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Testing Methods For Describing Rye Whole Meal Quality

Ponomareva ML*, Ponomarev SN, Mannapova GS, Gilmullina LF, Fomin SI, Ilalova LV, Vafina GS, and Kirillova ES.

Tatar Scientific Research Institute of Agriculture – Subdivision of the Federal State Budgetary Institution of Science «Kazan Scientific Center of Russian Academy of Sciences», Kazan, Orenburg tract, 48.

ABSTRACT

The objective was to assess different winter rye varieties onset of the indicators defining baking, functional and technological properties and to reveal correlations between analytical values rye whole meal. In our work we have evaluated 10 Russian winter rye varieties by 18 indicators of baking and rheological properties including using the known devices (Amylograph Brabender, Farinograph, Hagberg-Perten Falling Number).In addition, swelling curve characteristics, viscosity water extract (VWE), content water soluble pentosans and protein were assessed. Along with well-known techniques was showed the possibility of using Amylograph Brabender to determine the viscosity at a temperature of 30°C. High correlation swelling curve parameters, specifically maximum swelling after holding at 30oC for 30 min, with falling number, amylograph peak viscosity and the viscosity of water extract (0.85; 0.90; 0.94, respectively) was shown. The high intervarietal variability in dough stability time, rate of swelling, viscosity water extract and falling quality number were found in this study. The best results of structural-mechanical properties of dough were obtained for variety Zilant. Strong positive relationship was established between viscosity water extract and maximum swelling (r = 0.94), temperature at peak viscosity(r = 0.72), falling number (r = 0.82).
Keywords: winter rye, whole meal, dough, Amylograph, Farinograph, viscosity, falling number.

**Corresponding author*

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INTRODUCTION

Rye is one of the best crops where soil fertility is low and winter temperatures are extreme. It is the most winter hardy of all small cereal grains [1]. Rye is predominantly grown on infertile and sandy soils of the central and eastern parts of Europe, which are characterized by a low water holding capacity. Therefore rye is considered a cereal of the European continent because it accounts for 85 % of the world production. For example, approximately 13 million tons of rye grain were harvested in the world, of which 11 million tons were grown on the European continent with an average yield about 3 tons /ha in 2016 [2].

Russia is one of the largest countries in the world that takes the second place in the rye grain production after Germany. Until 1970, winter rye was the main cereal crop in Russia; its acreage exceeded the winter wheat ones. From 1970, the growing area of rye continuously decreased to 2% of total arable land in Russia today. Over the past four decades, the sowing area of winter rye in Russia has reduced by six times (from 7.75 million hectares in 1970 to 1.25 million hectares in 2016). For a long period, the cultivation of traditional Russian grain with extensive farming was the most economically beneficial, especially since the agro-climatic conditions of Russia are optimal for rye. In 2016, 2.5 million tons of rye grain was harvested [3].

The main chemical constituents of the rye grain are the same in other cereals: starch, dietary fiber (DF), protein, and mineral matter. Winter rye contains 73% insoluble dietary fiber and the proportion of soluble fibers at 27% compared to other grains is relatively high [4]. Rye fibers are more beneficial to health than dietary fibers in many ways. They positively influence bowel activity, metabolism, and the quantity, quality, and composition of the intestinal flora. The nutritional benefits of high rye consumption include positive effects on digestion and decrease risk of heart disease, hypercholesterolemia, obesity, and non-insulin dependent diabetes, and its thought rye also has a protective effect against some hormone-dependent cancer types [5].

Hansen et al (2002) reported that the main component of rye DF are arabinoxylans (AX) or pentosans, with the content in rye grain of 6.5–12.2% d.m., compared to 6–7% d.m. in wheat [6]. AX has high water holding capacity, which is influenced by the solubility and structural features of the polymer [7]. In bread making parts water-extractable arabinoxylans (WE-AX) affected loaf volume and crumb structure of rye bread positively, whereas water unextractable (WU–AX) showed negative effects on these parameters. WU–AX backfire the dough and end-product properties by disrupting the cell wall film [8, 9]. Rye flour with good baking value should be characterized by high AX content and also high proportion WE-AX. Cereal AX represents a very structurally heterogeneous group, in which the ratio of arabinose to xylose, the pattern of arabinose substitution and the degree of polymerization can vary significantly [10]. The hydrolysis of WU- AX changes their solubility and causes an increase dough viscosity and reduction of water binding capacity [11]. These changes caused an increase in bread volume and decrease crumb hardness. Thus AX affect the physicochemical properties and processing behavior of cereal grains in milling, brewing, and baking due to their high viscosity and water retention properties [12].

Rye grain contains enzymes that attack all of its major constituents, and especially the starch-degrading amylases play a key role in relation to the baking quality of the flour [9]. The activity of the amylases is measured using the Falling Number (FN) method [13]. The starch quality and the breakdown through activity of α-amylase are also measured by the amylograph test. The maximum viscosity of rye slurry heated in the amylograph and the temperature at maximum viscosity, which are normally reached between 62 and 75 °C, and used as quality criteria [14]. The water absorption of rye flour is measured by the Farinograph method. The basis of the equipment is a recording dough mixer that measures torque needed for mixing dough at a constant speed and temperature. This quality parameter is correlated to the amount of water that can be added to the dough and there are to determine the economically important dough and bread yield achieved from given amount of flour. The lack of gluten formation in rye dough enhances the role of the swelling substances (mainly AX) for the dough structure. The water absorption is dependent on the content and properties of AX. Especially the proportion of WE-AX to total AX is considered to be important for water absorption. The role of the rye proteins for the water absorption of rye whole meal and rye flour is probably low compared to wheat as a higher proportion of the rye proteins are water soluble [10].

Another method is used to assess properties of dough connected with AX content and activity cell wall degradation enzymes is the swelling curve test [15]. This parameter characterizes indirectly the intensity of enzymatic processes during the first phase of baking. A lot of authors studied the swelling curve test [6, 16–18], but there are no papers concerning possibility of using it for the evaluation of the baking quality of rye flour instead of the traditional estimates of amylographic viscosity.

Our objective was to assess different winter rye varieties onset of the indicators defining baking, functional and technological properties and to reveal correlations between analytical values rye whole meal.

MATERIAL AND METHODS

Rye grain harvested at the field trials of Tatar Scientific Research Institute of Agriculture, located at Laishev district, Republic Tatarstan, Russia (UTM N55.649 E49.3083) in two growing seasons (2014-2015 and 2015-2016). The ten different rye cultivars (*Secale cereale L.*) included modern varieties from Russia both own selection and other breeding organizations (Tatarskaya 1, Estafeta Tatarstana, Radon, Ogonek, Tantana, Podarok, Zilant, Populyaciya 17, Parcha, Pamyati Kunakbaeva). Original seed material was used each year. Each cultivar was grown in four replicated plots of 16 m^2 size in randomized block design. Grain samples from each plot were selected and analyzed separately.

The rye grain was milled to whole meal flour (rye flours with extraction rate of 100%) with Perten Instruments Laboratory Mill 3100 with 0.8 mm sieve. Moisture content of flour samples was determined using air-oven method (AACC 44-15A from 2000). Falling number was determined by ISO 3093 (2009) standard method by means of equipment Falling Number 1500 [13]. For analysis of starch gelatinization properties was used Amylograph Brabender (Germany) according to the international standard method (ISO 7973-2013). The acquired diagram was evaluated for amylograph peak viscosity (APV) in amylograph units and the gelatinization temperature (initial and maximum). For analysis of rheological properties was used Farinograph Brabender as described in the standard methods (ICC method 115/1). The water absorption of rye whole meal was measured as follows: 200 g of flour (14% moisture basis) was mixed in a 300 g farinograph bowl with distilled water to a final dough consistency of 300± 10 BU after 10 min of kneading time according to Kim M. Y. et al [19]. For all samples the following farinograms parameters were determined: water absorption (WA) of flour and flour blends, stability of dough (S), development time of dough (DDT), and the degree of softening (DS). Water soluble pentosans (WSP) content was determined according to Hashimoto et al. method [20] modified by Delcour et al. [21] for rye grain. Kinematic viscosity of water extract (VWE) of the rye was performed according to the method advanced by Boros D. et al. [22], glass capillary viscometer 1.52 Labtex in centistokes (more details in [23]). The protein content was analyzed by semi-micro method Kjeldahl (AOAC 984.13). Swelling curve measurements were performed under 4.3.1 instructions for Amylograph Brabender. In order to determine swelling characteristics (on 14% moisture base) whole meal rye (130 g) was mixed with 400 ccm distilled water of approximately 32 °C into measuring cylinder. For this purpose the weighed amount of flour was filled into a glass container of 1 liter content (preserving glass) and slowly added the 400 ccm tempered water while stirring continuously until a homogenous smooth suspension has been formed. Then the flour–water suspension passed into the Amylograph bowl, scraping the glass container thoroughly so that the loss of substance is negligible. For the measurement, we inserted a sensor, set the thermo regulator to 30 °C and disengaged thermo regulator drive, as the test was carried out at a constant temperature of 30 °C. Then the swelling behavior was recorded for 30 minutes in the form of a curve. Using the swelling curve we determined the following characteristics: initial swelling (IS) in AU, maximum swelling (MS) in AU, swelling time (TS) in minutes, swelling rate (RS) in AU/ min.

The one-way analysis of variance (ANOVA) was calculated for the obtained data, applying the Microsoft Excel for Windows 7.0 and SPSS software package was used. All experiments were duplicated and the means were compared using Multiple Ranges Duncan's test ($p < 0.05$). Pearson correlation coefficients for relationships between various whole meal flour properties were calculated and statistical differences at $p < 0.05$ were considered to be significant.

EXPERIMENTAL

The protein content ranged from 9.86 to 11.09 % of 14% moisture. The FN of the grain samples changed from 150 s (Ogonek) to 198 s (Parcha) (Table 1). The amylograph peak viscosity ranged from 455 to 750 AU, the temperature at peak viscosity varied between 69.6 and 73.1 °C, and the temperature at the beginning of gelatinization ranged between 53.1 and 55.4°C. The maximal APV was Populyaciya 17. The cultivar Parcha had very high gelatinization temperatures (>73 °C) combined with high amylograph viscosities.

The result (Table 1) shows Russian varieties are well differentiated by swelling parameters. The beginning of swelling varied from 375 (Ogonek) to 610 (Population 17), the maximum swelling - 560 to 855 AU. Significant differences between varieties in the rate of swelling were revealed. The highest value of the index was characterized by the varieties Ogonek and Podarok (of 5.7 and 5.75 UA/min) respectively. The highest viscosity water extract was registered in variety Population 17 (42.8 cSt). The minimum value of the indicator showed Ogonek and Podarok. These varieties showed the lowest content of water-soluble pentosans (1.55 and 1.53% dm). A similar value was determined Parcha (1.52%), but it had a significant water extract viscosity (38.7 cSt). Cultivars Zilant, Tantana and Estafeta Tatarstana distinguished the highest content of water-soluble pentosans.

The ability of flour to absorb and retain water defines the amount of bread, obtained from every 100 kg of flour. The water absorption of rye whole meal ranged from 63.7 to 65.8% (Table 1). Also note, differences between set of cultivars in WA and dough formation time were not statistically significant. The cultivar Zilant had high FQN (60.5) whereas other cultivar, such as Ogonek, had value two times lower (30.5 mm).

Table 2 presents the average values, limits and coefficient of variation of the studied parameters. Experimental tests have shown that the rye varieties did not practically differ in characteristics: the beginning and the peak temperature of gelatinization, water absorption, the time of gelatinization, the content of water-soluble pentosans and valorimetric value. The highest coefficients of variation were found for dough stability, viscosity water extract, rate of swelling, farinograph quality number.

Dough stability time (DST) indicated how much tolerance the flour has to over or under mixing. It is a primary index of flour quality and is one of the most considerable determinations made by Farinograph. The amplitude of the variability ranged from 1.7 to 4.8 min with the average value DST of 2.5 min. A higher value of stability means that the flour is more tolerant, that is typical to cultivar Zilant (Table 1). Experiments have shown that a highest intervarietal variability (CV=41.4%) was DST.

A significant variation was the rate of swelling (CV=32.5%) and the viscosity water extract (CV=28.6%). Based on this, the more differences between the varieties were identified, the higher opportunities are for the selection of alternative genotypes. The average water absorption was 64.39%, but no general differences were seen in WA between the different cultivars. Of all Farinograph-measured properties only FQN was also a highly variable indicator (CV=26.0%).

In the next step, we tried to find a relationship between the viscosity water extract, determined on capillary viscometer, with maximum swelling (final viscosity in swelling curve) after holding at 30°C for 30 min. Both viscosity measurements are made at similar temperatures, only VWE is done by the technician manually, and the MS is measured automatically on Amylograph.

Our results (Fig.1) clearly showed that the values VWE were positively and significantly correlated with viscosity parameters obtained on the basis of swelling curve. The regression line is represented by a simple linear equation, in this case $y = 0.082x – 29.53$ (R^2=0.886).

Table 3 presents the results of evaluation correlation between 18 indicators, studied in the laboratory. The analysis of relationships between the whole meal rye quality characteristics of revealed 29 pairs with significant coefficients correlation (in the table these values are shown in bold). In breeding program and official trials quality parameters of rye flour or whole meal can be measured using Amylograph and Falling Number equipments. As expected, the FN showed strong positive correlation with amylograph peak viscosity (r = 0.84) and temperature at peak viscosity (r = 0.91). The contents of protein had no influence on the amylograph properties. The results showed significant and positive correlation between the GT and FN, APV, TPV (r = 0.77, 0.78, 0.85, respectively, Table 3). These findings are in accordance with the results J.M. Brümmer [24].

We have obtained strong correlations between MS detected on the swelling curve with a number of indicators: FN, APV, TPV, GT, IS, RS (Table 3). Very important for breeding practical use is a high correlation coefficient MS and VWE (r = 0.94). The same strong relationships (slightly different in the correlation coefficient value) were found in the VWE with the same parameters as MS. For example, MS and FN (r = 0.85), but VWE and FN (r = 0.82), or MS and TPV (r = 0.80), but VWE and TPV (r = 0.72). The highest correlations were found between initial swelling and parameters MS, VWE and content water soluble pentosans (Table 3). Similar correlation was found by the others authors [16, 25, 26].

WA of flour depends on the latter's water binding capacity and thus determines the yield of dough and amount of water to be added in the preparation of the dough. Water absorption showed a positive substantial correlation with rate of swelling (r = 0.63).

Dough formation (development time) is the time required for flour dough to reach maximum consistency from beginning of kneading. This parameter correlated with test viscosity water extract (r = 0.66). We found a significant negative correlation between VV and DS (r = -0.91). Indicator IS had a high association with MS, VWE and WSP (Table 3). Dough stability (resistance) is a very important test, which characterizes the duration preserving the maximum consistency level of the kneading dough. DST showed strong negative relationship with protein content (r = -0.69).

FQN is a suitable factor in the bakery industry that could be very useful by predicting evaluation of flour quality quickly. The FQN is the distance in mm, along the time axis from the point of water addition to the point where the height in the center of the curve has dropped 20 FU. DST significantly correlated with farinograph quality number (r = 0.98).

RESULTS AND DISCUSSION

Historically, the properties of cereal flour, as well as the α-amylase activity at high temperatures are mostly examined by Amylograph Brabender and Hagberg-Perten Falling Number instruments. The Falling number (FN) is a method used to determine α-amylase activity in meal, whole meal and flour of rye. It measures time (expressed in seconds) required to stir and allows stirrer to fall through a hot water-flour system or meal gel undergoing liquefaction influenced by enzymes. Pre-harvest sprouting represents one of the major reasons for high α-amylase activity.

Amylographic investigations describe the viscosity of the flour, that is, the ability of dough swelling and gelatinization. The measurement principle Amylograph consists of heating the water-flour suspension at constant speed rate of 1.5 °C/min to 95°C or until the significant decrease of measured torque after the pasting peak is reached. Viscosity and maximum temperature gelatinization is assessed from the amylogram curve. Low values for viscosity and temperature at maximum gelatinization point are caused by high alpha-amylase activity and indicate an inelastic crumb and an all poor baking property, whereas temperature has higher relevance than viscosity. Too high enzymatic activity provokes increased degradation of starch, which loses the properties of water absorption during gelatinization. This process is indicated by the low amylographic data. The obtained results are influenced by different rye varieties flour properties, milling conditions, enzymatic activity. Good rye flour may show a maximum amylogram value of 520 AU together with a maximum temperature of 67.5°C and falling number 150-160 s [27].

From the point of view of physical colloidal chemistry "rye meal – water" is structurally difficult and multicomponent system. Viscosity rye meal water suspensions are the key parameter to characterize such a system. Its quantitative expression affects both the choice of the method dough obtaining and the determination of baking qualities.

Our study conducted that detected rye varieties significantly differ according to amylograph peak viscosity of flour – from 455 to 750 AU. These parameters are very important for the evaluation of susceptibility of starch on enzyme degradation and starch ability to swelling and gelatinization. Other parameters measured on Amylograph Brabender (TSG, TPV, GT) in compliance with international standard had a small variation (CV=1.1…5.8%). The cultivar Parcha had very high gelatinization temperatures (>73 °C) combined with high amylograph viscosities, maximal APV (750 AU) was Populyaciya 17. All varieties (except Ogonek and Podarok) had high bread-making quality requirements for rye flour.

There are a limited number of articles indicating that it is possible to register swelling curves reflecting the viscosity properties of the meal on the Amylograph. Stepniewska et al [16] showed in detail the possibility of using the swelling test for the evaluation of different types of flour according to the method of Drews [14]. They considered that the test of swelling curve is a 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. Most important, on the basis of the work of Drews [14] on introduction of a certain buffer for swelling curves, the "rye viscosity test" was developed. The test makes it possible to receive some additional information in about 30-45 minutes, the time that can usually be spared. Because of small sample quantities it is carried out by breeders as a selection criterion [27].

However, in the literature there are practically no reports about the possibility of using this device to determine the viscosity at a temperature of 30°C, although the instructions to the equipment provide for such a possibility. In our experiments the high correlation swelling curve parameters, specifically maximum swelling after holding at 30oC for 30 min, with falling number, amylograph peak viscosity and the viscosity of water extract (0.85; 0.90; 0.94, respectively) in grinding products is also shown. The high intervarietal variability in dough stability time, rate of swelling, viscosity water extract and falling quality number found in this study (Table 2) is in accordance with the range of variation reported by other authors [19, 28]. In summary, the swelling curve test (in difference from of Drew's test without heating at a temperature of 30 °C) can be used as useful tool for the evaluation of baking quality of whole meal rye flour for breeding purposes.

The Farinograph is a relatively quick and simple way to evaluate the rheological properties of dough, to give information concerning absorption and mixing characteristic of flours. Poutanen K. et al reported that Farinograph is among the most popular and accepted device for assessment of dough physical properties and could be used to investigate the influence of additives [29]. However, this test is used for a research of wheat flour quality most often. A method has recently been developed, which also makes it possible to determine the water absorption of rye flour [19, 28]. In work M. Y.Kim et. al. [19] it is specified that for rye WA depicts the amount of water absorbed by dough to reach a minimum viscosity of 300 FU.

Farinograph was used to measure dough quality Russian rye varieties and the (Table 3) result shows that the dough quality was affected differently. Dough formation time studied cultivars, used as an indicator of mixing, had almost identical values, at the same time dough stability significantly differed. Highest value of stability means showed Zilant (4.8 min.) and Tatarskaya 1 (4.1), whereas variety Ogonek had value DST only 1.7 minutes. Dough development time permits conclusion on speed of swelling, the fall consistency (degree of softening) shows whether the flour is strong or weak. 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.

High water absorption, combined with low degree of softening indicates good quality flour, whereas a high water absorption combined with a high degree of softening indicates poor quality flour. We have noted such combination of indicators at Radon and Parcha.

There are no significant correlation coefficients in the other parameters of Farinograph such as development time, degree of softening and valorimetric value with FQN. Dough stability time significantly correlated with farinograph quality number ($r = 0.98$) and showed negative relationship with protein content ($r = -0.69$).

The best results of structural-mechanical properties of dough were obtained for variety Zilant (DST=4.8; FQN=60.5). This is confirmed by high valorimetric value that characterizes elastic properties of dough (44%, Table 1). Callejo M.J. et al [27] considered that changes in rheological properties of rye dough, including softening of the dough during the resting period, have been associated with a decrease in water-holding properties of the arabinoxylans.

Previous studies have shown that pentosans content had wide genotypic variability in winter rye grain [23]. Many researchers suggest an indirect method of measuring amount of pentosans by viscosity water extract. The viscosity of the water- meal suspension can serve as an integral indicator of the quality of breeding material, delimiting rye lines for bakery and fodder [23, 25].

The results agreed with previous work stated that for the selection purposes the indicator of viscosity has to be essential.VWE is an effective test for measuring the viscous properties of whole meal flour, and for relating functionality to structural properties. Similar tendencies were observed by other authors [23, 30, 31]. Strong positive relationship was established between viscosity water extract and maximum swelling (r = 0.94), temperature at peak viscosity (r = 0.72), falling number (r = 0.82). The highest VWE was determined in cultivars Population 17 and Parcha, lowest values identified in Ogonek and Podarok. The rye populations with high viscosity had better bread-making characteristics than those ones with low viscosity. They surpassed the other varieties in a higher nature of grain (on 4.9%), size of grain (on 14.8%), falling number (on 90 s), a rate of amylogram (on 328 e.a.), temperature of gelatinization (on 2,5°C) [32].

Varieties Ogonek and Podarok showed the lowest content of water-soluble pentosans (1.55 and 1.53% dm). Cultivars Zilant, Tantana and Estafeta Tatarstana distinguished themselves the highest content of water-soluble pentosans. Parcha (1.52%), but it had a significant water extract viscosity (38.7 cSt). It is worth noting, the content WSP significantly was correlated with initial swelling at 30oC (r = 0.66, $p < 0.05$).

The results of parameters obtained on the basis of swelling curves were significantly different between studied cultivars. The initial swellings, which reflect the amount of water-binding material present in whole meal rye, ranged from 375 to 610 AU. Finally, our results clearly showed significant positive correlations between all viscosity parameters obtained on the basis of swelling curve and VWE as well as FN. Selection of young material in the breeding programs is mainly based on MS, which may also affect the amylograph properties and FN.

Table 1. Baking Quality Parameters and Grain Characteristics of Whole Meal Rye in Russia (2015-2016)

	Tatarskaya 1	Estafeta Tatarstana	Radon	Ogonek	Tantana	Podarok	Zilant	Populyaciya 17	Parcha	Pamyati Kunakbaeva
PC	10.02^{ab}	11.09^{c}	10.51^{ab}	10.64^{bc}	10.34^{ab}	10.14^{ab}	9.86^{a}	10.69^{bc}	10.04^{ab}	10.57^{bc}
FN	178^{bcd}	157^{ab}	178^{bcd}	150^{a}	185^{d}	160^{abc}	189^{d}	188^{d}	198^{d}	180^{cd}
APV	655^{bsd}	510^{ab}	600^{abcd}	520^{ab}	599^{abcd}	455^{a}	615^{abcd}	750^{d}	740^{cd}	700^{bcd}
TSG	53.9^{ab}	53.6^{ab}	54.6^{bc}	54.0^{ab}	55.4^{c}	53.1^{a}	54.6^{bc}	54.0^{ab}	54.0^{ab}	54.0^{ab}
TPV	70.5^{abc}	70.1^{ab}	71.8^{bcd}	69.6^{a}	72.0^{bcd}	69.9^{ab}	71.7^{abcd}	71.9^{bcd}	73.1^{d}	72.3^{cd}
GT	11.1^{b}	11.0^{b}	11.5^{bc}	10.4^{a}	11.1^{b}	11.2^{b}	11.4^{bc}	11.9^{cd}	12.7^{e}	12.2^{de}
IS	510^{bcd}	505^{bcd}	418^{ab}	375^{a}	535^{bcd}	465^{abc}	535^{bcd}	610^{d}	470^{abc}	550^{cd}
MS	700^{abcd}	660^{abc}	650^{abc}	560^{a}	745^{bcd}	583^{ab}	705^{abcd}	855^{d}	810^{cd}	748^{bcd}
TS	21.5^{ab}	18.75^{a}	24.5^{b}	29.0^{c}	21.5^{ab}	21.0^{ab}	20.5^{ab}	22.0^{ab}	23.0^{ab}	23.5^{b}
RS	7.65^{abc}	10.30^{cd}	9.60^{bc}	5.70^{a}	10.55^{cd}	5.75^{a}	8.55^{abc}	13.15^{def}	14.60^{f}	14.45^{ef}
VWE	31.30^{c}	26.50^{bc}	27.40^{c}	16.30^{a}	26.60^{c}	17.20^{a}	29.70^{c}	42.80^{e}	38.70^{de}	29.20^{c}
WSP	1.69^{abcd}	1.74^{d}	1.70^{bcd}	1.5^{ab}	1.75^{d}	1.53^{ab}	1.76^{d}	1.74^{d}	1.52^{a}	1.73^{cd}
WA	63.7	64.1	64.5	64.0	64.9	64.3	63.8	64.8	64.2	65.8
DF	2.2	2.5	2.4	2.0	2.2	2.2	2.1	2.5	2.5	2.2
DST	4.1^{bc}	2.1^{a}	2.0^{a}	1.7^{a}	2.5^{a}	2.0^{a}	4.8^{c}	1.9^{a}	2.3^{a}	1.9^{a}
DS	102.0	89.0	84.5	106.0	90.5	86.0	85.0	96.0	85.0	86.0
VV	39.0	43.0	43.0	38.5	43.0	44.0	44.0	40.5	43.5	41.0
FQN	53.0^{bc}	35.5^{a}	37.0^{a}	30.5^{a}	34.0^{a}	32.5^{a}	60.5^{c}	35.5^{a}	34.5^{a}	31.5^{a}

PC - Protein content (%); FN- Falling number (sec); APV-Amylograph peak viscosity (amylograph units, AU); TSG - temperature of start gelatinization (°C) ; TPV -temperature at peak viscosity (°C); GT - gelatinization time (minute); IS - initial swelling at 30 ^{o}C (AU), MS – maximum swelling after holding at 30^{o}C for 30 min (AU); TS – time of swelling (measure on swelling curve) (minute); RS - rate of swelling (UA/min) ; VWE – viscosity water extract (centistokes, cSt); WSP -water soluble pentosans (%); WA - water absorption (%); DF - dough formation time (minute); DST - dough stability (minute); DS - degree of softening (F.U.); VV - Valorimetric value (%), FQN -Farinograph quality number (mm).

a–f- mean in same column with the same subscripts are not statistically significantly different ($P<0.05$).

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Table 2. Summary statistic quality characteristics whole meal rye flour

Variable	Minimum	Maximum	Mean values	Std. deviation	Coefficient variation, %
PC, %	9,85	11,08	10,39	0,379	3.6
FN, sec	149,50	197,50	176,10	15,659	8.9
APV, au	455,00	750,00	614,40	99,332	16.2
TSG,°C	53,10	55,35	54,10	0,621	1.1
TPV, °C	69,60	73,05	71,27	1,170	1.6
GT, min	10,40	12,70	11,44	0,662	5.8
IS, au	375,00	610,00	497,25	68,032	13.7
MS, au	560,00	855,00	701,50	93,044	13.3
TS, min	18,50	29,00	22,50	2,828	12.6
RS, au/ min	5,70	14,60	10,03	3,259	32.5
VWE, cst	16,32	42,78	28,57	8,185	28.6
WSP, %	1,52	1,75	1,67	0,096	5.8
WA, %	63,70	65,75	64,39	0,614	1.0
DF, min	2,0	2,5	2,26	0,193	8.5
DST, min	1,7	4,8	2,50	1,037	41.4
DS, fu	84,50	106,00	91,00	7,742	8.5
VV, %	38,50	44,00	41,95	2,047	4.9
FQN, mm	30,50	60,50	38,45	9,998	26.0

PC - Protein content (%); FN- Falling number (sec); APV-Amylograph peak viscosity (amylograph units, AU); TSG - temperature of start gelatinization (°C) ; TPV -temperature at peak viscosity (°C); GT - gelatinization time (minute); IS - initial swelling at 30°C (AU), MS – maximum swelling after holding at 30°C for 30 min (AU); TS – time of swelling (measure on swelling curve) (minute); RS - rate of swelling (UA/min); VWE – viscosity water extract (centistokes, cSt); WSP -water soluble pentosans (%); WA - water absorption (%); DF - dough formation time (minute); DST - dough stability (minute); DS - degree of softening (F.U.); VV - Valorimetric value (%), FQN -Farinograph quality number (mm).

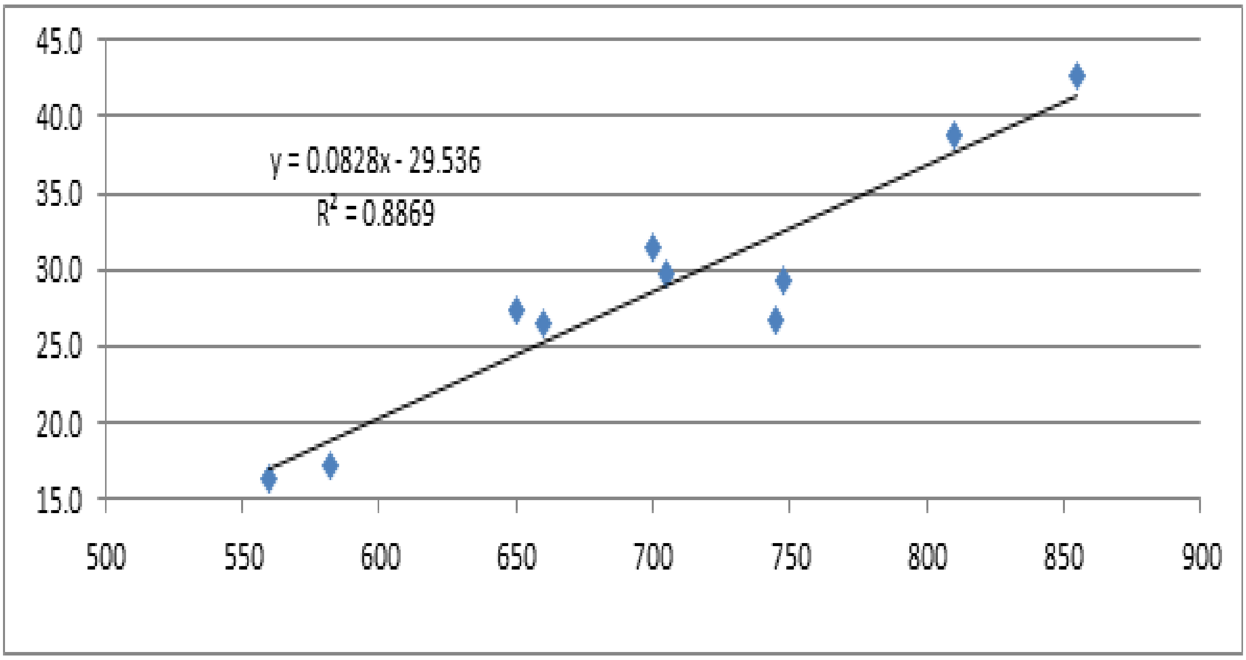

Fig1. The relationship between the viscosity of water extract and the swelling test (MS)

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Table 3: Correlation matrix of Baking Quality Parameters and Grain Characteristics of Whole Meal Rye

	PC	FN	APV	TSG	TPV	GT	IS	MS	TS	RS	VWE	WSP	WA	DF	DST	DS	VV	FQN
PC	1,00	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
FN	-0,50	1,00																
APV	-0,18	**0,84**	1,00															
TSG	-0,17	0,50	0,28	1,00														
TPV	-0,28	**0,91**	**0,81**	0,53	1,00													
GT	-0,22	**0,77**	**0,78**	0,00	**0,85**	1,00												
IS	0,00	0,55	0,55	0,13	0,42	0,42	**1,00**											
MS	-0,09	**0,85**	**0,90**	0,30	**0,80**	**0,76**	**0,76**	1,00										
TS	0,08	-0,24	0,03	0,12	-0,07	-0,16	-0,62	-0,30	1,00									
RS	0,17	**0,68**	**0,80**	0,20	**0,83**	**0,86**	0,55	**0,85**	-0,17	1,00								
VWE	-0,09	**0,82**	**0,90**	0,18	**0,72**	**0,74**	**0,66**	**0,94**	-0,29	**0,77**	1,00							
WSP	0,25	0,29	0,25	0,49	0,24	-0,03	**0,66**	0,37	-0,44	0,28	0,34	1,00						
WA	0,33	0,24	0,38	0,21	0,50	0,46	0,40	0,40	0,11	**0,63**	0,18	0,30	1,00					
DF	0,38	0,32	0,38	-0,14	0,37	0,53	0,25	0,53	-0,36	0,60	**0,66**	0,10	0,07	1,00				
DST	**-0,69**	0,38	0,12	0,24	0,06	-0,07	0,26	0,09	-0,40	-0,22	0,18	0,32	-0,53	-0,30	1,00			
DS	0,17	-0,40	-0,05	-0,10	-0,53	-0,56	-0,17	-0,20	0,46	-0,41	-0,15	-0,13	-0,31	-0,34	-0,02	1,00		
VV	-0,24	0,28	-0,19	0,12	0,33	0,31	0,08	0,06	-0,56	0,15	0,01	0,03	0,00	0,30	0,11	**-0,90**	1,00	
FQN	-0,60	0,35	0,14	0,19	0,03	-0,08	0,25	0,08	-0,38	-0,23	0,22	0,38	-0,55	-0,21	**0,98**	0,00	0,07	1,00

Note. Critical Values of the Coefficient of Rank Correlation r=0,63, is given for n = 10

CONCLUSION

In this study, we provided the evaluation of 10 Russian winter rye cultivars on 18 indicators of baking and rheological properties using known devices (Amylograph Brabender, Farinograph, Hagberg-Perten Falling Number) in lab. Along with well-known techniques was showed the possibility of using Amylograph Brabender to determine the viscosity at a temperature of 30°C. Swelling curve characteristics, viscosity water extract, content water soluble pentosans and protein were assessed. Differences of winter rye varieties and relationships between obtained values were discussed.

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Conflict of Interest

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

REFERENCES

[1] Schlegel Rolf HJ. Rye: genetics, breeding, and cultivation. Crc Press. 2013: 344
[2] FAOSTAT, 2016. Production. Crops. / Food and Agriculture Organization of the United Nations. http://faostat3.fao.org/browse/Q/QC/E.
[3] Federal State Statistics Service (Rosstat). http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/en
[4] Andersson R, Fransson G, Tietjen M, Aman P. Content and molecular weight distribution of dietary fiber components in whole-grain rye flour and bread. J of Agricultural and Food Chemistry, 2009, 57(5): 2004–2008.
[5] Jonsson K, Andersson R, Knudsen KEB, Hallmans G, Hanhineva K, Katina K, Lærke HN Rye and health-Where do we stand and where do we go? Trends in Food Science & Technology. 2018: 78–87.
[6] Hansen HB, Andreasen M, Nielsen M, Larsen L, Knudsen BK, Meyer A, Christensen L. Changes in dietary fibre, phenolic acids and activity of endogenous enzymes during rye bread-making J European Food Research and Technology. 2002; 214(1): 33-42.
[7] Izydorczyk MS, Biliaderis CG, Bushuk W. Physical properties of water-soluble pentosans from different wheat varieties. Cereal Chem.1991; 68(2):145-150.
[8] Biliaderis CG, Izydorczyk MS, Rattan O. Effect of arabinoxylans on bread-making quality of wheat flours JFood Chemistry.1995;53(2):165-171.
[9] Hansen H.B. et al. Grain characteristics, chemical composition, and functional properties of rye (Secale cereale L.) as influenced by genotype and harvest year J of agricultural and food chemistry. 2004;52(8):2282-2291.
[10] Weipert D Processing performance of rye as compared to wheat. Cereal Food World 1997; 42(8):706–712.
[11] Courtin CM, Delcour JA. Arabinoxylans and endoxylanases in wheat flour bread making. J Cereal Sci 2002;35:225–243
[12] Bastos R, Coelho E, Coimbra MA Arabinoxylans from cereal by-products: Insights into structural features, recovery, and applications. Sustainable Recovery and Reutilization of Cereal Processing By-Products. 2018:227-251.
[13] DIN EN ISO 3093 Wheat, rye and their flours, durum wheat and durum wheat semolina − determination of the falling number according to Hagberg-Perten (ISO 3093:2009). http://www.nal. din.de. Accessed 30 Oct 2016
[14] Drews E, Seibel W. Bread baking around the world. In Rye, Production, Chemistry and Technology; Bushuk W, Ed.; American Association of Cereal Chemists: St. Paul, MN, 1976.
[15] Bushuk W et al. Rye: production, chemistry and technology. American Association of Cereal Chemists, 2001. Ed. 2., St. Paul Minnesota.
[16] Stępniewska S, Słowik E, Cacak-Pietrzak G, Romankiewicz D, Szafrańska A, Dziki D. Prediction of rye flour baking quality based on parameters of swelling curve. European Food Research and Technology. 2018; 244 (6):989-997.

[17] Autio K, Flander L, Heinonen R, Kinnunen A Comparison of small and large deformation measurements of whole meal rye dough. J Cereal Chem 1999;76(6):912–914
[18] Salmenkallio-Marttila M, Hovinen S Enzyme activities, dietary fiber components and rheological properties of wholemeal flours from rye cultivars grown in Finland. J Sci Food Agric 2005;85:1350–1356
[19] Kim MY, Freund W, Chun SS. Determining the Water Absorption and Rheological Properties of Rye Dough Made Using the Planetary Mixer P 600 JFood Science and Biotechnology. 2009; 18(2):456-462.
[20] Hashimoto S, Shogren MD, Pomeranz Y. Cereal pentosans: their estimation and significance. I. Pentosans in wheat and milled wheat products. J Cereal Chem., 1987, 64(1): 30-34.
[21] Delcour JA, Vanhamel S, De Geest C. Physico-chemical and functional properties of rye nonstarch polysaccharides. I. Colorimetric analysis of pentosans and their relative monosaccharide compositions in fractionated (milled) rye products. JCereal Chem., 1989, 66(2): 107-111.
[22] Boros D, Marquardt RR, Slominski BA, Guenter W. Extract viscosity as an indirect assay for water-soluble pentosans content in rye. JCereal Chem., 1993, 70: 575-580.
[23] Ponomareva ML, Ponomarev SN, Tagirov MSh, Gilmullina LF, Mannapova GS. Pentosan content genotypic variability in winter rye grain Sel'skokhozyaistvennaya biologiya [Agricultural Biology], 2017;52(5):1041-1048.
[24] Bruemmer JM. Rye and its baking behaviour. Cereal Technol 2005;59:95–106.
[25] Weipert D. Fundamentals of Rheology and Spectrometry. In: Future of Flour – A Compendium of Flour Improvement;2006:117- 146.
[26] Callejo MJ, Bujeda C, Rodriguez G, Chaya C Alveoconsistograph evaluation of rheological properties of rye doughs. Span J Agric Res 2009;7(3):638–644.
[27] Brümmer J-M. Rye Flour. Future of flour: a compendium of flour improvement. Germany: Mühlenchemie.2006:179-191.
[28] Laidig F, Piepho HP, Rentel D, Drobek T, Meyer U, Huesken Breeding progress, variation, and correlation of grain and quality traits in winter rye hybrid and population varieties and national on-farm progress in Germany over 26 years JTheoretical and Applied Genetics. 2017;130(5): 981-998.
[29] Poutanen K, Katina K, Heiniö RL Rye. In: Zhou W (ed) Bakery products science and technology, 2nd edn. Wiley-Blackwell, Hoboken, 2014:75–87.
[30] Cyran MR, Ceglinska A. Genetic variation in the extract viscosity of rye (Secale cereale L.) bread made from endosperm and wholemeal flour: Impact of high-molecular-weight arabinoxylan, starch and protein. J. Sci. Food Agr., 2011;91(3): 469-479.
[31] Kulevatova TB, Bebyakin VM, Andreyeva LV, Osipova SV. Systematic aspects of winter rye testing for grain quality by physical properties of water shrot suspension JAchievements of Science and Technology of AICis.2010;5:27-29(in Russ.).
[32] Goncharenko AA, Timoshchenko AS, Berkutova NS. Viscosity of grain water extract in winter rye as universal parameter during breeding on principal use. Sel'skokhozyaistvennaya biologiya [Agricultural Biology], 2007; 3: 44-49 (in Russ.).