POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 40(4): 223–242, Y. 2025

DOI: 10.31648/pjns.10964

GRAIN, FLOUR AND DOUGH CHARACTERISTICS OF ORGANICALLY GROWN SPELT CULTIVARS IN RELATION TO BREAD PROPERTIES*

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Key words: organic spelt wheat, grain, flour, dough, bread properties, partial least square modelling.

Abstract

The aim of this study was to evaluate the selected physicochemical parameters of flours and rheological parameters of dough and quality parameters of breads of organically grown spelt cultivars, to evaluate the interrelationship between the analysis results and harvest year, and to describe the relationships between spelt flour quality parameters (explanatory variables, *X*) and its bread quality parameters (dependent variables, *Y*). The relationships were examined by partial least square regression (PLS-R) analysis. The PLS-R analysis was extended to PLS-path modelling (PLS-PM). Global goodness of fit for the first two PLS-R components, t_1 and t_2, were determined at $Q^2_{cum}= 0.127$, and it exceeded the threshold value of 0.0975. Two components were explained as 54.5% and 74.5% of variation in dependent and explanatory variables, respectively. Breads made from *cv. Oberkulmer Rotkorn* and *cv. Ostro* received the highest scores in terms of overall quality. The quality of spelt bread was mainly dependent on its grain parameters.

* This study was partially supported by a research grant from the State Committee for Scientific Research No. KBN 2 PO6R 031 27.

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Introduction

The annual consumption of cereal products in Poland has decreased steadily from around 115 kg per capita in the 1990s to around 70 kg per capita at present. Bread is the most widely consumed cereal product with an estimated 55% of the cereal product market, but its consumption has also decreased to approximately 35 kg per capita annually (SZAWARA-NOWAK 2013, Institute of Agricultural and Food Economics-Polish National Research Institute 2021). In recent years, domestic production of fresh bread has remained fairly stable at 1.4 million tons per year, whereas the production of confectionery goods and baked products with extended shelf-life continue to increase and their total production can be estimated at around 740 000 tons annually (Institute of Agricultural and Food Economics-Polish National Research Institute 2021).

Spelt (*Triticum aestivum* ssp. *spelta*) is predominantly grown in organic farms. The annual production of organically grown spelt is estimated at around 173 000 tons (IJHARS – Agricultural and Food Quality Inspection 2019). Spelt grain is processed into flour and is used in the production of various types of cereal products such as bread, crisp bread, pastries, pasta, groat, malt and soup and processed into animal feeds as well (WANIC et al. 2024, BOJŇANSKÁ and FRANČÁKOVÁ 2002, JURGA 2012, FRAKOLAKI et al. 2018).

In Poland, spelt flour is used in the production of speciality bread as an alternative to common wheat flours or usually in combination with common wheat flour and rye flour (JURGA 2012). Traditional bread made from 100% spelt flour is mainly produced in Germany and Austria (FRAKOLAKI et al. 2018, SCHOBER et al. 2002, SCHOBER et al. 2006, MAJEWSKA et al. 2007).

Spelt bread is characterized by an intense aroma, a desirable flavour, prolonged shelf-life and desirable texture. Its flavour is described as sweet and nutty (CAPOUCHOVA 2001, EVANS et al. 2014). According to several studies, the nutritional value of spelt wheat and spelt products exceeds that of common wheat is comparable to oat products (SZUMIŁO and RACHOŃ 2015). However, other studies investigating the nutritional value of spelt and other ancient wheat species did not explicitly confirm their superior health benefits relative to common wheat, which indicate that the variety of experimental materials is an important consideration (SHEWRY 2018).

The quality of spelt wheat products, including flour and bread, is influenced by numerous factors, including genotype (variety, number of kernels in spikelet), environmental factors (location, soil and weather conditions), agricultural system (sowing and harvesting methods), processing factors (dehulling process and milling process), and technological factors (flour properties, bread making methods) (SCHOBER et al. 2006, SZUMIŁO and Rachoń 2015, Shewry 2018, Grela 1996, Abdel-Aal 2008, Mikos and Podolska 2012, Majewska et al. 2018, Żuk-Gołaszewska et al. 2018). According to Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007, "organic production is an overall system of farm management and food production that combines best environmental and climate action practices, a high level of biodiversity, the preservation of natural resources ...". Moreover, organic production is subject to official controls and to other official activities carried out in accordance with Regulation (EU) 2017/625 to verify compliance with the rules on organic production and the labelling of organic products.

The quality of spelt flour is described with the gluten content, sedimentation value, amylolytic activity, and the rheological properties of its dough which are important for both product quality and process efficiency. The rheological properties of spelt flour are mainly determined with the farinograph and extensograph experiments, viscoelastic properties of gluten and pasting properties of starch (Jurga 2012, Frakolaki et al. 2018, Mondal and Datta 2008). Spelt flour is generally characterized as high gluten content; it has higher gluten content than common wheat flour. Spelt dough is less dense than that of made from common wheat flour. It was reported that spelt gluten has poorer rheological properties, and the spelt dough is more sensitive to intensive mixing and mechanical processing (Wanic et al. 2024, Frakolaki et al. 2018, Schober et al. 2006, Majewska et al. 2007).

Direct and indirect methods are applied to evaluate wheat flour quality. Indirect methods are used to determine the physicochemical properties of flour and the rheological properties of its dough. The direct approach involves laboratory baking trials of flour, mainly the bread making assessments. In general, certain relationships exist between the results of direct and indirect evaluations. However, bread making trial is still the most useful determinant in evaluating wheat flour quality, in particular for ancient spelt wheat (Schober et al. 2002, Zarzycki et al. 2014).

The aim of this study was to evaluate the selected physicochemical parameters of flours and rheological parameters of dough and quality parameters of breads of organically grown spelt cultivars, to evaluate the interrelationship between the analysis results and harvest year, and to describe the relationships between spelt flour quality parameters and its bread quality parameters.

Materials and Methods

Materials

Seven winter spelt cultivars, which were used in this study, were *cv. Ceralio* (CER), *cv. Schwabenkorn* (SKO), *cv. Franckenkorn* (FRA), *cv. Holstenkorn* (HOL), *cv. Schwabenspeltz* (SSP), *cv. Ostro* (OST) and *cv. Oberkulmer Rotkorn* (OBE). The Polish winter common wheat (*Triticum aestivum* ssp. *vulgare*) named as *cv. Korweta* (KOR) was used as a reference wheat cultivar. The spelt cultivars and reference cultivar of *cv. Korweta* were organically grown in the north-eastern region of Poland during three successive growing years which were 2004–2005 (first year, I), 2005–2006 (second year, II) and 2006–2007 (third year, III) as four replicates (n = 4) in each year. Detailed information about the agricultural technique and weather conditions in each growing year was presented in the previous study (ŻUK-GOŁASZEWSKA et al. 2018). Harvested grains of spelt cultivars were dehulled using the cereal thresher (Wintersteiger LD 180, Germany). After conditioning to 14.5% moisture content, all wheat grain samples were milled using laboratory roller mill (Brabender Quadrumat Junior, Germany) in order to obtain the light flour; besides flour extraction rates (%) were calculated. All wheat grain samples were also milled into wholegrain flour using a buhrstone mill (FP 950, Denmark).

Methods

Physicochemical analysis of flours

The wet gluten content was determined in a mechanical gluten washing system (Sadkiewicz® Instruments, Poland) according to PCS Standard PN-EN ISO 21415-2:2015-12 (Polish Committee for Standardization 2015). The Zeleny sedimentation test was determined according to PCS Standard PN-ISO 5529:1998 (Polish Committee for Standardization 1998). The amylograph properties for starch gelatinization and starch paste viscosity (B.U.) were measured according to PCS Standard PN-ISO 7973:2001 (Polish Committee for Standardization 2001) using Brabender amylograph (Germany) equipped with electronic temperature control. All physicochemical parameters with their units were shown in Table 1.

Table 1

The quality properties of grain, flour, dough and bread, and the notations for variables in Partial Least Square Regression (PLS-R) analysis and Partial Least Square Path Modelling (PLS-PM) analysis

PLS-R	PLS-PM		Quality properties	Unit
Variable	latent variable	manifest variable		
X Explanatory variable	LV1 Grain	g_1	wet gluten content of wholegrain flour	%
		g_2	flour extraction rate	%
	LV2 Flour	f_1	wet gluten content of light flour	%
		f_2	zeleny sedimentation index	cm^3
		f_3	initial temperature of starch gelatinization	°C
		f_4	peak temperature of starch gelatinization	°C
		f_5	maximum viscosity of starch paste	*B*.U.
	LV3 Dough	d_1	compressive strength of dough, f_w	N
		d_2	displacement, d_w (deformation at f_w)	mm
		d_3	dough compactness (f_w/ d_w)	N/mm
		d_4	maximum force of dough extrusion, f_{max}	N
		d_5	maximum energy of dough extrusion, e_{max}	J
		d_6	dough yield	%
Y Dependent variable	LV4 Bread	b_1	bread yield	%
		b_2	bread volume	cm^3
		b_3	crumb porosity	score
		b_4	organoleptic quality of bread	score

Rheological measurements of dough

The dough (550 g each) prepared for rheological tests consisted only of flour and water. The dough was prepared with constant hydration, and the dough yield was 155%, i.e. there were 55 parts by weight of water per 100 parts by weight of flour. The amount of water added was calculated each time while taking into account the moisture content of each flour sample. Then, the dough was kneaded in a laboratory mixer (GM-2 model, Sadkiewicz® Instruments, Poland) for 7 min which enabled the obtaining of constant consistency (MAJEWSKA 2004).

The rheological properties of 250 g dough pieces were assessed in the Instron 4301 (USA) device with the OTMS cell (cross-sectional area of 50 cm^2, perforated cell) according to the method described by MAJEWSKA (2004). Dough extrusion parameters for plotting the force versus displacement

(F_{max} vs d_w) curve were analysed (n = 4) in Instron IX Series AMTS v. 8.04 software. All rheological parameters and dough yields with their units were shown in Table 1.

Bread making process

The straight dough method was followed using a GM-2 laboratory mixer and a laboratory oven with the PL-10 fermentation chamber (Sadkiewicz® Instruments, Poland). Bread dough was prepared by mixing wheat flour, yeast (3%), table salt (1%) and water (added due to farinograph result) in a laboratory mixer and was kneaded for 7 min. Then, bread dough was fermented under conditions of 32°C temperature and 75–80% relative air humidity in a fermentation chamber for 2 hours. The dough was perforated after 80 min. A dough piece (250 g) was separated and formed manually. Then, the dough was placed in a baking pan and was left to final fermentation under the same fermentation conditions until full maturation. Dough was baked in a laboratory oven at 230°C for 30 minutes. Laboratory bread making trials were conducted in two series with two replicates for each. Crumb porosity was defined as Dallman score (HORUBAŁOWA and HABER 1994); bread volume (cm^3/100 g of flour) was determined using the Sa-Wy apparatus (Sadkiewicz® Instruments, Poland); total baking loss and bread yield [%] per 100 g of flour were also determined (HORUBAŁOWA and HABER 1994). In addition, the organoleptic evaluations of bread (external appearance, crust and crumb properties, flavour and aroma) were assessed as giving scores by 8 panellists, which were food technologists working at the Faculty of Food Science at the University of Warmia and Mazury in Olsztyn, Poland, according to the method of PCS Standard PN-A-74108:1996 (Polish Committee For Standardization 1996).

Statistical analysis

The statistical analyses were performed using the Statistica software (StatSoft) and XLSTAT software add-in for the Microsoft Excel programme. The mean values and the standard error of the mean (SEM) were determined in a descriptive statistical analysis. The variations in the analysed properties across the experimental years and the analysed cultivars, and the *year* x *cultivar* interaction were determined by analysis of variance (ANOVA). The means were compared in Tukey's honest significant difference (HSD) test at a significance level of $P < 0.01$.

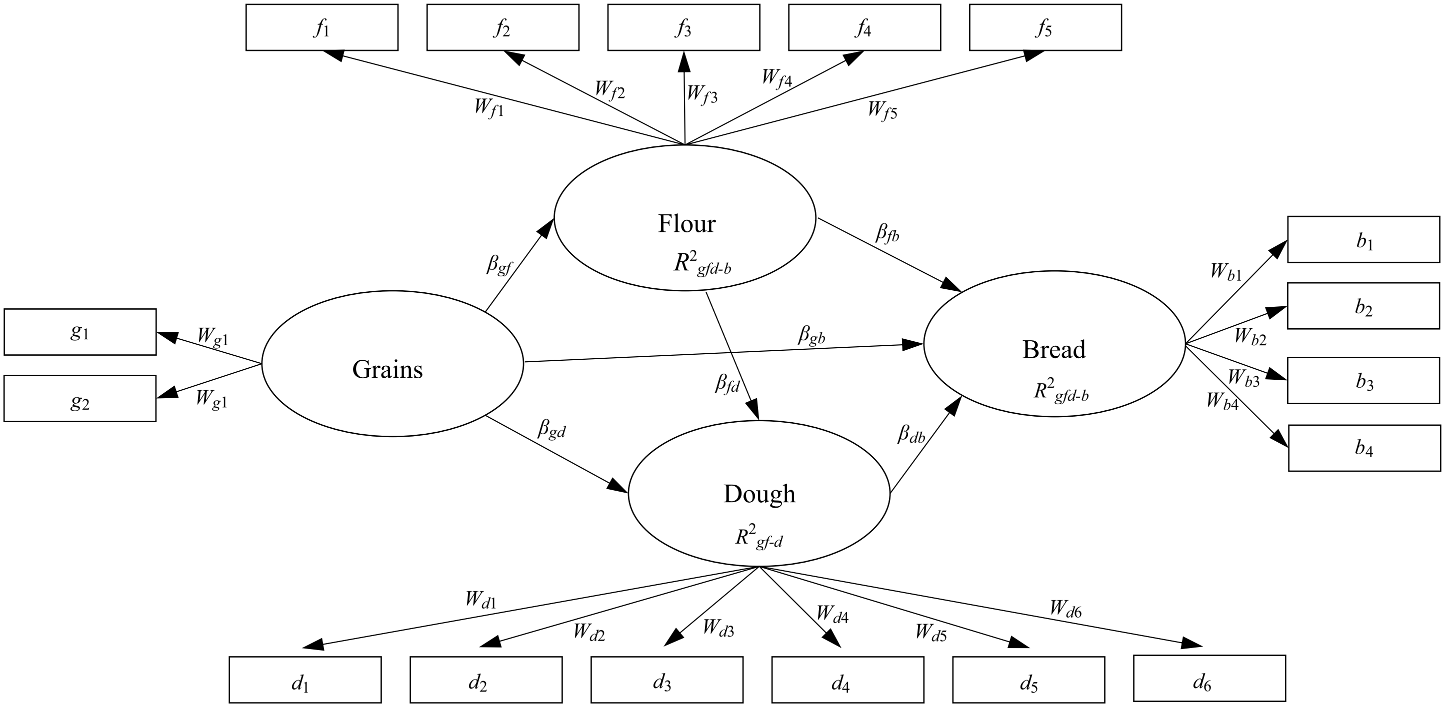

Fig. 1. A generic diagram of the PLS-PM causal model was describing the relationship between latent and manifest variables which were denoting the strength of common wheat and spelt wheat flours and the quality properties of their bread

The relationship between bread quality parameters (dependent variables, Y) and the spelt flour quality parameters (explanatory variables, X) was explored by partial least square regression (PLS-R) analysis. The PLS-R analysis was extended to path modelling (PLS-PM). The notations for the variables in each of two approaches were presented in Table 1.

The PLS-PM causal model for all studied cultivars was presented in Figure 1. Four latent variables – LVs (ellipses) corresponding to successive stages of the processing-grain, flour, dough and bread, and a set of manifest variables – MVs (rectangles) related to LVs were adopted. The following values were estimated: i) outer weights of MVs, w_i denoting the relative importance of each directly measured MV*i* (unitary change in LV with a change in MV); ii) path coefficients (β_i) among LVs which were standardized as regression coefficients; and iii) coefficients of determination (R^2) for endogenous LVs, flour, dough and bread.

Results and Discussion

Physicochemical properties of flour

Physicochemical properties of the spelt and common wheat cultivars were shown in Table 2. In all growing years, the wet gluten contents were significantly higher in the wholegrain flours (26.70–37.10%) and light flours (25.75–45.55%) of spelt cultivars than that of the wholegrain (19.15–24.10%) and light flours (21.20–22.50%) of common wheat cultivar. The highest average wet gluten contents were observed in both flours of *cv. Oberkulmer Rotkorn* and *cv. Ostro* cultivars (Table 2). Bojňanská and Frančáková (2002) reported that five cultivars of *Triticum spelta* L. had high wet gluten content as 37.12% on average of three year cultivations. However, the average SDS sedimentation value was low like 37.4 cm^3, which had a negative effect on bread volume and specific volume in their study. Bojňanská and Frančáková (2002) found that the flour obtained from *cv. Schwabenkorn* was characterized by high strength dough. Dough strength was estimated by the wet gluten and crude protein contents of wheat. The spelt wheat gluten was also characterized as high extensibility and low elasticity according to previous studies (Frakolaki et al. 2018, Majewska et al. 2007). Lacko-Bartošová et al. (2010) reported very high levels of wet gluten in spelt wheat. The contents of wet gluten in the grain of eight spelt cultivars ranged from 37.4% (*cv. Rouquin*) to 49.8% (*cv. Rubiota*) with an average of 42.9%. The grain of all spelt cultivars, except for *cv. Holstenkorn*, was characterized as high extensibility in their study. Lacko-Bartošová et al. (2010) reported that wet gluten content was influenced by weather conditions

Table 2

Physicochemical properties of flours milled from the reference wheat and the spelt cultivars (n = 2; mean)

Cultivar	Growing years (Y)	Wet gluten content of wholegrain flour [%]	Flour extraction rate [%]	Wet gluten content of light flour [%]	Zeleny S. index [cm^3]	Initial temperature of starch gelatinization [°C]	Peak temperature of starch gelatinization [°C]	Maximum viscosity of starch paste [B.U.]
cv. Korweta	I	21.40	68.0	22.50	36	56.90	68.90	497.5
	II	24.10	66.9	22.15	44	45.75	56.25	430.0
	III	19.15	67.1	21.20	37	62.00	83.40	365.0
cv. Ceralio	I	31.25	69.2	32.50	12	60.60	68.10	295.0
	II	27.75	60.6	29.60	14	45.35	49.85	170.0
	III	29.45	69.4	30.55	22	62.65	75.40	150.0
cv. Schwabenkorn	I	32.65	68.2	33.45	27	53.45	69.35	705.0
	II	30.95	64.8	34.05	24	45.35	49.70	120.0
	III	31.35	69.7	32.05	28	62.95	82.85	272.5
cv. Franckenkorn	I	26.70	69.2	27.30	17	50.05	65.85	872.5
	II	32.30	60.3	33.10	23	46.10	49.45	50.0
	III	28.00	66.4	29.25	27	64.15	92.65	545.0
cv. Holstenkorn	I	35.20	69.6	36.20	15	56.25	72.75	740.0
	II	33.15	59.9	33.05	17	46.85	53.95	195.0
	III	28.45	67.5	31.00	21	64.20	89.00	470.0
cv. Schwabenspeltz	I	32.00	62.2	27.65	27	58.20	71.35	532.5
	II	30.90	65.2	29.90	27	45.70	52.60	287.5
	III	29.70	58.5	28.95	37	63.40	81.80	382.5
cv. Ostro	I	37.10	68.9	45.55	23	59.65	72.40	475.0
	II	32.25	68.8	25.75	17	46.10	49.85	82.5
	III	31.70	66.3	29.90	17	64.30	77.80	144.0
cv. Oberkulmer Rotkorn	I	35.05	64.9	38.85	19	54.40	69.20	457.5
	II	34.00	63.6	35.90	20	45.35	48.70	75.0
	III	31.80	61.0	34.65	20	64.50	80.30	227.5
$HSD_{0.01}$ for: Year (Y)		0.541	0.80	0.392	0.8	1.146	1.158	12.33
Cultivar (C)		1.098	1.62	0.795	1.6	2.324	2.349	25.01
Interaction (YxC)		2.289	3.39	1.658	3.3	4.846	4.898	52.16

during the growing season, and it peaked in the years of high temperatures and uniform distribution observed during rainfall.

The Zeleny sedimentation index, which reflects gluten quality, ranged from 12 cm^3 to 37 cm^3 among the analysed spelt cultivars (Table 2). In *cv. Korweta*, the Zeleny sedimentation index values in three subsequent growing years were in the range of 36–44 cm^3 indicating high dough strength, and the Zeleny sedimentation index values were significantly higher than that of the majority of spelt cultivars. According to our findings, common wheat (*cv. Korweta*) had low wet gluten content, but its gluten quality was higher than that of the spelt wheat, since it was expected that it included high content of high-molecular weight glutenins which increased the dough strength (WYSOCKA et al. 2024). The spelt cultivars of *cv. Schwabenspelz* and *cv. Schwabenkorn* were characterized with satisfactory gluten quality and they included relatively high gluten contents in both of their wholegrain flour and light flour (Table 2). According to SCHOBER et al. (2006), typical spelt cultivars, which were average quality, were characterized by high contents of protein and wet gluten. It was reported that the quality and quantity of gluten were significantly affected by the growing year, cultivar and the interaction of both (SCHOBER et al. 2006). The flour extraction rates, which were in the ranges of 58.5–69.7% for spelt cultivars and 66.9–68.0% for reference wheat, were also affected by cultivar and an interaction of *growing year* and *genotype* (Table 2). Flour yield is one of the key parameters in the evaluation of the milling characteristics of wheat grain, and it is also correlated with selected bread properties including bread yield (negatively correlated) and baking loss (positively correlated).

The effect of *genotype* x *environment* interaction on selected parameters of wheat grain and flour quality is still poorly understood. That interaction explains the variance in quality attributes to a different extent, and the effects of genotype and environment are also determined by the magnitude of the studied wheat cultivars and the applied methods of data analysis (SCHOBER et al. 2006, SHEWRY 2018).

The activity of amylolytic enzymes in wheat and rye flour significantly influences bread quality. Dough fermentation capacity and bread crumb properties are mainly governed by amylolytic activity. In amylograph analysis, amylolytic enzyme activity is evaluated under conditions similar to bread baking in which starch gelatinization also occurs. In particular, in the first baking stage, gradual increase in dough temperature and enzyme activity subsequently takes place. In this study, the initial and peak temperatures of starch gelatinization of all wheat flours milled from the grains harvested in the third year of this study changed in the ranges of 62.0–64.50°C and 75.40–92.65°C, respectively. However, in the grains harvested in first and second years of the experiment, the initial and peak temperatures of starch gelatinization were lower in all wheat flours than that of the flours milled from the grains harvested in the third year (Table 2). In dough cell membranes, starch gelatinization occurs at around 65°C. Above the starch gelatinization temperature, the dough viscosity increases and the dough extensibility decreases due to protein denaturation upon heating, and the pressure increases in closed air pockets causing to the rupture of dough cell membranes (MONDAL and DATTA 2008). Starch gelatinization is also affected by dough fermentation and the applied baking process (POJIĆ et al. 2013).

The maximum viscosities of starch paste of common wheat cultivar in the first, second and third harvest years were 497.5, 430.0 and 365.0 B.U. respectively. On the other hand, in the spelt wheat cultivars, they changed in the ranges of 295.0–872.5 B.U., 75.0–287.5 B.U. and 144.0–545.0 B.U. in the same order of years, respectively (Table 2). The maximum viscosity values obtained with all spelt cultivars in the second growing year were obviously lower than that of value of common wheat. It can be stated that according to the starch gelatinization temperature results, in the second harvest year, all wheat samples easily gelatinized at lower temperatures and their gelatinization was completed at lower temperatures than that of the samples harvested in the first and third years. It meant that low energy was needed for their gelatinization. The peak viscosities of spelt wheat starches were lower than those of common wheat in the second harvest year that means high amylolytic activity and the starches of spelt wheat were easily degraded. In addition, the starch damage and starch morphology may also play significant role in peak viscosity. Instead, the maximum viscosity values obtained with all wheat samples in the first harvest year, which were in the range of 295.0–872.5 B.U., were higher than that of the grains harvested in the second and third years, that means low amylolytic activity and the starches resisted to amylolytic degradation and absorbed more water for swelling. These findings can be attributed to weather conditions during the second growing year and harvesting mentioned in the previous work (ŻUK-GOŁASZEWSKA et al. 2018). The experimental year, cultivar or genotype and their interaction had significant effects on the amylograph properties of flours (Table 2). It is reported that baking trials were essential for understanding the amylograph properties of different types of wheat flour. In addition, the applied bread making method was also an important consideration (FRAKOLAKI et al. 2018, SCHOBER et al. 2002, NOORT et al. 2017).

Rheological properties of dough and quality properties of bread

The rheological properties of dough play an increasingly important role in indirect evaluations of flour strength due to considerable advancements in analytical equipment and software. The instruments for evaluating the rheological properties of wheat dough register dough characteristics during mixing (like farinograph, mixograph) and stress-strain data for plotting force-displacement curves (like alveograph, extensograph). The rheological properties of wheat dough are also studied by using the Ottawa Texture Measuring System (OTMS) equipped with extrusion cells in an Instron universal testing device (KONOPKA et al. 2004). Dough resistance to compressive, extensional and shear deformation is measured during the test. The previous study revealed positive correlations between the rheological parameters of dough determined in an OTMS cell and in an alveograph (MAJEWSKA 2004).

Rheological properties of dough and quality properties of bread obtained from bread making trials were shown in Table 3. Hence, the rheological properties of spelt dough differed across the analysed spelt cultivars according to experimental year, however d_w and F_w/d_w values were generally similar in all wheat samples. Dough made from *cv. Korweta* had compressive strength, F_w, as 243.9, 311.3 and 213.8 N and maximum extrusion force, F_{max}, 349.5, 356.0 and 266.3 N in the first, second and third harvest years, respectively. These parameters were generally higher than those of the spelt cultivars in the same order of years. The compressive strength and maximum extrusion force values of spelt dough were in the ranges of 82.5–257.5 N and 103.9–372.5 N, respectively (Table 3). Generally, the rheological property of spelt dough was characterized as much lower than that of common wheat dough. This means more delicate and having low compressive strength, compactness and extrusion energy. Dough made from *cv. Oberkulmer Rotkorn* could be characterized as relatively higher and consistent values of rheological parameters across the experimental years, besides they were generally lower than the values of *cv. Korweta* except for its displacement (dw) values (Table 3).

The other studies also reported that the rheological properties of spelt dough were poorer than those of common wheat dough. Thus, the dough made from spelt flour was generally characterized by lower stability and elasticity and higher extensibility and water solubility (BOJŇANSKÁ and FRANČÁKOVÁ 2002, FRAKOLAKI et al. 2018, SCHOBER et al. 2002, MIKOS and PODOLSKA 2012). However, the dough made from selected spelt cultivars could be characterized as having high rheological properties in this study, where the high flour strength values were strongly revealing (Table 3). It was stated that the spelt products of reasonable quality, including bread, could be obtained by selecting the appropriate cultivar and/or by manipulating the processing conditions (ABDEL-AAL 2008).

The direct evaluation of flour strength in the laboratory bread making trials demonstrated that the quality of bread produced from selected spelt wheat cultivars was comparable to the quality of bread made from

Table 3

Rheological properties of dough and quality properties of bread obtained from bread making trials. (n = 4; mean)

Cultivar	Growing years (Y)	F_w (N)	d_w [mm]	F_w / d_w [N/mm]	F_{max} (N)	E_{max} (J)	Dough yield [%]	Bread yield [%]	Bread volume [cm^3]	Crumb porosity (score)	Bread quality (score)
cv. Korweta	I	243.9	22.2	11.0	349.5	9.3	151.7	127.5	441.8	80	27
	II	311.3	22.4	14.0	356.0	9.9	148.5	125.8	411.9	90	35
	III	213.8	21.6	9.9	266.3	7.6	151.2	133.1	381.5	90	36
cv. Ceralio	I	173.7	22.2	8.0	245.0	7.0	154.0	130.0	420.8	70	35
	II	82.5	24.1	3.4	103.9	3.0	151.0	126.6	514.5	70	32
	III	95.9	20.4	4.7	136.2	4.1	150.1	130.9	459.1	70	35
cv. Schwabenkorn	I	150.2	23.3	6.4	219.0	6.0	152.3	130.3	328.7	60	26
	II	105.2	25.0	4.2	132.9	3.7	151.7	128.6	479.8	60	34
	III	107.0	16.4	8.8	141.5	4.6	153.3	132.6	404.4	60	34
cv. Franckenkorn	I	126.3	24.2	5.2	190.0	4.6	151.8	130.3	340.2	70	25
	II	241.2	24.1	10.1	372.5	9.5	152.6	129.2	494.2	70	32
	III	121.4	9.9	12.4	152.5	4.5	152.0	134.5	322.4	90	27
cv. Holstenkorn	I	148.1	22.9	6.5	213.0	5.9	151.0	128.1	405.2	70	25
	II	257.5	23.4	11.1	356.5	9.7	151.9	129.2	408.0	70	30
	III	100.3	17.7	6.5	127.9	3.6	149.7	130.3	337.8	70	27
cv. Schwabenspeltz	I	125.9	22.5	5.6	198.0	5.3	151.1	130.0	285.1	80	29
	II	257.0	21.3	12.1	337.2	9.6	153.5	129.8	426.6	70	31
	III	133.1	20.1	6.6	182.1	5.5	150.8	132.0	508.1	70	29
cv. Ostro	I	120.4	25.5	4.7	175.0	4.4	151.0	128.2	380.3	70	30
	II	96.2	26.5	3.7	154.7	3.7	152.4	131.8	362.3	80	37
	III	89.3	24.1	3.7	118.3	3.4	151.7	131.7	372.4	60	36
cv. Oberkulmer Rotkorn	I	156.4	23.8	6.6	243.0	6.3	151.8	129.5	376.9	80	35
	II	125.1	25.0	5.1	202.8	4.9	155.0	133.0	337.6	80	36
	III	179.5	23.1	7.8	246.6	7.0	149.7	129.3	353.6	80	37
$HSD_{0.01}$ for: Year (Y)		7.21	3.23	NS	27.63	0.67	0.49	0.65	6.97	–	–
Cultivar (C)		14.62	NS	3.70	56.03	1.35	1.00	1.31	14.13	–	–
Interaction (YxC)		30.48	NS	7.71	116.83	2.82	2.08	2.73	29.47	–	–

cv. Korweta, besides it can be explained that the selected quality parameters were generally superior in the spelt wheat breads than those of common wheat bread (Table 3).

The bread quality properties are defined as bread dough yield, bread volume and density, and crumb porosity (MONDAL and DATTA 2008). In this research, bread dough yield was significantly affected by the interaction of *cultivar x growing year*. In the first and third years of the study, the dough yields of spelt and common wheat were similar, whereas in the second year, the spelt dough, in particular dough made from *cv. Schwabenspelz* and *cv. Oberkulmer Rotkorn* cultivars, had higher dough yield than that of common wheat dough. The results indicated that under different growing conditions, the dough yield was more stable in the spelt wheat than that of common wheat (Table 3).

The average bread volume per 100 g of flour ranged from 381.5 cm^3 to 441.9 cm^3 in *cv. Korweta*, and the average same property ranged from 285.1 cm^3 to 514.5 cm^3 in the studied spelt cultivars (Table 3).

The bread yields [%] of spelt wheat cultivars changed between 126.6–134.5% in three year experiments, besides the bread yield of common wheat changed between 125.8–133.1% in all growing years. In the first and second growing years, the spelt wheat cultivars gave higher bread yield than that of common wheat, but in the third year, the bread yield of *cv. Korweta* (133.1%) was higher than that of the spelt cultivars except for the bread yield of *cv. Franckenkorn* (134.5%, Table 3).

In this research, the crust colour of bread made from all spelt cultivars was light brown with a yellow hue. The crumb of spelt breads had a creamy yellow colour, besides the crumb of common wheat bread had a light creamy colour. The spelt breads could be characterized by better slice ability and had more distinctive flavour and aroma than that of common wheat bread. The flavours of bread made from *cv. Schwabenkorn*, *cv. Holstenkorn* and *cv. Oberkulmer Rotkorn* could be described as slightly nutty. Based on the results of the organoleptic evaluation, the tested bread loaves received the following average scores for overall quality in three years of experiments: *cv. Oberkulmer Rotkorn, cv. Ostro*, *cv. Ceralio, cv. Schwabenkorn, cv. Schwabenspelz, cv. Frankenkorn,* and *cv. Holstenkorn* spelt cultivars had 36, 34.3, 34, 31.3, 29.6, 28 and 27.3 points, respectively, and finally *cv. Korweta* as reference wheat had 32.6 point (Table 3).

In a study conducted by FRAKOLAKI et al. (2018), the spelt bread was characterized by lower specific volume and noticeably darker crust and crumb colour than that of common wheat bread. They reported that the starch in spelt wheat dough was hydrolysed more easily into sugars contributing to the Maillard reaction and caramelization occurring on the crust and crumb. Therefore, the colours of crust and crumb of spelt bread were darker in comparison with common wheat bread in this study. In addition, the lower volume of spelt wheat bread was correlated with the weaker gluten content and low amylograph peak viscosity values relative to common wheat gluten.

BOJŇANSKÁ and FRANČÁKOVÁ (2002) reported relatively low volume for spelt wheat bread per 100 g of flour, like in the range of 199.2 to 246.2 cm^3, and they reported relatively high bread yield, like in the range of 133.0–141.0%. It was found that the growing season was the main factor for higher bread volume. In this study, among the wheat cultivars harvested in the second year of the experiment, the highest bread volume was found with *cv. Ceralio* (514.5 cm^3) followed by *cv. Schwabenkorn* (479 cm^3) and *cv. Frankenkorn* (494.4 cm^3) cultivars. The bread volume of *cv. Schwabenspeltz* (508.1 cm^3) cultivar was the highest value among the wheat cultivars harvested in the third year of this study. It was observed that the bread volume of the remaining spelt cultivars was slightly influenced by the growing season (Table 3).

Correlations between the strength of flours and bread parameters vs. PLS components of t_1 and t_2

Partial Least Square Regression (PLS-R) was applied to compare common wheat and spelt cultivars in terms of flour strength and bread parameters. The global goodness of fit for the first two PLS components, t_1 and t_2, was determined at $Q^2_{cum} = 0.127$, and it exceeded the threshold value of 0.0975 (Figure 2). The two components explained as 54.5% and 74.5% of the variations in dependent (Y) and explanatory (X) variables, respectively.

In t_1 and t_2 coordinate space, the examined common wheat and spelt cultivars were diagonally aligned, but the estimated values of PLS components t_1 (–0.758) and t_2 (–0.442) of *cv. Korweta* indicated distinctively stronger correlation with common wheat rather than spelt wheat. Thus, the quality of spelt wheat bread was less correlated with the quality parameters of grain, flour and dough than that of the bread of *cv. Korweta*. The quality of common wheat bread was strongly correlated with the quality parameters of flour and dough corresponding to Zeleny sedimentation index (f_2), compressive strength of dough (d_1), maximum energy of dough extrusion (d_5) and crumb porosity (b_3). An analysis of other parameters under the diagonal associated with the flour and dough of *cv. Korweta* (d_3, d_4, f_4, f_5) revealed that the quality of spelt wheat bread, which was mainly determined by grain quality, was less correlated with flour strength and dough parameters compared to the *cv. Korweta* bread. Bread volume (b_2) was correlated (-0.414) with the component of t_2, and it can be considered as an intermediate parameter for comparing the quality of reference wheat and spelt bread (Figure 2).

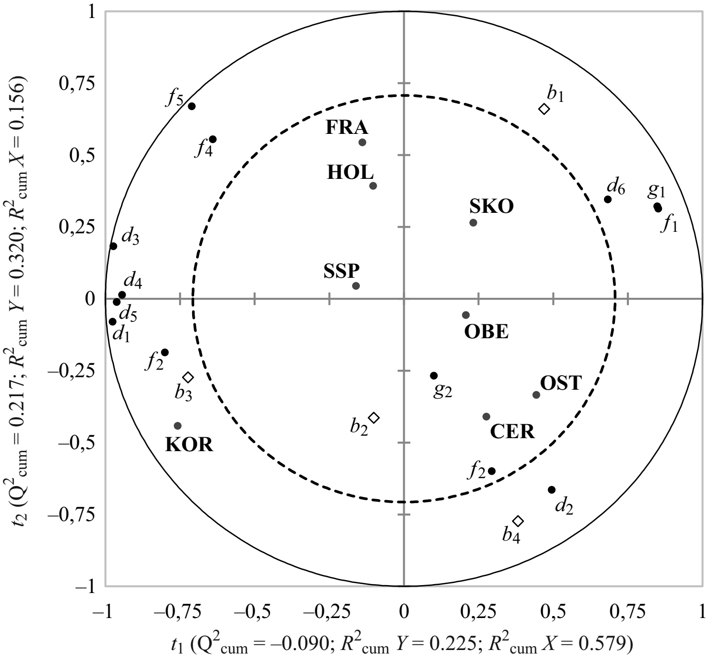

Fig. 2. A circle diagram presented the correlations among spelt cultivars, the quality properties of grain (g_1, g_2), flour (f_1–f_5), dough (d_1–d_6) and bread (b_1–b_4) vs. the first two PLS components of t_1 and t_2. The dotted circle represented a correlation of 0.7. CER: *cv. Ceralio*; SKO: *cv. Schwabenkorn*; FRA: *cv. Franckenkorn*; HOL: *cv. Holstenkorn*; SSP: *cv. Schwabenspeltz*; OST: *cv. Ostro*; OBE: *cv. Oberkulmer Rotkorn*; KOR: *cv. Korweta*

Flour extraction rate (g_2), which was a quality parameter, was the lowest explanatory power. The remaining parameters were strongly correlated with PLS components and they were interconnected with spelt wheat cultivars (Figure 2).

PLS components were positively correlated with *cv. Schwabenkorn* spelt wheat and the related parameters were the wet gluten contents of wholegrain (g_1) and light flour (f_1), dough yield (d_6) and bread yield (b_1). The second group of spelt cultivars that was positively correlated with the component of t_1 and negatively correlated with the component of t_2, was composed of *cv. Oberkulmer Rotkorn*, *cv. Ceralio* and *cv. Ostro* cultivars and the related parameters included the initial temperature of starch gelatinization (f_3), deformation (displacement) corresponding to the compressive strength of dough (d_2) and the bread score (b_4). The third group of spelt wheat cultivars was composed of *cv. Schwabenspeltz*, *cv. Holstenkorn* and *cv. Frankenkorn* cultivars which were negatively correlated with t_1 and positively correlated with t_2. These cultivars were weakly correlated with the flour strength and dough parameters (f_4, f_5, d_3, d_4), and they were not correlated with specific bread properties (Figure 2).

Path modelling of the strength of flours and their bread making properties

It was shown in Table 4 that the latent variables (LV1-4) were influenced by variety. In the LV1 for grain, the wet gluten content of wholegrain (w_{g1}) was more important parameter for *cv. Korweta* than that of the spelt cultivars

Table 4

Outer weights MVs (w_i) describing the corresponding LVs and direct paths (*β)* for endogenous latent variables

Latent variables	w	KOR	CER	FRA	HOL	OBE	OST	SKO	SSP
Grain	w_{g1}	1.019	0.536	0.512	-0.424	0.525	0.733	0.575	0.347
	w_{g2}	0.127	0.517	-0.498	0.900	0.512	0.367	0.620	0.760
Flour	w_{f1}	-0.250	0.324	0.330	-0.022	-0.383	0.309	-0.155	-0.123
	w_{f2}	-0.189	0.019	0.017	0.166	0.202	0.328	0.273	0.289
	w_{f3}	0.275	0.331	-0.244	0.359	0.403	0.053	0.209	0.328
	w_{f4}	0.298	0.301	-0.286	0.360	0.344	0.073	0.252	0.333
	w_{f5}	-0.200	0.242	-0.320	0.289	-0.095	0.313	0.320	0.119
Dough	w_{d1}	0.247	0.203	0.246	0.219	0.208	0.242	0.256	0.195
	w_{d2}	0.128	-0.196	0.130	0.104	-0.164	0.010	-0.137	0.139
	w_{d3}	0.232	0.225	0.040	0.175	0.212	0.232	0.172	0.179
	w_{d4}	0.201	0.205	0.244	0.217	0.101	0.191	0.275	0.215
	w_{d5}	0.230	0.208	0.246	0.217	0.182	0.225	0.319	0.196
	w_{d6}	-0.163	0.132	0.213	0.181	-0.194	-0.212	0.252	0.214
Bread	w_{b1}	0.610	-0.226	-0.242	0.295	-0.323	0.381	-0.325	-0.312
	w_{b2}	-0.358	0.282	0.369	-0.253	-0.065	-0.292	0.413	-0.434
	w_{b3}	0.043	-0.264	-0.180	-0.282	0.361	-0.104	0.258	-0.038
	w_{b4}	0.108	-0.264	0.358	-0.263	0.627	0.381	0.280	0.546
Endogenous latent variables									
Flour	β_g	-0.990**	0.987**	0.930**	0.987**	-0.915**	0.794	0.905*	-0.837*
	R^2	0.981	0.975	0.865	0.974	0.838	0.630	0.819	0.700
Dough	β_g	1.161	-0.154	0.034	-0.068	0.720	0.640*	0.882	-0.281
	β_f	0.221	1.059	0.963*	-0.931*	1.395	0.398	0.016	-1.209**
	R^2	0.889	0.825	0.989	0.997	0.625	0.973	0.805	0.972
Bread	β_g	2.245	-0.798	-0.143	2.873	-0.924	-0.157	-1.249	0.606
	β_f	3.692*	0.423	1.443	3.752	0.157	-0.713	0.487	-0.853
	β_d	0.644	-0.337	0.401	5.770	-0.205	-0.156	-0.173	-0.464
	R^2	0.978	0.981	0.996	0.957	0.929	0.984	0.975	0.992

* and ** – significant at $P < 0.05$ and $P < 0.01$, respectively. CER: *cv. Ceralio*; SKO: *cv. Schwabenkorn*; FRA: *cv. Franckenkorn*; HOL: *cv. Holstenkorn*; SSP: *cv. Schwabenspeltz*; OST: *cv. Ostro*; OBE: *cv. Oberkulmer Rotkorn*; KOR: *cv. Korweta.*

whose MVs values significantly contributed to grain. In *cv. Korweta*, MVs of flour and dough were equally important, and bread yield (w_{b1}) was the most important MV for pronouncing bread. The high weights of spelt cultivars were connected with the initial temperature of starch gelatinization (w_{f3}, *cv. Ceralio, cv. Holstenkorn, cv. Oberkulmer, cv. Schwabenspeltz*). The weights associated with dough were relatively low, whereas the weights associated with bread yield (w_{b1}, *cv. Ceralio, cv. Frankenkorn, cv. Schwabenkorn*) and the bread score (w_{b4}, *cv. Frankenkorn, cv. Oberkulmer, cv. Ostro, cv. Schwabenspeltz*) were relatively found as high (Table 4).

The direct path coefficients for LVs in common wheat and spelt wheat exhibited a similar pattern for flour and grain and displayed a different pattern for dough and bread (Table 4). In the determination of dough, the value of the path coefficient for grain was higher than that of flour, whereas an inverse relationship was noted in spelt cultivars, excluding *cv. Schwabenkorn* cultivar which had an inverse relationship with positive (*cv. Ceralio, cv. Frankenkorn, cv. Oberkulmer, cv. Ostro*) and negative (*cv. Holstenkorn*, *cv. Schwabenkorn*) estimates. In *cv. Korweta*, the highest estimates of paths for bread were related to flour followed by grain and dough. The spelt cultivar of *cv. Holstenkorn* followed these paths only, although the estimate for dough was highly stated than that of grain and flour. The remaining spelt cultivars were also strongly differentiated according to the estimates (Table 4).

Conclusions

In conclusion, the flour strength of spelt wheat and the results of bread making trials were not bound to simple linear relationship. Thus, bread baking tests were required to reliably evaluate the strength of spelt flour. The quality of bread from selected spelt wheat cultivars was comparable to bread made of common wheat. Breads made of cv. *Oberkulmer Rotkorn* and cv. *Ostro* cultivars received the highest overall score in terms of quality parameters. The quality of spelt wheat bread, which was mainly connected with grain quality, was less correlated with the flour strength and dough parameters when compared to common wheat bread.

Accepted for print 12.12.2025

References

ABDEL-AAL E.S.M. 2008. *Effects of baking on protein digestibility of organic spelt products determined by two in vitro digestion methods*. Food Sci. Technol.-LEB, 41: 1282–1288.

Bojňanská T., Frančáková H. 2002. *The use of spelt wheat (Triticum spelta* L.*) for baking applications*. Rostlinna Výroba, 48: 141–147.

Capouchova I. 2001. *Technological quality of spelt (Triticum spelta* L.*) from ecological growing system*. Scientia Agriculturae Bochemica, 32: 307–322.

Evans J.R., Neeson R.V., Burnett D.J., Luckett D.J., Fettell N.A. 2014. *Phosphorus-use efficiency, growth and yield of spelt wheat (Triticum aestivum* ssp. *spelta) compared with standard wheat (T. aestivum* ssp. *vulgare) in south-eastern Australia*. J. Organic Systems, 9: 63–78.

Frakolaki G., Giannou V., Topakas E., Tzia C. 2018. *Chemical characterization and bread making potential of spelt versus wheat flour*. J. Cereal Sci., 79: 50–56.

Grela E.R. 1996. *Nutrient composition and content of antinutritional factors in spelt (Triticum spelta* L.*) cultivars*. J. Sci. Food Agr., 71: 399–404.

Horubałowa A., Haber T. 1994. *Analiza techniczna w piekarstwie (Technical analysis in baking). 4th edition supplemented*. WSIP, Warszawa, Poland.

IJHARS – Agricultural and Food Quality Inspection. 2019. *The report on organic farming in Poland in 2017–2018*, Warszawa, p. 101, Poland.

Institute of Agricultural and Food Economics-Polish National Research Institute. 2021. *Cereal market – condition and economic perspectives*. 61: 1–52 (ISSN 1231–3149).

Jurga R. 2012. *Spelt wheat – nutritional and baking value and possibilities of using its preserves*. Przegląd Zbożowo-Młynarski, 11: 7–9.

Konopka I., Fornal Ł., Abramczyk D., Rothkaehl J., Rotkiewicz D. 2004. *Statistical evaluation of different technological and rheological tests of Polish wheat varieties for bread volume prediction*. Int. J. Food Sci. Tech., 39: 11–20.

Lacko-Bartošová M., Korczyk-Szabó J., Ražný R. 2010. *Triticum spelta – a specialty grain for ecological farming systems*. Res. Jr. Agril. Sci., 42: 143–147.

Majewska K., Dąbkowska E., Grabowska E., Tyburski J., Czaplicki S. 2018. *Composition of fatty acids in dark flour from spelt and common wheat grain grown organically in Poland*. Pol. J. Natur. Sc., 33: 75–88.

Majewska K., Dąbkowska E., Żuk-Gołaszewska K., Tyburski J. 2007. *Baking quality of flour obtained from grain of chosen spelt varieties (Triticum spelta* L.*)*. Żywność Nauka Technologia Jakość, 2: 60–71.

Majewska K.M. 2004. *Studies of wheat grain technological quality parameters in the aspect of its geometrical features*. Dissertations and Monographs, UWM, Olsztyn, 98: 1–93.

Mikos M., Podolska G. 2012. *Bread-making quality of old common bread (Triticum aestivum* ssp. *vulgare L.) and spelt (Triticum aestivum* ssp. *spelta* L.*) wheat cultivars*. The J Food, Agric. Environ., 10: 221–224.

Mondal A., Datta A.K. 2008. *Bread baking – A review*. J. Food Eng., 86: 465–474.

Noort M.W.J., Mattila O., Katina K., Van Der Kamp J. 2017. *Health Bread: Whole grain and high fibre breads with optimized textural quality*. J. Cereal Sci., 78: 57–65.

Pojić M., Hadnadev M., Hadnadev T.D. 2013. *Gelatinization properties of wheat flour as determined by empirical and fundamental rheometric method*. Eur. Food Res. Technol., 237: 299–307.

Polish Committee for Standardization. 1996. *Methods of analysis. Bakery products*. PCS standard. PN-A-74108:1996.

Polish Committee for Standardization. 1998. *Wheat. Determination of sedimentation index – Zeleny test*. PCS standard. PN-ISO 5529:1998.

Polish Committee for Standardization. 2001. *Cereals and milled cereal products. Determination of viscosity of flour. Method using an amylograph*. PCS standard. PN-ISO 7973:2001.

Polish Committee for Standardization. 2015. *Wheat and wheat flour. Gluten content. Part 2. Determination of wet gluten quantity and gluten index by mechanical equipment*. PCS standard. PN-EN ISO 21415–2:2015–12.

Schober T.J., Bean S.R., Kuhn M. 2006. *Gluten proteins from spelt (Triticum aestivum* ssp. *spelta) cultivars: A rheological and size-exclusion high-performance liquid chromatography study*. J. Cereal Sci., 44: 161–173.

SCHOBER T.J., CLARKE C.I., KUHN M. 2002. *Characterization and functional properties of gluten proteins in spelt cultivars using rheological and quality factor measurements.* Cereal Chem., 79: 408–417.

SHEWRY P.R. 2018. *Do ancient types of wheat have health benefits compared with modern bread wheat?* J. Cereal Sci., 79: 469–476.

SZAWARA-NOWAK D. 2013. *Bioactive components of breads.* Towaroznawcze Problemy Jakości, 3: 103–115.

SZUMIŁO G., RACHOŃ L. 2015. *Yields and quality of spring spelt wheat grain depending on sowing material.* Pol. J. Agro., 20: 9–14.

WANIC M., JASTRZĘBSKA M., KOSTRZEWSKA M.K., PARZONKA M. 2024. *Spelt in diversified and spelt-based crop rotations: Grain yield and technological and nutritional quality.* Agriculture, 14: 1123.

WYSOCKA K., CACAK-PIETRZAK G., FELEDYN-SZEWCZYK B., STUDNICKI M. 2024. *The Baking quality of wheat flour (Triticum aestivum* L.*) obtained from wheat grains cultivated in various farming systems (Organic vs. Integrated vs. Conventional).* Appl. Sci., 14(1886): 1–19.

ZARZYCKI P., KASPRZAK M., RZEDZICKI Z., SOBOTA A., SYKUT-DOMAŃSKA E. 2014. *Rheological properties of wheat flour slurry as indicators of baking quality of wheat flour.* Żywność Nauka Technologia Jakości, 6: 50–66.

ŻUK-GOŁASZEWSKA K., MAJEWSKA K.M., TYBURSKI J., GOŁASZEWSKI J. 2018. *Physical and technological properties of kernels and flour made from spelt grown in an organic farming system in north-eastern Poland.* J. Cereal Sci., 79: 501–507.