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ORIGINAL PAPER

Effects of sowing date variation on winter wheat (*Tritium aestivum* L.) quality and grain yield*

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Abstract

Effective management decisions in agriculture, such as timely sowing and harvesting, are crucial for achieving high and stable crop yields. This study analyzed the effects of sowing date on the yield of winter wheat (*Tritium aestivum* L.). The data used for this analysis were obtained from winter wheat sowing experiments conducted at the Experimental Station in Krasne, University of Rzeszów in Poland, between 2018 and 2021. The first factor examined was the sowing date: I – recommended, II – 30-day delay and III – 60-day delay. The second factor involved two varieties of wheat: RGT Bilanz and RGT Kilimanjaro. The grain yield determined in 2020 decreased by 1.11 t ha^{-1} compared to the yield obtained in 2019. Wheat sown on the recommended date produced the highest yield (7.99 t ha^{-1}), while yields with 30- and 60-day sowing delays were significantly lower. Compared to the 60 day delay, the recommended sowing date significantly affected the SPAD and LAI indices, and yield components such as the number of ears per 1 m^2 ground area and the number of grains per spike. In addition, sowing wheat on the first date resulted in an increase in protein, starch, phosphorus and potassium content in the grain compared to the third date. It also led to an increase in iron content and a decrease in fiber levels compared to the second and third dates. The variety RGT Bilanz had a significantly higher LAI value, and starch, phosphorus, manganese and iron content in the grain, while the variety RGT Kilimanjaro was characterized by a higher concentration of protein, potassium, zinc and copper in the grain.

Keywords: cultivar, sowing seeds, yield, chemical composition

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INTRODUCTION

Cereals occupy a significant area in Poland, estimated at 70% of all arable land, of which the largest area is devoted to common wheat (*T. aestivum*) – Grabiński (2016). The grain yields obtained are high and of good quality, which is the result of proper selection of location and agricultural technology (Oleksiak 2014, 2016). In wheat, sowing grain at the optimal time is crucial, but sometimes postponed due to late forecrop harvests like corn for grain or sugar beets. Klepeckas et al. (2020) reported that climate warming could lead to changes in recommendations regarding wheat sowing dates. A study by Rezaie et al. (2022) confirmed that delaying wheat sowing date was necessary in some regions due to the observed climate changes. Qiao et al. (2023) predicted that the optimal sowing date for wheat would be earlier in humid regions but later in warming and dry areas. Korbas and Mrówczyński (2020) and Qiao et al. (2023) reported that sowing date determined plant response to photoperiodism and vernalization, which in turn influenced reproductive organ development. A later sowing date results in a shorter period of vegetative and generative development. Ma et al. (2018) concluded that depending on the sowing date, an appropriate sowing density should be applied, and recommended increasing the seed rate for delayed sowing. Dubis and Budzyński (2006) found that winter wheat sowing in the third ten days of September had the most favorable effect on yield components and grain yield. Shah et al. (2020) reported that increased sowing rates compensated for the decline in wheat yields due to delayed sowing; however, they did not confirm such a relationship for very late sowing (more than two weeks). Weber and Podolska (2008) demonstrated that wheat yields were highest when sown early, especially with simplified tillage, compared to the optimal and delayed sowing dates. Weber (2009) found that the optimal sowing date resulted in stable wheat yields over the years of the study. Delayed sowing dates significantly reduced the yields of most of the varieties tested, especially with less dense sowing. Ren et al. (2019) showed that in the area of their trial, it was possible to shift the recommended sowing date from September 22-23 to October 1. Jarecki and Bobrecka-Jamro (2019*b*) found that delaying the sowing date of winter oilseed rape did not reduce yield but changed seed quality. Fu et al. (2023) reported that delaying the sowing of winter wheat could reduce yields by up to 13.7%, but correct nitrogen fertilization mitigated yield losses. On poorer soils, the delay in the sowing date did not cause such large yield decreases as on better soils (Oleksiak, Mańkowski 2007). Yield losses were smaller when very high doses of mineral fertilizers were applied. On less fertile soils, the yield reduction due to delayed sowing was not as significant as on richer soils. In turn, Brzozowska and Brzozowski (2020) showed that higher NPK fertilization had a significant effect only on nitrogen content in seeds but did not compensate for the delay in sowing. Costa et al. (2013) demonstrated that the optimal sowing date depended on the location of the experiments, emphasizing the need to conduct research in different habitats in this area. A study by Jarecki and Bobrecka-Jamro (2019*a*) proved that sowing spring wheat in the fall was a good alternative to late harvested preceding crops, resulting in higher grain yields by 0.7 t ha^{-1} (10.8%) compared to spring sowing yields.

The objective of the experiment was to assess the impact of a delayed sowing date on yield and grain quality of two winter wheat varieties. The research hypothesis assumed that varying sowing dates would alter the yield and quality of the grain.

MATERIALS AND METHODS

The field research was conducted at the University of Rzeszów Experimental Station in Krasne, Poland (50°03′N 22°05′E), over three growing seasons: 2018/2019, 2019/2020 and 2020/2021.

The experiment was established on Luvisol soil (IUSS Working Group WRB), on plots of 15 m^2 in four replications. The first factor was the sowing date of winter wheat (I – recommended, II – 30-day delay, III – 60-day delay), and the second was the variety (RGT Bilanz and RGT Kilimanjaro, RAGT Semences Polska Sp. z o.o.). RGT Bilanz is a medium-late variety of winter wheat with very high yield potential and very good winter hardiness. RGT Kilimanjaro is a variety with a very high and stable yield achieved in all years of research and in all growing conditions.

The experiment was conducted in a Randomized Complete Block Design (RCBD) with split-5-plot arrangement and four replications.

The soil had a slightly acidic pH and a medium-high humus content. The content of available phosphorus and potassium was high, while that of magnesium and sulfur was low (Table 1). Each year, soil samples from

Table 1

Chemical analysis of soil

Parameter	Unit	2018	2019	2020
pH in KCl	-	6,1	5,8	5,7
Humus	(g kg^{-1})	15,4	12,8	13,1
P	(mg 100 g^{-1} soil)	8,5	7,9	7,5
K		18,9	19,5	19,5
Mg		6,4	6,6	5,9
Fe	(mg 1000 g^{-1} soil)	1602	2418	3177
Zn		10,4	8,9	13,1
Mn		348	433	522
Cu		4,4	5,4	6,3
B		1,1	1,2	0,8

the experimental field (30 cm deep) were analyzed in the Regional Chemical-Agricultural Station in Rzeszów.

The weather data for the experiment was obtained from the Meteorological Station of the University of Rzeszów, located 10 km away from the study site.

The area of a single plot was 15.0 m^2, and the separation strips were 1-m-wide. Wheat seeds were sown at a depth of 3.5 cm and the width of the inter-rows was 12.5 cm.

The preceding crop was winter oilseed rape, followed by stubble cultivation, harrowing and plowing. A cultivation unit was used before each sowing. The seeds were treated with Gizmo 060 FS (tebuconazole) at a dose of 50 ml 100 kg^{-1} grain. Sowing on the recommended dates was carried out on 09/24/2018, 09/23/2019 and 09/28/2020, while delayed sowing was performed on 10/24/2018, 10/23/2019, 10/28/2020 and 11/23/2018, 11/22/2019 and 11/27/2020. The sowing density was 350 seeds m^{-2}, and pesticides were applied according to the manufacturer's recommendations. Chemical treatments (Table 2) were applied using a tractor sprayer, with a spray liquid at a dose of 250-350 dcm^3 ha^{-1}.

Table 2

Chemical plant protection treatments

Preparation	Dose (kg ha^{-1} or dcm^3 ha^{-1})	Sowing date		
		I	II	III
Expert Met 56 WG	0.35	BBCH 11	-	-
Huzar Active Plus	1.0	BBCH 25		
Antywylegacz 725 SL + Moddus 250 EC	1.0 + 0.3	BBCH 30		
Boogie Xpro 400 EC	1.5	BBCH 39		
Karate Zeon 050 CS	0.1	beginning of hatching of cereal leaf beetle larvae		
Fandango 200 EC	1.0	BBCH 58		

Nitrogen fertilization (ammonium nitrate) was applied in two periods: after the start of vegetation in spring at a dose of 60 N kg ha^{-1}, and at the beginning of stem elongation at a dose of 60 N kg ha^{-1}. Fertilizations with phosphorus (granulated simple superphosphate) and potassium (potassium salt) were both applied during plowing for sowing at doses of 60 and 90 kg ha^{-1}, respectively. Basfoliar 2.0 36 Extra was used for foliar fertilization (4.5 l ha^{-1}) in the following stages: formation of side shoots, emergence of flag leaf, emergence of inflorescence, and heading.

Development stages were determined using the BBCH scale (Bundesanstalt, Bundessortenamt und Chemische Industrie). Soil Plant Analysis Development (SPAD) was measured with a SPAD 502P chlorophyll meter (Konica Minolta, Japan). Leaf area index (LAI) values were determined using an AccuPAR LP-80 apparatus (Meter, USA). SPAD (15 flag leaves in each plot, middle part of the leaf) and LAI (four measurements in each plot) measurements were taken at the BBCH 75 stage.

Ear counts were recorded from a 1 m^2 area prior to harvesting. The mean number of grains per ear and thousand grain weight (TGW) were determined on random plants collected from an area of 0.5 m^2. Harvesting was carried out with a plot harvester at the full maturity stage. The yield obtained was expressed per 1 ha and 14% grain moisture content. The chemical composition of the grain was analyzed using the near infrared method and a FT-LSD MPA spectrometer (Bruker company, Germany) in the laboratory of the Plant Production Department of the University of Rzeszów. To determine the content of individual elements (in two repetitions), grain samples were mineralized in an open system using HNO_3:$HClO_4$:H_2SO_4 at a ratio of 20:5:1 with a Tecator heating block (FOSS, Denmark). The content of K, Mg, Zn, Mn, Fe, and Cu in the samples was determined using atomic absorption spectroscopy (FAAS) with a Hitachi Z-2000 apparatus (Tokyo, Japan). The phosphorus content was determined using a Shimadzu UV-VIS spectrophotometer (Kyoto, Japan) and the vanadium-molybdenum method.

The least significant difference (LSD) test was applied to separate significant means, at a level of $\alpha=0.05$. Calculations (variance analyses) were performed using the ANALWAR-5.3.FR statistical software.

RESULTS AND DISCUSSION

The results of the current study indicated that the varying weather conditions (Figure 1) in individual years had a significant effect on the investi-

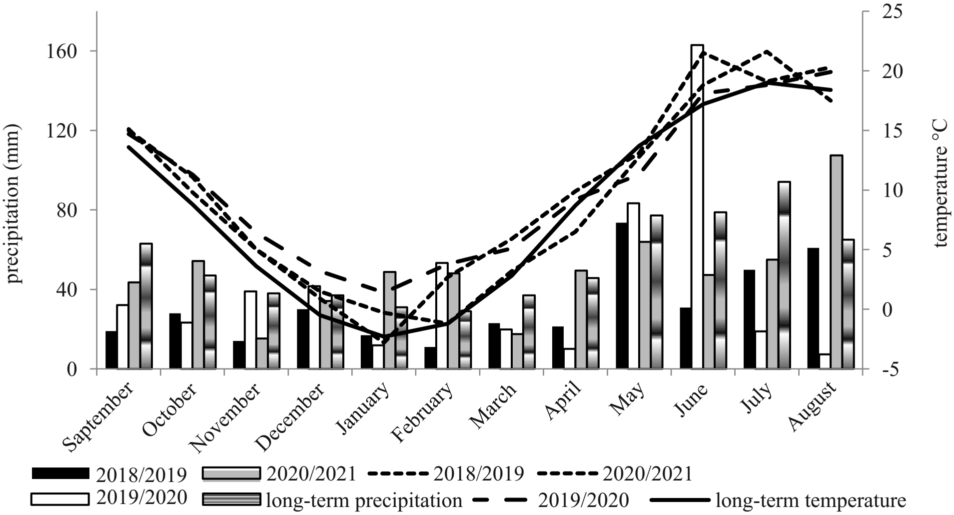

Fig. 1. Weather conditions in the research seasons

gated traits and parameters, including grain quality. During each fall, air temperatures were higher than the long-term average, while precipitation was either lower or similar to long-term data, which allowed sowing on the planned dates. The coldest month in 2019 and 2020 was January, while in 2021 it was February. Generally, the spring weather conditions were favorable for plant growth, except for the month of April 2020, when there was little precipitation, and in 2021, when air temperatures were below the long-term average. In 2020, there was a substantial amount of rainfall in June, while in July and August there was very little rain. In August 2021, heavy rainfall made it difficult to harvest grain, especially from the delayed sowing dates.

It is essential to determine the optimal planting period to identify varieties suitable for evaluation in the prevailing cropping pattern of a particular area. Grabiński (2016) reported that the weather had a significant impact on the yield of both winter and spring wheat forms. For the winter form, the course of the weather is important already in the fall and winter seasons. Therefore, the latter author recommended selecting cultivars with the appropriate winter hardiness for a particular region. Yang et al. (2019) stressed that global warming and drought posed a serious threat to wheat production in many parts of the world, necessitating the breeding of new varieties and the improvement of agricultural technology. Allard et al. (2019) demonstrated that adjusting the date of sowing and other agricultural treatments to the geographic regions was necessary for successful wheat cultivation.

SPAD index measurements showed that the plants sown on the recommended date were nourished most optimally, while those sown 60 days later had significantly worse nutrition. Similar results were observed for the LAI index. Both indices varied over the years of research. In 2019, the SPAD index was 52.6 and in 2020 it was the lowest and amounted to 47.8. In addition, the variety RGT Bilanz appeared to perform better with respect to the LAI index values than the variety RGT Kilimanjaro. Significantly more ears per m^2 and number of grains per ear were recorded in optimally sown crops compared to sowing delayed by 60 days. The thousand-grain weight was not modified as a result of different sowing dates. Although yield components did not differ significantly between cultivars, they showed variations over the years of the study (Table 3).

Jarecki and Czernicka (2022) obtained similar results of the SPAD and LAI indices in winter wheat. Comparable results were also reported by Jarecki and Czernicka (2022), who found that the SPAD and LAI indices in winter wheat could be used to predict plant growth and yield. Klepeckas et al. (2020) and Shah et al. (2020) confirmed that the LAI index was affected by the wheat sowing date, which modified yield components and grain yield. Podolska and Wyzińska (2011) showed that delayed sowing of winter wheat resulted in a decrease in the number of ears and grains per square meter, but did not affect the TKW seed index. In addition, the resulting decreases in yield components depended on the weather conditions during

Table 3

Field and biometric measurements

Specification	SPAD	LAI	Number of ears (pcs m^{-2})	Number of grains per ear	Thousand grain weight (g)
Sowing date					
Recommended	53.1	4.16	586.2	32.3	41.8
30 day-delay	50.6	3.96	573.9	31.5	41.5
60 day-delay	48.4	3.79	553.5	29.8	40.6
$LSD_{0,05}$	4.62	0.343	31.61	2.41	n.s.
Cultivar					
RGT Bilanz	51.6	4.12	568.3	31.6	41.1
RGT Kilimanjaro	49.8	3.82	574.1	30.8	41.5
$LSD_{0,05}$	n.s.	0.281	n.s.	n.s.	n.s.
Year					
2019	52.6	3.81	573.6	32.3	42.9
2020	47.8	4.15	575.2	29.9	39.8
2021	51.7	3.95	564.8	31.4	41.2
$LSD_{0,05}$	3.76	0.326	8.64	2.27	2.98
Mean total	50.70	3.97	571.2	31.2	41.30

n.s. – non-significant differences

the plants' growing period. Sattar et al. (2010) demonstrated that delayed sowing of wheat resulted in decreased number of grains per ear, thousand grain weight, and yield, but also in an increase in the protein content in the grain. Szumiło and Rachoń (2008) reported that delaying the sowing date reduced the yield of spelt (*Triticum spelta*), durum wheat (*Triticum durum*) and common wheat (*Triticum aestivum*) by an average of 17.3%, mainly due to a significant decrease in the number of spikes per square meter.

Figure 2 shows that the grain yield was the highest when the wheat was sown on the recommended date, with an average yield of 7.99 t ha^{-1} in the experiment. The yield of wheat sown 30 and 60 days later was significantly lower, with differences amounting to 5.1% and 18.5% respectively. At the same time, it was shown that the yield between the second and third sowing date differed significantly by 1.07 t ha^{-1}, while the highest wheat yields were achieved in 2019, and the lowest in 2020, indicating that weather conditions had a significant impact on the crop.

Podolska and Wyzińska (2011) concluded that sowing delayed by 4 weeks resulted in up to a 36% decrease in grain yield, depending on the variety.

Weber and Biskupski (2007) reported that certain varieties of winter wheat were characterized by a high tolerance for delayed sowing dates, while others responded with a significant decrease in yields. In another study,

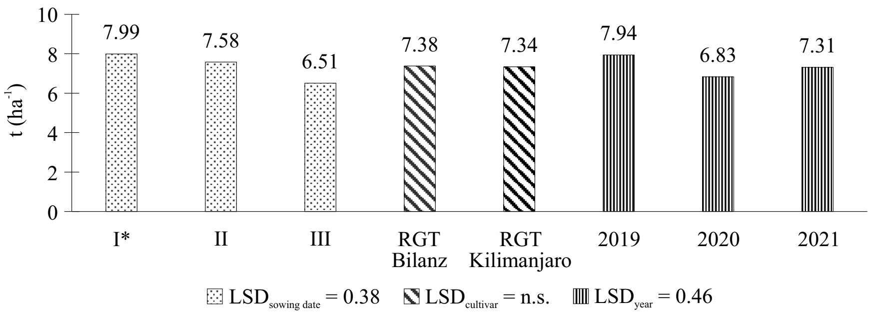

Fig. 2. Winter wheat grain yield (t ha^{-1})
* sowing date (I – recommended, II – 30 day-delay., III – 60 day-delay.)

Weber and Biskupski (2008) confirmed that a two-week sowing delay reduced yields of Kobiera and Rywalka varieties, while Satyna showed increased tolerance to late sowing. Korbas and Mrówczyński (2020) showed that sowing date mainly affected the number of ears, with fewer ears produced when sowing was delayed. The highest wheat yields were obtained at 500-550 ears per square meter. Gandjaeva (2019) concluded that delayed sowing carried risks, especially in unfavorable weather conditions or due to agricultural mistakes.

Petrychenko et al. (2021) reported that wheat sowing on September 30 was optimal, resulting in a yield of 9.43 t ha^{-1}, while sowing in November and December led to yield decreases of 1.89 t ha^{1} and 2.40 t ha^{1}, respectively.

Sowing winter wheat on the recommended date, compared to delayed sowing by 60 days, resulted in an increase in protein and starch content in the grain, and a decrease in fiber content. The variety RGT Kilimanjaro contained more protein and less starch in the grain compared to the variety RGT Bilanz. The chemical composition of the grain varied significantly over the years of study, as shown in Table 4.

Contrary to findings of Shah et al. (2020), our study (Table 4) did not confirm that delayed sowing resulted in an increase in protein and starch content in the grain. However, Mikos-Szymańska and Podolska (2016) demonstrated that delayed sowing had a minor effect on the chemical composition of wheat grain, with cultivars and weather conditions having a greater impact on this trait. Ralcerowicz and Knapowski (2004) found that postponing the sowing date by two weeks compared to the optimal period caused a significant increase in protein content, but led to a decrease in both grain yield and protein yield. Similarly, Sułek (2009) showed that delaying the sowing date of spring wheat also led to an increase in protein content.

Sowing wheat in the first period resulted in increased levels of phosphorus and potassium compared to the third period and higher iron content compared to the second and third dates. The content of the other elements did not vary under the influence of varying seed sowing date. The content of determined elements in the grain varied significantly among the tested cultivars, except for magnesium (Table 5). The study also found that the levels

Table 4

Basic chemical composition of grain (g kg^{-1})

Specification	Protein	Starch	Ash	Fiber
Sowing date				
Recommended	141	632	147	276
30 day-delay.	138	625	150	291
60 day-delay.	135	618	153	297
$LSD_{0,05}$	5.6	12.9	n.s.	13.0
Cultivar				
RGT Bilanz	132	634	152	291
RGT Kilimanjaro	144	616	148	285
$LSD_{0.05}$	9.5	16.8	n.s.	n.s.
Year				
2019	135	629	144	287
2020	143	615	157	294
2021	136	631	149	283
$LSD_{0.05}$	7.5	14.3	11.0	9.0
Mean total	138	625	150	288

n.s. – non-significant differences

Table 5

Content of macronutrients and micronutrients in grain

Specification	P	K	Mg	Zn	Mn	Cu	Fe
	(g kg^{-1})			(mg kg^{-1})			
Sowing date							
Recommended	3.36	3.85	1.27	38.4	26.2	2.29	52.3
30 day-delay.	3.28	3.75	1.25	39.4	27.1	2.33	48.6
60 day-delay.	3.23	3.71	1.23	39.2	26.5	2.37	46.3
$LSD_{0.05}$	0.11	0.13	n.s.	n.s.	n.s.	n.s.	3.26
Cultivar							
RGT Bilanz	3.36	3.68	1.28	38.2	27.9	2.20	49.8
RGT Kilimanjaro	3.22	3.86	1.22	39.8	25.3	2.46	48.3
$LSD_{0.05}$	0.12	0.16	r.n.	1.41	2.24	0.22	1.13
Year							
2019	3.25	3.73	1.25	39.3	27.8	2.21	46.6
2020	3.38	3.87	1.23	37.1	26.6	2.33	52.5
2021	3.24	3.71	1.27	40.6	25.4	2.45	48.1
$LSD_{0.05}$	0.11	0.13	r.n.	2.86	2.12	0.21	3.34
Mean total	3.29	3.77	1.25	39.0	26.6	2.33	49.1

n.s. – non-significant differences

of phosphorus, potassium and micronutrients differed significantly between the individual years of research. Brzozowska and Brzozowski (2020) reported that sowing winter wheat at different dates did not significantly affect the levels of macronutrients in the grain, except for a slight decrease in phosphorus content from 3.00 to 2.91 g kg^{-1} d.m. when sowing was delayed.

CONCLUSIONS

On the basis of the conducted research, it can be concluded that the weather conditions exerted an effect on all yield components studied, except for magnesium content. The grain yield in 2019 was 7.94 t ha^{-1}, while it was 1.11 t ha^{-1} lower in 2020. The study found that the SPAD, LAI, number ears per m^2 and number of grains per earindices were significanlty higher for the recommended sowing dates. Different sowing dates (I – recommended, II – 30-day delay and III – 60 day delay) affected the grain yield, which was 7.99 t ha^{-1}, 7.58 t ha^{-1} and 6.51 t ha^{-1}, respectively. Compared to the third sowing date, it was found that the content of protein, starch, phosphorus, potassium and iron were higher in the grain from the recommended sowing period. In contrast to the third sowing dates, the lowest fiber content was observed in the seeds from the recommended sowing period, while there were no significant differences between the individual wheat cultivars tested. The results revealed that the variety RGT Bilanz was characterized by a significantly higher LAI index and starch content in the grain, while the variety RGT Kilimanjaro had the highest protein level in the grain. Apart from magnesium, the content of macro- and micronutrients in the grains varied between these two wheat cultivars.

In summary, it has been proven that timely sowing of winter wheat is an important part of agronomic management to obtain high yields of good quality grain.

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