Original scientific paper
Journal of Central European Agriculture, 2024, 25(4), p.945-954

DOI: /10.5513/JCEA01/25.4.4131

Response of winter wheat to diversified sowing date and sowing density

Reakcja pszenicy ozimej na zróżnicowanie terminu siewu i gęstości siewu

Wacław JARECKI (✉)

Department of Crop Production, University of Rzeszów, A. Zelwerowicza 4, 35-601 Rzeszów, Poland

✉ Corresponding author: wjarecki@ur.edu.pl

Received: October 10, 2023; accepted: September 4, 2024

ABSTRACT

Common wheat (*Triticum aestivum* L.) is the most important cereal in the world because its grains serve as the primary food for humans and also constitute good fodder for animals. Among the important aspects of the agronomy of this species are the sowing date and sowing density, as both affect yield components and grain yield. A three-year field experiment investigated the response of winter wheat to varying sowing dates (recommended, delayed by 30 days and delayed by 60 days) and sowing densities (recommended, increased by 10% and increased by 20%). It was demonstrated that the soil plant analysis development (SPAD) index, number of grains per ear, and thousand seed weight (TSW), were the highest when the seeds were sown at the recommended sowing date and density. On the other hand, the highest leaf area index (LAI) and the number of ears per square meter were obtained when the seeds were sown at the recommended sowing date but with a 20% increased sowing density. Delaying the sowing date, especially by 60 days, reduced grain yield. Increasing seed sowing density by 10% was beneficial when sowing was delayed by 30 days. However, increasing the density of sowing postponed by 60 days did not produce the expected results. The protein content in the grain exceeded 14% at the optimal sowing date and recommended sowing density, as well as when the sowing date was delayed by 30 days, and the sowing density was either recommended or increased by 10%. It should therefore be concluded that delaying the sowing date of winter wheat, especially by 60 days, is unjustified in the study area. For sowings delayed by 30 days, the decrease in yield can be partially compensated by increasing the sowing rate by 10%.

Keywords: *Triticum aestivum* L., sowing seeds, yield components, yield, protein

ABSTRAKT

Pszenica zwyczajna (*Triticum aestivum* L.) jest najważniejszym zbożem na świecie, ponieważ jej ziarna są głównym pokarmem dla ludzi a także dobrą paszą dla zwierząt. Do ważniejszych elementów agrotechniki tego gatunku należy termin siewu i gęstość siewu, ponieważ oba wpływają na komponenty plonu i plon ziarna. W trzyletnim doświadczeniu polowym zbadano reakcję pszenicy ozimej na zróżnicowany termin siewu (zalecany, opóźniony o 30 dni, opóźniony o 60 dni) i gęstość siewu (zalecana, zwiększona o 10%, zwiększona o 20%). Wykazano, że SPAD - Soil Plant Analysis Development, liczba ziaren w kłosie i MTZ były największe po wysianiu ziarna w terminie i gęstości siewu zalecanej. Z kolei największy LAI – Leaf Area Index oraz liczba kłosów na 1 m^2 uzyskano po wysiewie ziarna w terminie zalecanym ale zwiększonej o 20% gęstości wysiewu. Opóźnienie terminu siewu a zwłaszcza o 60 dni skutkowało zmniejszeniem plonu ziarna. Zwiększenie gęstości wysiewu ziarna o 10% było korzystne w terminie siewu opóźnionym o 30 dni. Natomiast zwiększenie gęstości siewu w terminie opóźnionym o 60 dni nie przyniosło oczekiwanych rezultatów. Zawartość białka w ziarnie przekroczyła 14% gdy termin siewu był optymalny a gęstość siewu zalecana oraz gdy termin siewu był opóźniony o 30 dni a gęstość siewu była zalecana lub zwiększona o 10%. Należy zatem wnioskować, że opóźnianie terminy siewu pszenicy ozimej a zwłaszcza o 60 dni jest nieuzasadnione w rejonie badań. Przy siewach opóźnionych o 30 dni spadek plonu można częściowo zrekompensować zwiększoną normą wysiewu o 10%.

Kľúčové slová: *Triticum aestivum* L., siew nasion, komponenty plonu, plon, białko

INTRODUCTION

Wheat is one of the most important crops in the world with significant economic importance because many food products are made from the grain of this species. Therefore, agricultural research constantly improves the agronomy of new wheat varieties to achieve stable, high-yielding, and good-quality grain yields (Chiriţă et al., 2023). In some regions of the world, climate change poses a threat to wheat production, which requires the improvement of varieties and the implementation of new solutions in cultivation technology (Yang et al., 2019). Many authors have concluded (Klepeckas et al., 2020; Aula et al., 2022; Qiaoyan et al., 2022) that changes may occur, e.g., in the recommendations regarding the sowing dates and sowing density of winter wheat. Timely grain sowing is considered one of the better methods for the adaptation of this species to climate change and mitigating its effects (Dueri et al., 2022). The optimum sowing date for wheat is predicted to be earlier in wet regions but later in warming up and dry areas (Qiao et al., 2023). Rezaie et al. (2022) have argued in their study that early sowings can have a positive impact on wheat yields, but according to Aula et al. (2022), they can also increase insect and disease pressure. Research by Shah et al. (2020) demonstrated that the recommended sowing date ensured proper seed germination, plant growth and development, ultimately shaping grain yields. Klepeckas et al. (2020) showed that delaying wheat sowing by 7 days shortened the grain filling period and reduced yields by 6 to 7.7%. The later the sowing dates, the higher the yield losses, which is why continuous research in this area is considered important for agricultural practice. In this aspect, Oleksiak (2014) has reported that in Poland, despite the awareness of the significance of timely sowing of winter wheat, a large proportion of plantations is sown late. This is most often the result of late harvesting of pre-crops such as maize for grain or sugar beets. Ma et al. (2018) reported that when sowing is delayed, its density should be increased by 5-10% to compensate for yield losses. Shah et al. (2020) have confirmed that increasing sowing density is beneficial when sowing winter wheat is slightly delayed, but ineffective for very late sowing. Jarecki and Bobrecka-Jamro (2019) demonstrated that so-called facultative wheat varieties can be used for late autumn sowings. These are spring wheat varieties that show good winter hardiness. The yields obtained from such sowings were shown to be satisfactory, but only when the winter was mild. Research conducted by Allard et al. (2019) has suggested that determining the optimal sowing date is associated with the research region. Therefore, depending on the trial location, different sowing dates for winter wheat were recommended, ranging from mid-August to the end of September. Similarly, determining the optimal seed sowing density was dependent on the study site. At two locations, increasing the number of sown seeds from 250 to 550 per square meter resulted in a 9% increase in yield, while in the third location, it was not justified. Ren et al. (2019) have argued that both the sowing date and sowing density are crucial for winter wheat yielding. Based on the conducted research, they demonstrated that in the study area, it was possible to shift the recommended sowing date by about a week. Costa et al. (2013) confirmed that sowing date and sowing density modified wheat yield but that the effect of sowing date was greater than sowing density. Zecevic et al. (2014) and Bastos et al. (2020) have concluded that the results of studies on the response of winter wheat to different seeding densities are not always unequivocal in field experiments due to variable weather conditions in the years of the study and genetic traits of the cultivated varieties (e.g., winter hardiness). Bastos et al. (2020) have suggested that increasing seeding density can be beneficial in adverse weather conditions, but when weather conditions are favorable, lower seeding density may yield equally good results. Additionally, plants exhibit so-called compensatory abilities, and with less dense emergence, they tend to tiller more vigorously. It should also be noted that modern measurement techniques allow for a quick and non-destructive assessment of plant condition (Shah et al., 2020; Jarecki and Czernicka, 2022; Li et al., 2023; Yin et al., 2023), and depending on the measurements obtained, appropriate adjustment, e.g. of spring nitrogen dose can be applied (Fu et al., 2023). Interesting research results were presented by Mikos-

Szymańska and Podolska (2016), who found that grain quality parameters of common wheat and spelt were better when the sowing date was delayed by 2 weeks and the sowing density was 300 or 450 grains/m^2.

The aim of the research was to determine the response of winter wheat to different sowing dates (recommended, delayed by 10 days, delayed by 20 days) and sowing densities (recommended, increased by 10%, increased by 20%). The research hypothesis assumed that an increase in grain sowing density would be well-founded only for delayed sowing dates.

MATERIALS AND METHODS

The field experiment was set up at the Experimental Station of the University of Rzeszów in Krasne (50°03′N 22°05′E), near Rzeszów, Poland. The experiment was conducted in three growing seasons: 2019/2020, 2020/2021 and 2021/2022. The studied factors were: sowing date (optimal, delayed by 30 days, delayed by 60 days) and sowing density (recommended, increased by 10%, increased by 20%). The variety RGT Comandor (DANKO Hodowla Plant Sp. z o.o., Choryń, Poland), recommended for cultivation in the study area, was selected for the trial. The experiment was conducted in four replicates in a split-plot design.

The experiment was established on medium soil, good wheat complex, soil quality class III in Poland. The soil was characterized by a slightly acidic pH and moderate humus content. The content of assimilable phosphorus and potassium was high, while magnesium was at a moderate level (Table 1).

Table 1. Chemical analysis of soil

Parameter	Unit	2019	2020	2021
pH in KCl	-	6.1	6.0	5.7
Humus	%	1.4	1.1	1.2
P_2O_5	mg/100 g soil	19.1	18.6	17.3
K_2O		24.5	22.6	22.1
Mg		6.6	5.9	5.6

Soil samples were analyzed at the Regional Chemical and Agricultural Station in Rzeszów, according to Polish standards.

Weather conditions were compiled using data from the Meteorological Station of the University of Rzeszów, approx. 10 km from the experimental site.

The surface area of a single plot was 15.0 m^2. Wheat grain was sown at a depth of 3.5 cm, with a row spacing of 12.5 cm. The preceding crop was winter oilseed rape, and the field was disc-harrowed after its harvest. Before sowing, a combined cultivator and NPK mineral fertilization were applied. The nitrogen (ammonium nitrate 34% N), phosphorus (superphosphate 19% P_2O_5), and potassium (potassium salt 60% K_2O) doses were 30, 60, and 90 kg/ha, respectively.

The seeds were treated with Gizmo 060 FS (tebuconazole) at a rate of 50 ml/100 kg grain. Optimal sowings were carried out on 23/09/2019, 28/09/2020 and 26/09/2021. Delayed sowings were conducted on 23/10/2019, 28/10/2020 and 26/10/2021, as well as on 22/11/2019, 27/11/2020 and 25/11/2021. The recommended sowing density for the variety RGT Comandor is 340 seeds/m^2, and for experimental purposes, it was increased by 10% or 20%. Plant protection products were used according to the manufacturer's recommendations after prior monitoring of the plantation. Chemical sprayings (Table 2) were applied using a tractor-mounted sprayer, with a liquid volume ranging from 200 to 300 l/ha. Plant development stages were determined according to the BBCH scale (Bundesanstalt, Bundessortenamt und Chemische Industrie) used in the EU.

In the spring, nitrogen fertilization (ammonium nitrate) was applied at two dates: at the beginning of vegetation at a dose of 60 N kg/ha and the stem shooting stage (21 BBCH) at a dose of 60 N kg/ha. For foliar fertilization, Basfoliar 2.0 36 Extra was used at the following growth stages: tillering (21 BBCH), flag leaf (39 BBCH) and earing (51 BBCH), at the doses recommended by the manufacturer.

Table 2. Chemical plant protection treatments

Preparation	Active substance	Dose (kg/ha or l/ha)	Application phase
Expert Met 56 WG	tribuzin; flufenacet	0.35	BBCH 12
Huzar Active Plus	2,4-D; iodosulfuron methyl sodium; thiencarbazone-methyl	1.0	BBCH 25
Antywylegacz 725 SL + Moddus 250 EC	chlormequat chloride + trinexapac ethyl	1.0 + 0.3	BBCH 30
Boogie Xpro 400 EC	prothioconazole; bixafen; spiroxamine; N,N-Dimethyl decanamide	1.5	BBCH 39
Karate Zeon 050 CS	lambda-cyhalothrin	0.1	beginning of hatching of cereal leaf beetle larvae
Fandango 200 EC	fluoxastrobin; prothioconazole	1.0	BBCH 58

Plant nutritional status (soil plant analysis development, SPAD) was measured using a SPAD 502P chlorophyll meter (Konica Minolta, Japan). Leaf area index (LAI) was measured using an AccuPAR LP-80 apparatus (Meter, USA). Leaf stomatal conductance (Gs) was determined with a Porometer SC-1 apparatus (Meter, USA). SPAD, LAI (m^2/m^2) and Gs ($mmol/m^2s$) measurements were carried out at the flowering stage (65 BBCH) on 10 flag leaves in the morning.

Ear density was counted on a 1 m^2 area before harvest. The number of grains per ear and TSW were counted for plants harvested from 0.5 m^2. The harvest was conducted using a plot harvester at full maturity (89 BBCH). The obtained yield was calculated per hectare with a grain moisture content of 14%.

The chemical composition of the grain (total protein) was determined using the near-infrared method on a MPA FT-LSD Spectrometer (Bruker, Germany) in the laboratory of the Department of Plant Production at the University of Rzeszów.

The results were statistically analyzed according to the TIBCO Statistica 13.3.0 (TIBCO Software Inc., Palo Alto, CA, USA) program. Statistical differences ($P \leq 0.05$) between the analyzed parameters were obtained using analysis of variance (ANOVA), followed by Tukey's HSD test.

RESULTS AND DISCUSSION

Air temperatures and precipitation varied between study years (Figure 1). In autumn, the weather conditions were favorable for plant growth. Low rainfall was recorded only in October 2021. During winter, air temperatures were higher or close to the long-term average. In spring, air temperatures were similar to the long-term average. However, the total precipitation was low in April 2020, as well as in May and June 2022. Below-average rainfall was also recorded in July and August 2020 and 2022. High precipitation occurred in August 2021, coinciding with the grain harvest period.

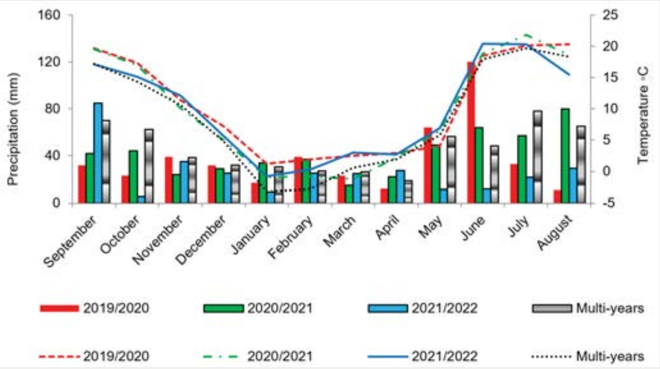

Figure 1. Weather conditions

Skowera et al. (2023) have shown that in Poland, the lowest risk of precipitation deficits occurs in May (from 15% to 32%), while the highest risk of rainfall shortage is observed in June (from 22% to 56%). This is an unfavorable phenomenon since from mid-June, winter wheat is in the so-called grain-filling stage. Jing et al. (2020) and Li et al. (2020) have suggested that water deficiency is one of the major environmental limitations affecting the yields of winter wheat. On the other hand, Xu et al. (2023) have reported that air temperatures play an equally important role in the proper growth and development of field crops, and their unfavorable patterns can be just as detrimental as a lack of precipitation. From previous studies (Darguza and Gaile, 2019; Heil et al., 2020; Szczepanek et al., 2022), it can be concluded that weather conditions often influence the results of field experiments. Therefore, the studied parameters or traits of crops vary significantly in the years of the study or are affected by the interaction of the factor tested with the experimental years. For this reason, meteorological conditions have a significant impact on the results of long-term field trials and their repeatability in subsequent seasons.

The SPAD index measurement showed that the most optimally nourished plants were those sown at the recommended density and time. Increasing the quantity of seeds sown by 20% significantly reduced SPAD scores in each variant. As expected, the highest leaf area index (LAI) was achieved after sowing grain at the recommended date and increasing seeding density by 20%. Significantly lower LAI readings were obtained after sowing at the recommended grain density but with delayed sowing by 30 and 60 days. There were no interactions observed between the factors tested on leaf stomatal conductance (Gs) measurements. On average, in the present experiment, the Gs index was 576.9 mmol/m^{2}s (Table 3).

Yin et al. (2023) have shown that taking measurements on plants during the growing season allows for an increase in the range of results and evaluates the effectiveness of the factors tested in experiments. As an example, they have provided the SPAD measurement, which indicates the nutritional status of plants and has long been applied in agricultural practice. According to Shah et al. (2020), the LAI index is another useful measurement for assessing the architecture of cultivated plants. The latter authors showed that with delayed sowing of winter wheat, the LAI index and plant biomass were reduced. On the other hand, Li et al. (2023) demonstrated that the size of leaf stomata and their conductance in winter wheat leaves decreased due to rising temperatures and drought stress,

Table 3. The influence of the interaction of sowing date and sowing density on selected plant measurements (average over years)

Sowing date	Sowing density	SPAD	LAI (m^2/m^2)	Gs (mmol/m^{2}s)
Recommended	recommended	53.61^{a}	3.78^{ab}	592.5^{a}
	increased 10%	50.30^{ab}	3.96^{ab}	586.2^{a}
	increased 20%	47.72^{bc}	4.05^{a}	585.9^{a}
30 day delay	recommended	52.40^{ab}	3.66^{b}	583.2^{a}
	increased 10%	49.60^{ab}	3.87^{ab}	575.6^{a}
	increased 20%	46.54^{c}	3.98^{ab}	569.8^{a}
60 day delay	recommended	51.55^{ab}	3.60^{b}	574.9^{a}
	increased 10%	48.62^{abc}	3.79^{ab}	566.5^{a}
	increased 20%	45.61^{c}	3.88^{ab}	557.7^{a}
Mean		49.5	3.8	576.9

Mean values with different letters ($^{a-c}$) in columns are statistically different ($P < 0.05$)

which had a significant impact on photosynthesis and transpiration. In a previous study, Jarecki and Czernicka (2022) confirmed the usefulness of field measurements of plant parameters, such as SPAD, LAI and Gs, in assessing the effectiveness of fertilization of winter wheat and the response of plants to the applied fertilizers.

As the sowing density increased, the number of ears per square meter was also higher. It was shown that sowing seeds at the optimum date and increased sowing density by 20% had the most beneficial effect on ear density. Significantly fewer ears per unit area were observed after sowing grain at the recommended density but with a 30 or 60-day delay.

The number of grains per ear was highest when sowing was carried out at the optimum date and recommended density. Significantly lower results were obtained when sowing density was increased by 20% or 10% but when sowing date was delayed by 60 days.

The most beneficial effect on TSW was achieved by sowing grain at the optimal date and at the recommended sowing density or increased by 10%. A significantly lower TSW was obtained as a result of increasing the sowing density by 20% in all variants, and in each variant with a delayed sowing time of 60 days (Table 4).

Sobko et al. (2023) showed in their study that the number of ears per 1 m^2 was dependent on the sowing date. They obtained the lowest number of ears after sowing wheat on October 1 and November 1. Different sowing dates did not affect the number of grains per ear, but significantly modified TSW. These authors achieved the lowest TSW after sowing wheat on October 10 or 20. Szczepanek et al. (2022) demonstrated that increasing the sowing density to 600 seeds/m^2 increased the number of ears and grain yield, but only in the year when drought stress occurred. Additionally, the increased sowing density contributed to a higher disease pressure. Spink et al. (2000) observed a significant interaction between sowing density and the time of sowing winter wheat. The later the sowings, the more increased sowing densities resulted in better outcomes. The reduced plant density was compensated for by a higher number of stems per plant, number of grains per ear, and to a lesser extent, TSW. Qiaoyan et al. (2022) reported that winter wheat yield was more influenced by sowing date than sowing density. However, they concluded that agriculture recommendations could vary depending on the variety. Zecevic et al. (2014) and Dueri et al. (2022) confirmed that sowing density mainly differentiated the number of ears per square meter, while the number of grains per

Table 4. The influence of the interaction of sowing date and sowing density on yield components (average over years)

Sowing date	Sowing density	Number of ears (pcs/m^2)	Number of grains per ear	Thousand grain weight (g)
Recommended	recommended	485.3^{abc}	41.6^{a}	42.3^{a}
	increased 10%	506.3^{ab}	39.4^{a}	41.6^{a}
	increased 20%	513.6^{a}	37.2^{b}	39.7^{b}
30 day delay	recommended	475.2^{bc}	39.7^{a}	40.3^{ab}
	increased 10%	496.4^{abc}	39.3^{a}	40.2^{ab}
	increased 20%	503.7^{ab}	37.4^{b}	39.6^{b}
60 day delay	recommended	466.5^{c}	38.8^{ab}	39.3^{b}
	increased 10%	493.2^{abc}	37.3^{b}	39.4^{b}
	increased 20%	487.7^{abc}	37.6^{b}	39.7^{b}
Mean		492.0	38.8	40.2

Mean values with different letters ($^{a-c}$) in columns are statistically different ($P < 0.05$)

ear and TSW were modified to a lesser extent. On the other hand, Zhang et al. (2023) demonstrated that the number of grains per ear and thousand seed weight were influenced by varying sowing densities.

On average, in the present experiment, wheat yielded the highest after sowing at the optimum date and recommended sowing density. The yield obtained was 8.54 t/ha. Increasing the sowing density by 20% at the optimum date was unjustified. Delaying the sowing date by 60 days resulted in a reduced yield. Increasing seed sowing density by 10% was beneficial when sowing was delayed by 30 days. However, the increased density of seeding with a 60-day delay in sowing did not bring the expected results because the obtained yield differences were statistically insignificant. Wheat produced the highest yield (8.49 t/ha) in 2020, with yields decreasing by 13.4% and 15.1% in 2021 and 2022, respectively (Table 5).

Shah et al. (2020) demonstrated that winter wheat yield decreased by 1% with each day of delay in sowing date. The lower yields were mainly due to a decrease in yield components and plant biomass. In addition, the plant developmental stages were shortened and the air temperature was elevated during the grain-filling period. On the other hand, increased sowing density mitigated yield losses with a one-week delay in sowing, partially compensated two-week delay, but did not compensate for the yield decrease in cases of delays exceeding two weeks.

The results of Sobko et al. (2023) confirmed that delaying the sowing date of winter wheat resulted in a decrease in grain yield. The average yields obtained by the latter authors, depending on the sowing date, were: September 1 – 5.72 t/ha, September 10 – 5.54 t/ha, September 20 – 5.41 t/ha, October 1 – 5.45 t/ha, October 10 – 4.87 t/ha, October 20 – 5.11 t/ha, November 1 – 5.06 t/ha. Fu et al. (2023) also reported in their study that delaying winter wheat sowing reduced yields from 6.14% to 13.72%; however, increased nitrogen fertilization alleviated this decline. The application of a higher amount of nitrogen not only increased the annual yield but also the income from cultivation, despite the higher costs incurred.

Ma et al. (2018) demonstrated that the yield of winter wheat was significantly influenced by the interaction between sowing date and sowing density. Therefore, these authors argued that both agronomic measures should be optimally determined in agriculture practice

Table 5. Grain yield in the years of research (t/ha)

Sowing date	Sowing density	2020	2021	2022	Mean over the years
Recommended	recommended	9.15^{a}	8.42^{a}	8.06^{a}	8.54^{a}
	increased 10%	8.98^{ab}	8.01^{ab}	7.90^{ab}	8.30^{ab}
	increased 20%	8.06^{c}	7.39^{bc}	7.31^{bc}	7.59^{b}
30 day delay	recommended	8.56^{ab}	7.15^{bc}	7.09^{bcd}	7.60^{b}
	increased 10%	8.74^{ab}	7.44^{bc}	7.35^{bc}	7.84^{ab}
	increased 20%	8.37^{ab}	7.06^{bc}	6.95^{cd}	7.46^{b}
60 day delay	recommended	8.13^{bc}	6.71^{c}	6.48^{d}	7.11^{b}
	increased 10%	8.11^{bc}	6.85^{c}	6.78^{cd}	7.25^{b}
	increased 20%	8.35^{ab}	7.11^{bc}	6.96^{cd}	7.28^{b}
Mean		8.49	7.35	7.21	7.68

Mean values with different letters ($^{a-d}$) in columns are statistically different ($P < 0.05$)

depending on habitat conditions. Many publications (Gandjaeva, 2019; Ren et al., 2019; Liu et al., 2023) have also demonstrated that timely sowing of winter wheat is an important element of agronomy affecting the resulting yields. Korkhova et al. (2023), on the other hand, have concluded that the size and quality of wheat yield is mainly influenced by weather conditions. With respect to common wheat, the yield difference obtained between the study years ranged from 5.02 to 6.94 t/ha. Darguza and Gaile (2019) also showed differences in wheat yields over the years of their trial, as the yields collected in 2017 (7.17 t/ha) were higher than those obtained in 2018 (6.18 t/ha).

The protein content in the grain exceeded 14% at the optimal sowing date and recommended sowing density, as well as when the sowing date was delayed by 30 days and sowing density was either recommended or increased by 10%. Grain contained the least protein in all variants with an increased sowing density by 20% and when sowing was delayed by 60 days sowing density increased by 10% (Figure 2).

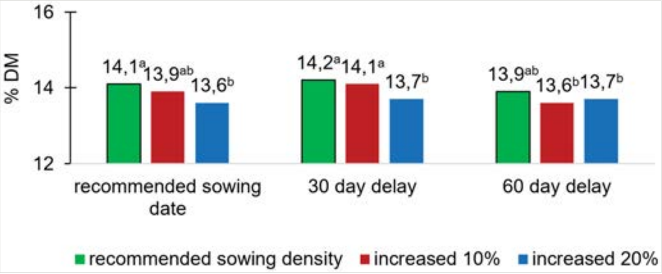

Figure 2. Effect of the interaction of the studied factors on protein content in grain in % DM

A study by Sobko et al. (2023) showed that with delayed sowing of winter wheat, the protein content in the grain was higher (for most varieties) compared to grain harvested from early sowing dates. However, the differences were not large and generally insignificant. Mikos-Szymańska and Podolska (2016) reported that variation in sowing date and sowing density had little effect on the quality of winter wheat grain. The genotype and harvest year exerted the main influence on the chemical composition of the grain. Research conducted by Korkhova et al. (2023) also demonstrated that the grain protein content was variable mainly during the years of the study and ranged from 11.8 to 15.7% DM. On the other hand, Sattar et al. (2010) and Shah et al. (2020) proved that delayed sowing of winter wheat increased the protein content in the grain.

CONCLUSIONS

The weather conditions during the years of the present research varied and affected winter wheat yields. The highest yields were obtained in 2020, while in 2021 and 2022, they were lower by 13.4% and 15.1%, respectively. It was shown that wheat yielded the highest when sown at the optimal time and recommended sowing density. This was the result of an increase in the number of grains per ear and TSW. A 10% increase in seeding density was well-founded if the sowing date was delayed by 30 days. In contrast, increasing the density of sowing delayed by 60 days did not produce the expected results. SPAD index measurements showed that the plants were most optimally nourished after sowing at the recommended time and density. Increasing the amounts of seeds sown by 20% significantly reduced SPAD readings in all variants. The largest leaf area (LAI) was acquired after sowing grain at the recommended date and increasing sowing density by 20%. Significantly lower LAI readings were obtained when grains were sown at the recommended density but with delays of 30 and 60 days. No significant differences in leaf stomatal conductance (Gs) measurements were observed. The fewest ears per unit area were obtained with a 60-day delayed sowing at the recommended density. The highest protein content in the grain was obtained at the optimal sowing date and recommended sowing density. Similar protein content was also acquired when sowing time was delayed by 30 days and sowing density was either recommended or increased by 10%. Grain contained the lowest protein content in all variants with an increased sowing density of 20% and when sowing was delayed by 60 days and density increased by 10%. In summary, winter wheat should be sown in the study area at the recommended sowing date and density. An increase in sowing density by 10% allows to compensate for the yield loss resulting from a 30-day delay in sowing.

REFERENCES

Allard, F., Vanasse, A., Pageau, D., Tremblay, G., Durand, J., Vachon, E. (2019) Determination of optimal sowing dates and densities of winter wheat under Quebec growing conditions. Canadian Journal of Plant Science, 99 (2), 221-231. DOI: https://doi.org/10.1139/cjps-2018-0165

Aula, L., Easterly, A.C., Creech, C.F. (2022) Winter wheat seeding decisions for improved grain yield and yield components. Agronomy, 12, 3061. DOI: https://doi.org/10.3390/agronomy12123061

Bastos, L.M., Carciochi, W., Lollato, R.P., Jaenisch, B.R., Rezende, C.R., Schwalbert, R., Vara Prasad, P.V., Zhang, G., Fritz, A.K., Foster, Ch., Wright, Y., Young, S., Bradley, P., Ciampitti, I.A. (2020) Winter wheat yield response to plant density as a function of yield environment and tillering potential: A review and field studies. Frontiers in Plant Science, 11, 54. DOI: https://doi.org/10.3389/fpls.2020.00054

Chiriţă, S., Rusu, T. Urda, C., Cheţan, F., Racz, I. (2023) Winter wheat yield and quality depending on chemical fertilization, different treatments and tillage systems. AgroLife Scientific Journal, 12 (1), 34-39.

Costa, R., Pinheiro, N., Almeida, A.S., Gomes, C., Coutinho, J., Coco, J., Costa, A., Maçãs, B. (2013) Effect of sowing date and seeding rate on bread wheat yield and test weight under Mediterranean conditions. Emirates Journal of Food and Agriculture, 25 (12), 951-961. DOI: https://doi.org/10.9755/ejfa.v25i12.16731

Darguza, M., Gaile, Z. (2019) Yield and quality of winter wheat, depending on crop rotation and soil tillage. Research for Rural Development, 2, 29-35. DOI: https://doi.org/10.22616/rrd.25.2019.045

Dueri, S., Brown, H., Asseng, S., Ewert, F., Webber, H., George, M., et al. (2022) Simulation of winter wheat response to variable sowing dates and densities in a high-yielding environment. Journal of Experimental Botany, 73 (16), 5715-5729. DOI: https://doi.org/10.1093/jxb/erac221

Fu, Z., Zhang, K., Zhang, J., Zhang, Y., Cao, Q., Tian, Y., Zhu, Y., Cao, W., Liu, X. (2023) Optimizing nitrogen application and sowing date can improve environmental sustainability and economic benefit in wheat-rice rotation. Agricultural Systems, 204, 103536. DOI: https://doi.org/10.1016/j.agsy.2022.103536

Gandjaeva, L. (2019) Effect of sowing date on yield of winter wheat cultivars Grom, Asr and Kuma in Khorezm region. Bulgarian Journal of Agricultural Science, 25 (3), 474–479.

Heil, K., Lehner, A., Schmidhalter, U. (2020) Influence of climate conditions on the temporal development of wheat yields in a long-term experiment in an area with pleistocene loess. Climate, 8 (9), 100. DOI: https://doi.org/10.3390/cli8090100

Jarecki, W., Czernicka, M., (2022) Yield and quality of winter wheat (*Triticum aestivum* L.) depending on multi-component foliar fertilization. Journal of Elementology, 27 (3), 559-567. DOI: https://doi.org/10.5601/jelem.2022.27.2.2286

Jarecki, W., Bobrecka-Jamro, D. (2019) Reaction of facultative cultivars of spring wheat to autumn and spring sowing dates. Polish Journal of Agronomy. 39, 52-57. DOI: https://doi.org/10.26114/pja.iung.387.2019.39.07

Jing, B.H., Wang, C., Khan, S., Yuan, Y.C., Yang, W.D., Feng, M.C. (2020) Yield response of winter wheat (*Triticum aestivum* L.) to water stress in Northern China: A meta-analysis. Applied Ecology AND Environmental Research, 18 (1), 433-446. DOI: http://dx.doi.org/10.15666/aeer/1801_433446

Klepeckas, M., Januškaitienė, I., Vagusevičienė, I., Juknys, R. (2020) Effects of different sowing time to phenology and yield of winter wheat. Agricultural and Food Science, 29 (4), 346-358. DOI: https://doi.org/10.23986/afsci.90013

Korkhova, M., Panfilova, A., Domaratskiy, Y., Smirnova, I. (2023) Productivity of winter wheat (*T. Aestivum*, *T. Durum*, *T. Spelta*) depending on varietal characteristics in the context of climate change. Ecological Engineering and Environmental Technology, 24 (4), 236-244. DOI: https://doi.org/10.12912/27197050/163124

Li, D., Lou, R., Li, Y., Bian, Z., Zhu, Y.N. (2020) Effects of multi-stage continuous drought on photosynthetic characteristics, yield and water use efficiency of winter wheat. Phyton-International Journal of Experimental Botany, 89 (3), 691-703. DOI: https://doi.org/10.32604/phyton.2020.010661

Li, Q., Gao, Y., Hamani, A.K.M., Fu, Y., Liu, J., Wang, H., Wang, X. (2023) Effects of warming and drought stress on the coupling of photosynthesis and transpiration in winter wheat (*Triticum aestivum* L.). Applied Sciences, 13, 2759. DOI: https://doi.org/10.3390/app13052759

Liu, J., He, Q., Zhou, G., Song, Y., Guan, Y., Xiao, X., Sun,W., Shi, Y., Zhou, K., Zhou, S., et al. (2023) Effects of sowing date variation on winter wheat yield: Conclusions for suitable sowing dates for high and stable yield. Agronomy, 13 (4), 991. DOI: https://doi.org/10.3390/agronomy13040991

Ma, S.Ch., Wang, T.Ch., Guan, X.K., Zhang, X. (2018) Effect of sowing time and seeding rate on yield components and water use efficiency of winter wheat by regulating the growth redundancy and physiological traits of root and shoot. Field Crops Research, 221, 166-174. DOI: https://doi.org/10.1016/j.fcr.2018.02.028

Mikos-Szymańska, M., Podolska, G. (2016) The effects of sowing date and seeding rate on spelt and common wheat protein composition and characteristics. Quality Assurance and Safety of Crops & Foods, 8 (2), 289-300. DOI: https://doi.org/10.3920/QAS2014.0574

Oleksiak, T. (2014) Effect of sowing date on winter wheat yields in Poland. Journal Centtral European Agriculture, 15 (4), 83-99. DOI: https://doi.org/10.5513/JCEA01/15.4.1513

Qiao, S., Harrison, S.P., Prentice, I.C., Wang, H. (2023) Optimality-based modelling of wheat sowing dates globally. Agricultural Systems, 206, 103608. DOI: https://doi.org/10.1016/j.agsy.2023.103608

Qiaoyan, C., Xingqi, O., Xinhua, L., Wenhui, W., Kandyba, N. (2022) Effect of different sowing date, planting density on yield and main agronomic traits in winter wheat variety Bainong 207. Bulletin of Sumy National Agrarian University. The Series: Agronomy and Biology, 45 (3), 71-77. DOI: https://doi.org/10.32845/agrobio.2021.3.9

Ren A., Sun M., Wang P., Xue L., Lei M., Xue J., Gao Z., Yang Z., (2019) Optimization of sowing date and seeding rate for high winter wheat yield based on pre-winter plant development and soil water usage in the Loess Plateau, China. Journal of Integrative Agriculture, 18 (1), 33-42. DOI: https://doi.org/10.1016/S2095-3119(18)61980-X

Rezaie, B., Hosseinpanahi, F., Siosemardeh, A., Darand, M., Bannayan, M. (2022) Shifting the sowing date of winter wheat as a strategy for adaptation to climate change in a Mediterranean-type environment. International Journal of Plant Production, 16, 595-610. DOI: https://doi.org/10.1007/s42106-022-00202-7

Sattar, A., Cheema, M.A., Farooq, M., Wahid, M.A., Wahid, A., Babar, B.H. (2010) Evaluating the performance of wheat cultivars under late sown conditions. International Journal of Agriculture and Biology, 12 (4), 561-565.

Shah, F., Coulter, J.A., Ye, Ch., Wu, W. (2020) Yield penalty due to delayed sowing of winter wheat and the mitigatory role of increased seeding rate. European Journal Agronomy, 119, 126120. DOI: https://doi.org/10.1016/j.eja.2020.126120

Skowera, B., Baranowska, A., Węgrzyn, A., Bartoszek, K., Wojkowski, J., Ivanišová, E. (2023) The meteorological conditions of precipitation deficits in the cultivation of winter wheat in central and eastern Poland. Journal of Ecological Engineering, 24 (9), 50-62. DOI: https://doi.org/10.12911/22998993/168349

Sobko, M., Butenko, Y., Davydenko, G., Solarov, O., Pylypenko, V., Makarova, V., Mikulina, M., Samoshkina, I., Antonovskyi, O., Poriadynskyi, V. (2023) Ecological and economic study of wheat winter varieties by different geographical origin. Ecological Engineering and Environmental Technology, 24 (1), 12-21. DOI: https://doi.org/10.12912/27197050/154912

Spink, J.H., Semere, T., Sparkes, D.L., Whaley, J.M., Foulkes, M.J., Clare, R.W., Scott, R.K. (2000) Effect of sowing date on the optimum plant density of winter wheat. Annals of Applied Biology, 137 (2), 179-188. DOI: https://doi.org/10.1111/j.1744-7348.2000.tb00049.x

Szczepanek, M., Lemańczyk, G., Nowak, R., Graczyk, R. (2022) Response of Indian dwarf wheat and persian wheat to sowing density and hydrothermal conditions of the growing seasons. Agriculture, 12 (2), 205. DOI: https://doi.org/10.3390/agriculture12020205

Xu, C., Lin, M., Fang, Q., Chen, J., Yue, Q., Xia, J. (2023) Air temperature estimation over winter wheat fields by integrating machine learning and remote sensing techniques. International Journal of Applied Earth Observation and Geoinformation, 122, 103416. DOI: https://doi.org/10.1016/j.jag.2023.103416

Yang, C., Fraga, H., Van Leperen, W., Trindade, H., Santos, J.A. (2019) Effects of climate change and adaptation options on winter wheat yield under rainfed Mediterranean conditions in southern Portugal. Climatic Change, 154, 159-178. DOI: https://doi.org/10.1007/s10584-019-02419-4

Yin, Q., Zhang, Y., Li, W., Wang, J., Wang, W., Ahmad, I., Zhou, G., Huo, Z. (2023) Estimation of winter wheat SPAD values based on UAV multispectral remote sensing. Remote Sensing, 15 (14), 3595. DOI: https://doi.org/10.3390/rs15143595

Zecevic, V., Boskovic, J., Knezevic, D., Micanovic, D. (2014) Effect of seeding rate on grain quality of winter wheat. Chilean Journal of Agricultural Research, 74 (1), 23-28. DOI: http://dx.doi.org/10.4067/S0718-58392014000100004

Zhang, F., Zhang, D., Li, L., Zhang, Z., Liang, X., Wen, Q., Chen, G., Wu, Q., Zhai, Y. (2023) Effect of planting density on canopy structure, microenvironment, and yields of uniformly sown winter wheat. Agronomy, 13 (3), 870. DOI: https://doi.org/10.3390/agronomy13030870