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MILLING QUALITY AND FLOUR STRENGTH OF THE GRAIN OF WINTER WHEAT GROWN IN MONOCULTURE

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ABSTRACT

The aim of this study was to determine the milling quality and flour strength of the grain of winter wheat grown in monoculture or after oil plants (winter rapeseed, spring rapeseed, white mustard and Indian mustard) in production systems characterized by varied intensity. Wheat grain harvested in three growing seasons (2006/2007, 2007/2008, 2008/2009) was analyzed to determine its bulk density, vitreousness, flour extraction rate, protein content, wet gluten concentrations, SDS sedimentation value and falling number.

Bulk density of grain and the percentage of kernels with partially or completely vitreous endosperm were lower in winter wheat grown in two-year monoculture than in winter wheat grown after oil plants. An increase in nitrogen fertilization rates (by 60 kg ha^{-1}) and two fungicide treatments improved kernel plumpness and grain vitreousness, in particular in winter wheat grown in monoculture.

The choice of forecrops had no significant influence on the protein content of wheat grain. The quality of the protein complex, including gluten content, was higher in the grain of wheat grown after oil plants than in the grain of winter wheat grown in monoculture. The grain of winter wheat grown after winter rapeseed was characterized by higher falling number than the grain of plants grown in short-term (2-year) monoculture. An increase in nitrogen fertilization rates (from 90 to 150 kg ha^{-1}) and protection against fungal infections (two fungicide treatments) also increased total protein content, wet gluten concentrations, the amount of SDS-insoluble protein and falling number. The noted improvements were more pronounced in the grain of winter wheat grown in monoculture than in the grain of winter wheat grown after oil plants.

Key words: winter wheat, forecrop, production intensity, grain quality assessment.

INTRODUCTION

The biological diversity of agricultural ecosystems in Europe has been decreasing steadily since the 1980s. Monocotyledonous cereal species have a predominant share of the crop structure. In European crop rotation systems, the average share of cereals is estimated at 77%, ranging from 70-74% in Germany, France, Great Britain and Poland to nearly 90% in Finland and Slovenia (Majewski, 2010). Monocultures significantly reduce wheat yield, which is determined by soil quality and the duration of monoculture. The grain yield of winter wheat grown after cereal forecrops or in short-term (2-3 year) monoculture is lower by 1 Mg ha^{-1}, i.e. by 14-30%, in comparison with winter wheat grown after oil plants (Weber, 2000; Wesołowski et al., 2007). Budzyński (2012) demonstrated that the grain yield of 6-8 year monocultures of winter wheat was 22% lower in comparison with the yield of wheat plants grown in a crop rotation scheme. In monocultures grown for 21-25 years, grain yield was reduced by 42%, and in monocultures grown for another 10 years – by 54%. The observed decrease in the yield of winter wheat monocultures can be minimized through the application of intensive production techniques, mainly nitrogen fertilization and antifungal protection.

Wheat monoculture farming, which results from the loss of biodiversity in agricultural ecosystems, can also affect the technological quality of flour (Woźniak et al., 2014). The selection of appropriate qualitative and quantitative technological parameters determines the extent to which a given cultivar's potential can be fully deployed (Dubis, 2012). Oilseed crops of the family *Brassicaceae* hold a leading position in the

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ranking of forecrops for winter wheat. Their percentage share of cropland in Europe has been increasing due to their significant role in food and energy security on the one hand (Jankowski et al., 2015), and in agricultural ecosystems on the other (Jankowski et al., 2014ab). The processing suitability of wheat is conditioned mainly by the cultivar, i.e. the genetic profile, but it can be considerably improved through the application of modern cultivation techniques (Biel and Maciorowski, 2012). The objective of this study was to determine the effect of forecrop species (oil plants of the family *Brassicaceae* or winter wheat) on the processing suitability of the grain of winter wheat grown as a successive crop. Winter wheat was cultivated in treatments characterized by varied production intensity (nitrogen fertilization and antifungal protection) to verify the working hypothesis that intensive production can minimize monoculture's adverse effects on grain quality.

MATERIAL AND METHODS

We analyzed the quality of winter wheat grain grown in a split-plot field experiment with three replications. The experimental variables were:

First-order variable – forecrop species: (Ia) winter rapeseed, (Ib) spring rapeseed, (Ic) white mustard, (Id) Indian mustard, (Ie) winter wheat;

Second-order variable – production technology with winter wheat as a successive crop.

Cultivation measures/growth stage		Production technology	
		Low-input	Medium-input
Top-dressing with nitrogen (kg ha^{-1})	BBCH 29	60	90
	BBCH 32	30	60
Disease control	BBCH 00	seed dressing (30 g triadimenol; 4 g imazalil; 3.6 g fuberidazole per 100 kg seeds)	seed dressing (30 g triadimenol; 4 g imazalil; 3.6 g fuberidazole per 100 kg seeds)
	BBCH 32	—	picoxystrobin 150 g ha^{-1}; flusilazole 125 g ha^{-1}; carbendazim 62.5 g ha^{-1}; proquinazid 30 g ha^{-1}
	BBCH 39	—	picoxystrobin 100 g ha^{-1}; flusilazole 75 g ha^{-1}; carbendazim 37.5 g ha^{-1}; famoxate 50 g ha^{-1}; flusilazole 53.35 g ha^{-1}

The following pre-sowing fertilization treatment was applied: 30 kg N ha^{-1} (ammonium nitrate), 17 kg P ha^{-1} (triple superphosphate) and 100 kg ha^{-1} K (potash salt). In each year of the study, winter wheat cv. Olivin was sown in the second half of September with the density of 450 dressed kernels per 1 m^2 of plot area. In spring, two nitrogen fertilization treatments (BBCH 29 and 32) were applied at the rate of 60 and 30 ha^{-1} (low-input production) or 90 and 60 ha^{-1} (medium-input production). Herbicide treatment was applied at the first leaf unfolded stage (BBCH 11) with 1,000 g ha^{-1} of pendimethalin and 500 g ha^{-1} of isoproturon in all production systems. In the low-input system, disease control was limited to seed dressing, whereas in the medium-input system, two chemical treatments were additionally applied at stages BBCH 32 and 29 (second-order factor in the experimental design). Each year, winter wheat was harvested in the first half of August. Plot size was 18 m^2.

Winter wheat was threshed, and grain samples of 2 kg were collected from every production system. Grain was analyzed to evaluate its bulk density (standard PN-73/R-74007:1973), vitreousness (standard PN-70/R-74008:1970), protein content (Kjeldahl method, ICC-Standard 105/2, Tecator system), SDS sedimentation value (Axford et al., 1978) and falling number (ICC-Standard 107/1).

The results of chemical analyses were processed by ANOVA in accordance with the experimental method. Mean values from every treatment were compared by Duncan's test.

LSD values were calculated for 5% error rate. The results were processed in the Statistica 10.1 PL application.

RESULTS

Weather conditions

There are two different climate zones in Poland that cause significant variations in weather conditions between years. In years characterized by favorable weather, the processing suitability of high-quality varieties of spring and winter wheat grain grown with the application of suitable cultivation measures can exceed grain purchasing standards. In less supportive years, even grain with the most favorable genetic traits may not conform to the above standards (Rozbicki, 2002). The processing suitability of winter wheat grain is most affected by weather conditions during grain formation and ripening stages. Moderate temperatures and adequate exposure to sunlight are required for the completion of the above grain development stages. High temperature can lower yield (premature drying of shoots and decrease in thousand seed weight) and deteriorate the processing suitability of grain. In our experiment, weather conditions during grain formation and ripening stages in the 2006/2007 season exceeded the requirements for winter wheat. In the last two growing seasons, mean daily air temperature after the heading stage was 0.3°C (2007/2008) and 1.3°C (2008/2009) lower than the optimum. Precipitation levels exceeded water requirements for wheat only in the 2008/2009 growing season. The first two years of the study were characterized by a water deficit that ranged from 36% (2006/2007) to 75% (2007/2008).

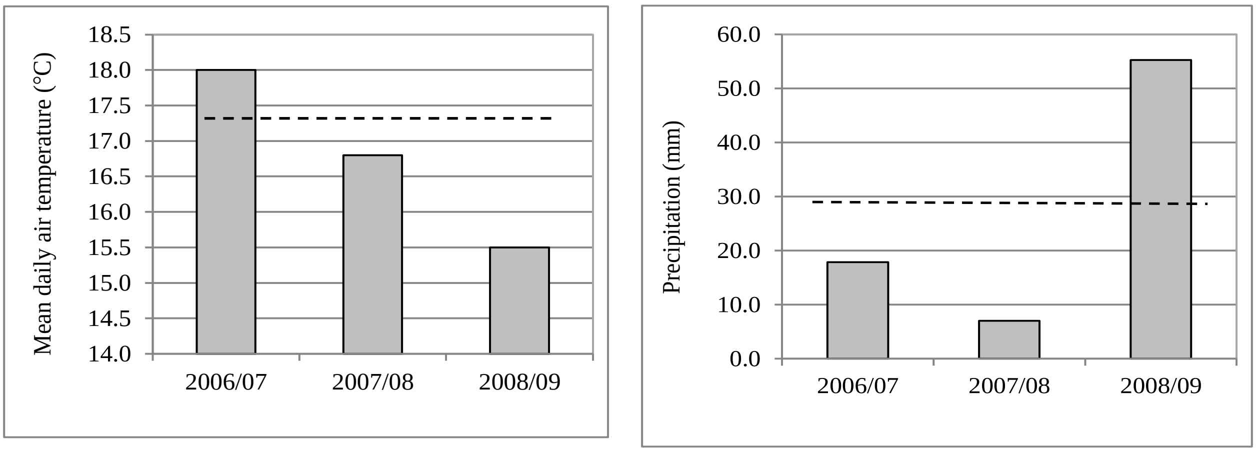

Figure 1. Precipitation and temperature conditions during the heading and ripening stages of winter wheat (optimal values for the Region of Warmia and Mazury; Dzieżyc, 1993)

Milling quality of wheat grain

Bulk density (test weight) of wheat grain was estimated at 77 kg hl^{-1}, and it was not significantly (±1%) affected by weather conditions throughout the experimental period. The grain of winter wheat grown in monoculture was characterized by significantly lower bulk density (by approx. 1 kg hl^{-1}) (Table 1).

Significant differences in grain vitreousness were noted between treatments (Table 2). In the first and second growing season, the percentage of kernels with partially or completely vitreous endosperm was estimated at only ca. 26% and 10%, respectively. Satisfactory vitreousness values (around 79%) were noted only in the third growing season. In absolute terms (9-point scale), the degree of grain vitreousness was estimated at 1° (2007/2008), 2-4° (2006/2007) and 8-9° (2008/2009). On average, the grain of winter wheat grown in monoculture and after Indian mustard was characterized by significantly lower vitreousness (Table 2)

An increase in nitrogen fertilization rates (by 60 kg ha^{-1}) and two fungicide treatments significantly improved kernel plumpness (by approximately 1% on average) and grain vitreousness (by approximately 11% on average) (Tables 1 and 2), in particular in winter wheat grown in monoculture.

Higher nitrogen fertilization rates and comprehensive fungicide treatments increased grain vitreousness more than two-fold in monocultures (Table 2).

Table 1. Bulk density (kg hl^{-1}) of wheat grain

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	76.8	76.7	77.2	78.0	75.0	76.7
	Medium-input	78.3	77.9	78.7	77.6	76.5	77.8
2007/2008	Low-input	77.8	77.3	77.8	77.3	77.3	77.5
	Medium-input	78.7	78.5	79.5	79.1	78.1	78.8
2008/2009	Low-input	76.1	75.9	76.2	75.3	74.8	75.7
	Medium-input	75.7	76.3	76.3	75.8	75.8	76.0
2006/2007	—	77.6	77.3	78.0	77.8	75.8	77.3
2007/2008		78.3	77.9	78.7	78.2	77.7	78.2
2008/2009		75.9	76.1	76.3	75.6	75.3	75.8
—	Low-input	76.9	76.6	77.1	76.9	75.7	76.6
	Medium-input	77.6	77.6	78.2	77.5	76.8	77.5
Mean		77.3	77.1	77.7	77.2	76.3	—
LSD: forecrop – 0.8; production technology – 0.3.							

Table 2. Vitreousness (%) of wheat grain

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	27.0	22.0	13.0	10.0	13.5	17.1
	Medium-input	28.0	27.5	39.0	12.5	27.5	26.9
2007/2008	Low-input	8.5	5.5	8.0	6.5	7.5	7.2
	Medium-input	9.5	11.0	7.5	19.0	11.5	11.7
2008/2009	Low-input	77.5	78.0	78.5	77.0	36.0	69.4
	Medium-input	92.0	90.5	88.5	78.0	90.5	87.9
2006/2007	—	27.5	24.8	26.0	11.3	20.5	26.0
2007/2008		9.0	8.3	7.8	12.8	9.5	9.5
2008/2009		84.8	84.3	83.5	77.5	63.3	78.7
—	Low-input	37.7	35.2	33.2	31.2	19.0	31.2
	Medium-input	43.2	43.0	45.0	36.5	43.2	42.2
Mean		40.4	39.1	39.1	33.9	31.1	—
LSD: forecrop – 3.2; production technology – 4.7.							

Wheat grain was characterized by a high flour extraction rate at 76% on average. Forecrop species and production intensity of winter wheat had no significant effect on the flour extraction rate (Table 3).

Table 3. Flour extraction rate (%)

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	76.1	75.9	76.6	76.7	74.7	76.0
	Medium-input	77.0	77.3	76.7	76.8	75.5	76.7
2007/2008	Low-input	76.9	78.2	78.7	79.0	78.4	78.2
	Medium-input	79.2	78.9	78.6	79.5	78.9	79.0
2008/2009	Low-input	74.6	75.1	74.3	74.8	74.6	74.7
	Medium-input	74.0	74.7	74.7	74.6	73.8	74.4
2006/2007	—	76.6	76.6	76.7	76.8	75.1	76.4
2007/2008		78.1	78.6	78.7	79.3	78.7	78.7
2008/2009		74.3	74.9	74.5	74.7	74.2	74.5
—	Low-input	75.9	76.4	76.5	76.8	75.9	76.3
	Medium-input	76.7	77.0	76.7	77.0	76.1	76.7
Mean		76.3	76.7	76.6	76.9	76.0	—
LSD: n.s.							

Flour strength of wheat grain

In the first two growing seasons, the protein content of wheat grain was significantly below standard requirements, and it was determined in the range of 101 to 123 g kg^{-1} DM of grain (1-4 on the 9-point scale) (Table 4). In the third growing season, the protein content of grain reached 119-142 g kg^{-1} DM of grain (3-8). Forecrop species had no significant impact on the protein content of grain. The protein content of winter wheat grain produced in a low-input system was somewhat higher than 108 g kg^{-1} DM of grain. An increase in nitrogen fertilization rates (from 90 to 150 kg ha^{-1}) and protection against fungal infections (two treatments) increased total protein content by 12% to 121 g kg^{-1} DM of grain (Table 4).

The grain of winter wheat grown in monoculture was characterized by significantly lower wet gluten concentrations than the grain of winter wheat grown after oil plants (Table 5).

The minimum required wet gluten levels (>26%) were noted only in the third growing season in winter wheat plants grown after winter rapeseed in the medium-input production system (Table 5). An analysis of the data for the entire experimental period indicates that the grain of winter wheat grown after winter rapeseed and white mustard was characterized by higher wet gluten concentrations. The lowest gluten content was noted in the grain of wheat plants grown in monoculture (Table 5).

Table 4. Total protein content (g kg^{-1} DM) of wheat grain

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	108.3	101.3	102.2	103.0	107.8	104.5
	Medium-input	116.6	113.1	115.6	110.8	118.8	115.0
2007/2008	Low-input	104.1	96.9	99.3	100.7	103.7	100.9
	Medium-input	112.8	113.9	114.0	119.7	114.9	115.1
2008/2009	Low-input	120.8	120.3	119.4	121.7	115.1	119.5
	Medium-input	135.4	135.2	133.2	134.5	128.0	133.3
2006/2007	—	112.5	107.2	108.9	106.9	113.3	109.8
2007/2008		108.5	1054	106.7	110.2	109.3	108.0
2008/2009		128.1	127.8	126.3	128.1	121.6	126.4
—	Low-input	111.1	106.2	107.0	108.5	108.9	108.3
	Medium-input	121.6	120.7	120.9	121.7	120.6	121.1
Mean		116.4	113.5	114.0	115.1	114.7	—
LSD: production technology – 1.3.							

Table 5. Wet gluten content (%) of wheat grain

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	21.1	17.5	18.6	18.6	18.4	18.8
	Medium-input	23.6	23.5	23.4	21.0	22.4	22.8
2007/2008	Low-input	17.4	13.4	15.4	13.2	14.9	14.9
	Medium-input	20.0	20.5	20.4	21.3	20.4	20.5
2008/2009	Low-input	25.6	22.7	22.9	23.6	20.40	23.0
	Medium-input	27.4	26.9	26.8	26.9	25.90	26.8
2006/2007	—	22.4	20.5	21.0	19.8	20.4	20.8
2007/2008		18.7	17.0	17.9	17.3	17.7	17.7
2008/2009		26.5	24.8	24.9	25.3	23.2	24.9
—	Low-input	21.4	17.9	19.0	18.5	17.9	18.9
	Medium-input	23.7	23.6	23.5	23.1	22.9	23.4
Mean		22.5	20.8	21.3	20.8	20.4	—
LSD: production technology – 0.6							

SDS sedimentation values were determined in the range of 70-78 ml (Table 6), and they were insignificantly affected by weather conditions throughout the experiment. Even in the first and second growing season when the harvested grain was characterized by relatively low concentrations of wet gluten, the volume of proteins insoluble in sodium dodecyl sulfate exceeded 68% (6-8° on the 9-point scale). SDS sedimentation values varied subject to forecrop species and production intensity.

The analyzed parameter was lower (by approximately 1-3%) in the grain of winter wheat grown in monoculture than in the grain of winter wheat grown after oil plants. An increase in nitrogen fertilization rates (from 90 to 150 kg ha^{-1}) and protection against fungal infections (two treatments) increased SDS sedimentation volume by more than 5 ml (Table 6).

Table 6. SDS-sedimentation test (ml)

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	73.0	67.0	66.5	65.5	69.5	68.3
	Medium-input	75.0	72.0	69.0	67.0	73.5	71.3
2007/2008	Low-input	77.0	72.0	72.0	73.0	72.0	73.2
	Medium-input	84.0	83.5	83.0	84.5	80.0	83.0
2008/2009	Low-input	74.5	77.0	76.0	76.5	74.5	75.7
	Medium-input	76.0	81.0	77.5	79.0	78.5	78.4
2006/2007	—	74.0	69.5	67.8	66.3	71.5	69.8
2007/2008		80.5	77.8	77.5	78.8	76.0	78.1
2008/2009		75.3	79.0	76.8	77.8	76.5	77.1
—	Low-input	74.8	72.0	71.5	71.7	72.0	72.4
	Medium-input	78.3	78.8	76.5	76.8	77.3	77.6
Mean		76.6	75.4	74.0	74.3	74.7	—
LSD: production technology – 1.6.							

The average falling number was determined in the range of 328-357 s (Table 7). In each year of the study, the discussed parameter exceeded the minimum requirements (200 s) for wheat cultivars in the Polish quality classification system. The grain of winter wheat grown after winter rapeseed was characterized by higher falling number (by approximately 19 s) than the grain of winter wheat grown in monoculture. Intensification of the production process also improved the falling number of wheat flour by approximately 15 s (Table 7).

The results of the study validate the hypothesis that intensification of the production process of winter wheat grown in two-year monoculture significantly improves milling quality and flour strength.

Table 7. Falling number (s) of wheat grain

Growing season	Production technology	Forecrop					Mean
		Rapeseed		Mustard		Winter wheat	
		winter	spring	white	Indian		
2006/2007	Low-input	304	285	324	281	317	302
	Medium-input	357	317	284	299	289	309
2007/2008	Low-input	329	324	285	295	318	310
	Medium-input	326	350	306	337	338	331
2008/2009	Low-input	397	417	426	359	361	392
	Medium-input	426	415	403	395	413	410
2006/2007	—	331	301	304	290	303	306
2007/2008		328	337	296	316	328	321
2008/2009		412	416	415	377	387	401
—	Low-input	343	342	345	312	332	335
	Medium-input	370	361	331	344	347	350
Mean		357	351	338	328	339	—
LSD: production technology – 11							

DISCUSSION

The processing suitability of grain is determined by its morphological and anatomical properties, in particular bulk density and vitreousness. Bulk density is a measure of kernel plumpness, whereas vitreousness characterizes endosperm microstructure and is directly associated with the content of gluten proteins in grain (Daniel and Triboi, 2000). In this study, the grain of winter wheat grown in monoculture was characterized by significantly lower bulk density and vitreousness. In the work of Woźniak (2006b) and Jaskulska et al. (2013), the application of non-cereal forecrops (peas, potatoes) increased the bulk density of winter wheat grain by approximately 1%. In an earlier study (Woźniak, 2004), the cited author demonstrated that a higher share of spring wheat in crop rotation (25, 50, 75 and 100%) decreased the bulk density of grain by up to 6%.

The results of studies evaluating the impact of intensified production on the milling quality of wheat grain are often contradictory. Various authors have demonstrated that bulk density of wheat grain was not influenced (Woźniak, 2006a), was reduced (Budzyński et al., 2004) or improved (Narkiewicz-Jodko et al., 2008; Ellmann, 2011a) by high-input cultivation measures. In this study, an increase in nitrogen fertilization rates (by 60 kg ha^{-1}) and antifungal protection (two treatments) improved kernel plumpness and grain vitreousness. In other studies (Budzyński et al., 2004; Narkiewicz-Jodko et al., 2008; Ellmann, 2011a), intensified nitrogen fertilization also increased the percentage of vitreous kernels in wheat crops.

Flour extraction rate is the key determinant of the milling quality of grain. This parameter is highly correlated with kernel plumpness. High flour extraction rates are reported in plump kernels with large endosperms. In our study, wheat grain was characterized by a high flour extraction rate of approximately 76%. The discussed parameter was not significantly influenced by the choice of forecrop species or production intensity. In a study by Budzyński et al. (2004), nitrogen fertilization and fungicide treatment had a minor (statistically non-significant) effect on flour extraction rate, whereas Dubis (2012) reported that fungicide treatment and higher nitrogen fertilization rates improved the flour extraction rate of spring wheat.

The protein content of grain is one of the most important determinants of flour strength. In this experiment, forecrop species had no significant influence on the protein content of winter wheat grain (Table 4). In a study by Woźniak (2006b), the highest protein content was reported in the grain of winter wheat grown after potatoes (141 g kg^{-1} DM) and in three-year monoculture (140 g kg^{-1} DM), whereas significantly lower protein concentrations (136 g kg^{-1} DM) were noted in the grain of crops grown after peas. The protein content of winter wheat grain is highly influenced by production intensity, in particular nitrogen fertilization rates (Borkowska and Grundas, 2007; Narkiewicz-Jodko et al., 2008; Weber et al., 2008; Shi et al., 2010; Dubis, 2012; Bobrecka-Jamro et al., 2013). In this study, an increase in nitrogen fertilization rates (from 90 to 150 kg ha^{-1}) and protection against fungal infections (two treatments) increased the total protein content of wheat grain by 12%.

The gluten content of wheat grain is a critical determinant of its processing suitability. In this study, the grain of winter wheat grown in monoculture was characterized by significantly lower (by 0.4-2.1%) wet gluten content than the grain of winter wheat grown after oil plants. Woźniak (2004, 2006b) also demonstrated a strong correlation between forecrop species and the wet gluten content of grain in a successive crop (winter and spring wheat). Wet gluten content was significantly higher in the grain of winter wheat grown after potatoes (34.0%) and in three-year monoculture (33.3%) than in winter wheat grown after peas (32.7%) (Woźniak, 2006b). An increase in the share of spring wheat in crop rotation (from 25% to 100%) decreased (from 34% to 32%) the wet gluten content of grain (Woźniak, 2004). In this experiment, the minimum wet gluten requirements for winter wheat grain were met only in the third growing season in the medium-input production system. The beneficial effects of higher nitrogen fertilization rates on the gluten content of spring and winter wheat grain were also observed by other authors (Peltonen and Virtanen, 1994; Podolska et al., 2005; Gąsiorowska and Markiewicz, 2007; Sułek and Podolska, 2008; Ellmann, 2011a; Dubis, 2012).

The quality of gluten proteins is analyzed in evaluations of flour strength (Podolska, 2008). Protein quality is often assessed based on SDS sedimentation values that indicate the size of protein aggregates. In this study, SDS sedimentation values were determined at 70-78 ml, subject to forecrop species and production intensity. The volume of SDS-insoluble proteins was smaller (by approximately 1-3%) in the grain of winter wheat grown in monoculture than in the grain of winter wheat grown after oil plants. Similar results were noted by Woźniak (2006b). In an earlier study, the cited author (Woźniak, 2004) demonstrated that a higher share of spring wheat in crop rotation improved SDS sedimentation values by approximately 9%. In this study, an increase in nitrogen fertilization rates (from 90 to 150 kg ha^{-1}) and two fungicide treatments increased SDS sedimentation volume by more than 5 ml. The beneficial effects of nitrogen fertilization on the quality of protein in the grain of winter and spring wheat were also observed by other authors (Gianibelli and Sarandon, 1991; Budzyński et al., 2004; Podolska et al., 2005; Piekarczy, 2010; Ellmann, 2011b; Dubis, 2012). In the work of Podolska et al. (2005) and Dubis (2012), fungicide treatment lowered protein quality in wheat grain.

The enzymatic properties of grain, in particular the activity of α-amylase expressed by the falling number, significantly influence flour strength. The grain of winter wheat grown after winter rapeseed was characterized by higher falling number (by around 19 s) than the grain of monoculture crops. Intensified production also led to an improvement in the falling number of wheat flour (by around 15 s). Significant correlations between falling number, forecrop species and cultivation measures (fertilization and fungicide treatment) were also noted by Woźniak (2004, 2006b), Budzyński et al. (2004), Narkiewicz-Jodko et al. (2008) and

Ellmann (2011b). According to Budzyński et al. (2004), the discussed parameter is also significantly affected by weather conditions during grain ripening. For this reason, in other studies, cultivation measures had a different effect on the falling number of grain than that reported in this experiment (Cacak-Pietrzak et al., 2008; 2009; Podolska, 2007; Dubis, 2012).

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