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Implementation of the Nitrates Directive and its influence on the baking value of winter wheat

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A b s t r a c t. The purpose of this work was to determine the effects of lowering nitrogen fertilization on the baking value of winter wheat cultivars and it also serves as a response to the implementation of the Nitrates Directive. Nine wheat cultivars were tested, which represented four technological groups that are included in the Polish National List of Agricultural Plant Varieties. The wheat was cultivated over a period of two seasons as a two-factor field experiment designed to utilize the method of randomized blocks, in four replicates. Two distinct applications of nitrogen fertilizer were adopted in the experiment: 120 and 200 kg ha^{-1} N. The Zeleny index, the quantity of protein and gluten, and the alveograph characteristics were determined in order to assess the baking value of the wheat. Lowering the level of nitrogen fertilization to 120 kg ha^{-1} N caused a negative effect on the quality of the wheat, with regard to a lower Zeleny index, protein and gluten quantity. The alveograph parameters were affected by wheat cultivars while the nitrogen dose applied and the crop year had no effect. Lowering the degree of nitrogen fertilization of wheat crops to comply with the Nitrates Directive implementation may cause the production of wheat with a lower protein quantity which is a crucial parameter in grain trading. However, the reduction in nitrogen fertilization causes only a slight, statistical non-significant reduction in the alveograph characteristics of wheat flour dough.

K e y w o r d s: alveograph characteristics, dough properties, grain quality, nitrogen fertilization, wheat genotypes

INTRODUCTION

The EU Nitrates Directive (91/676/EEC) is an integral part of the Water Framework Directive and is one of the basic tools in the preservation of water quality to counteract the adverse effects of agricultural pressures (EU Commission, 1991). The implementation of Nitrates Directive 91/676/EEC in Poland was introduced by the Regulation of the Government (Dz. U. 2020 poz. 243). The purpose of the Nitrates Directive is to bring about a reduction of water pollution generated or induced by nitrates from an agricultural origin and prevent further such pollution. One of the first, key recommendations for farmers is not to exceed the annual nitrogen dose of 170 kg ha^{-1}. The application of nitrogen fertilizers must be preceded by an analysis of the mineral composition of the soil – on this basis, the maximum fertilizer dose is calculated. One part of the Codes of Good Agricultural Practice is the establishment of a fertilizer scheme on a farm-by-farm basis and the keeping of documentation concerning fertilizer application (Mihăiescu *et al.*, 2010).

According to the amount of cereals harvested, common wheat (*Triticum aestivum* L.) is globally the second largest crop and only exceeded by maize. The world production

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of wheat is 766 million tonnes, which includes 156 million tonnes in the EU. With 10.8 million tonnes of wheat harvested in 2019, Poland was the 15th largest wheat producer in the world and the 4th largest in the EU (FAOSTAT, 2021). More than 50% of wheat production is used to manufacture baked goods and confectionery.

The quality of the wheat grain determines the strategy for its use, therefore not only the yield but also the quality of the grain produced is important. The most important component of plant nutrition, which often to a great extent determines not only the wheat yield level, but most particularly the grain baking quality is nitrogen (Valdés Valdés *et al.,* 2020). It is also one of the most mobile plant nutrients in the soil. Therefore, it is important to evaluate the use of high nitrogen fertilizer rates, because unsuitable nitrogen doses lead to an increased rate of nitrate leaching (Huang *et al.*, 2018) which contributes to the eutrophication of surface waters.

Grain quality and the rheological properties of the dough produced using the flour from that grain are for the most part influenced by the following factors: weather conditions (temperature, rainfall), the genotype, agronomy trials especially nitrogen fertilization and the complex interaction of these factors (Vázquez *et al.,* 2012; Kaya and Akcura, 2014; Rozbicki *et al.,* 2014). The significance of the impact of these elements is increasing for plant breeders who create wheat cultivars with a high degree of crop potential together with specific and consistent quality characteristics in order to meet market needs for farmers, grain traders and end-use processors (Kaya and Sahin, 2015).

The most important quality parameters in grain trading are: wheat grain gluten content, protein content and the sedimentation index, which characterizes both the milling and baking quality. In commercial contracts, the requirements for protein content are determined according to the purpose of the flour in order to produce a specific assortment of bread. Low protein flour (8-10% dry basis, d.b.) with a low gluten content is used to produce wafers, cookies and biscuits. For leavened breads, however, flour with a higher protein content (12-15% d.b.) is characterized by a strong gluten complex as a favourable degree of extensibility is required (Hui *et al.*, 2006). These parameters are largely influenced by the cultivar used, the available nitrogen, and the moisture and temperature conditions under which the crop is grown (Saint Pierre *et al.,* 2008; Valdés Valdés *et al*., 2020). Valdés Valdés *et al*. (2020) noted that under rainy conditions, the nitrogen treatments (0, 100, 200 and 300 kg N ha^{-1}, respectively) did not influence grain hardness, the test weight, flour yield and ash content, but the grain protein content increased significantly (6, 7 and 10% with N rates of 100, 200 and 300 kg N ha^{-1}, respectively), as compared to the control (0 kg N ha^{-1}). The sedimentation volume increased by 5, 9 and 12% with the application of 100, 200 and 300 kg N ha^{-1}, respectively in comparison with the control (0 kg N ha^{-1}) (Valdés Valdés *et al*., 2020). The grain quality parameters based on protein quantity and quality (gluten content, gluten index, sedimentation value) may be essentially improved through crop management experience, in particular by the nitrogen fertilization level (Rozbicki *et al*., 2015). The results of the work of Denčić *et al.* (2011) who studied a large group of wheat genotypes originating from 28 countries showed considerable variances in the rheological properties of dough depending on the cultivar used, *i.e*., water absorption, farinograph quality number and baking value. The variation in the baking score was 10 times higher between the varieties than across the harvest years, in contrast to the results obtained by Rozbicki *at al.* (2015). They affirmed that most of the baking quality traits are influenced far more by the weather conditions (*i.e.* location and year) than by the genotype (cultivars). The constituents of the degree of variance showed the particularly substantial influence of the crop season on water absorption, loaf volume and baking score, as well as the notable impact of the environment on protein content and dough development time.

Most of the wheat available on the world market is traded based upon alveograph requirements which describe dough resistance to extension and imitates the uni- or biaxial deformation of dough which takes place during fermentation and oven rise (Codina *et al*., 2012; Kaya and Sahin, 2015). The stages of the alveograph procedure simulates the sheeting, rounding and moulding of the dough portion during the baking process (Dapčević Hadnađev *et al*., 2011). The alveograph test is a method which is used to an increasing extent by trading companies for the determination of the rheological properties of dough which add to the information that was previously provided by indirect methods which are commonly used such as the Zeleny sedimentation index, and the quantity of protein and gluten. Alveograph parameters, such as the baking value ‘W’ and ‘P/L’ index (tenacity to extensibility ratio) have become the basis of the quality system for wheat grain evaluation in France, Spain, Italy and Argentina. Alveograph parameters are becoming increasingly widespread in other regions of the world and in various countries (including South America, Australia and the Far East, the United Kingdom, the United States) (Carson and Edwards, 2009; Mironeasa and Codina, 2013; Sanchez-Garcia *et al*., 2015). Based on the variations in these parameters of wheat flours, the preferable uses for different batches of wheat flour were recommended, for example, for bread, baked rolls and pastries (Jeantet *et al.*, 2016).

The purpose of this work was to determine the effects of lowering nitrogen fertilization in response to the implementation of the Nitrates Directive on the baking value of winter wheat cultivars harvested in Poland under two levels of a nitrogen fertilization system. The research hypothesis assumed that changes in grain quality caused by lowering the levels of nitrogen fertilization will produce varied responses according to the cultivars/genotypes studied and the harvest year. However, it is possible to indicate the cultivars for which a further increase in nitrogen fertilization does not result in a higher baking value ‘W’, and the ones that produce flour that is suitable for pastry making or baking purposes.

MATERIAL AND METHODS

The research work concerns nine winter wheat cultivars representing four technological groups approved by the Polish National List of Agricultural Plant Varieties which is issued yearly by COBORU (The Research Centre for Variety Testing): elite bread, E (*cv.* ‘Astoria’), quality bread, A (*cv.* ‘Bamberka’, ‘Kepler’, ‘Meister’ and ‘Oxal’), bread, B (*cv.* ‘Fidelius’, ‘Kampana’ and ‘KWS Dacanto’), and also the other included feed cultivars, C (‘Forkida’) group.

Field trials were conducted during the 2017-2018 and 2018-2019 growing seasons at the Experimental Station in Osiny (51°28′45 N 22°03′16 E), by the Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB) Puławy, Poland. The soil was a pseudopodzolic, class IIb soil belonging to a very good rye soil complex which is characteristic for the region. Winter rape was the forecrop. Before the onset of the trial the soil was analysed down to a depth of 30 cm. The soil was characterized by 6.23 pH_{KCl}, and the soil fertility indicators were 20.5 mg of K_2O, 26.3 mg of P_2O_5 and 6.8 mg of Mg per 100 g of soil. Two nitrogen fertilization doses of 120 and 200 kg ha^{-1} N were applied. The Nitrogen in the planned total dose of 120 and 200 kg ha^{-1} was applied in divided doses, specifically, 40% after the resumption of spring vegetation, 30% at the stem elongation stage and 30% at the heading stage. Winter wheat was sown on October 4th, 2017, and on September 28th, 2018 (optimal dates) at the seed rate of 450 germinable kernels per m^2. The area of the harvested land plot was 30 m^2. Pre-sowing practices such as pre-sowing ploughing and mineral fertilization (NPK) were completed before sowing. A 350 kg ha^{-1} dose of Polifoska 6-NPK (6 20 30) fertilizer was applied, which was at a concentration equivalent to 21 kg of N, 70 kg of P_2O_5 and 105 kg of K_2O per ha. All of the winter wheat cultivars were chemically protected against pests. Weed control consisted of the application of 1.0 l ha^{-1} of 675 SL + 0.6 l ha^{-1} of Medax Top + 1.5 l ha^{-1} of Capalo. Disease control consisted of the application of 1.0 l ha^{-1} of Tilt Turbo at the flag leaf stage and 2.0 l ha^{-1} of Adaxar Plus, after blossoming. Pests control consisted of the application of 0.3 l ha^{-1} of Fury 100 EW at the flag leaf stage. The crop was harvested at full maturity on July 28th, 2018, and on August 8th, 2019.

The protein content (ISO 20483:2013), gluten quantity (ISO 21415-2:2015) and Zeleny sedimentation index (ISO 5529:2007) were determined in order to evaluate the baking value of the tested wheat cultivars. A grinder (FN 3100, Perten InstrumentsAB, Sweden) was used to mill the grain samples to wholemeal flours to conduct protein and gluten quantity analyses. Samples for the Zeleny sedimentation test were prepared by grinding the wheat to flour using a Sedimat laboratory mill (Brabender GmbH and Co. KG, Germany). The rheological characteristics of the dough were determined using an alveograph test (ISO 27971:2015). The wheat samples were moistened with water until a moisture value of 16% was achieved. A rotary blender (ChopinTechnologies, France) was used to distribute the water evenly across the surface of the grains. After being left overnight for 24 ± 1 h, the wheat samples were milled using a laboratory mill, Chopin-Dubois1 (ChopinTechnologies, France) in order to obtain flour for the measurement of the rheological characteristics of the dough using an AlveographNG (ChopinTechnologies, France). Each alveograph curve was analysed with respect to the following parameters: ‘W’ – baking strength of the flour (area under the curve), ‘P’ – dough deformation resistance, ‘L’ – dough biaxial extensibility (measure of how much dough can be extended before it breaks), ‘P/L index’ – configuration ratio (ISO 27971:2015).

The results were statistically estimated using a one-way analysis of variance (ANOVA) with a subsequent Tukey’s HSD test. The four main factors were: the wheat cultivar used, the technological group according to COBORU, the nitrogen fertilization used and the harvest year. Correlations between the alveograph characteristics and Zeleny sedimentation index, protein and gluten quantity were assessed with a significance level of $p < 0.05$ and $p < 0.01$. The correlation and principal component analysis (PCA) was performed on the average results of each cultivar in order to show how the cultivars were differentiated in terms of the tested traits and also to show the relationship between the individual parameters. Data were analysed using Statistica 13 software.

RESULTS AND DISCUSSION

The impact that protein quantity and quality have on both the baking properties of wheat cultivars and on the baking process may be determined by estimating the water absorption ability, dough stability, resistance and elasticity (Dhaka *et al.*, 2012). A high dough yield and high-volume bread are obtained from flour with a high protein content (Codina and Paslaru, 2008). The wheat grain that has been harvested in recent years in Poland is characterized by a protein content in the range of 8.6 to 17.5% d.b. (Szafrańska 2021). The protein quantity of the analysed wheat cultivars ranged from 10.8 to 14.5% d.b. (Table 1) which indicates that the flour obtained from the tested samples is appropriate for the production of many types of bread, cakes, cookies and pastries (Hui *et al.*, 2006). The protein content depended on the wheat cultivar used, the technological group and the degree of nitrogen fertilization (Table 1). The highest average protein content was noted for

Table 1. Qualitative features of winter wheat cultivars

Factor	Protein content (N x 5,7) (% d.b.)	Gluten content (%)	Zeleny sedimentation index (cm^3)	Alveograph parameters			
				W ($\times 10^{-4}$J)	P (mm)	L (mm)	P/L
Wheat cultivar							
Astoria	$13.3^{a} \pm 1.1$	$29.3^{a} \pm 3.4$	$46^{a*} \pm 12$	$340^{a*} \pm 71$	$98^{c*} \pm 9$	108 ± 35	1.05 ± 0.54
Bamberka	$12.9^{ab} \pm 0.6$	$29.8^{a} \pm 1.3$	$43^{ab*} \pm 4$	$357^{a*} \pm 34$	$124^{a*} \pm 9$	86 ± 17	1.51 ± 0.36
Fidelius	$12.4^{ab} \pm 0.6$	$26.2^{ab} \pm 2.4$	$34^{abc*} \pm 15$	$242^{ab*} \pm 18$	$96^{c*} \pm 13$	71 ± 10	1.39 ± 0.41
Forkida	$11.8^{ac} \pm 0.7$	$26.0^{ab} \pm 2.1$	$25^{bc*} \pm 7$	$88^{b*} \pm 14$	$37^{d*} \pm 4$	88 ± 16	0.43 ± 0.06
Kampana	$12.5^{ab} \pm 0.5$	$28.9^{ab} \pm 1.6$	$30^{abc*} \pm 7$	$170^{b*} \pm 37$	$59^{c*} \pm 6$	112 ± 15	0.53 ± 0.05
Kepler	$12.1^{abc} \pm 0.3$	$27.8^{ab} \pm 1.9$	$28^{abc*} \pm 9$	$201^{ab*} \pm 80$	$78^{bc*} \pm 2$	80 ± 37	1.34 ± 1.06
KWS Dacanto	$11.4^{c} \pm 0.6$	$24.6^{b} \pm 2.2$	$22^{c*} \pm 10$	$176^{b*} \pm 70$	$79^{bc*} \pm 5$	64 ± 31	1.59 ± 1.05
Meister	$12.7^{ab} \pm 0.6$	$28.3^{ab} \pm 2.0$	$42^{ab*} \pm 7$	$199^{ab*} \pm 17$	$80^{bc*} \pm 3$	91 ± 13	0.90 ± 0.18
Oxal	$12.1^{abc} \pm 0.7$	$26.4^{ab} \pm 2.2$	$30^{abc*} \pm 10$	$216^{ab*} \pm 53$	$79^{bc*} \pm 6$	86 ± 19	0.95 ± 0.25
Technological group according to COBORU							
Elite bread (E)	$13.3^{a} \pm 1.1$	29.3 ± 3.4	$46^{a} \pm 12$	$340^{a*} \pm 71$	$98^{a*} \pm 9$	107 ± 35	1.05 ± 0.54
Quality bread (A)	$12.4^{bc} \pm 0.6$	28.1 ± 2.1	$36^{ab} \pm 10$	$243^{a*} \pm 82$	$90^{a*} \pm 21$	86 ± 21	1.17 ± 1.17
Bread (B)	$12.1^{c} \pm 0.7$	26.6 ± 2.7	$29^{b} \pm 12$	$196^{ab*} \pm 54$	$78^{ab*} \pm 18$	82 ± 29	1.17 ± 0.76
Other (C)	$11.8^{c} \pm 0.7$	26.0 ± 2.1	$25^{b} \pm 7$	$88^{b*} \pm 14$	$37^{b*} \pm 4$	88 ± 16	0.43 ± 0.06
Nitrogen fertilization (kg ha^{-1} N)							
120	$12.0^{b*} \pm 0.6$	$26.3^{b*} \pm 2.3$	$29^{b*} \pm 10$	213 ± 78	81 ± 25	83 ± 18	1.03 ± 0.42
200	$12.7^{a*} \pm 0.8$	$28.7^{a*} \pm 2.2$	$38^{a*} \pm 12$	229 ± 105	82 ± 24	92 ± 31	1.12 ± 0.81
Harvest year							
2018	12.3 ± 0.7	27.8 ± 2.3	$37^{a*} \pm 10$	221 ± 83	80 ± 26	90 ± 16	0.93 ± 0.41
2019	12.4 ± 0.9	27.1 ± 2.8	$30^{b*} \pm 13$	221 ± 102	82 ± 23	84 ± 32	1.22 ± 0.79

a, b, c, d – values marked with the same letters do not differ significantly at $p < 0.05$ and $*p < 0.01$, respectively, d.b. – dry basis.

the wheat cultivar ‘Astoria’ (13.3% d.b.) and the lowest for ‘KWS Dacanto’ (11.4% d.b.). The wheat cultivar that was admitted to the elite bread group (E) was characterized by a significantly higher protein content than the wheat cultivars admitted to the bread wheat (B) and the other included feed cultivars (C) groups.

The wheat samples cultivated under a higher level of nitrogen fertilization (200 kg ha^{-1} N) were characterized by a higher protein content (on average 0.7% d.b. higher) than the cultivars that were cultivated under a lower level of nitrogen fertilization (120 kg ha^{-1} N) (Table 1). Among the analysed cultivars, the exception was the ‘Kepler’ cultivar, for which a higher dose of nitrogen fertilization resulted in a reduction in the protein content (Fig. 1A). The differences between the protein content analysed in the tested wheat samples of *cv*. ‘Astoria’ that were cultivated under a higher and lower level of nitrogen fertilization was 2.5 points of d.b. Bayoumi and El-Demardash (2008) proved that less starch is accumulated in the grain, and a higher grain protein concentration, along with high grain yield results as a response to a high rate of N application in the six tested wheat crossbreeds. Vázquez *et al.* (2012) and Kaya and Akcura (2014) pointed out that the environment provides a greater variation in protein content than the genotype.

Gliadins and glutenins are the two main components of the gluten fraction. This plastic-elastic fraction is responsible for the physical properties of wheat flour dough (Codina and Paslaru, 2008). The gluten content of the tested wheat cultivars ranged from 22.6 to 32.7% (Fig. 1 B) and depended on the wheat cultivars grown and the applied regime of nitrogen fertilization (Table 1). The highest gluten content was noted for the wheat cultivars of ‘Astoria’ and ‘Bamberka’ (29.3 and 29.8%, respectively) and the lowest for the cultivar ‘KWS Dacanto’ (24.6%). The greatest degree of variability in gluten content was found for the cultivar ‘Astoria’ (standard deviation, SD 3.4) whereas the lowest value occurred for the ‘Bamberka’ cultivar (SD 1.3). Nitrogen fertilization has a substantial influence over the quality of the protein found in the wheat grain (Bayoumi and El-Demardash, 2008; Xue *et al.* 2019). The higher level of nitrogen fertilization had a positive effect on increasing the gluten content, this was also shown in previous studies

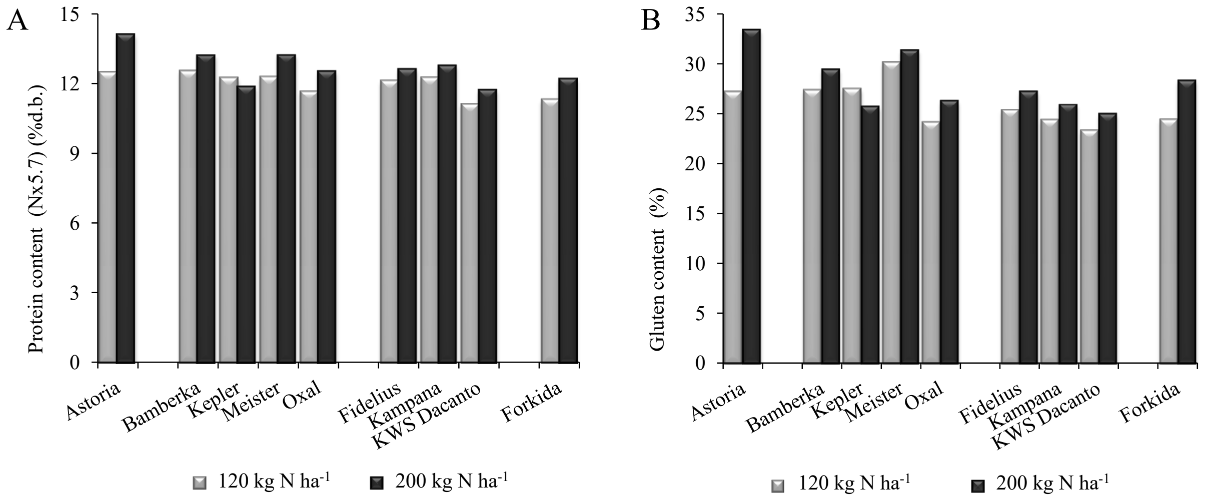

Fig. 1. Protein (A) and gluten (B) content of the tested wheat cultivars depends on nitrogen fertilization (the average value from the crop year of 2018 and 2019). $LSD_{0.05}$ for PC, 2014, nitrogen fertilization (NF) – 0.162; $LSD_{0.05}$ for interaction PC, 2015, NF – 0.147; $LSD_{0.05}$ for interaction GC, 2014, NF – 4.073; $LSD_{0.05}$ for interaction GC, 2015, NF – 1.199.

by Szafrańska *et al.* (2015). The studies of Vázquez *et al.* (2012) and Kaya and Akcura (2014) showed that the quality parameters were determined for the most part by the environment, while the effect of the genotype had less influence on the whole. However, Vázquez *et al.* (2012) also noted the variability in quality between the genotypes and hence highlighted the fact that different genotypes produce different qualities of wheat grain in various environments. A statistical analysis of the data showed that there was no influence of the crop year on the gluten content. For this reason the results produced by each cultivar were presented in terms of figures which expressed the average value of each year. The wheat cultivated under a higher level of nitrogen fertilization (200 kg ha^{-1} N) was characterized by a higher gluten content by an average of 2.4% in comparison to the cultivars that were cultivated under a limited level of nitrogen fertilization (120 kg ha^{-1} N) (Table 1). Among the analysed cultivars the exception was cultivar 'Kepler', for which a higher dose of nitrogen fertilization resulted in a reduction of gluten quantity in both years by 1.8% (Fig. 1B). No effect of the higher nitrogen fertilization dose on gluten content was observed on the rest of the tested cultivars. The greatest influence of nitrogen fertilization on the gluten content of the tested cultivars was observed on the cultivar 'Astoria' (6.2% on average).

The Zeleny sedimentation index can be used to determine the properties of gluten proteins in both quantitative and qualitative terms (Hrušková *et al.*, 2006). The values of the Zeleny sedimentation index are within the range of 7 cm^3 which is characteristic for feed wheat with a low quality of gluten proteins to 75 cm^3 – for strong wheat with a very good gluten quality. A highly favourable baking value characterizes wheat flour with a Zeleny sedimentation index above 40 cm^3. The wheat used in general baking should have a range of between 30 and 40 cm^3. Wheat with a Zeleny index lower than 20 cm^3 is generally considered to be inappropriate for baking (Jeantet *et al.*, 2016). According to this criterion, 31% of the tested wheat samples were characterized by a Zeleny sedimentation index of over 40 cm^3 which indicates the very favourable baking potential of the wheat cultivars. 17% of the tested wheat samples were characterized by a Zeleny sedimentation index of below 20 cm^3 which means that the level of gluten protein is unsuitable for bread production, however, the flour obtained from such wheat grain can be used for biscuit making. In this group there were three samples of bread cultivar 'KWS Dacanto' and two samples of feed cultivar 'Forkida'. The highest Zeleny sedimentation index was noted in wheat samples from the harvest year of 2018 (37 cm^3), and the lowest for the harvest year of 2019 (30 cm^3) (Table 1). Cultivar 'Astoria' was admitted to the best quality elite group and was characterized by the highest Zeleny sedimentation index (46 cm^3) with one of the highest degrees of variability of this parameter (standard deviation 12 cm^3) in comparison with other wheat cultivars. The variability in the Zeleny sedimentation index depends on the variety, this was confirmed by Valdés Valdés *et al.* (2020).

The rheological characteristics of flour differed significantly according to the particular wheat cultivar used, as there are long-range effects on the end use quality of the wheat depending on which cultivar is cultivated (Amjid *et al.,* 2013). The Alveograph dough strength 'W', a criterion of baking quality in the tested wheat flour samples was found to be in the range of 69 to 420×10^{-4} J which is in accordance with the results of Dapčević Hadnađev *et al.* (2011) and Jeantet *et al.* (2016), who pointed to its extensive technological suitability. In comparison with previous studies by Hrušková and Šmejda (2003) concerning the quality evaluation of wheat harvested in the Czech Republic, wheat cultivated in Poland was characterized by

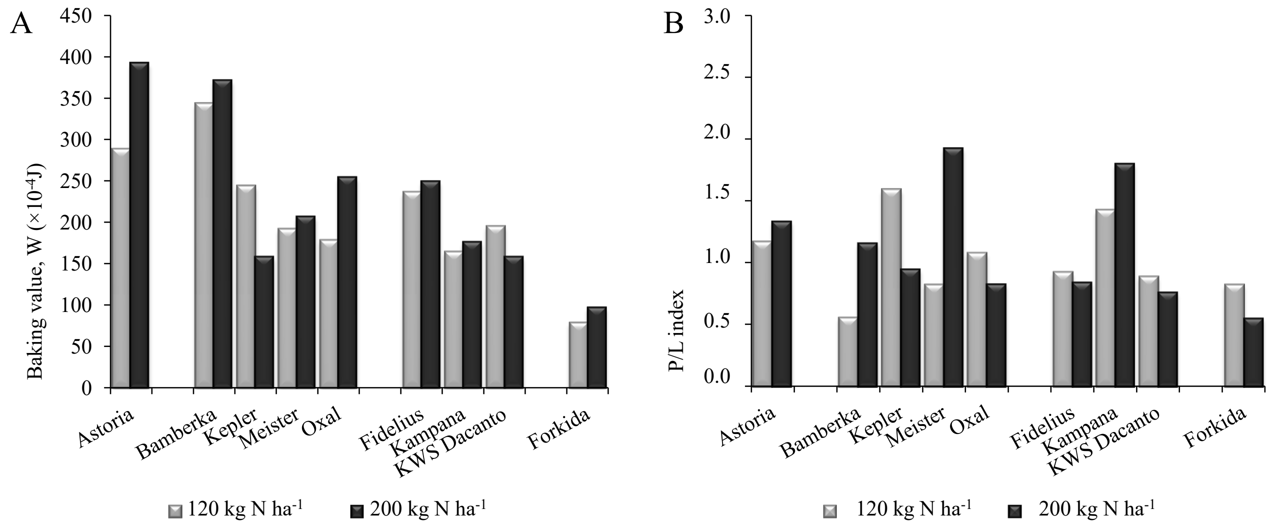

Fig. 2. Baking value W ($\times 10^{-4}$ J) (A) and the tenacity to extensibility ratio (P/L index) (B) of the tested wheat cultivars depend on the rate of nitrogen fertilization (the average value from the crop year of 2018 and 2019). $LSD_{0.05}$ for interaction W, 2014, nitrogen fertilization (NF) – 86.64; $LSD_{0.05}$ for interaction W, 2015, NF – n.s.; $LSD_{0.05}$ for interaction P/L, 2014, NF – 0.724; $LSD_{0.05}$ for interaction P/L, 2015, NF – n.s.

the wider range of the baking value 'W' (78-392×10^{-4} J as compared to 79-286×10^{-4} J). According to Bordes *et al.* (2008) good quality wheat and elite wheat with the highest quality should be characterized by a dough strength 'W' value in the range of 220 to 300×10^{-4} J and greater than 300×10^{-4} J, respectively, whereas the baking value 'W' of confectionary wheat should range from 160 to 200×10^{-4} J (Dapčević Hadnađev *et al.*, 2011). Most of the tested wheat cultivars (40%) were appropriate for the production of crescent, wheat and toast bread ('W' in the range 200-300×10^{-4} J). 20% of the tested wheat samples were characterized by a dough strength 'W' of over 300×10^{-4} J which is appropriate for the production of frozen dough, pizza dough or hamburger buns. 28% of the tested wheat cultivars were suitable for household use, biscuits, cookies and baguettes ('W': 100-200×10^{-4} J) (Jeantet *et al.*, 2016).

The alveograph baking value 'W' varied between the tested cultivars and the technological groups (Table 1). The wheat cultivar 'Forkida' was characterized by the lowest dough baking strength 'W' (88×10^{-4} J) which indicates the lowest quality of the gluten complex and its suitability for the production of waffles, for example (Jeantet *et al.*, 2016). Wheat cultivars 'Bamberka' and 'Astoria' were characterized by the highest dough baking strength ('W': 357 and 340×10^{-4} J, respectively) which is suitable for the production of such assortment of bread in which the dough should be characterized by a strong gluten complex, *i.e.* bread rolls. There were no significant statistical differences among the tested grain samples harvested in 2018 and 2019 and from the different nitrogen fertilization systems (Table 1). However, the dough from the wheat flour samples cultivated with the higher level of nitrogen fertilization system (200 kg ha^{-1} N) were characterized by a slightly higher average baking value 'W' in comparison with the dough from the wheat samples cultivated with the nitrogen fertilization level of 120 kg N ha^{-1} (20 and 12×10^{-4} J, respectively in the harvest year of 2018 and 2019). Significant differences between the cultivars were noted (Fig. 2A). The wheat sample cultivars of 'Kepler' and 'KWS Dacanto' cultivated under the limited nitrogen fertilization system were characterized by a higher, more favourable baking value 'W' in comparison to the wheat samples cultivated with the higher nitrogen fertilization dose. The results indicate that there is no economic justification for the use of higher doses of nitrogen fertilization for these two cultivars. The differences between the baking value 'W' of the cultivars 'Bamberka', 'Meister' and 'Fidelius' that were cultivated under the higher nitrogen fertilization system were only slightly higher than those grown with lower doses of nitrogen, and met the requirements of repeatability of the standard ISO 27971:2015.

The dough baking strength 'W' and the 'P/L' index (tenacity to extensibility ratio) are common indicators used in the grain trade and for the prediction of flour processing behaviour (Indrani *et al.*, 2007; Vizitiu *et al.*, 2012). A 'P/L' index of 0.50 indicates either resistant and very extensible dough or moderately extensible less resistant dough. A 'P/L' index value of over 1.50 is characteristic of a very strong and moderately extensible dough. A 'P/L' index in the range of 0.40 to 0.80 is appropriate for baking. Wheat suitable for confectionary products should characterized by a 'P/L' value below 0.50 (Dapčević Hadnađev *et al.*, 2011). The average tenacity to extensibility ratio in the tested dough from the wheat flour samples ranged from 0.5 to 1.9 (Fig. 2B). 46% of the tested wheat cultivar samples were characterized by a dough 'P/L' index in the range of 0.5 to

1.0 which is appropriate for cookie production. The dough obtained from the rest of the wheat cultivars (43% of the tested samples) was characterized by high tenacity values and a limited extensibility ('P/L' index above 1.0). Three wheat samples of *cv.* 'Astoria', 'Meister' and 'Kampana' that were cultivated under the higher level of nitrogen fertilization system and harvested in 2019 were characterized by a tenacity to extensibility ratio of over 2.0 which is not desirable in bread production because the dough is too strong and the bread obtained from the dough with such parameter values is characterized by low porosity. In comparison, the wheat harvested in the Czech Republic showed an even higher 'P/L' ratio (in the range of 0.7-5.7) (Hrušková and Šmejda, 2003).

The results of the PCA analysis revealed that the analysed cultivars substantially differed by the alveograph parameters. The results of a principal component analysis demonstrated that the first two principal components (PC1, PC2) accounted for 84.26% of the variation (Fig. 3). PC1 explained 61.90% and the PC2 explained 22.36% of the variation. PC1 was positively related to the Zeleny sedimentation index, protein quantity and alveograph baking strength 'W' and 'P/L'. PC2 was positively related to the 'P/L' index (tenacity to extensibility ratio), and negatively related to alveograph parameter 'L'.

Figure 4 shows that all grain samples of cultivars 'Astoria', 'Bamberka', 'Fidelius' and 'Meister' are classified in the right section of the chart which indicates the relatively higher values of the Zeleny sedimentation index, protein and gluten quantity, and alveograph parameters 'W', 'P' as compared to the other tested wheat cultivars which are grouped on the left section of the chart. Moreover, grain samples of *cv.* 'Bamberka' were assigned the highest values

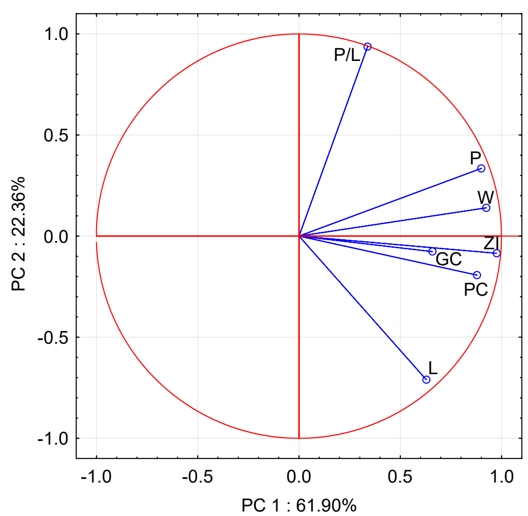

Fig. 3. Variable graph of PCA showing the quality parameters of GC – gluten content, PC – protein content, ZI – Zeleny sedimentation index, W, P, L, P/L – alveograph parameters.

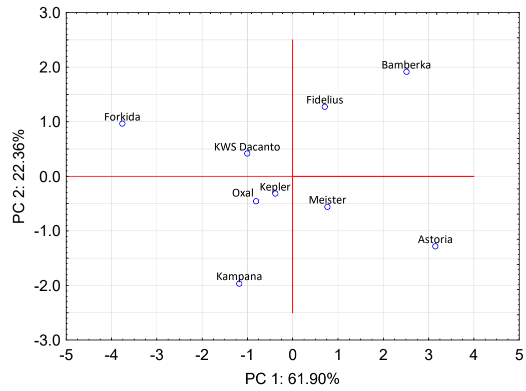

Fig. 4. Variable graph of PCA showing the varieties of winter wheat.

along the PC2 axis, while *cv.* 'Kampana' was assigned the lowest value along the PC2 axis which indicates that those aforementioned cultivars differed significantly in terms of such alveograph parameters as: 'P/L' and 'L'. Cultivar 'Kampana' was characterized by the highest value 'L' and the lowest value 'P/L' while *cv.* 'Bamberka' was characterized by the lowest value 'P/L' and the highest value 'L'.

CONCLUSIONS

1. Winter wheat cultivars were differentiated with regard to their protein and alveograph characteristics. The wheat cultivar classified as a part of the elite bread group according to COBORU was characterised by a larger protein content, gluten quantity and alveograph baking value 'W' than the other wheat cultivars tested.

2. Wheat cultivated under an excessive amount of nitrogen fertilization 200 kg N ha^{-1} as compared to 120 N ha^{-1} was characterized by a higher Zeleny sedimentation index, protein content and gluten quantity while there was no significant impact on the alveograph characteristics of the wheat flour dough.

3. The rheological characteristics of the wheat flour dough that were tested by alveograph were influenced by wheat cultivars. Among the tested wheat cultivars, 'Bamberka' and 'Astoria' were characterized by the highest baking dough strength ('W' above 340×10^{-4} J) which indicates their suitability for use in the production of frozen dough, pizza and hamburger rolls. The baking dough strength of the remaining tested wheat cultivars ranged from 200 to 300×10^{-4} J. Between the tested cultivars, cultivar 'Forkida' (the bread quality wheat) was characterized by a weaker tenacity 'P', and 'Kampana' was characterized by the highest extensibility 'L'.

4. The harvest year only had a crucial impact on the Zeleny sedimentation index. Wheat samples which were characterized by a higher protein and gluten quantity were also characterized by a higher dough baking strength 'W' and elasticity 'L'.

5. Lowering the nitrogen fertilization rate by 40% had no negative effect on the alveograph parameters of the tested cultivars. Differences in the baking value 'W' were at an acceptable level for individual baking purposes. However, the reduction in the nitrogen dose caused a lowering in the protein and gluten content and also in the Zeleny sedimentation index. Research should be continued with other nitrogen fertilization doses and also the scope of the research should be extended to include the evaluation of the baking value by the laboratory baking test.

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