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Influence of post-harvest maturation on the amylolytic activity of wheat grain and the properties of bread

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Abstract. The aim of this study was to determine the quantitative and qualitative changes in the starch complex and the amylolytic activity of wheat grain during its post-harvest maturity. This information is necessary for the proper determination of the level of quality requirements for wheat grain purchased immediately after harvest.

The common wheat cultivars: Kandela, Bamberka and KWS Ozon were tested during this study. Because of the variability of weather conditions, three wheat cultivars were tested (two winter wheat cultivars and one spring wheat cultivar) from two consecutive crop years. Immediately after grain harvest and during the next 12 weeks in two-weeks intervals the falling number, amylograph properties, rheological properties of dough and laboratory baking test was performed.

Tested wheat cultivars were characterized by low amylolytic activity. Changes of the baking value of tested wheat cultivars during their post-harvest maturation were dependent on wheat cultivar and harvest year. Wheat from the 2016 harvest was characterized by significantly lower amylolytic activity compared to grain from 2015 harvest. Amylolytic activity decreased during post-harvest maturation, i.e. the falling number increased as well as the dough torque in point C4 and C5 of mixolab curve. There was also an increase in the volume of bread compared to the evaluation of the samples tested immediately after harvest. The highest values were obtained in the 4th week after harvest. The changes were dependent on wheat cultivar. However, in the case of the assessment of the rheological characteristics of the dough (except point C4) they were not statistically significant.

Keywords: alpha-amylase, bread, mixolab, technological value, wheat

INTRODUCTION

The technological value of wheat grain can be assessed in many aspects. Its suitability for use as a raw material for flour production for baking purposes is very well determined by rheological characteristics, evaluated using apparatus such as farinograph, alveograph or mixolab (Codina et al., 2010). Such instruments are increasingly used in domestic grain processing companies (mainly mills) and companies using flour as a raw material for further processing (e.g., bakeries and pasta factories).

Wheat grain purchase is more and more often conducted not only based on requirements specified for traditional quality characteristics but also in terms of dough rheological characteristics. The purchase of grain is executed by grain trading companies both in the period directly after harvest (most often purchase directly from grain producers) and in a later period, i.e., after completion of post-harvest maturation (trading in grain which has already been stored and undergone post-harvest maturation) (Rothkaehl et al., 1997).

For milling companies obtaining grain from the same region each year, the standard practice is to gradually increase the proportion of grain from new-harvest in relation to grain from the previous year's harvest started from 5 to 10% (Fowler, 2014). This allows the post-harvest maturation time of the grain to be extended as much as possible until the mill is required to use 100% new-harvest grain. The time also allows the production technology of bakeries to adapt to changes in the quality of the flour supplied. In recent years, it has been observed that more and more grain is diverted to milling immediately after harvest. This creates new challenges for the milling and baking industry, as flour from grain that has not undergone post-harvest maturation is characterized by a lower baking value (Wang, Flores, 1999; Dirndorfer, 2012). Freshly harvested wheat grain has a lower milling and baking value (Szafrańska, Stępniewska, 2021).

Freshly harvested grain exhibits a significant intensity of vital processes that affect its quality and durability during storage (Janić Hajnal et al., 2014). The rate of intensity of life processes depends first of all on the degree of maturity. As the maturation process proceeds, the water content

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of the grain decreases, and the intensity of life processes decreases. During post-harvest maturation, quantitative and qualitative modifications of the protein and starch complex, and the state of enzymatic activity occur, ultimately improving grain quality and flour's baking value (Sypuła, Dadrzyńska, 2008; Mense, Faubion, 2017). A characteristic feature of the maturation process is the predominance of the synthesis process over the decomposition and hydrolysis of chemical compounds. Under typical storage conditions, the maturation process occurs within 10–12 weeks at a temperature of 15–45 °C and grain moisture below 14% (Tipples, 1995; Sypuła, Dadrzyńska, 2008).

After several weeks of grain storage, the pericarp and seed coat is more easily separated from the grain endosperm, the flour extract increases, and the ash content decreases. Kuchciak and Czubaszek's (2015) results, who obtained higher total flour yields in industrially milled grain 8–10 weeks after harvest compared to the grain after 3–4 weeks, confirm the above. However, such trait varied according to the wheat cultivar. Flour from wheat grain milled a few weeks after harvest is characterized by higher water absorption, better dough mixing tolerance, more remarkable ability to retain gases in the dough, and higher loaf volume (Dirndorfer, 2012).

The work carried out by Rothkaehl et al. (1997) determined the level of post-harvest maturation changes in the values of basic qualitative parameters in terms of protein complex characteristics, such as gluten quantity, gluten weakening, Gluten Index, and Zeleny sedimentation index. Spring and winter wheat cultivars with different technological values and different states of enzymatic activity (the falling number for individual samples ranging from 130 to over 300 seconds) were included in this study. The obtained results indicated changes in numerical values of parameters such as gluten weakening and Zeleny sedimentation index, enabling the determination of different requirements for these quality characteristics for wheat grain purchased in the first 6 weeks after harvest and later. Also, Sypuła and Dadrzyńska (2008) point to a decrease in the amount and weakening of gluten and a reduction in the activity of amylolytic enzymes during 21 weeks of grain storage after harvest. Such information is of great practical significance, especially for companies purchasing grain directly from its producers ("straight from the field" grain) who do not have suitable conditions for its storage and in the years when low grain yields and poor quality grain are observed. Environmental conditions in the growing season and during grain harvest in our country, changing in particular years, are conducive to high variability of quality features of wheat grain harvested in Poland.

Wheat cultivars concerning their suitability for baking can be divided into three groups according to the COBORU classification (Drążkiewicz et al., 2020). Cultivars with excellent milling and baking value – the so-called elite cultivars (group E), cultivars with good quality features, the so-called quality cultivars (group A), and of medium quality, the so-called bread cultivars (group B). In Poland, two forms of wheat are produced – winter and spring. The winter form is characterized by higher yield than the spring one and has a better milling value of the grain. On the other hand, the spring form is characterized by a better baking value (Podolska, 2007). It is expected that due to the indicated differences, the tendency of changes in the milling and baking value during post-harvest maturation will vary depending on the technological group and form of wheat.

Variations of the essential quality parameters indicate that after the post-harvest maturation period, changes of dough rheological characteristics should also be expected. However, there are no literature data available to determine the extent to which quantitative values of particular dough rheological characteristics change in this period for parameters obtained with amylograph or mixolab. Such information is necessary for the proper determination of quality requirements for wheat grain purchased directly after harvest.

This study aimed to determine the changes in the amylolytic-starch complex of wheat grain during post-harvest maturation and their effect on the baking properties of flour defined, among other things, by assessing the rheological properties of dough and performing laboratory baking trials.

MATERIALS AND METHODS

The study included three wheat cultivars representing two technological groups: Kandela (spring wheat, group A), Bamberka (winter wheat, group A), and KWS Ozon (winter wheat, group B). Wheat grain was obtained from the experimental field (collection of cultivars) of the Mazovian Agricultural Advisory Centre in Warsaw, Poświętne Branch. A one-factor experiment was carried out using the long strip method.

Winter wheat was grown on a soil classified as bonitation class II. For the grain harvested in 2015, the forecrop comprised potatoes, and for the grain harvested in 2016, winter oilseed rape. Fertilisation rates converted to pure nutrient equivalents (kg ha^{-1}) were applied in the following combinations: in 2015: pre-plant: N – 21.5, P – 55, K – 100, in 2016. N – 19.5, P – 50, K – 100; top dressing: N – 70 in both years. The sowing rate of winter wheat cultivars was to 380 germinable seeds m^{-2}. Weed control was applied during the growing period (Lintur 70 WG at 180 g ha^{-1} and Komplet 560 SC at 0.5 l ha^{-1}). Wheat grain was harvested on 28 July 2015 and 7 August 2016.

Spring wheat was grown on a soil classified as bonitation class IIIa (in 2015) and class II (in 2016). The forecrop was maize. The sowing rate of spring wheat was 450 germinable seeds m^{-2}. Fertilization converted to nutrient equivalents (kg ha^{-1}) was applied in the following combinations: in 2015: pre-sowing N – 79, P – 49, K – 131; in 2016: pre-sowing N – 79.6, P – 50, K – 120.

Immediately after grain harvest, and then at two-week intervals for twelve weeks, the following quality parameters characterizing the activity of amylolytic enzymes were determined: falling number of grain and obtained flour (according to PN-EN ISO 3093:2010), amylograph properties (according to PN-ISO 7973:2001), rheological properties of dough by mixolab (according to ISO 17718:2013).

Laboratory grain milling was performed using a Chopin Dubois mill (CD) according to the milling procedure in PN-EN ISO 27971:2015. Wheat grain samples weighing 3 kg were moistened to 16% water content 24±1 h before milling.

Laboratory baking test was carried out by preparing the dough using the direct Berlin method with dough mixing in a KitchenAid Classic mixer (1st gear mixing time 2 minutes; 2nd gear – mixing time 4 minutes). The dough was prepared from 1000 g of flour (14% moisture), baker's yeast, and salt in the amount of 3% and 1%, respectively, concerning the flour and water in the amount needed to obtain a dough with the consistency of 350 FU. The dough was fermented for 60 minutes with a folding after 30 minutes, then divided into pieces, which after rounding on a maturograph rounder, were placed in the baking tins. The final rise of the dough in the baking tins lasted from 43 to 60 minutes. Baking was carried out in a Nabertherm laboratory electric batch oven at 230 °C for 30 minutes. The bread loaves obtained were evaluated 20±4 hours after baking. The volume was determined according to PN-A-74108, and the result was converted to 100 g flour. Bread crumb colour was evaluated using Minolta Chroma Meter Cr-310. The bread crumb colour results were reported in terms of 3-dimensional colour values based on *L**, *a**, *b**.

Statistical analysis was performed using the Statistica 13 package from StatSoft. To determine the influence of factors such as wheat cultivar, year of the grain harvest, and a period after harvest, in which laboratory milling was performed to obtain flour for further research, on obtained quality features of grain, flour, dough, and bread, the method of three-factor analysis of variance was used. The t-Tukey test was used to compare the mean values. All statistical calculations were carried out at a significance level of $\alpha = 0.05$ and $\alpha = 0.01$. Relations between selected quality parameters were tested with Pearson linear correlation coefficient ($\alpha = 0.05$).

A principal component analysis (PCA) of the results was carried out to determine to what extent the grain, flour and dough samples differed and which of the parameters had the most significant influence on this.

RESULTS AND DISCUSSION

The activity of amylolytic enzymes in flour is derived from the characteristics of the grain from which it is produced. It also depends on the cultivar of wheat, an enzymatic activity state of grain, treatments to which grain was subjected before milling, or storage conditions of flour af-

Table 1. MS values variability components in the analysis of variance (ANOVA) quality parameters of the starch-amylolytic complex of wheat grain, flour and bread.

Factor/Parameter		Wheat cultivar (A)	Harvest year (B)	Week after harvest (C)	Interaction A×B	A×C	B×C	A×B×C
Falling number of grain		2539**	2101**	979**	1085**	82	132.4	136
Falling number of flour		2853**	2584**	1772**	1564**	107	382*	71.4
Amylograph parameters								
Maximum viscosity		86280**	634678**	4719	221776**	3165	5419	2952
T_i		8.7**	2.8*	0.5	1.02	0.2	0.8	0.3
T_f		22.0**	10.0**	0.1	3.5**	0.2	0.3	0.2
Mixolab parameters								
C3		0.0051**	0.043**	0.0005	0.2020**	0.0002	0.0006	0.0004
C4		0.1907**	0.3185**	0.0025*	0.0421**	0.0024*	0.0010	0.0004
C5		0.629**	1.495**	0.024	0.233**	0.007	0.005	0.010
β		0.0040*	0.0027*	0.0012	0.0065*	0.0013	0.0010	0.0006
γ		0.019	0.003	0.004	0.006	0.005	0.005	0.005
Bread qualitative features								
Bread yield		84.9**	73.6**	10.3**	4.8**	1.2	2.6**	0.4
Volume from 100 g of flour		729	2050	686	159	331	1654	857
Bread color	*L*	14.6**	2.6	1.0	10.2*	0.4	0.2	1.5
	a	0.9480**	2.3665**	0.9481*	0.0001	0.0123	0.0146	0.0245
	b	18.04**	0.80**	0.03	0.75**	0.04	0.12	0.04

*significant at α=0.05; **significant at α=0.01

Abbreviation: T_i, T_f – temperature of gelatinization – initial and final, respectively ter milling. The activity level of amylolytic enzymes in flour greatly influences the quality of bread obtained from it (Mangan et al., 2016).

The statistical analysis showed a significant effect of wheat cultivar, year of the grain harvest, and the period after grain harvest on the value of the falling number of grain and flour obtained from it (Table 1). It was found that the grain of the studied wheat cultivars was characterized by the low activity of amylolytic enzymes, as evidenced by a falling number above 300 s (Rachoń et al., 2016). The

Table 2. Results of starch properties of tested wheat cultivars during post harvest maturation.

Factor	Falling number		Maximum viscosity [AU]	Temperature of gelatinisation	
	grain [s]	flour [s]		initial [°C]	final [°C]
Range	336–428	346–462	720–1540	55.5–59.5	89.5–93.5
Wheat cultivar					
Bamberka	394 a*	422 a*	1088 b*	57.8 b*	92.2 a*
KWS Ozon	396 a*	412 b*	1175 a*	57.6 b*	92.7 a*
Kandela	370 b*	392 c*	1258 a*	59.2 a*	90.1 b*
Harvest year					
2015	379 b*	402 b*	1041 b*	57.9 b	91.1 b*
2016	394 a*	416 a*	1307 a*	58.5 a	92.2 a*
Week after harvest					
0	368 d*	378 c*	1190 a	57.7 a	91.8 a
2	374 d*	405 b*	1145 a	58.1 a	91.8 a
4	388 c*	414 a*	1193 a	58.2 a	91.8 a
6	393 bc*	419 a*	1135 a	58.4 a	91.6 a
8	396 ab*	418 a*	1205 a	58.3 a	91.4 a
12	400 a*	417 a*	1173 a	58.4 a	91.7 a

a, b, c – homogenous groups obtained by the t-Tukey's test at α=0.05 and α=0.01*, respectively.

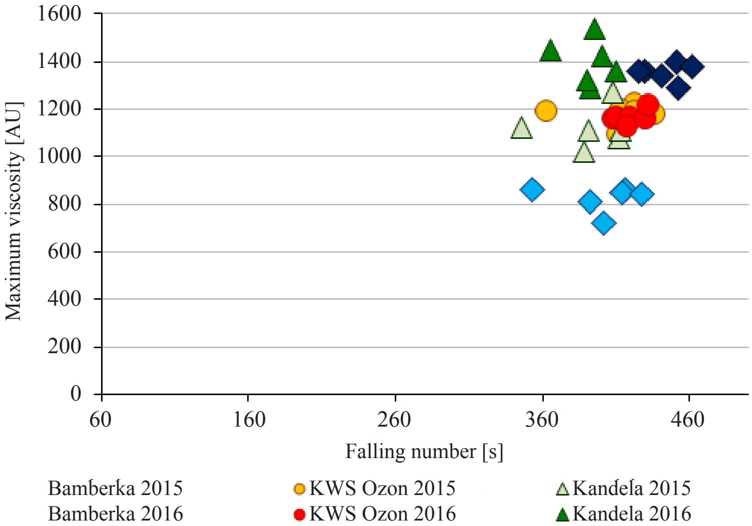


Figure 1. Falling number and maximum viscosity of flour of tested wheat cultivars from 2015 and 2016 harvest year.

wheat grain of the Kandela cultivar was characterized by a significantly lower falling number (mean: 370 s) (Table 2) compared to the wheat grain of the KWS Ozon and Bamberka cultivars (mean: 396 and 394 s, respectively) (Table 2). However, from the technological point of view, these differences were not significant. It was observed that flour obtained from grains of wheat cv. Bamberka, in spite of the highest falling number value, was simultaneously characterized by the lowest maximum viscosity of flour gel among the tested wheat cultivars (on average 1088 AU) (Table 2). The opposite situation was observed in the case of the Kandela cultivar. The high flour falling numbers of all tested wheat cultivars at a level close to 400 s and peak viscosity of flour gel above 1000 AU allow us to conclude that bread obtained from the tested flour may characterized by a low volume, spherical shape, and crumbly crumb (Rothkaehl et al., 1997; Szafrańska, 2014). For the grain and flour, the research material from the 2016 harvest was characterized by a higher falling number than that from the 2015 harvest.

It was found that the falling number of grain increased significantly during 12 weeks of grain maturation after harvest (Table 2), which is consistent with the results obtained by Elmann (2011). The falling number of flour significantly increased up to 4th week after harvest, then its values were similar, 417–419 s. In the case of flour from the wheat grain of the cultivars KWS Ozon and Kandela, the falling number values in individual weeks after grain harvest were similar in both years of the study. However, in the case of the Bamberka cultivar, higher falling number values both determined in the grain and the obtained flour (on average by 37 and 43 s, respectively) were found for samples from the 2016 harvest.

Flour obtained from spring wheat of the Kandela cultivar was characterized by significantly the highest initial temperature of starch gelatinization and the lowest final temperature of starch gelatinization compared to the other two wheat cultivars. The results obtained in the assessment of the amylographic characteristics of the flour were in the range typical for wheat flour type 550 (Szafrańska, 2014). No statistically significant differentiation was found in the maximum viscosity and the initial and final temperature of starch gelatinization during grain maturation after harvest (Table 1, Table 2). On the other hand, these parameters were differentiated between the grain harvest years.

The maximum amylograph viscosity of flour obtained from wheat grains of the Bamberka and Kandela cultivars from the 2016 harvest was approximately 530 AU and 280 AU higher, respectively than from the 2015 harvest (Figure 1). It should be noted that this is a significant variation, taking into account the slight difference in falling number for Bamberka (43 s) and no difference for Kandela. Such results may have been influenced by the different accumulation of α and β amylase enzymes during plant vegetation. Despite the slightly higher values of the falling number of the wheat grain of the KWS Ozon cultivar from the 2016 harvest (by 8 s on average), the maximum viscosities were lower by 12 AU on average. The year of grain harvest also significantly affected the final temperature of starch gelatinization. Significantly higher temperatures were found for samples from the 2016 harvest (92.2 ^{o}C on average; Table 2). Wheat grains of the Bamberka cultivar from the 2016 harvest were characterized by a significantly lower alpha-amylase activity, resulting in a higher value of the final temperature of starch gelatinization (by 2.1 ^{o}C on average) in comparison to samples from the 2015 harvest. In the case of the cultivar KWS Ozon, the final temperature of starch gelatinization was higher on average by 1.2 ^{o}C, while in the case of the cultivar Kandela it was lower on average by only 0.1 ^{o}C.

The value of the flour starch-amylolytic complex was also evaluated based on dough rheological properties using a mixolab, assessing the quality of protein and starch in a single test. The starch properties were determined according to the dough torque values at points C3, C4, and C5 of the graph, the initial starch gelatinization temperature D2 and the final starch gelatinization temperature D3, and the β and γ slopes (Banu et al., 2011; Wiwart et al., 2017).

The β and γ slopes describe variations in dough consistency as a results of increasing or decreasing its temperature during the determination (Koksel et al., 2009). The β slope characterizing the increase in dough resistance due to swelling of starch granules as a result of increasing the temperature from 30 to 90 ^{o}C during analyse (Stoenescu et al., 2010; Banu et al., 2011), ranged from 0.37 to 0.55 Nm min^{-1} (Table 3). The cultivar Bamberka was characterized by a significantly higher starch gelatinization rate than the cultivar KWS Ozon (β slope: 0.498 and 0.479 Nm min^{-1}, respectively) (Table 3). The β slope slightly increased during the grain maturation, but the changes were not statistically significant (Table 3). The values of slope γ, characterizing the speed of enzymatic starch degradation, ranged from -0.42 to -0.01 Nm min^{-1}. No significant differentiation of the index between wheat cultivars, grain harvest years, and post-harvest grain maturation period were observed.

The dough torque at point C3 of the graph depends on the value of the β slope, i.e., the rate of the starch gelatinization process. A high value of dough torque at point C3 of the graph indicates high dough elasticity and is characteristic of flour fractions obtained from the central parts of the endosperm (Banu et al., 2011). The dough torque measured at point C4 of the graph, according to Banu et al. (2011), reflects the stability of the starch gel to heating. The dough torque at point C5 of the graph provides information on starch retrogradation (Haros et al., 2006; Rachoń et al., 2016). The flour of the tested wheat cultivars varied in dough torque at the indicated characteristic points of the graph (Table 3). The significantly lowest dough torque at points C3, C4, and C5, were characterized by doughs from flour obtained from Bamberka cultivar, while the significantly highest dough torque at points C3 and C5 was observed in doughs from flour of the Kandela cultivar. Flour samples obtained from the milling of Bamberka cultivar were simultaneously characterized by the lowest maximum flour gel viscosity, despite the highest falling number values. A significant effect of grain harvest year was also noted on the dough torque value at points C3, C4, and C5 of the graph (Table 1, Table 3). Flour from grains from the 2016 harvest, with lower alpha-amylase activity, had higher dough torque values at points C3, C4, and C5 of the graph (Table 3). In the case of spring wheat cultivar Kandela, which had the lowest average falling number, the highest torque values in points C3, C4 and C5 were found. At the same time, it was observed that, despite the slightest difference in falling number values between grain harvest years of the Kandela cultivar, the differences

Table 3. Results of the evaluation of flour dough from tested wheat cultivars by mixolab characterizing the starch properties.

Factor	C3 [Nm]	C4 [Nm]	C5 [Nm]	β [Nm/min]	γ [Nm/min]
Range	1.92–2.15	1.31–1.95	2.47–3.749	0.37–0.55	-0.42 – -0.01
Wheat cultivar					
Bamberka	1.98 c*	1.45 b*	2.68 c*	0.498 a	-0.072 a
KWS Ozon	2.05 b*	1.61 a*	2.96 b*	0.468 b	-0.091 a
Kandela	2.10 a*	1.77 a*	3.38 a*	0.479 ab	-0.051 a
Harvest year					
2015	2.03 b*	1.54 b*	2.88 b*	0.492 a	-0.054 a
2016	2.06 a*	1.68 a*	3.14 a*	0.471 b	-0.089 a
Week after harvest					
0	2.03 a	1.57 b	2.95 a	0.464 a	-0.047 a
2	2.04 a	1.63 a	2.96 a	0.470 a	-0.120 a
4	2.04 a	1.60 ab	3.02 a	0.488 a	-0.057 a
6	2.04 a	1.61 ab	3.01 a	0.490 a	-0.066 a
8	2.05 a	1.62 a	2.99 a	0.480 a	-0.072 a
12	2.05 a	1.61 ab	3.12 a	0.499 a	-0.067 a

a, b, c – homogenous groups obtained by the t-Tukey's test at α = 0.05 and α = 0.01*, respectively.

in dough torque at points C3, C4, and C5 were the highest among the cultivars tested and amounted to respectively: 0.07, 0.27 and 0.52 Nm. Such variation in results may be influenced by the spring form of wheat and different weather conditions during plant vegetation in both years.

The present study concluded that the dough torque at points C3, C4, and C5 of the graph increased slightly with time after grain harvest; however, these variations were statistically significant only for the dough resistance at point C4 (Table 1, Table 3).

The literature data on the relationship between the falling number and the dough torque at points C3, C4, and C5 of the mixolab graph is inconsistent. The results of the studies by Kahraman et al. (2008) and Ozturk et al. (2008), as well as the results obtained in the present study, showed that there was no significant interaction between falling number and dough torque measured at the characteristic points C3, C4, and C5 of the graph. The studies of Peňa et al. (2007), Codina et al. (2010), and Capouchová et al. (2012), it was found that with an increase in the falling number of flour, the dough torque at the points of the graph describing the properties of the starch contained in the flour also increased. Banu et al. (2011) and Rachoń et al. (2016) obtained positive correlation coefficients of falling number with dough torque only at points C4 and C5. Negative correlations were shown for falling number and dough torque at point C3. On the other hand, Dhaka et al. (2012) showed negative correlations between falling number and dough torque measured at all points of the graph, i.e., C2, C3, C4, and C5.

The activity of amylolytic enzymes characterized by the maximum viscosity of the suspension in the studies by Peňa et al. (2007) and Codina et al. (2010), as well as in the present work, showed a stronger correlation with the dough torque at points C3, C4 and C5 (correlation coefficients r = 0.614, r = 0.689 and r = 0.700, respectively) than with the falling number of grain and flour ($r < -0.22$). The reason for the differences should be found in the determination method, which in the amylographic and mixolab assessment is based on gradual heating of the test sample, close to the conditions prevailing inside the dough piece during baking. In evaluating the falling number, on the other hand, there is a more rapid inactivation of enzymes under the influence of high temperature (Rothkaehl, 2003).

The loaves of bread obtained in laboratory baking test were characterized by a proper external appearance with the shape of a well-risen loaf and appropriate crust colour, as well as relatively uniform crumb porosity (Figure 2). Sensory attributes such as taste and smell were characteristic of this kind of bread.

The bread yield ranged from 133 to 146% (Table 4). Its differentiation was influenced by the cultivar of wheat, the year of grain harvest, and the period of maturation after harvesting (Table 1, Table 4). The bread made from flour of the Kandela cultivar and bread made from flour from the 2016 grain harvest demonstrated significantly lower bread yields.

The bread volume calculated to 100 g of flour, the primary measure of its quality, ranged from 295 to 431 cm^3. There was no significant differentiation of the discussed bread quality parameter depending on the wheat cultivar, year of the grain harvest, and a week after grain harvest (Table 1, Table 4). Similar to Dirndorfer's (2012) study, bread volume was increased during the post-harvest maturation of grain compared to the evaluation of the tested grain samples immediately after harvest. The highest values were obtained in the 4th week after harvest. However, the observed differences were statistically insignificant. On the other hand, in the study by Elmann (2011), bread obtained from grain flour after six months of storage was characterized by a smaller volume than that from newly-harvested grain directly .

Bamberka KWS Ozon Kandela

Figure 2. Bread obtained from tested wheat cultivars.

Table 4. Results of laboratory baking from tested wheat cultivars flour.

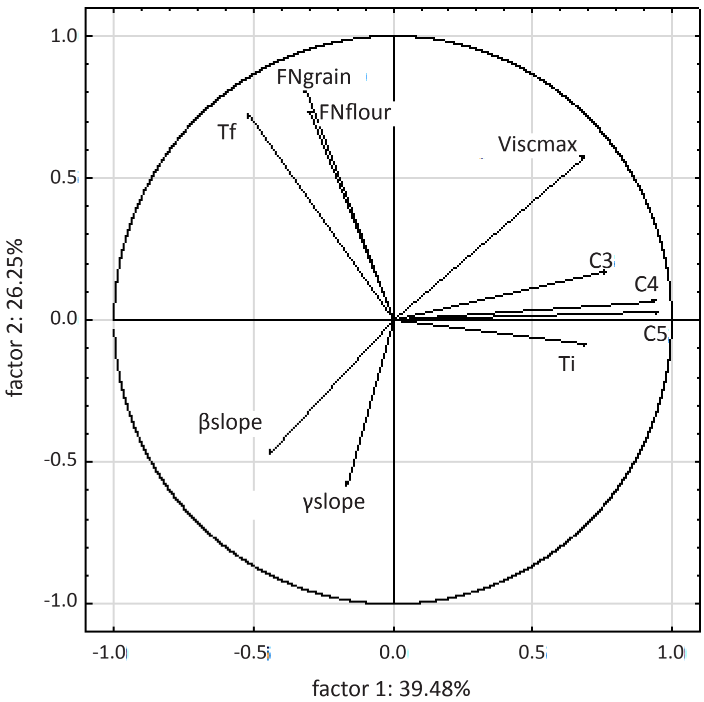
Factor	Bread yield [%]	Volume from 100 g of flour [cm^3]	Bread crumb color		
			L	*a*	*b*
Range	133–146	295–431	71.0–81.9	-2.10 – -1.73	19.74–25.31
		Wheat cultivar			
Bamberka	141 a*	383 a	76.4 a*	-1.02 b*	20.92 c*
KWS Ozon	141 a*	357 a	74.3 b*	-0.96 a*	22.74 b*
Kandela	137 b*	367 a	74.8 b*	-1.47 c*	23.25 a*
		Harvest year			
2015	141 a*	364 a	75.4 a	-0.89 a*	22.45 a*
2016	138 b*	372 a	74.9 a	-1.41 b*	21.04 b*
		Week after harvest			
0	138 b*	352 a	74.8 a	-1.23 a	22.23 a
2	138 b*	367 a	74.9 a	-1.23 a	22.28 a
4	140 a*	383 a	74.4 a	-1.20 ab	22.37 a
6	141 a*	373 a	75.4 a	-1.28 a	22.34 a
8	140 a*	376 a	75.4 a	-0.89 b	22.38 a
12	140 a*	363 a	74.8 a	-1.06 ab	22.22 a

a, b, c – homogenous groups obtained by the t-Tukey's test at α = 0.05 and α = 0.01*, respectively.

The tested bread was distinguished by the crumb *L* brightness ranging from 71 to 82. It was found that only the genetic factor had a significant effect on such parameter (Table 1, Table 4). It was proved that the crumb of bread made from flour obtained from Bamberka cultivar was characterized by the significantly highest brightness (mean 76.4) (Table 4) in comparison with bread crumb made from flour of KWS Ozon and Kandela cultivars (mean 74.3 and 74.8, respectively) (Table 4). The *a** values of the studied bread crumb showed negative values (from -2.10 to -1.73), indicating a high contribution of the green shade to the colour. Bread crumb from KWS Ozon grain had significantly less green cast to its colour than did the bread crumb from flour of the other wheat cultivars (Table 4). The post-harvest grain maturation period influenced the decrease of the share of the green hue in the crumb colour. The *b** values of the tested bread crumb took positive values, which indicates a large percentage of yellow shade in the crumb colour. To a statistically significant degree, the above parameter was influenced by the wheat cultivar and the harvest year (Table 1). The significantly lowest value of *b** value was characteristic for bread crumb made of flour obtained from Bamberka cultivar (mean 20.92) (Table 4), while the significantly highest value for bread crumb made of flour from Kandela cultivar (mean 23.25) (Table 4). Bread made of Bamberka cultivar was assessed the most favourably in terms of the crumb colour and structure (Figure 2).

A principal component analysis (PCA) was conducted to determine to what extent the tested wheat cultivars were differentiated in terms of the properties of the starch-amylolytic complex and which experimental factor had the most significant influence on this. The PCA analysis showed that the first two principal components (factor 1 and factor 2) explained a total of 65.73% of the preliminary results (Figure 3). The first main component (factor 1) explained 39.48% of the variability in the initial results. It was found that factor one was positively related to the mixolab parameters such as: dough torque at points C3, C4, C5 and amylograph parameters: initial temperature of starch gelatinization and maximum viscosity. Such parameters exerted the most significant negative influence on factor 1 as the final temperature of starch gelatinization determined by the amylograph test and the β-slope determined from the graph obtained with mixolab. The second principal component (factor 2) explained 26.25% of the variation in results. The most considerable contributions to factor 2 were the flour and grain falling number, the final temperature of starch gelatinization, and the maximum viscosity determined by the amylograph test.

Figure 4 shows the distribution of the tested wheat grain samples in the area of the first two factors. It shows that among the three factors of the experiment, the genetic factor had the most extensive influence on the properties of the starch-amylolytic system of the grain of the tested wheat cultivars. In Figure 4, wheat grain samples of the Kandela cultivar are located on the right side of the graph along the axis of the first factor, while grain samples of the other wheat cultivars are situated on the left side of the graph. The dough obtained from the flour of the Kandela cultivar compared to the one from the other tested cultivars grains were characterized by a relatively higher value of such parameters determined from the graph obtained by the mixolab as C3, C4, and C5 and a lower value of the β slope. Moreover, starch gel obtained from flour of Kandela were characterized by a higher initial temperature of gelatinization and a higher maximum viscosity, and a lower final temperature of starch gelatinization compared to suspensions obtained from flour of Bamberka and KWS



Abbreviation: FNgrain – falling number of wheat; FNflour – falling number of flour; Viscmax – maximum viscosity; βslope – slope beta; γslope – slope gamma; Ti – initial temperature of gelatinization; Tf – final temperature of gelatinization.

Figure 3. Loading plot of the first and second principal components on parameters characterized the properties of starch-amylolytic complex of tested wheat cultivars.

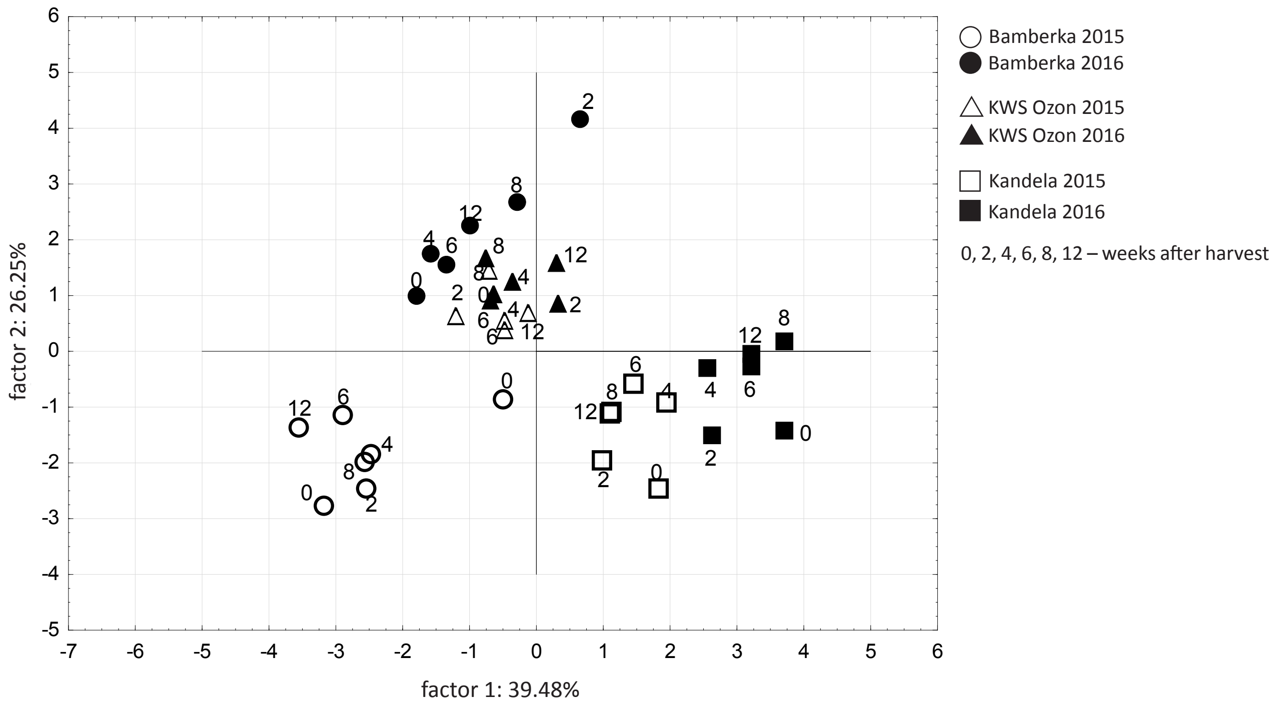


Figure 4. Loading plot of the first and second principal components of tested wheat cultivars on variables characterized the properties of starch-amylolytic complex of tested wheat cultivars.

Ozon cultivars. A significant effect of grain harvest year on the properties of the starch-amylolytic complex was found only for the cultivar Bamberka. In Figure 4, grain samples of the Bamberka cultivar from the 2015 harvest have negative values along the axis of the second factor, while those from the 2016 harvest take positive values along the axis of the second factor. Against this background, it can be concluded that both grain and flour of the Bamberka cultivar from the 2016 harvest were characterized by a higher falling number, and gels obtained from the flour were distinguished by a higher final starch gelatinization temperature and a higher maximum viscosity compared to samples from the 2015 harvest. Based on the analysis of Figures 3 and 4, it was also found that the dough made from grain flour of the Bamberka cultivar from the 2016 harvest had relatively lower values of the β and γ slope compared to the dough made from grain flour of this cultivar from the 2015 harvest.

CONCLUSIONS

1. The tested wheat cultivars from two harvested years were characterized by low amylolytic enzymes activity.
2. The grain harvest year had a significant effect on the quality parameters of the tested wheat cultivars. The wheat grain from the 2016 harvest was characterized by a significantly lower amylolytic enzyme activity compared to the grain from the 2015 harvest.
3. The activity of amylolytic enzymes determined by the falling number decreased during the post-harvest grain maturation period. However, no significant changes were found in the maximum viscosity determined by an amylograph.
4. During the post-harvest maturation period, there was a slight increase in dough torque at the characteristic points of the C3, C4, and C5 graph obtained with the mixolab, indicating a decrease in amylolytic enzyme activity. However, such modifications were not statistically significant (except for point C4) and varied within the wheat cultivar.
5. The bread obtained in laboratory baking test was characterized by a proper external appearance with the shape of a well-risen loaf and suitable crust colour and relatively uniform crumb porosity. The process of post-harvest maturation of grain positively influenced a slight increase in bread volume, but the changes were not statistically significant.
6. Milling companies purchasing wheat grain immediately after harvest should consider a change in the value of the falling number of grain during post-harvest maturation. On the other hand, the differences in the values of other parameters characterizing the properties of starch, determined by amylograph and mixolab, are within the reproducibility limits of the indicated methods of determination.

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