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Reaction of selected winter wheat cultivars to an increase in the intensity of cultivation technology

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Abstract. The field experiment with winter wheat was conducted in the years 2016–2019 at the Experimental Stations of Cultivar Assessment in Przecław. The experimental factors were: I – agricultural technology with different intensity level (medium-intensity A1 and high-intensity A2), II – cultivar of winter wheat (‘Hondia’, ‘RGT Kilimanjaro’, ‘Patras’, ‘Pokusa’). Wheat production technologies were differed in the use of plant protection products, doses of mineral fertilization and additional use of foliar fertilization and growth regulator in high-intensity technology. The use of technology with a higher intensity level significantly increased the value of yield-forming parameters, grain yield and grain quality parameters, but did not differentiate the fiber and ash content in the grain. ‘RGT Kilimanjaro’ was distinguished from the other cultivars by the highest level of grain yield, the most favorable values of grain quality parameters (protein, gluten content, test weight, sedimentation index) and the lowest fat and ash content. Weather conditions prevailing in the 2018/2019 season, characterized by a low rainfall sum and high temperature during the formation of kernels, increased the value of grain quality and chemical parameters, but caused a decrease in grain yield.

Keywords: winter wheat, cultivation technology, grain yield, grain quality

INTRODUCTION

Of cereal crops grown in Poland, wheat (*Triticum aestivum* L.) occupies the largest area. In recent years, the wheat cropping area amounted to 2.41 million hectares. Moreover, grain yields have increased from an average of 1.99 t ha^{-1} in the 1960s to 4.06 t ha^{-1} in 2018 (FAOSTAT, 2020). Wheat is of significant importance both in Poland as well as in other countries in the world due to high yields, suitable chemical composition and technological properties of grain. Wheat is the most important cereal sold on international markets. In addition, 80% of world production comes from winter wheat (Franch et al., 2015).

According to Budzyński (2012), the popularity of wheat cultivation in Poland, especially the winter form, results from a great progress in breeding and the introduction of new cultivars to agricultural practice that are characterised by high and stable yields and good quality grain with versatile use for producers, processors and consumers alike. The new wheat cultivars have greater resistance to biotic and abiotic stress that manifest themselves at lower fertilisation and plant protection levels. The new cultivars are also characterized by a high grain protein content, a basic criterion for wheat baking quality assessment (Biel, Maciorowski, 2012; Harasim, Matyka, 2009; Mwadzingeni et al., 2016; Wicki, 2017).

Wheat grain as a raw material for different purpose should meet the quality and technological requirements. Therefore, adoption of proper production technology is crucial (Sułek, 2017). The level of production intensity, adjusted to prevailing soil and climatic conditions, besides the quantity and quality of grain yield as well as purchase price, is an important element determining the profitability of wheat cultivation (Nowak et al., 2014). Apart from the fertilization and plant protection, the level of yield and technological value of winter wheat grains, are affected by genetic factors that control usable traits of wheat cultivars (Horvat et al., 2015; Lloveras et al., 2004).

The main aim of the study was the evaluation of the cultivation technology intensity on winter wheat productivity as affected by variety. It was hypothesized that intensification of production technology, including increased nitrogen fertilization, additional foliar fertilization with microelements and fungicide protection, will positively affect grain yield and quality of wheat cultivars.

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MATERIALS AND METHODS

A replicated field trial with winter wheat was conducted in 2016/2017, 2017/2018 and 2018/2019 at the Variety Testing Station at Przecław (50°11'N, 21°29'E). Two-factorial experiment was established as a randomized split-plot design, in two replications. The first research factor was the level of production technology intensity (average – A1 and high – A2), while the second were the following winter wheat cultivars rated as quality class A: 'Hondia' (Danko HR), 'RGT Kilimanjaro' (RAGT 2n), 'Patras' (DSV Polska) and 'Pokusa' (Hodowla Roślin Strzelce sp. z o.o. Grupa IHAR). The cultivars are characterized by high grain quality parameters and are recommended for cultivation in Podkarpackie voivodeship.

'Hondia' shows the following characteristics: good fertility, medium height, high resistance to lodging, TGW high to very high, good grain uniformity, medium test weight, large falling number, medium resistance to preharvest sprouting.

'RGT Kilimanjaro' has a very high potential, short-stalked plants. The cultivar exhibits high resistance to lodging, late heading, average TGW, average grain uniformity, high test weight, very high falling number.

'Patras' demonstrates high and stable yield, medium height, medium resistance to lodging, very high TGW, good uniformity, medium test weight, high falling number, medium resistance to preharvest sprouting

'Pokusa' shows good yields, moderate yield increase in conditions of high crop-management level, low winter resistance, tolerance to soil acidity, low resistance to lodging, medium resistance to preharvest sprouting, low TGW, good grain uniformity, medium protein content, low flour yield (Lista opisowa ..., 2014).

Each year winter wheat was grown after winter rape.

Mineral fertilization was applied according to COBORU methodology for winter wheat testing (Table 1). In each year of the experiment, winter wheat was sown in the third decade of September at a density of 400 grains per m^2.

The total and net plot area amounted to 19.5 m^2 and 15.0 m^2, respectively.

Before harvest, ear number per 1 m^2 was counted, and 20 ears were randomly sampled to determine the number of grains per ear.

Pesticides were applied in accordance with the producers' recommendations (Table 2). Wheat was harvested in the phase of full grain maturity (BBCH 89-92) with combine plot harvester. Yield per 1 ha was adjusted to 15% moisture content.

The experiment was conducted on soil classified as Fluvic Cambisols (*CMfv*) (IUSS Working Group WRB, 2015) (2016/2017 and 2018/2019 – silt loam, 2017/2018 – clay loam). Soil samples were analysed according to Polish National Standards in an accredited laboratory operated by the Chemical-Agricultural Station in Rzeszów. The soil physical and chemical properties are presented in Table 3.

Weather conditions are described according to the data from Variety Testing Experimental Station in Przecław (Table 4). The highest sum of precipitation (616.8 mm) was recorded in the 2016/2017 season, which was 13.1% higher compared to long-term average. In the seasons 2017/2018 and 2018/2019, average daily temperature exceeded the long-term average. Whereas in 2016/2017, the average daily air temperature reached 6.6°C and was 9.6% lower compared to the multi-annual average. During the experiment period, the highest average air temperature of 20.8°C occurred in June 2019 and was 23.1% higher than

Tabela 1. Fertilization of winter wheat.

Fertilizer	Dose		Application time (BBCH)
	A1	A2	
P_2O_5	70 kg ha^{-1}		before sowing
K_2O	105 kg ha^{-1}		before sowing
N	21 kg ha^{-1}		before sowing
	50 kg ha^{-1}	60 kg ha^{-1}	24-27
	40 kg ha^{-1}	50 kg ha^{-1}	32-33
	-	20 kg ha^{-1}	54-56
Plonvit Z foliar fertilizer	-	1 dm^3	31
	-	1 dm^3	39

A1 – average level of production technology; A2 – high level of production technology

Tabela 2. Plant protection treatments in winter wheat.

Specification		Dose [dm^3 ha^{-1}]		Application time (BBCH)
Pesticide	Trade name (active substance)	A1	A2	
Herbicides	Maraton 375 SC (pendimethalin +izoproturon)	4.0		23-27
	Huzar Activ 387 OD (iodosulfuron-methyl-sodium+2,4-D)	1.0		30-32
Insecticides	Karate Zeon 050 CS (lambda-cyhalothrin)	0.1		55-59
Fungicides	Soligor 425 EC (protioconazole+spiroksamin+tebuconazole)	-	1.0	31
	Artea 330 EC (propiconazole+cyproconazole)	-	0.5	39
Growth regulator	Moddus 250 (trinexapac-ethyl)	-	0.4	29-31

A1 – average level of production technology; A2 – high level of production technology

Tabela 3. Soil characteristic before experiment.

Traits	Years		
	2016/2017	2017/2018	2018/2019
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
P_2O_5 [mg kg^{-1}]	204	129	173
K_2O [mg kg^{-1}]	270	180	250
Mg [mg kg^{-1}]	127	140	229
Fe [mg kg^{-1}]	2289.0	2523.0	2222.0
Zn [mg kg^{-1}]	14.2	13.3	12.8
Mn [mg kg^{-1}]	389.0	251.4	265.1
Cu [mg kg^{-1}]	6.0	6.2	6.4
B [mg kg^{-1}]	1.1	1.3	1.5

average temperature of that month in the long-term perspective.

The laboratory tests

Crude protein content in grain was determined with Kjeldahl method (PN-EN ISO 20483), wet gluten content – with Glutomatic 2200 system (PN-A-74042), sedimentation index – with Zeleny test (PN-EN ISO 5529), and falling number with Hagberg-Perten method (PN-EN ISO 3093). Test weight was measured with densitometer equipped with 1000 ml cylindrical shaped container (PN-EN ISO 7971-3). TGW was determined at 14% moisture content. Contents of crude fat (Soxhlet method), crude fibre (Henneberg-Stohman method modified by Pruszyński) and crude ash (burning of plant material in 600°C according to PN-EN ISO 2171), were also analysed.

The statistical analysis

The results obtained in the field experiments and laboratory analyses have been statistically analysed according to the experimental design. The outcomes were tested under analysis of variance (ANOVA). The significance of differences between the mean values was assessed using Tukey's HSD test with the significance level at $\alpha = 0.05$. The calculations were made with the TIBCO Statistica 13.3 statistical software.

RESULTS AND DISCUSSION

The application of a higher cultivation intensity level significantly modified the grain yield (Table 5). In A2 technology (with a high level of agrotechnology), the yield was 9.63 t ha^{-1} and was 14.0% higher than in A1 technology, i.e. with an medium level (8.45 t ha^{-1}). A similar relation was found by Oleksy et al. (2008), who in the study with winter wheat obtained a yield increase of 12.6% as a result of intensive cultivation technology. The analysed winter wheat cultivars yielded from 8.65 to 9.39 t ha^{-1}. The highest yield was obtained from 'RTG Kilimanjaro'. No significant interaction of cultivation technology with the cultivar on the grain yield was found in the conducted research.

Intensive tillage technology significantly increased selected yield components such as ear density, number of grains per ear, TGW. 'RGT Kilimanjaro' had the largest number of ears, higher by 7.8%, 9.8% and 15.9% compared to 'Pokusa', 'Patras' and 'Hondia', respectively. Also in the study carried out by Podolska and Sułek (2012) higher levels of cultivation intensity resulted in a significant increase in the ear density and number of grains per ear. Podolska and Sułek (2002) and Fotyma (2005) found the positive effect of nitrogen fertilization on the number and weight of grains per ear, and Klimont and Osińska (2004) showed that more intensive crop protection increased wheat yield and number of grains per ear. TGW ranged from 37.3 ('RGT Kilimanjaro') to 42.3 g ('Patras'). Similar values from 36.5 to 45.5 g were reported by Cacak-Pietrzak et al. (1999). Weather conditions affected yield of the tested wheat cultivars. The greatest grain yield was obtained in the 2017/2018 season with optimal values of precipitation and temperature that approximated the long-term averages. There was also a significant correlation between cultivation technology and growing season on grain yield (Fig. 1). Furthermore, a favourable effect of technology inten-

Tabela 4. Weather conditions during the experiment (SDOO Przecław).

Year	Miesiąc; Month											Period
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	IX-VII
	Rainfalls [mm]											Sum
2016/2017	44.7	91.4	98.1	33.2	13.8	21.0	38.4	78.3	111.9	41.6	44.4	616.8
2017/2018	110.6	79.0	41.8	32.3	18.3	24.7	40.9	15.7	68.8	47.4	108.3	587.8
2018/2019	33.5	50.4	9.6	38.6	38.9	10.7	24.3	62.1	182.0	19.2	45.1	514.4
1956-2015	55.2	41.8	39.8	36.4	34.1	33.5	35.2	49.8	38.1	82.1	99.2	545.2
	Temperature [°C]											Mean
2016/2017	12.9	6.5	2.2	-0.2	-6.9	-1.6	4.9	7.1	12.5	17.4	17.9	6.6
2017/2018	12.5	8.7	3.1	1.9	0.6	-4.8	-2.4	12.2	15.4	16.9	18.5	7.5
2018/2019	13.4	9.1	3.4	0.6	-2.9	1.3	3.2	7.8	12.6	20.8	17.7	7.9
1956-2015	13.1	8.0	3.5	-0.5	-3.2	-1.5	3.3	7.9	13.9	16.9	18.9	7.3

Tabela 5. The effect of production technology intensity, cultivar and year on winter wheat yield components.

Factor		Number of ears per m^2	Number of grains per ear	Thousand grain weight [g]	Grain yield [t ha^{-1}]
Technology	A1	506.1 a	41.7 a	38.7 a	8.45 a
	A2	547.2 b	44.1 b	41.4 b	9.63 b
Cultivar	‘Hondia’	491.0 a	45.2 c	39.0 a	8.65 a
	‘RGT Kilimanjaro’	569.3 c	43.1 b	37.7 a	9.39 c
	‘Patras’	518.3 b	42.6 b	42.3 b	9.14 bc
	‘Pokusa’	528.1 b	40.8 a	41.2 b	8.99 ab
Year	2016/2017	565.0 b	43.1 b	40.8 b	9.40 b
	2017/2018	558.3 b	44.9 c	41.5 b	10.27 c
	2018/2019	456.7 a	40.6 a	37.9 a	7.46 a
Mean		526.7	42.9	40.1	9.04
Technology (T)		*	*	*	*
Cultivar (C)		*	*	*	*
Year (Y)		*	*	*	*
T × C		ns	*	ns	ns
T × Y		*	ns	ns	*
C × Y		*	ns	*	*
T × C × Y		ns	ns	ns	ns

Values marked with the same letter are not significantly different, p≤ 0.05, * significant differences p≤ 0.05, ns – insignificant differences
A1 – average level of production technology; A2 – high level of production technology

sification was found, but the positive impact was lower in the 2018/2019 season characterized by worse weather conditions. The lowest yields were observed in 2018/2019 for both A1 and A2 technologies. The yields of winter wheat grown at the high level of wheat management in the 2016/2017 season, were significantly higher vis-a-vis those obtained in the 2017/2018 season at an average level of crop management techniques. The effect of interaction of the growing season with cultivars on grain yield was also confirmed (Fig. 2). Weather conditions in the season 2018/2019 resulted in a yield decrease for all cultivars under investigaton. In 2017/2018 ‘RGT Kilimanjaro’ and ‘Hondia’ yielded significantly higher than in 2016/2017, whereas ‘Patras’ and ‘Pokusa’ did not show such a correlation.

Increasing the level of crop management techniques from average to high resulted in an increase in grain quality parameters (Table 6). Higher wet gluten content was characteristic for wheat grain from the treatments with A2 technology, i.e. 27.7%, compared to A1 technology, where the average gluten content was 25.7% (Table 6). In the experiment conducted by Stankowski et al. (2004), the average gluten content was higher and, depending on the cultivar, ranged from 39.5 to 42.0%, whereas a lower content of wet gluten was recorded by Budzyński et al. (2008).

One of the most important wheat technological parameters is the sedimentation index (Zeleny index). It determines approximately the baking value of wheat flour. In the study by Mazurek et al. (1999), the average sedimentation index for winter wheat cultivars ranged from 30.2 to 32.5 cm^3 regardless of nitrogen fertilization level. In our experiment, the average value of Zeleny index was higher and amounted to 46.0 cm^3. The average falling number was 351 s.

In the studies carried out by Knapowski and Ralcewicz (2004) and by Podolska et al. (2005), the average cultivar-dependent values of the falling number, amounted to 346–381 s and 242–294 s respectively. In this study, wheat grain produced in the treatments with high level of crop management technology was characterized by a higher falling number by 4.7% in comparison with the grains obtained from treatments with average level of technology. The grain bulk density (mass per hectolitre) is affected by grain plumpness, grain structure and tegument thickness. It also determines the grain milling value (Cacak-Pietrzak et al., 2005; Segit, Szwed-Urbaś, 2009). The bulk density of grain depended on production technology. As a result of the A2 technology application, the value of this parameter increased by 0.9%. Test weight of ‘Hondia’ (74.5 kg hl^{-1}) and ‘Patras’ (74.8 kg hl^{-1}) was significantly lower than that of ‘RTG Kilimanjaro’, the latter having the highest value of this parameter (80.0 kg hl^{-1}). Cacak-Pietrzak and Gondek (2010) and Harasim and Wesołowska-Trojanowska (2010) found that test weight (grain bulk density) ranged from 73.2 up to 78.6 kg hl^{-1}. Weather conditions significantly affect the formation of wheat grain quality features. Abovementioned relation was also confirmed in this study. In June and July of the 2018/2019 season with temperature close to that in the long-term period and low total precipitation during grain ripening, more favourable gluten parameters and falling numbers were obtained. On the other hand, in the seasons 2016/2017 and 2017/2018 with more abundant precipitation, a lower value of qualitative parameters (gluten content and falling number) was observed. According

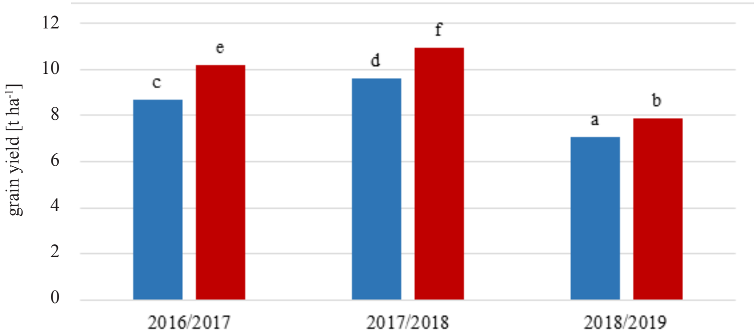

Figure 1. The effect of interaction between production technology intensity and year on winter wheat grain yield.

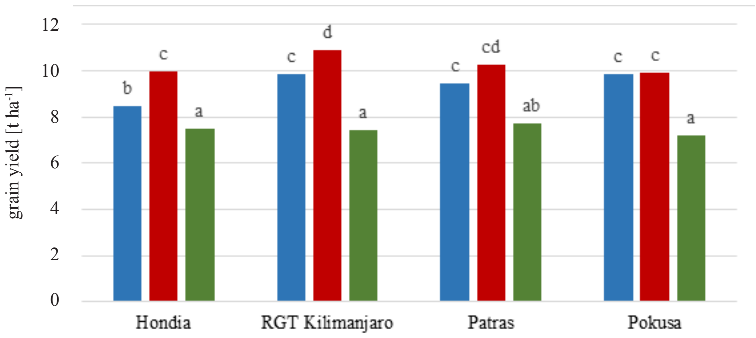

Figure 2. The effect of interaction betweeen year and cultivar on winter wheat grain yield.

Table 6. The effect of production technology intensity, cultivar and year on winter wheat grain parameters.

	Factor	Test weight [kg hl^{-1}]	Falling number [s]	Gluten content [%]	Zeleny's index [cm^3]
Technology	A1	75.9 a	343 a	25.7 a	43.1 a
	A2	76.6 b	359 b	27.7 b	48.8 b
Cultivar	'Hondia'	74.5 a	362 b	26.4 b	45.3 a
	'RGT Kilimanjaro'	80.0 c	387 c	27.9 d	49.2 b
	'Patras'	74.8 a	388 c	27.1 c	45.5 a
	'Pokusa'	75.7 b	269 a	25.5 a	43.8 a
Year	2016/2017	76.5 b	359 b	24.6 a	42.4 a
	2017/2018	77.0 c	318 a	26.8 b	46.9 b
	2018/2019	75.3 a	377 c	28.7 c	48.6 b
Mean		76.3	351	26.7	46.0
Technology (T)		*	*	*	*
Cultivar (C)		*	*	*	*
Year (Y)		*	*	*	*
T × C		ns	ns	*	ns
T × Y		ns	ns	ns	ns
C × Y		*	*	*	*
T × C × Y		ns	*	*	*

A1 – average level of production technology; A2 – high level of production technology
Values marked with the same letter are not significantly different, p≤ 0.05, * significant differences p≤ 0,05, ns – insignificant differences

Tabela 7. Skład chemiczny ziarna w zależności od technologii uprawy, odmiany oraz lat badań.

Factor		Total protein [g·kg^{-1}]	Fat [g·kg^{-1}]	Fibre [g·kg^{-1}]	Ash [g·kg^{-1}]
Technology	A1	118.0 a	15.9 b	24.9 a	17.4 a
	A2	127.6 b	15.1 a	24.3 a	17.1 a
Cultivar	'Hondia'	121.4 ab	16.3 b	27.1 c	18.1 b
	'RGT Kilimanjaro'	127.3 c	13.4 a	23.7 b	17.0 a
	'Patras'	122.8 b	16.3 b	20.7 a	17.1 a
	'Pokusa'	119.8 a	16.1 b	26.9 c	16.9 a
Year	2016/2017	118.0 a	15.3 ab	24.9 b	17.5 b
	2017/2018	119.3 a	14.9 a	19.9 a	16.6 a
	2018/2019	131.1 b	16.4 b	29.0 c	17.8 b
Mean		122.8	15.5	24.6	17.3
Technology (T)		*	*	ns	ns
Cultivar (C)		*	*	*	*
Year (Y)		*	*	*	*
T × C		ns	ns	ns	ns
T × Y		ns	ns	ns	ns
C × Y		*	*	*	ns
T × C × Y		*	ns	ns	*

A1 – average level of production technology; A2 – high level of production technology
Values marked with the same letter are not significantly different, p≤ 0.05, * significant differences p≤ 0.05, ns – insignificant differences

to the Podolska study (2008), grain quality parameters are also determined by environmental conditions.

The applied cultivation technologies significantly influenced the protein content in grain (Table 7). The evidence for the above is the fact that in the treatments that involved A2 technology the grain protein content was higher by 8.1% in comparison to that in the treatment with A1 technology. The average grain protein content in cultivars ranged from 119.8 to 127.3 g kg^{-1} and differed from that reported by Biel and Maciorowski (2012) – from 151.0 to 176.0 g kg^{-1} for spring and winter wheat. Oleksy et al. (2008) showed differences in cultivars grain protein content, values of this parameter increasing with the intensity of winter wheat cultivation from 114.0 to 123.0 g kg^{-1}. This was confirmed in this study. Nowak et al. (2004) and Gąsiorowska and Makarewicz (2007) showed that wheat cultivars react individually to the level of nitrogen fertilization, which is reflected in variable grain protein content. The highest protein content was obtained in the last year of this study with a temperature similar to that in the long-term period value and a low amount of precipitation during grain ripening, while in the first two years with a higher sum of precipitation, the values of this parameter were significantly lower. The content of the other components was dependent mainly on cultivar and year of study, while the impact of production technology was less visible. The average crude fat content in grain amounted to 15.5 g kg^{-1}. It was ranged from 13.4 to 16.3 g kg^{-1} in tested cultivars. Similar results were obtained by Charalampopoulos et al. (2002) and Augustyn and Barteczko (2009), who found that fat content of winter grains is within 10.6 to 25.8 g kg^{-1}. The average crude fibre content of the grain amounted to 24.6 g kg^{-1}, and was affected by cultivar. The highest content of crude fibre was found in 'Hondia' (27.1 g kg^{-1}) and 'Pokusa' (26.9 g kg^{-1}), and the lowest in 'Patras' (20.7 g kg^{-1}). In the research conducted by Rahman and Kader (2011), crude fibre content was lower, and ranged from 19.3 to 22.0 g kg^{-1}, depending on cultivar. This study also showed significant variability in crude ash content from 16.6 to 17.8 g kg^{-1}. According to Cyran (1997), the ash content in wheat does not exceed 2.0% d.m., which is confirmed by the results of this study.

CONCLUSIONS

1. Intensification of production technology significantly increased values of winter wheat yield components and grain quality, but had no effect on fibre and ash content in the grain of the tested cultivars.
2. The cultivars differed significantly for the parameters under study. The highest yield and the highest value of most of the examined qualitative parameters of grain with the lowest fat content was characteristic for the cultivar 'RGT Kilimanjaro'.
3. In the season 2018/2019, with low sum of precipitation and high temperature in the period of grain filling, the highest protein, fat, fibre and ash content and the lowest yield, were recorded.

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