0 <sup>a</sup> ± 0.7
F6	170	170 <sup>ab</sup> ± 4	145 <sup>cd</sup> ± 1	60.8 <sup>g</sup> ± 2.5	89.8 <sup>f</sup> ± 2.1	29.0 <sup>f</sup> ± 0.4	50.4 <sup>e</sup> ± 0.2
F7	172	176 <sup>b</sup> ± 4	149 <sup>e</sup> ± 1	32.2 <sup>b</sup> ± 0.1	43.9 <sup>b</sup> ± 1.5	11.7 <sup>b</sup> ± 0.6	49.5 <sup>d</sup> ± 0.1
F8	174	186 <sup>c</sup> ± 1	143 <sup>b</sup> ± 1	45.4 <sup>e</sup> ± 0.6	59.6 <sup>d</sup> ± 0.8	14.2 <sup>c</sup> ± 0.3	49.5 <sup>d</sup> ± 0.2
F9	174	185 <sup>c</sup> ± 4	144 <sup>c</sup> ± 1	40.0 <sup>d</sup> ± 1.1	53.7 <sup>c</sup> ± 0.8	13.7 <sup>c</sup> ± 0.3	50.3 <sup>c</sup> ± 0.2
F10	176	193 <sup>d</sup> ± 4	146 <sup>d</sup> ± 1	35.9 <sup>c</sup> ± 0.4	59.4 <sup>d</sup> ± 0.8	23.5 <sup>e</sup> ± 0.4	50.2 <sup>e</sup> ± 0.1

The values designated by the different letter in the columns of table are statistically significantly different ( $\alpha=0.05$ )

YD dough yield, BV specific bread volume, YB yield of bread, CH1 crumb bread hardness 1 day after baking, CH4 crumb bread hardness 4 days after baking, HI hardness increase after 3 days storage of bread, CM crumb moisture

**Table 6** Pearson's correlations coefficients between of rye flour quality parameters

	AC	FPS	FN	APV	WA	TP	WEP	WUP	%WEP	VA	VB	VC	logVB – logVC	YD
PC	0.645*	-0.754*	NS	-0.297	NS	0.689*	NS	NS	NS	NS	NS	NS	NS	NS
AC		-0.917**	-0.659*	-0.848**	NS	NS	NS	0.653*	-0.641*	NS	NS	NS	-0.754*	NS
FPS			NS	0.731*	NS	NS	NS	-0.661*	NS	NS	NS	NS	NS	NS
FN				0.811**	NS	NS	0.759*	NS	0.745*	0.868**	0.848**	0.690**	0.792**	NS
APV					0.703*	NS	0.632*	NS	0.619*	0.824**	0.805**	NS	0.921**	0.625*
WA						0.698*	NS	NS	NS	0.698*	0.719*	0.648*	0.692*	0.759*
TP							0.604*	NS	NS	NS	0.658*	0.851**	NS	0.734*
WEP								NS	0.930**	0.802**	0.852**	0.897**	0.672*	NS
WUP									-0.730*	NS	NS	NS	NS	NS
% WEP										0.693*	0.722*	0.688*	0.624*	NS
VA											0.989**	0.834**	0.935**	0.650*
VB												0.897**	0.915**	0.674*
VC													0.655*	0.681*
logVB – logVC														NS

NS not significant, PC protein content, AC ash content, FSD the percentage of flour passing through the sieve 95 µm, FN falling number, APV amylograph peak viscosity, WA water absorption, TP total pentosans content, WEP water extractable pentosans content, WUP water unextractable pentosans content, VA initial viscosity at 30°C, VB viscosity when the sample reaching 42°C, VC viscosity after holding at 42°C for 30 min, logVB – logVC logarithmic decrease of viscosity at 42 °C, YD dough yield

\*Correlation is significant at  $p < 0.05$  level

\*\*Correlation is significant at  $p < 0.01$  level



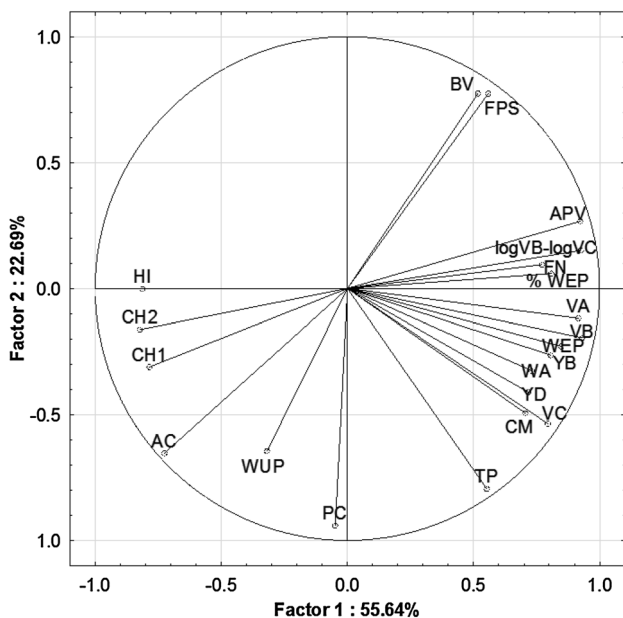
**Table 7** Pearson’s correlations coefficients between of rye flour and bread properties

	BV	YB	CH1	CH4	HI	CM
PC	−0.789**	NS	NS	NS	NS	NS
AC	−0.903**	NS	0.724*	0.644*	NS	NS
FPS	0.896**	NS	−0.639*	NS	NS	NS
FN	NS	NS	NS	NS	NS	NS
APV	0.746*	NS	−0.824**	−0.667*	−0.808**	NS
WA	NS	NS	−0.627*	NS	−0.669**	NS
TP	NS	0.797**	NS	NS	NS	0.793**
WEP	NS	0.758*	NS	NS	NS	0.761*
WUP	NS	NS	NS	NS	NS	NS
%WEP	NS	NS	NS	NS	NS	0.615*
VA	NS	NS	NS	NS	NS	NS
VB	NS	0.649*	NS	−0.640*	−0.639*	0.674*
VC	NS	0.819**	NS	NS	NS	0.805**
logVB − logVC	0.637*	NS	−0.802**	−0.789**	−0.727*	NS

NS not significant, PC protein content, AC ash content, FSD the percentage of flour passing through the sieve 95 μm, FN falling number, APV maximum amylograph peak viscosity, WA water absorption, TP total pentosans content, WEP water extractable pentosans content, WUP water unextractable pentosans content, VA initial viscosity at 30 °C, VB viscosity when the sample reaching 42 °C, VC viscosity after holding at 42 °C for 30 min, logVB − logVC logarithmic decrease of viscosity at 42 °C, BV specific bread volume, YB yield of bread, CH1 crumb bread hardness 1 day after baking, CH4 crumb bread hardness 4 days after baking, HI hardness increase after 3 days storage of bread, CM crumb moisture

\*Correlation is significant at  $p < 0.05$  level

\*\*Correlation is significant at  $p < 0.01$  level



**Fig. 2** Principal component analysis: loading plot of PC1 and PC2 for the evaluated parameters of rye flour

curves line are close to each other on the plot are positively correlated while those whose curves run is opposite are negatively correlated. Variables located in the perpendicular directions along the PC axis are independent of each

other. The first and the second component described 55.64 and 22.69% of the variance, respectively. Together, the first two components represent 78.33% of the total variability. The first principal component was positively related to the all parameters obtained from swelling curve: AV, FN, WA, WEP, YD, CM and was negatively related to AC and crumb hardness. The second principal component was positively correlated with FSD, TP, BV and negatively correlated with PC. Figure 2 shows that VA and VB were strongly correlated with WEP, FN and WA. Beside this, the values of VC positively influenced on CM, YB, YD, WA, WEP and TP. Whereas the logarithmic decrease of viscosity positively correlated with APV, FN and %WEP, while negatively correlated with crumb hardness and hardness increase during storage of bread.

### Conclusions

The test of swelling curve is simple and adequate method for the evaluation of the baking quality of rye flour. The parameters obtained on the basis of swelling curve especially correlated with enzymes activity, the content of water extractable pentosans and bread properties. The highest correlation were found between parameters VA and VB and the falling numbers. Most importantly, the viscosity parameters significantly correlated with bread yield, volume and crumb

hardness. Especially the swelling curve change in viscosity was negatively correlated with bread hardness. In summary, the swelling curve test can be used as useful tool for the evaluation of baking quality of rye flour.

### Compliance with ethical standards

**Conflict of Interest** The authors declare that there is no conflict of interest regarding the publication of this article.

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