Journal of Elementology ISSN 1644-2296

Jańczak-Pieniążek M., Buczek J., Jarecki W., Bobrecka-Jamro D. 2020.
Effect of high nitrogen doses on yield, quality and chemical composition grain of winter wheat cultivars.
J. Elem., 25(3): 1005-1017. DOI: 10.5601/jelem.2020.25.1.1994

RECEIVED: 24 March 2020
ACCEPTED: 3 June 2020

ORIGINAL PAPER

EFFECT OF HIGH NITROGEN DOSES ON YIELD, QUALITY AND CHEMICAL COMPOSITION GRAIN OF WINTER WHEAT CULTIVARS*

Marta Jańczak-Pieniążek, Jan Buczek, Wacław Jarecki, Dorota Bobrecka-Jamro

Department of Plant Production
University of Rzeszow, Rzeszów, Poland

Abstract

Nitrogen fertilization is the basic element of a wheat cultivation technology, affecting the volume and quality of grain yield. The aim of this study, conducted in 2016-2019, was to assess the yield, quality parameters and chemical composition of the grain of hybrid cultivars fertilized with higher doses of nitrogen compared to a winter wheat population cultivar. The experiment was established on brown peat with the textural composition of silt loam (2016/2017 and 2018/2019) and clay loam (2017/2018). The soil was classified as a Fluvic Cambisol (CMfv). The first factor studied was nitrogen fertilization at doses: N_{150} – 150 kg ha^{-1} (three applications: 60+50+40) and N_{200} – 200 kg ha^{-1} (four applications: 60+80+40+20). The second factor was four cultivars of winter wheat: hybrid cultivars Hyking, Hypocamp and Hyvento, and a population variety Artist. The grain of the hybrid cultivars had good quality parameters (Hyking, Hyvento) and higher yields as well as a greater content of iron, copper, zinc and phosphorus in the grain (Hypocamp) compared to the population cultivar. The weather conditions with less rainfall, including a very dry period during wheat grain formation and maturation, depressed the grain yield but resulted in better quality traits and a higher content of macro- and micronutrients (Fe, Zn, Cu) in the grain. The application of a nitrogen dose of 200 kg ha^{-1} compared to 150 kg ha^{-1} caused an increase in the yield and quality of the hybrid wheat grain, without differentiating the mineral composition of grain in terms of the content of K, Ca and Mg as well as Zn and Mn.

Keywords: hybrid wheat, nitrogen fertilization, yield, quality parameters, macronutrients, micronutrients, variety.

Jan Buczek, PhD DSc Eng., Department of Plant Production, University of Rzeszów, Zelwerowicza 4, 35-601 Rzeszów, Poland, e-mail: janbuczek7@gmail.com

* Grant for the development of research potential.

INTRODUCTION

Common wheat is the popular crop in the world, with a sown area of 219 million ha (FAOSTAT 2018). This plant has great economic significance owing to the high yielding potential, appropriate chemical composition and technological properties of the grain (Franch et al. 2015). Despite the low protein content in grain, wheat provides as much of this nutrient (about 60 million tons per year) as the total soybean cultivation does. This explains the great nutritional importance of wheat protein in the countries where wheat products constitute the basic and significant part of diet (Shewry 2009). The chemical composition of wheat grain has a significant impact on its quality. Whole grain of wheat is the basic source of carbohydrates, protein and minerals.

The quantity and quality of wheat grain yield is affected by both varietal and environmental factors. According to Podolska (2008), nitrogen fertilization is one of the most important factors influencing the yield of winter wheat by increasing productive tillering and reducing withering of lateral shoots, which increases the number of ears. Nitrogen also plays a crucial role in shaping the technological value of grain, especially in determining the concentration of protein stored in kernels (Zörb et al. 2018).

Currently, the main goal of plant breeding is to obtain wheat cultivars that produce stable yields, have the desired quality characteristics and are resistant to adverse environmental conditions, including abiotic stresses caused by climate change (Glenn et al. 2017, Liu et al. 2017). It is estimated that the area occupied by hybrid wheat accounts for less than 1.0% of total world wheat plantations (Singh et al. 2015). Hybrid wheat is grown in Europe over an area of more than 560 thousand ha, and 80% of hybrid cultivars are grown in France, while 20% are in Germany, Hungary, Italy, the Czech Republic, Slovakia, Romania and Portugal (Gupta et al. 2019). In hybrid wheat, the vigor achieved through the cross-fertilization of genetically different parent lines is intended to ensure an improved phenotype and traits expected in plant production, such as faster plant growth and differentiation, higher and stable grain yield, better resistance to stressful environmental conditions (Singh et al. 2010) and greater competitiveness in relation to diseases and weeds (Longin et al. 2012). However, little is known about the yielding level of wheat hybrid cultivars, especially the technological quality and mineral composition of grain (Zhao et al. 2013, Mühleisen et al. 2014).

The aim of this study was to assess the yield, quality parameters and chemical composition of grain of hybrid cultivars fertilized with higher nitrogen doses in comparison with a population cultivar of winter wheat.

The research hypothesis assumes that nitrogen doses and weather conditions during the growing season will significantly modify the yield as well as the quality parameters and chemical composition of grain in the studied winter wheat cultivars.

MATERIALS AND METHODS

A controlled field experiment was established in the seasons 2016/2017, 2017/2018 and 2018/2019, at the Experimental Station for Cultivar Assessment in Przecław (50°11'N, 21°29'E). This two-factor experiment was carried out in a split-block design with four replications. The first factor studied was nitrogen fertilization at doses: N_{150} – 150 kg ha^{-1} (three applications: 60+50+40) and N_{200} – 200 kg ha^{-1} (four applications: 60+80+40+20). Fertilization with nitrogen (NH_4NO_3) was carried out first in spring (after starting the growth) and during the growing period; the second dose was supplied at the stage of shooting (BBCH 32-33) and the third one - at the heading stage (BBCH 54-56). As for the nitrogen fertilization N_{200} – 200 kg ha^{-1}, the third dose was applied at the flag leaf stage (BBCH 39) and the fourth one - at the heading stage (BBCH 54-56).

The second factor comprised four cultivars of winter wheat: hybrid cultivars Hyking, Hypocamp and Hyvento (breeder Saaten Union Recherche SAS, France) and a population variety Artist (breeder DSV, Poland). The area of a plot was 16 m^2. In all the studied years, wheat was sown in the last ten days of September, at a sowing density of 220 seeds m^{-2} (hybrid cultivar) and 400 seeds m^{-2} (population cultivar). Winter oilseed rape was the previous crop. After the previous crop was harvested, the field underwent shallow plowing (10-12 cm deep), harrowing and pre-sowing plowing (20-22 cm deep). Fertilization with phosphorus ($Ca(H_2PO_4)_2$) at a dose of 100 kg ha^{-1} and potassium (KCl) at a dose of 150 kg ha^{-1} was performed once in the autumn. Foliar fertilization with Plonvit Z at a dose of 1 dm^3 ha^{-1} was used twice, at BBCH 31 and 39. Plant protection products were used in accordance with the recommendations of the Institute of Plant Protection - National Research Institute in Poznań (Table 1). Wheat was harvested at full grain maturity (BBCH 89-92) using a plot harvester. The grain yield from the plots was calculated per 1 ha at 15% moisture content.

Table 1

Dates and doses of application of pesticides

Specification (active substance)	Dose (dm^3·ha^{-1})	BBCH stage
[1]Karate Zeon 050 CS (lambda-cyhalothrin)	0.1	55-59
[2]Maraton 375 SC (pendimethalin+izoproturon)	4.0	23-27
[2]Huzar Activ 387 OD (iodosulfuron-methyl-sodium +2,4-D)	1.0	30-32
[3]Soligor 425 EC (prothiconazole+spiroxamine+tebuconazole)	1.0	31
[3]Artea 330 EC (propiconazole+cyproconazole)	0.5	39
[4]Moddus 250 EC (trinexapac-ethyl)	0.4	29-39

[1] insecticide, [2] herbicide, [3] fungicide, [4] growth regulator

Soil and weather conditions

The experiment was established on brown peat with the textural composition of silt loam (2016/2017 and 2018/2019) and clay loam (2017/2018). According to WRB FAO (2015), the soil was classified as a Fluvic Cambisol *(CMfv)*. Soil samples were analyzed in an accredited laboratory of the District Chemical and Agricultural Station in Rzeszów, in accordance with the Polish standards. The typical physical and chemical properties of the soil assessed before the experiment are given in Table 2.

Table 2

Basic soil characteristics prior to the experiment (soil layer 0-35 cm)

Traits	Years		
	2016/2017	2017/2018	2018/2019
	value		
pH in KCl	7.42	6.10	6.00
Organic C (g kg^{-1})	21.6	20.5	19.8
N_{min} (kg ha^{-1})	60.1	53.4	65.0
	content of available nutrients (mg kg^{-1})		
P	204.0	129.5	73.0
K	270.1	180.4	250.3
Mg	127.5	140.1	229.6
Fe	2289.0	2523.0	2222.0
Zn	14.2	13.3	12.8
Mn	389.0	251.4	265.1
Cu	6.0	6.2	6.4
B	1.1	1.3	1.5

Data on the weather conditions are given according to the Experimental Station for Cultivar Assessment in Przecław. During the autumn growth of plants, the weather conditions were favorable, and it was only in the season 2018/2019 that the amount of rainfall was 43.3 mm lower compared to many years. The average temperature during winter dormancy was higher than the long-term, except for the season 2016/2017. The spring-summer growing period in the seasons 2016/2017 and 2018/2019 can be classified as moist, and the season 2017/2018 as quite dry (Table 3).

Analytical methods

Crude grain protein content was evaluated by the Kjeldahl method (PN-EN ISO 20483), wet gluten content using a Glutomatic 2200 device (PN-A-74042), sedimentation rate using the Zeleny test (PN-EN ISO 5529), and the falling number by the Hagberg-Perten method (PN-EN ISO 3093). The test weight was determined using a densimeter equipped with a cylinder

Table 3

Selyaninov's hydrothermic coefficients (k) in spring-summer vegetation period

Year	Month				Mean
	April	May	June	July	
2016/2017	3.79/eh	2.88/vh	0.80/d	0.80/d	2.07/h
2017/2018	0.42/vd	1.43/o	0.94/d	1.88/rh	1.17/rd
2018/2019	2.93//vh	4.63/eh	0.31/ed	0.82/d	2.17/h
1956-2015	1.75/rh	1.81/rh	1.55/o	1.45/o	1.64/rh

Coefficient (k) value (Skowera 2014): ed - extremely dry, vd - very dry, d - dry, rd - rather dry, o - optimal, rh - rather humid, h - humid, vh - very humid, eh - extremely humid

1000 ml (PN-EN ISO 7971-3), and the 1000 grain weight at 15% moisture (PN-68/R-74017). Glassiness of grain was determined on a Sadkiewicz farinotom by cutting 50 grains and assessing the cross-section of cut grains (PN-70/R-74008). Moreover, crude fat (Soxhlet method), crude fiber (Henneberg-Stohman method in Pruszyński modification) and crude ash (by incinerating the material at 600°C in accordance with PN-EN ISO 2171) were assessed.

Macronutrients and micronutrients were determined in the Laboratory of the Faculty of Biology and Agriculture at the University of Rzeszów. To determine elements, grain samples were mineralized in HNO_3: $HClO_4$: HS_2O_4 in a 20:5:1 ratio, in an open system in a Tecator heating block. The content of Ca, K, Mg, Zn, Mn, Cu, Fe was determined in the samples by atomic absorption spectroscopy (FAAS), using a Hitachi Z-2000 apparatus (Japan). A UV-VIS Shimadzu spectrophotometer (Japan) was used for the determination of phosphorus (P) by the vanadate-molybdate method.

Statistical analyses

The results of the study were statistically analyzed with the analysis of variance (ANOVA), using the statistical software TIBCO Statistica 13.3.0 (StatSoft, Tulsa, USA). Significance of differences between treatments was verified by the Tukey's test, at the significance level $P \leq 0.05$. Values marked with the same letter in tables do not differ significantly at $P \leq 0.05$ in the Tukey's test.

RESULTS AND DISCUSSION

The use of a higher dose of nitrogen fertilization (N_{200}), resulted in an increase in wheat grain yield by 0.73 t ha^{-1} compared to a dose of N_{150} (Table 4). The increase in grain yield at the N_{200} nitrogen dose was caused by increasing productive tillering and consequently a higher number of ears, a finding confirmed in the study by Podolska (2008).The response of wheat

Table 4

Grain yield (t ha^{-1}) and macroelement content in grain depending on N-fertilization, cultivar and year (g kg^{-1} DM)

Factors		Grain yield	P	K	Ca	Mg
N dose (kg ha^{-1})	cultivars					
N_{150}	Hyking	8.20^{e}±0.47	7.95^{a}±0.77	4.02^{bc}±1.55	0.45^{a}±0.07	0.75^{a}±0.07
	Hypocamp	9.54^{b}±0.94	7.85^{c}±0.89	4.93^{a}±0.89	0.55^{a}±0.09	0.85^{a}±0.08
	Hyvento	9.05^{cd}±0.64	7.65^{bc}±0.74	4.75^{cd}±0.74	0.52^{a}±0.08	0.87^{a}±0.08
	# Artist	8.74b^{c}±0.59	7.52^{b-d}±0.69	4.57^{a}±0.69	0.35^{a}±0.09	0.79^{a}±0.09
N_{200}	Hyking	9.35b^{c}±0.80	8.25^{a}±0.68	4.58^{cd}±0.69	0.47^{a}±0.13	0.82^{a}±0.09
	Hypocamp	10.10^{a}±0.68	8.64^{a-c}±0.70	5.12^{a}±0.37	0.54^{a}±0.08	0.95^{a}±0.09
	Hyvento	9.62^{b}±0.65	8.08^{a-d}±0.48	5.22^{b-e}±0.73	0.53^{a}±0.08	0.87^{a}±0.08
	# Artist	9.39b^{c}±0.64	8.01^{e} ±0.34	4.39^{a} ±0.67	0.43^{a}±0.04	0.85^{a}±0.07
N_{150}		8.88^{b}±0.81	7.74^{a} ±0.78	4.57^{a} ±1.02	0.47^{a} ±0.10	0.82^{a}±0.10
N_{200}		9.61^{a}±0.72	8.25^{b} ±0.63	4.83^{a} ±0.69	0.49^{a} ±0.09	0.87^{a}±0.08
Hyking		8.77^{d}±0.87	8.10^{a}±0.80	4.30^{b}±1.18	0.46^{b}±0.10	0.79^{a}±0.09
Hypocamp		9.82^{a}±0.84	8.25^{a} ±0.81	5.03^{a} ±0.66	0.55^{a}±0.08	0.90^{a}±0.08
Hyvento		9.33^{b}±0.68	7.87^{b}±0.60	4.99^{a}±0.74	0.53^{ab}±0.08	0.87^{a}±0.08
# Artist		9.06^{c}±0.68	7.77^{b}±0.53	4.48^{b}±0.66	0.39^{c}±0.07	0.82^{a}±0.08
2016/2017		9.51^{b}±0.77	8.31^{a}±0.39	4.65^{b}±1.05	0.52^{a}±0.08	0.87^{a}±0.09
2017/2018		9.78^{a}±0.60	7.12^{c}±0.40	4.02^{c}±0.38	0.41^{b}±0.07	0.74^{b}±0.07
2018/2019		8.45^{c}±0.46	8.55^{a}±0.46	5.42^{a}±0.28	0.52^{a}±0.12	0.92^{a}±0.07

population cultivar

to an increased dose of nitrogen was also found by Klikocka et al. (2016) and Faizy et al. (2017). The hybrid cultivar Hypocamp obtained significantly higher yield than the hybrids Hyvento (by 5.0%) and Hyking (by 10.7%) and the population cultivar Artist (by 7.7%).

According to Reynolds et al. (1996) and Whitford et al. (2013), hybrid wheat cultivars are characterized by stability of yield as well as high grain and straw productivity, and the increase in the level of yield compared to population cultivars ranges from 3.5 to 15.0% (Singh et al. 2015). The interaction of nitrogen fertilization and cultivars showed that the hybrid cultivar Hyking responded most strongly to a dose of N_{200}, producing 12.3% higher grain yield compared to that harvested at a dose of N_{150}. Response of the other cultivars to the effect of dose N_{200} on grain yield was similar. Svečnjak et al. (2013) reports that wheat grain yield is distinctly influenced by a cultivar genotype and year of cultivation, while the cultivar and nitrogen fertilization interaction has a weaker effect. According to Linina and Ruza (2018), higher values of the Selyaninov's coefficient in the period from wheat heading to maturing ensure a higher grain yield, which was confirmed in the present study in the 2017/2018 season.

Nitrogen fertilization at a dose of N_{200} resulted in an increase in the content of P in wheat grain. The difference was 0.51 g kg^{-1} in relation to a dose of N_{150}. However, no significant effect of a nitrogen dose on K, Ca and Mg content in wheat grain was found (Table 4). An increase in the P content and a significant increase in Ca in wheat grain fertilized with a nitrogen dose of 200 kg ha^{-1} was shown by JASKULSKA et al. (2018). KLIKOCKA et al. (2018) reports that the content of macronutrients in spring wheat grain, except for P, increased in direct proportion to the increase in the N fertilization dose, and was the highest after the application of 120 kg ha^{-1} (K – 4.55; Mg – 1.69 and Ca – 0.46 g kg^{-1}). According to PSZCZÓŁKOWSKA et al. (2018), N fertilization of wheat in the range from 0 to 180 kg ha^{-1} did not result in differentiation of the P, Mg and Ca content in grain, and the highest K content was recorded for a dose of 60 kg ha^{-1}.

Wheat grain contained significantly more K and Ca in the hybrid cultivars Hypocamp and Hyvento, and more P in Hypocamp and Hyking in comparison with the population cultivar Artist. In contrast, the Mg content was not significantly modified by the varietal factor. The content of macronutrients in the grain of those cultivars was similar to the amounts of K, Ca and Mg found by JASKULSKA et al. (2018) and PSZCZÓŁKOWSKA et al. (2018), which the P content was higher. The cultivar and fertilization interaction showed that a higher dose of N_{200} resulted in an increase in the P content in the grain of the hybrid Hypocamp (by 10.1%) and Hyvento (by 5.6%) and the population Artist (by 6.5%). The hybrid cultivars Hyking and Hyvento also responded by a significant increase in the grain K content along with an increase in the nitrogen dose (N_{200}), by 13.9% and 9.9%, respectively (WOJTKOWIAK et al. 2018).

Wheat grain grown in the seasons 2016/2017 and 2018/2019, where April and May were very and extremely humid and June and July extremely dry and dry (Table 3), was characterized by a higher concentration of macronutrients (Table 4). The influence of weather conditions on the content of macronutrients in grain was observed in common wheat by WOŹNIAK and STĘPNIEWSKA (2017), in durum wheat by FICCO et al. (2009), in spelt wheat by GRZEBISZ et al. (2019), and in einkorn wheat by ERBA et al. (2011).

Increasing the nitrogen fertilization level supplied to the wheat cultivars from 150 to 200 kg ha^{-1} did not affect the content of Zn and Mn in the grain. However, a higher dose of N_{200} caused a significant increase in the content of Fe and Cu from 3.4 to 16.2% (Table 5). According to PSZCZÓŁKOWSKA et al. (2018), increased nitrogen fertilization did not differentiate Zn and Mn content in the wheat grain, while Cu content was the highest in the treatment without nitrogen fertilization, and Fe reached the maximum value (39.90 mg kg^{-1}) for a dose of 120 kg ha^{-1}. SVEČNJAK et al. (2013) reports that for a nitrogen dose of 194 kg ha^{-1} compared to 67 kg ha^{-1}, the increase in the

Table 5

Microelement content in grain depending on N-fertilization, cultivar and year (mg kg^{-1}DM)

Factors: N dose (kg ha^{-1})	Factors: cultivars	Fe	Cu	Zn	Mn
N_{150}	Hyking	52.13^{a} ±3.51	3.02^{b}±0.31	38.20^{a}±2.28	29.39^{a}±1.43
	Hypocamp	52.30^{c} ±3.56	3.14^{a}±0.08	41.80^{a}±1.55	31.28^{a}±3.36
	Hyvento	51.21^{a}±4.09	2.63^{c}±0.27	39.01^{a}±3.09	28.63^{a}±1.02
	# Artist	50.50^{a}±4.49	2.56^{c}±0.29	37.87^{a}±2.93	26.19^{b}±0.87
N_{200}	Hyking	53.85^{cd}±4.70	3.75^{cd}±0.24	38.70^{a}±2.91	31.02^{a}±3.08
	Hypocamp	56.41^{de}±4.71	4.01^{b}±0.39	40.32^{a}±2.59	30.93^{a}±0.23
	Hyvento	51.05^{a}±4.66	2.92^{c}±0.30	38.58^{a}±2.43	29.68^{a}±1.07
	# Artist	51.38^{a}±0.61	2.50^{c}±0.29	38.24^{a}±2.99	26.94^{b}±2.07
N_{150}		51.42^{b}±3.84	2.84^{b}±0.43	39.22^{a}±2.84	28.87^{a}±2.60
N_{200}		53.17^{a}±4.20	3.30^{a}±0.40	38.96^{a}±2.68	29.64^{a}±2.47
Hyking		52.22^{b}±3.95	3.39^{a}±0.28	38.45^{b}±2.51	30.21^{a}±2.44
Hypocamp		54.35^{a}±4.52	3.58^{a}±0.31	41.06^{a}±2.18	31.10^{a}±2.28
Hyvento		51.69^{b}±4.23	2.78^{b}±0.31	38.80^{b}±2.66	29.16^{a}±1.14
# Artist		51.31^{b}±3.06	2.53^{b}±0.28	38.06^{b}±2.83	26.56^{b}±1.56
2016/2017		54.13^{a}±2.18	3.13^{a}±0.38	35.90^{c}±1.74	28.33^{a}±2.23
2017/2018		49.08^{b}±2.47	2.76^{b}±0.38	39.94^{b}±1.42	28.62^{a}±1.42
2018/2019		55.51^{a}±2.13	3.31^{a}±0.28	41.43^{a}±0.99	30.82^{a}±3.04

population cultivar

content of micronutrients in wheat grain was on average 9.2% (Zn), 13.2% (Cu), 14.0% (Fe) and 19.7% for Mn. Shi et al. (2010) showed an increase in the content of Zn, Cu and Fe in the wheat grain for a dose of 130 kg ha^{-1}, while a further increase in fertilization to a dose of 300 kg ha^{-1} did not cause an increase in the content of these elements.

The content of micronutrients in the wheat grain was variable during the years of the study. Significantly more Fe, Cu and Zn in the grain was found in the season 2018/2019, with moderate rainfalls of 514.4 mm and higher monthly temperatures (June and July) during the grain formation period (Klikocka et al. 2018).

The hybrid cultivars contained significantly more Fe and Zn in the grain for Hypocamp, and more Mn for Hypocamp, Hyking and Hyvento. The varietal factor differentiated the Cu content in the wheat grain in decreasing order of Artist > Hyvento > Hyking > Hypocamp. Among the wheat cultivars tested, the hybrids Hyking and Hypocamp responded with a significant increase in Fe and Cu for a dose of N_{200} in the range from 1.72 to 4.11 mg kg^{-1} and from 0.73 to 0.87 mg kg^{-1} (Svečnjak et al. 2013).

The highest level of micronutrients in the wheat grain was found for Fe, and the lowest – for Cu (Fe > Mn > Zn > Cu). The amount of Zn and Mn in the wheat grain was close to the value of these elements found by Pandey et al. (2016). However, the content of Fe was higher and of Cu lower than the values found by Kwiatkowski et al. (2015) in spring and winter wheat grain grown in both conventional and organic farming.

Increasing the level of nitrogen fertilization from 150 to 200 kg ha^{-1} significantly affected the increase in the quality parameters of grain: total protein (by 8.0%), gluten content (by 9.9%), Zeleny's sedimentation index (by 15.9%), grain vitreousness (by 7.3%) and the falling number by 14.7% (Table 6). An increase in the value of wheat grain quality parameters was demonstrated in the nitrogen dose range from 85 to 175 kg ha^{-1} by Skudra and Ruza (2016) and from 100 to 200 kg ha^{-1} by jaskulska et al. (2018). Nowak et al. (2014) and Gąsiorowska and Makarewicz (2007) report that wheat cultivars respond individually to the level of nitrogen fertilization, and this is manifested in grain quality changes, including the protein content. Hybrid cultivars had the highest content: Hyking – of total protein, gluten and the value of Zeleny's sedimentation index, and Hyvento – of grain

Table 6

Quality parameters of grain depending on N-fertilization, cultivar and year

Factors		Total protein (g kg^{-1})	Gluten content (%)	Zeleny's index (ml)	Falling numer (s)	Vitreousness (%)
N dose (kg ha^{-1})	cultivars					
N_{150}	Hyking	$123.5^{cd}\pm6.7$	$26.3^{c}\pm1.5$	$43.7^{b}\pm5.4$	$253^{e}\pm29$	$57.5^{cd}\pm10.4$
	Hypocamp	$118.8^{d}\pm5.0$	$23.7^{e}\pm1.5$	$36.3^{d}\pm2.7$	$238^{f}\pm22$	$43.8^{e}\pm0.9$
	Hyvento	$120.7^{d}\pm6.7$	25.5^{c}d±0.6	$41.3^{b}\pm4.1$	$344^{b}\pm21$	$68.5^{b}\pm4.4$
	# Artist	$113.0^{e}\pm7.7$	$22.7^{e}\pm1.1$	$35.0^{c}\pm3.0$	$325^{c}\pm27$	$52.8^{d}\pm2.6$
N_{200}	Hyking	$135.2^{a}\pm11.5$	$29.8^{a}\pm2.6$	$51.0^{a}\pm4.5$	$271^{d}\pm34$	$74.0^{a}\pm6.1$
	Hypocamp	$128.0^{bc}\pm4.5$	$25.6^{cd}\pm1.0$	$43.8^{b}\pm3.9$	$272^{d}\pm22$	$52.5^{d}\pm3.4$
	Hyvento	$132.8^{ab}\pm8.4$	$28.8^{b}\pm1.4$	$49.7^{a}\pm6.6$	$359^{a}\pm15$	$74.0^{a}\pm2.7$
	# Artist	$121.5^{d}\pm7.6$	$25.0^{d}\pm0.9$	$41.7^{b}\pm4.5$	$348^{ab}\pm27$	$60.8^{c}\pm4.8$
N_{150}		$119.0^{b}\pm7.3$	$24.6^{b}\pm1.9$	$39.1^{b}\pm5.2$	$290^{b}\pm52$	$55.7^{b}\pm10.6$
N_{200}		$129.4^{a}\pm9.5$	$27.3^{a}\pm2.6$	$46.5^{a}\pm6.1$	$313^{a}\pm48$	$65.3^{a}\pm10.2$
Hyking		$129.3^{a}\pm10.8$	$28.0^{a}\pm2.7$	$47.3^{a}\pm6.1$	$262^{c}\pm32$	$65.8^{b}\pm11.8$
Hypocamp		$123.4^{b}\pm6.6$	$24.7^{c}\pm1.6$	$40.1^{b}\pm5.1$	$255^{d}\pm28$	$48.1^{d}\pm5.1$
Hyvento		$126.8^{ab}\pm9.7$	$27.2^{b}\pm2.0$	$45.5^{a}\pm6.8$	$352^{a}\pm19$	$71.3^{a}\pm4.5$
# Artist		$117.3^{c}\pm8.5$	$23.9^{d}\pm1.5$	$38.3^{b}\pm5.1$	$337^{b}\pm29$	$56.8^{c}\pm5.6$
2016/2017		$116.8^{c}\pm6.3$	$24.6^{c}\pm2.1$	$38.6^{b}\pm4.0$	$295^{b}\pm55$	$58.6^{b}\pm11.4$
2017/2018		$124.0^{b}\pm8.6$	$26.0^{b}\pm2.4$	$45.9^{a}\pm6.9$	$282^{c}\pm44$	$61.9^{a}\pm11.8$
2018/2019		$131.8^{a}\pm8.5$	$27.2^{a}\pm2.7$	$43.9^{a}\pm7.0$	$327^{a}\pm44$	$61.0^{a}\pm11.6$

population cultivar

vitreousness and the falling number. In addition, the protein content in the grain of the cultivars Hyking and Hyvento at a dose of N_{150} did not differ significantly from the other cultivars fertilized with a dose of N_{200}.

Among the studied physical properties of grain, the hybrid cultivar Hypocamp was characterized by the highest weight of 1000 grains, while Hypocamp and Hyvento had significantly the highest bulk density. An increase in fertilization from N_{150} to N_{200} resulted in a significant increase in the value of this parameter by 2.2%, which was not shown for the weight 1000 grain (Table 7). Abedi et al. (2011) showed an increase in the 1000

Table 7

Physical and chemical properties of grain depending on N-fertilization, cultivar and year

Factors		Weight of 1000 grains (g)	Test weight (kg hl^{-1})	Fat	Fibre	Ash
N dose (kg ha^{-1})	cultivars			(% DM)		
N_{150}	Hyking	42.9^{ac}±2.5	74.3^{c}±1.5	14.5^{c}±1.7	25.8^{a}±5.1	18.1^{a}±1.7
	Hypocamp	44.1^{ab}±2.7	75.5^{b}±0.3	14.4^{c}±1.4	25.9^{a}±5.1	18.0^{ab}±1.2
	Hyvento	39.3^{c}±2.9	75.8^{b}±1.7	17.0^{a}±1.8	23.8^{c}±4.1	18.0^{ab}±1.6
	[#] Artist	39.3^{c}±1.4	74.2^{c}±1.0	15.3^{b}±2.4	25.4^{ab}±7.7	18.4^{bc}±1.0
N_{200}	Hyking	42.8^{ac}±3.5	76.2^{b}±1.5	14.9^{bc}±3.3	23.4^{cd}±2.8	16.9^{d}±1.5
	Hypocamp	45.6^{a}±3.2	77.4^{a}±0.4	13.4^{d}±1.0	22.5^{d}±3.4	17.1^{cd}±1.2
	Hyvento	41.7^{ac}±2.4	77.0^{a}±1.9	17.3^{a}±1.4	24.5^{bc}±5.5	17.5^{bc}±2.0
	[#] Artist	40.1^{bc}±1.5	75.6^{b}±0.6	15.5^{b}±1.8	24.2^{bc}±4.9	17.5^{a}±1.0
N_{150}		41.4^{a}±3.2	74.9^{b}±1.4	15.3^{a}±2.0	25.2^{a}±5.4	18.1^{a}±1.3
N_{200}		42.6^{a}±3.3	76.6^{a}±1.4	15.3^{a}±2.4	23.7^{a}±4.1	17.3^{a}±1.4
Hyking		42.9^{ab}±2.9	75.2^{b}±1.7	14.7^{c}±2.5	24.6^{a}±4.1	17.0^{b}±1.7
Hypocamp		44.8^{a}±2.9	76.5^{a}±1.0	13.9^{d}±1.3	24.2^{a}±4.5	17.5^{b}±1.2
Hyvento		40.5^{bc}±2.8	76.4^{a}±1.8	17.1^{a}±1.6	24.2^{a}±4.7	17.3^{b}±1.8
[#] Artist		39.7^{c}±1.5	74.9^{b}±1.1	15.4^{b}±2.0	24.8^{a}±6.2	18.9^{a}±1.1
2016/2017		41.5^{ab}±1.4	75.8^{b}±1.8	14.8^{b}±1.0	25.2^{b}±0.8	18.6^{a}±0.8
2017/2018		43.3^{a}±3.5	76.5^{a}±0.9	15.2^{b}±2.8	19.0^{c}±1.4	16.1^{b}±0.8
2018/2019		41.1^{b}±4.0	74.9^{c}±1.5	15.9^{a}±2.4	29.1^{a}±3.6	18.4^{a}±0.8

[#] population cultivar

grain weight of winter wheat in the range from 37.5 to 45.8 g for nitrogen fertilization at doses from 0 to 360 kg ha^{-1}. Wojtkowiak et al. (2018) did not show the effect of varietal differentiation and nitrogen dose on the wet gluten content and grain bulk density in any of the tested wheat cultivars.

In the present study, the average fat content in grain was 15.3 g kg^{-1} and ranged from 10.6 to 25.8 g kg^{-1} (Charalampopoulos et al. 2002, Barteczko et al. 2009). The varietal factor differentiated the crude fat content in the grain in descending order of Hyvento>Artist>Hykin>Hypocamp. The highest ash content was found in the population cultivar Artist. Significant effect of the cultivar on the raw fiber content and nitrogen fertilization on fat, fiber and raw ash content in the grain was not found The growing season 2018/2019, with a very dry and dry period of wheat maturation (June and July) favored significantly higher values of grain quality and chemical parameters (Woźniak, Staniszewski 2007, Jaskulska et al. 2018).

CONCLUSIONS

1. Quality parameters as well as mineral composition and yield of the grain of winter wheat cultivars were modified by the cultivar genotype and climatic conditions and, to a lesser extent, by nitrogen doses.

2. The grain of hybrid cultivars was characterized by good grain quality parameters (Hyking, Hyvento), higher yield and a higher content of Fe, Cu and Zn and P in grain (Hypocamp) compared to the population cultivar Artist.

3. The weather conditions in the growing season 2018/2019, with a smaller amount of rainfall, and with a very dry and dry period of wheat grain formation and maturation, caused a decrease in grain yield but resulted in higher values of quality traits and the content of macro- and micronutrients (Fe, Zn, Cu) in grain.

4. The application of a nitrogen dose of 200 kg ha^{-1} compared to 150 kg ha^{-1} resulted in an increase in the yield and quality of hybrid wheat grain, without the differentiation the mineral composition of grain in terms of the content of K, Ca and Mg as well as Zn and Mn.

REFERENCES

Abedi T., Alemzadeh A., Kazemeini S.A. 2011. *Wheat yield and grain protein response to nitrogen amount and timing.* Aust. J. Crop Sci., 5(3): 330-336.

Barteczko J., Augustyn R., Lasek O., Smulikowska S. 2009. *Chemical composition and nutritional value of different wheat cultivars for broiler chickens.* J. Anim. Feed Sci., 18(1): 124-131. DOI: 10.22358/jafs/66375/2009

Charalampopoulos D., Wang R., Pandiella S.S., Webb C. 2002. *Application of cereals and cereal components in functional foods: a review.* Int. J. Food Microbiol., 79: 131-141. DOI: 10.1016/ /S0168-1605(02)00187-3

Erba D., Hidalgo A., Bresciani J., Brandolini A. 2011. *Environmental and genotypic influences on trace element and mineral concentrations in whole meal flour of einkorn (Triticum monococcum* L. *subsp. monococcum).* J. Cereal Sci., 54: 250-254. DOI: 10.1016/j.jcs.2011.06.011

Faizy S.E.D., Mashali S.A., Youssef S.M., Elmahdy S.M. 2017. *Study of wheat response to nitrogen fertilization, micronutrients and their effects on some soil available macronutrients.* J. Sus. Agric. Sci., 43(1): 55-64. DOI: 10.21608/JSAS.2017.3491

FAOSTAT. 2018. Available online: http://faostat.fao.org (accessed on 03 March 2020)

Ficco D.B.M., Riefolo C., Nicastro G., De Simone V., Di Gesu A.M., Beleggia R., Platani C., Cattivelli L., De Vita P. 2009. *Phytate and mineral elements concentration in a collection of Italian durum wheat cultivars.* Field Crop Res., 111(3): 235-242. DOI: 10.1016/j. fcr. 2008.12.010

Franch B., Vermote E.F., Becker-Reshef I., Claverie M., Huang J., Zhang J., Justice C., Sobrino J.A. 2015. *Improving the timeliness of winter wheat production forecast in the United States of America, Ukraine and China using MODIS data and NCAR Growing Degree Day information.* Remote Sens. Environ., 161: 131-148. DOI: 10.1016/j.rse.2015.02.014

Gąsiorowska B., Makarewicz A. 2007. *The influence of different nitrogen fertilization ways on the grain quality of spring cereal cultivars.* Fragm. Agron., 2(94): 102-109. (in Polish)

Glenn K.C., Alsop B., Bell E., Goley M., Jenkinson J., Liu B., Martin C., Parrott W., Souder C., Sparks O., Urquhart W., Ward J.M., Vicini J.L. 2017. *Bringing new plant varieties to market: plant breeding and selection practices advance beneficial characteristics while minimizing unintended changes.* Crop Sci., 57: 2906-2921. DOI: 10.2135/cropsci2017.03.0199

Grzebisz W., Barłóg P., Kryszak J., Łukowiak R. 2019. *Pre-anthesis nutritional status of spelt wheat as a tool for predicting the attainable grain yield.* Agronomy, 9: 558. DOI: 10.3390/ /agronomy9090558

Gupta P.K., Balyan H.S., Gahlaut V., Saripalli G., Pal B., Basnet B.R., Josh A.K. 2019. *Hybrid wheat: past, present and future.* Theor Appl Genet., 132: 2463-2483. DOI: 10.1007/s00122-019-03397-y

IUSS Working Group WRB. 2015. *International soil classification system for naming soils and creating legends for soil maps.* Word Reference Base for Soil Resources 2014, update 2015. Word Soil Resources Reports No. 106.

Jaskulska, I., Jaskulski, D., Gałęzewski, L., Knapowski, T., Kozera W., Wacławowicz R. 2018. *Mineral composition and baking value of the winter wheat grain under varied environmental and agronomic conditions.* J. Chem., 1-7. DOI: 10.1155/2018/5013825

Klikocka H., Cybulska M., Barczak B., Narolski B., Szostak B., Kobiałka A., Nowak A., Wójcik E. 2016. *The effect of sulphur and nitrogen fertilization on grain yield and technological quality of spring wheat.* Plant Soil Environ., 62(5): 230-236. DOI: 10.17221/18/2016-PSE

Klikocka H., Marks M., Barczak B., Szostak B., Podleśna A., Podleśny J. 2018. *Response of spring wheat to NPK and S fertilization. The content and uptake of macronutrients and the value of ionic ratios.* Open Chem., 16: 1059-1065. DOI: 10.1515/chem-2018-0116

Kwiatkowski C.A., Haliniarz M., Tomczyńska-Mleko M., Mleko S., Kawecka-Radomska M. 2015. *The content of dietary fiber, amino acids, dihydroxyphenols and some macro- and micronutrients in grain of conventionally and organically grown common wheat, spelt wheat and millet.* Agr. Food Sci., 24: 195-205.

Linina A., Ruza A. 2018. *The influence of cultivar, weather conditions and nitrogen fertilizer on winter wheat grain yield.* Agron. Res., 16(1): 147-156. DOI: 10.15159/ar.18.034

Liu G., Zhao Y., Mirdita V., Reif J.C. 2017. *Efficient strategies to assess yield stability in winter wheat.* Theor. Appl. Genet., 130(8): 1587-1599. DOI: 10.1007/s00122-017-2912-6

Longin C.F.H., Mühleisen J., Maurer H.P., Zhang H., Gowda M., Reif J.C. 2012. *Hybrid breeding in autogamous cereals.* Theor. Appl. Genet., 125: 1087-1096. DOI: 10.1007/s00122-012-1967-7

Mühleisen J., Piepho H.P., Maurer H.P., Longin C.F.H., Reif J.C. 2014. *Yield stability of hybrids versus lines in wheat, barley, and triticale.* Theor. Appl. Genet., 127: 309-316. DOI: 10.1007/ /s00122-013-2219-1

Nowak A., Haliniarz M., Kwiatkowski C. 2014. *Economical aspects of selected production technology of spring wheat cultivation.* Annals PAAAE, 16(2): 200-205. (in Polish)

Pandey A., Kamran Khan M., Hakki E.E., Thomas G., Hamurcu M., Gezgin S., Gizlenci O., Akkaya S.M. 2016. *Assessment of genetic variability for grain nutrients from diverse regions: potential for wheat improvement.* SpringerPlus. 5: 1912. DOI: 10.1186/s40064-016-3586-2

Podolska G. 2008. *Effect of nitrogen fertilization doses and way of its application on yield and* *technological quality of winter wheat cultivars grain.* Acta. Sci. Pol., Agric., 7(1): 57-65. (in Polish)

Pszczółkowska A., Okorski A., Olszewski J., Fordoński G., Krzebietke S., Chareńska A. 2018. *Effects of pre-preceding leguminous crops on yield and chemical composition of winter wheat grain.* Plant Soil Environ., 64: 592-596. DOI: 10.17221/340/2018-PSE

Reynolds M.P., Rajaram S., McNab A. 1996. *Increasing yield. Potential in wheat: Breaking the barriers.* Chapter 2. *Hybrid wheat: Advances and challenges.* CIMMYT. Proc. of a Workshop Held in Ciudad Obregon, Sonora, Mexico.

Shewry P.R. 2009. *Wheat.* J. Exp. Bot., 60(6): 1537-1553. DOI: 10.1093/jxb/erp058

Shi R., Zhang Y., Chen X., Sun Q., Zhang F., Romheld V., Zou C. 2010. *Influence of long-term nitrogen fertilization on micronutrient density in grain of winter wheat (Triticum aestivum L.).* J. Cereal Sci., 51: 165-170. DOI: 10.1016/j.jcs.2009.11.008

Singh S.P., Srivastava R., Kumar J. 2015. *Male sterility systems in wheat and opportunities for hybrid wheat development.* Acta Physiol. Plant., 37: 1713. DOI: 10.1007/s11738-014-1713-7

Singh S.K., Chatrath R., Mishra B. 2010. *Perspective of hybrid wheat research: A review.* Ind. J. Agric. Sci., 80(12): 1013-1027

Skowera B. 2014. *Changes of hydrothermal conditions in the Polish area (1971–2010).* Fragm. Agron., 31(2): 74-87. (in Polish)

Skudra I., Ruza A. 2016. *Winter wheat grain baking quality depending on environmental conditions and fertilizer.* Agron. Res., 14(S2): 1460-1466.

Svečnjak Z., Jenel M., Bujan M., Vitali D., Dragojevic V.I. 2013. *Trace element concentrations in the grain of wheat cultivars as affected by nitrogen fertilization.* Agr. Food Sci., 22: 445-451. DOI: org/10.23986/afsci.8230

Whitford R., Fleury D., Reif J.C., Garcia M., Okada T., Korzun V., Langridge P. 2013. *Hybrid breeding in wheat: technologies to improve hybrid wheat seed production.* J. Exp. Bot., 64(18): 5411-5428. DOI: 10.1093/jxb/ert333

Wojtkowiak K., Stępień A., Orzech K. 2018. *Effect of nitrogen fertilisation on the yield components, macronutrient content and technological quality parameters of four winter wheat (Triticum aestivum ssp. vulgare) varieties.* Fragm. Agron., 35(2): 146-155. (in Polish) DOI: 10.26374/fa.2018.35.23

Woźniak A., Staniszewski M. 2007. *The influence of weather conditions on grains quality of spring wheat cv. Opatka and winter wheat cv. Korweta.* Acta Agrophys., 9(2): 525-540. (in Polish)

Woźniak A., Stępniewska A. 2017. *Yield and quality of durum wheat grain in different tillage systems.* J. Elem., 22(3): 817-829. DOI: 10.5601/jelem.2016.21.4.1304

Zhao Y., Zeng J., Fernando R., Reif J.C. 2013. *Genomic prediction of hybrid wheat performance.* Crop Sci., 53: 802-810. DOI:10.2135/cropsci2012.08.0463

Zörb C., Ludewig U., Hawkesford M.J. 2018. *Perspective on wheat yield and quality with reduced nitrogen supply.* Trends Plant Sci., 23(11): 1029-1037. DOI: 10.1016/j.tplants.2018.08.012